

Biostratigraphy of the Ludlow chitinozoans from East Baltic drill cores

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Abstract. The distribution of chitinozoans in the East Baltic Ludlow sequences was studied in the Ohesaare, Ventspils, Pavilosta, and Dubovskoye drill core sections. The *Angochitina elongata*, *Eisenackitina lagenomorpha*, and *Eisenackitina barrandei* biozones were described and correlated with the regional stratigraphical units, as well as with conodont and vertebrate biozones in the Ohesaare core.

Key words: chitinozoans, biostratigraphy, Ludlow, Silurian, East Baltic.

INTRODUCTION

The distribution of chitinozoans in the Wenlock–Ludlow boundary beds in five East Baltic drill cores (Ohesaare, Kolka, Ventspils, Pavilosta, Gussev-1) has been described in Nestor (2007). Up to now only a brief review of chitinozoan distribution in the Ludlow sections of Estonia, based on the Ohesaare (V. Nestor 1990, 1997) and Ruhnu cores (Nestor 2003), is available. The first, lowest stratigraphical level identified by chitinozoans is at the base of the Torgu Formation of the Paadla Regional Stage, where *Angochitina elongata* appears. Chitinozoans are absent below this level in the Soeginina Beds, recently attributed to the Ludlow by Viira & Einasto (2003). *Angochitina elongata* is a zonal species of the global biozone, widely distributed around the world in the lower part of the Ludlow (Verniers et al. 1995). This biozone forms a base for the discussion in the present paper.

Graptolite data are very scarce above the *Lobograptus scanicus* Biozone in the East Baltic Ludlow. R. Ulst (in Gailite et al. 1987) has identified all the graptolites collected from the Pavilosta and Ventspils drill cores, but these were only rare findings, which did not allow exact identification of the biozonal boundaries. This is also true for the graptolite records from the Dubovskoye core (Kaljo & Sarv 1976). Therefore, the boundary between the Gorstian and Ludfordian stages in the studied drill cores has been drawn tentatively.

In the present paper the distribution of chitinozoans in the Ohesaare, Ventspils, Pavilosta, and Dubovskoye (Northern-Gusevskaya 2) core sections is considered. As Nestor (2007) discussed also the distribution of chitinozoans in the lowermost Ludlow, this interval is not dealt with in the present article. Chitinozoan data

from the Kolka core are also omitted due to their great similarity to those from the Ohesaare core and the much greater number of samples in Kolka, empty of chitinozoans. The data of the Gussev-1 core are replaced by the chitinozoan succession of the Dubovskoye core, where the series of samples is more representative, as chitinozoan samples are missing from the uppermost 23 m of the Ludlow in the former core. Besides, all chitinozoan data from the omitted drill cores confirm the information presented below.

The main aim of this paper is to present more biostratigraphical information concerning the Ludlow of the East Baltic region and to improve the chitinozoan distribution data in general. Most of the studied samples have been collected together with colleagues in the Skrunda, Riga, and Gussev depositories between 1980 and 1986. Several papers have been published on these materials, concerning assemblages of trilobites (Männil 1982), ostracodes (Sarv 1982), conodonts (Viira 1982), and vertebrates (Märss 1986), which enabled us to compare chitinozoan assemblages with some other faunas (see below).

The studied specimens are housed at the Institute of Geology at Tallinn University of Technology (collection GIT 576).

GEOLOGICAL SETTING

The studied drill cores represent open shelf, transitional facies, and shelf depression deposits (Fig. 1). The Torgu Formation and the upper part of the Kuressaare Formation of the Ohesaare core are predominantly characterized by argillaceous nodular limestones; the lower part of the Kuressaare Formation is represented by calcareous and

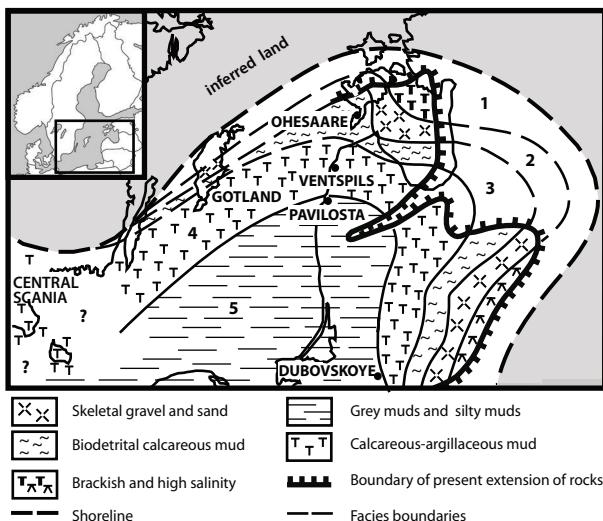


Fig. 1. Location of the studied core sections (black dots). General facies zonation of the Baltic Gulf in the early Ludlow from Kaljo & Martma (2006). Facies belts: 1, tidal flat/lagoon; 2, shoal; 3, open shelf; 4, transition from open to deep shelf; 5, shelf depression.

dolomitic argillaceous marlstones. Ludlow deposits in the Ventspils, Pavilosta, and Dubovskoye cores are of deeper water origin. The Dubysa Formation is characterized by argillaceous marlstones with rare thin limestone interbeds, the Engure Formation by different marlstones with limestone nodules, and the Mituva and Ventspils formations consist of nodular limestones with a number of hardgrounds. The mainly dolomitic mudstones in the upper Ludlow succession of the Dubovskoye core belong to the Uljanov Formation (Koren & Suyarkova 2007) (Fig. 2).

Conodont-based correlations between Saaremaa (Estonia) and Gotland (Sweden) have revealed a major gap in the middle part of the Ludlow sequence of Estonia, between the Paadla and Kuressaare regional stages (Jeppsson et al. 1994). The extent of this gap in the Ohesaare core is supposed to be smaller than in the outcrop area (Viira & Aldridge 1998). A gap in the lowermost Ludlow of Estonia has been observed earlier, based on the chitinozoan succession (missing biozones) (Nestor 1982). In the other East Baltic sections (Ventspils and Pavilosta), the Ludlow deposits are represented more or less in full extent. In the Dubovskoye core we have studied only the upper part of the Ludlow, i.e. the Ludfordian Stage.

A model of oceanic and climatic cyclicity, linked to the sedimentological and biotic changes in the Ludlow, was proposed by Jeppsson & Aldridge (2000). They determined two levels of intense faunal extinctions, the Linde and Lau events in the mid-Ludlow. According to Kaljo et al. (1998), carbon isotope cycling is one

Series	Stage	Grapt. zone	Reg. stage	Chitinozoan biozone	Ohesaare core	Ventspils core	Pavilosta core	Dubovskoye core	
LUDLOW	Ludfordian	<i>P. tumescens</i> / <i>S. leintwardinensis</i>	Kuressaare K _a	<i>Eisenacktinina barrandei</i>	Kuresaare Formation	Ventspils Form.	Pagegai Formation	?	
				<i>Eisenacktinina lagenomorpha</i>		Mituva Formation			
	Gorstian	<i>P. tumescens</i> / <i>S. leintwardinensis</i>	Paadla K ₂	<i>Angochitina elongata</i>	Tahula Beds	Engure Formation	Dubysa Formation		
				<i>Ancyrochitina desmea</i>	Torgu Formation	Dubysa Formation			
				<i>Conochitina postarmillata</i>	Soeginina Beds?	?			

Fig. 2. Chitinozoan biozonation and correlation of lithostratigraphical units in the Ludlow of the Ohesaare, Ventspils D-3, Pavilosta, and Dubovskoye drill cores after Gailite et al. (1987) and H. Nestor (1995). Reg., regional.

feature of environmental cyclicity and the most positive excursions occur after important faunal extinctions, usually tied to regression and cooling of climate. Carbon isotopes have been studied and $\delta^{13}\text{C}$ curves compiled for the Ohesaare and Ventspils cores (Kaljo et al. 1998; Kaljo & Martma 2006). The $\delta^{13}\text{C}$ curve of the late Gorstian Linde Event (Jeppsson & Aldridge 2000) is hardly recognizable in the East Baltic cores (Kaljo & Martma 2006). The peak values of the mid-Ludfordian $\delta^{13}\text{C}$ excursion occur within the limits of the Lau Event, defined by conodonts (Jeppsson & Aldridge 2000). Among the studied sections the Lau Event is expressively reflected in the Ventspils core, approximately within the depth interval 460–470 m, in the upper part of the Mituva Formation (Kaljo et al. 1998; Kaljo & Martma 2006). In the chitinozoan succession this event is characterized by the extinction of 14 species. High values of the carbon isotope curve have been reported from various localities around the world, giving evidence of the global dimension of this event (Martma et al. 2005; Calner & Eriksson 2006). In the Ohesaare core the peak level of the carbon isotope excursion is represented by a gap (Kaljo et al. 1998).

ON THE BOUNDARY OF THE GORSTIAN AND LUDFORDIAN STAGES

According to Kaljo & Paškevičius (1993), the *P. tumescens* and *S. leintwardinensis* graptolite biozones have not been established in the East Baltic drill cores

and the boundary between the Gorstian and Ludfordian stages falls somewhere within the middle of the regional *P. tauragensis* Zone. Graptolites are scarce, but chitinozoans occur abundantly in the East Baltic upper Silurian sections, as well as in the type Ludlow area, studied by Sutherland (1994). According to the last paper, only minor changes occur in the chitinozoan succession at the boundary of the Gorstian and Ludfordian stages. Most of the species which appear in the Upper Elton or Bringewood formations range over this boundary. However, there are some species (Sutherland 1994, text-fig. 6) with overlapping ranges at the stages boundary, e.g. *Belonechitina mortimerensis* disappearing below the boundary and *E. lagenomorpha?* appearing a bit lower. After being absent in the Upper Elton Formation, *Angochitina elongata* re-appears in the lowermost part of the Ludfordian Stage. A similar situation occurs in the Ventspils core in the interval 512–516 m and in the Pavilosta core in 744.3–745.3 m, though *A. elongata* is not found above this interval in the latter section. These distribution data were not sufficient for recognizing this boundary in the Ohesaare core (Fig. 3) but allowed us to establish the provisional position of the stages boundary in the Ventspils and Pavilosta cores (Figs 4, 5). In the Dubovskoye core only sediments of the Ludfordian Stage are represented (Fig. 6).

CHITINOZOAN BIOSTRATIGRAPHY

The Ludlow chitinozoans from Baltic glacial erratics were first described by Eisenack (1931), from Gotland by Eisenack (1964), and from Estonia (Saaremaa = Ösel) by Eisenack (1970). Laufeld (1974) identified among other species, many Ludlow taxa from the Gotland sequence, but without establishing biozonal units. V. Nestor (1990) distinguished six preliminary biozones from the East Baltic Ludlow cores. The first short account of chitinozoan biostratigraphy in the Ludlow of Shropshire was published by Dorning (1981). A complete review of chitinozoans from the Ludlow type area was provided by Sutherland (1994), who established 12 numerical biozones in the interval from the Lower Elton Formation to the Lower Whitcliffe Formation. A year later Verniers et al. (1995) published a global biozonation of Silurian chitinozoans with three biozones and two undefined intervals in the zonal succession of the Ludlow Series. Nestor (2007) defined and described two new regional biozones (*Conochitina postarmillata* and *Ancyrochitina desmea*), which filled the previous lower Ludlow gap in the chitinozoan zonal succession (Fig. 7). The younger biozones from the Ludlow of East Baltic drill cores are described in ascending order.

The *Angochitina elongata* Biozone

Eisenack (1931) described the holotype of *Angochitina elongata* from an erratic boulder and defined a neotype from the Hemse Marl of Gotland (Eisenack 1964). In the type Ludlow area this species appears 24 m below the top of the Middle Elton Formation, Gorstian Stage, correlated with the uppermost part of the *Lobograptus scanicus* graptolite Biozone (Sutherland 1994). In the Pavilosta core R. Ulst identified the highest *L. cf. scanicus* at 806.50 m and *Saetograptus chimaera* at 811.30 m, but the lowest *Pristiograptus tumescens* at 784.10 m. In the Ventspils core *L. ex. gr. scanicus* was established at 609.40 m, *S. chimaera* at 600 m, and *P. tumescens* (single finding) at 574.30 m (Gailite et al. 1987). Thus, the East Baltic chitinozoan data confirm the opinion of Sutherland (1994) that the lower boundary of the *A. elongata* Biozone corresponds to the uppermost part of the *scanicus* graptolite Zone.

In the East Baltic sequences the *A. elongata* Biozone coincides with the lower and middle parts of the Torgu Formation, the upper part of the Dubysa Formation, and the lower part of the Engure Formation, which all are characterized by a diverse and abundant assemblage of chitinozoans. Many species from the uppermost Wenlock range into the Ludlow of the Ventspils and Pavilosta cores: *Conochitina pachycephala* Eisenack (Fig. 8M), *C. claviformis* Eisenack (Fig. 8N), *C. tuba* Eisenack (Fig. 8O), *C. rudda* Sutherland (Fig. 8L), *Cingulochitina convexa* (Laufeld) (Fig. 8T), *Linochitina erratica* Eisenack (Fig. 8V), and *Cingulochitina gorstyensis* Sutherland (Fig. 8U). According to Sutherland (1994, p. 39), the lowest occurrence of the last species is in the mid-Gorstian in the type Ludlow area (see also Nestor 2007, p. 123). *Belonechitina latifrons* (Eisenack) (Fig. 8P), *B. lauensis* (Laufeld) (Fig. 8R), *Ancyrochitina diabolus* Eisenack (Fig. 8I), *A. desmea* Eisenack (Fig. 8H), and *A. goggicensis* Sutherland (Fig. 8J) range from the basal Ludlow upwards. According to Sutherland (1994, p. 39), the last species appears already in the upper part of the Much Wenlock Limestone.

The zonal species, *Angochitina elongata* Eisenack (Fig. 8A), appears together with *Angochitina echinata* Eisenack (Fig. 8F) in the Ohesaare and Ventspils cores (Figs 3, 4), Palencia (North Spain) (Schweineberg 1987), Skåne (Sweden) (Grahn 1996), Amazonas Basin (North Brazil) (Grahn 2005), and probably also in the type Ludlow area (*Angochitina* sp. aff. *echinata* in Sutherland 1994). *Angochitina ambrosi* Schweineberg (Fig. 8B, C) is previously only known from Gondwana, Palencia, and is for the first time identified in Baltic sections. *Sphaerochitina impia* Laufeld (Fig. 8E) and *Ancyrochitina brevispinosa* Eisenack (Fig. 8D) were identified only in

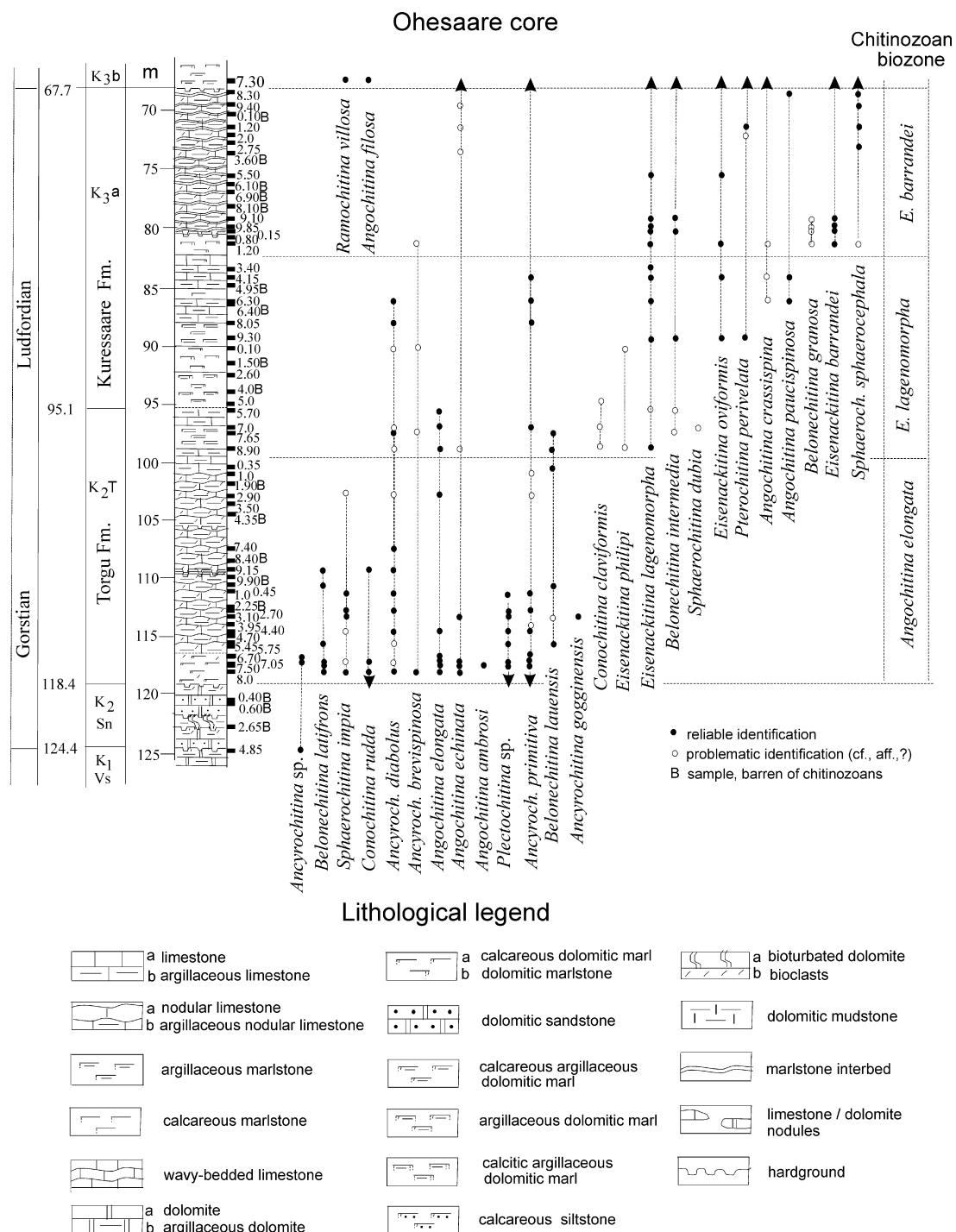


Fig. 3. Lithological log, legend, and ranges of chitinozoan species in the Ludlow of the Ohesaare drill core. K₁, Rootsiküla Stage, Vs, Vesiku Beds; K₂, Paadla Stage, Sn, Soeginina Beds; K_{3a}, Kuressaare Stage; K_{3b}, Kaugatuma Stage. The legend follows H. Nestor (1990).

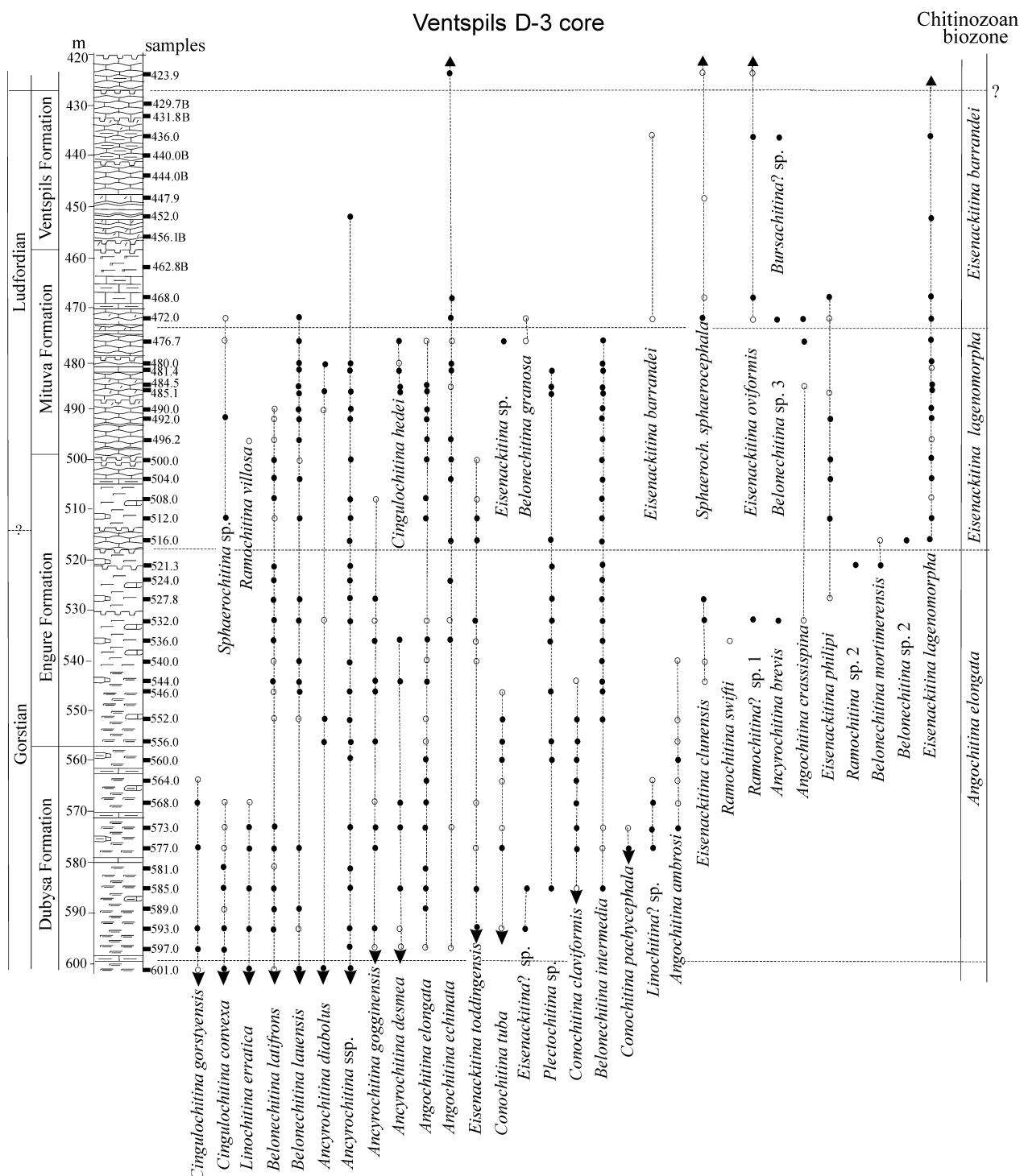


Fig. 4. Lithological log (compiled after Gailite et al. 1987) and ranges of chitinozoan species in the upper part of the Gorstian Stage and in the Ludfordian Stage of the Ludlow in the Ventspils D-3 drill core. For legend see Fig. 3.

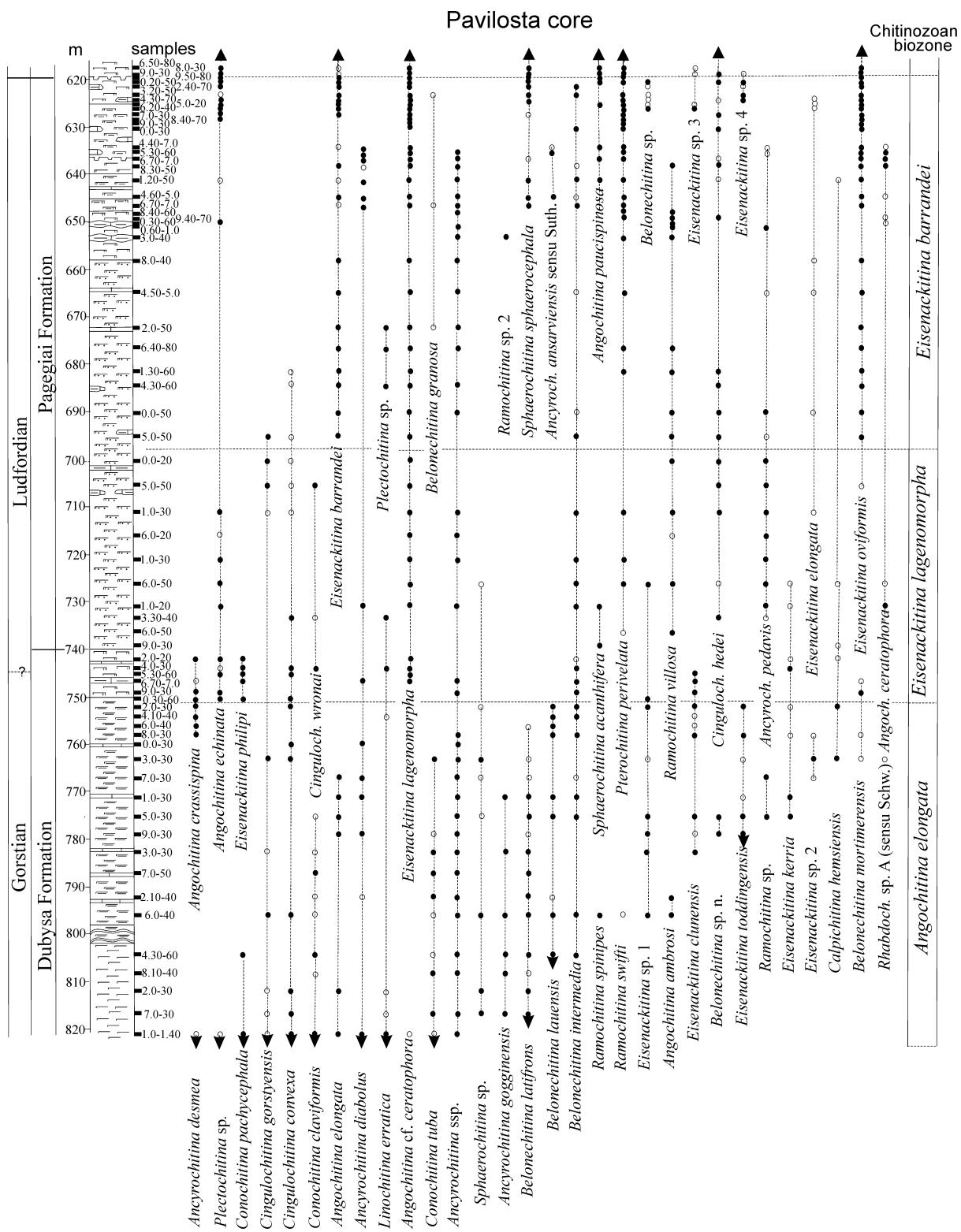


Fig. 5. Lithological log (compiled after Gailite et al. 1987) and ranges of chitinozoan species in the upper part of the Gorstian Stage and in the Ludfordian Stage of the Ludlow in the Pavilosta drill core. For legend see Fig. 3.

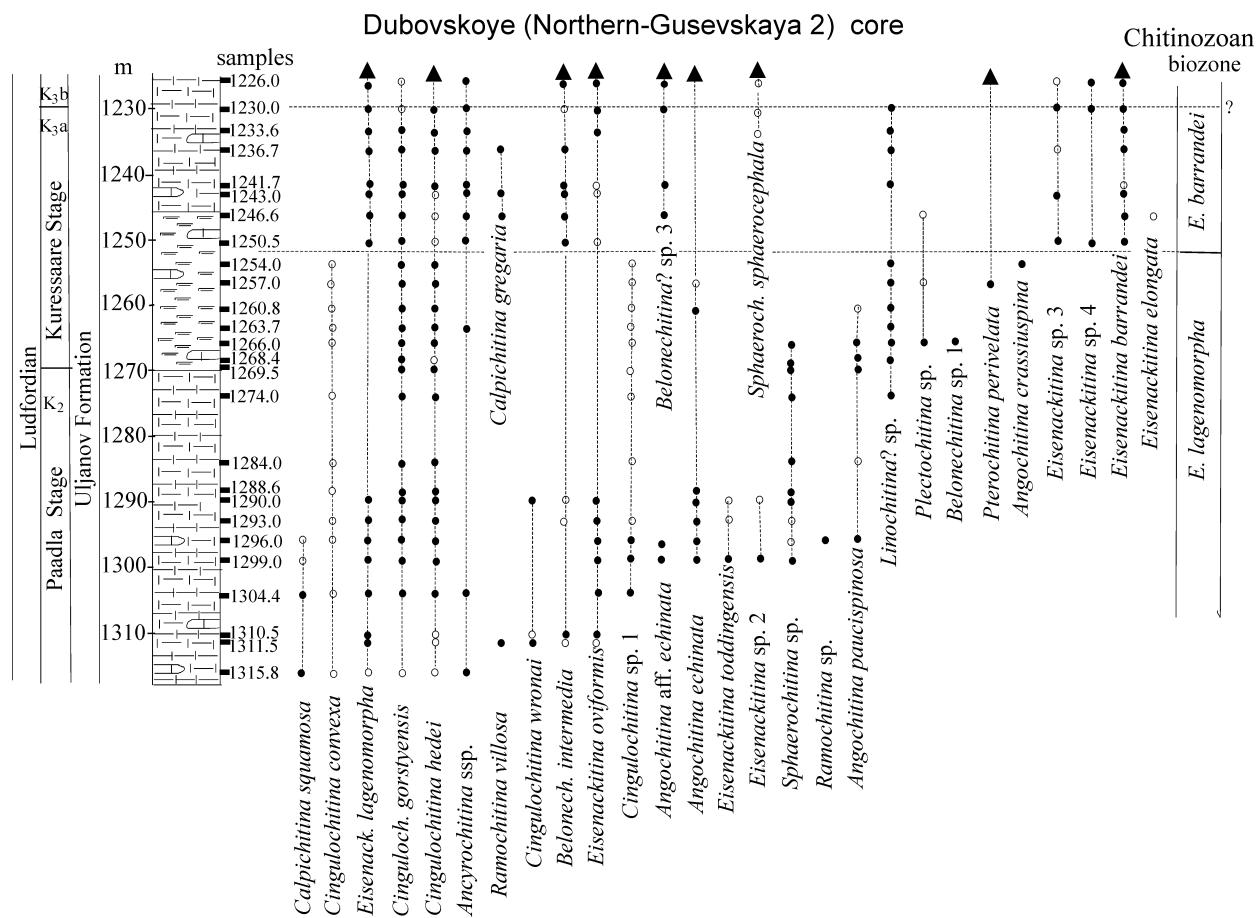


Fig. 6. Lithological log (compiled after Kaljo & Sarv 1976) and ranges of chitinozoan species in the Ludfordian Stage of the upper Ludlow in the Dubovskoye drill core. For legend see Fig. 3.

the Ohesaare core. *Ramochitina spinipes* (Eisenack 1964) (Fig. 8G), a characteristic species of the lower part of the Hemse Beds, was recognized only in the Pavilosta core. *Eisenackitina intermedia* (Eisenack) (Fig. 8Y) is widely distributed, but the appearance level of this taxon is variable. In the outcrop area of the Brabant Massif, in the Ronquières Formation (Verniers et al. 2002) and in the Prague Basin of the Barrandian area (Morávek 2007) it appears in the lowermost Ludlow, in the type Ludlow area (Sutherland 1994) and in the Ventspils and Pavilosta cores it appears in the middle of the Gorstian Stage, in the lower part of the *Angochitina elongata* Biozone. In Gotland (Laufeld 1974), Skåne (Grahn 1996), and in the Ohesaare core its first occurrence is higher, within the Ludfordian Stage. It is not excluded that these differences in the species appearances might have been caused by local facies differences. *Ramochitina swifiti* Sutherland (Fig. 8W), *Eisenackitina toddingensis* Sutherland (Fig. 8Z), *E. kerria* Miller, Sutherland &

Dorning (Fig. 8X), and *E. clunensis* Miller, Sutherland & Dorning (Fig. 9A) are previously known from the Welsh Basin, and were for the first time identified in the East Baltic Ludlow. The first two species occur in the upper Gorstian of the type Ludlow area (Sutherland 1994) and two others in the uppermost Ludfordian of the Clun area (Miller et al. 1997). *Belonechitina mortimerensis* Sutherland (Fig. 8S) has been identified in the upper Gorstian of the type Ludlow area (Sutherland 1994) and at the same stratigraphic level in the Pavilosta and Ventspils cores. The finding of *Ancyrochitina brevis* Taugourdeau & Jekhowsky (Fig. 8K) in the upper part of the Gorstian Stage in the Pavilosta core is also notable, as this species is known from the Pridolian strata (Jaglin & Paris 2002).

A number of chitinozoan species of the studied cores are left in open nomenclature, as the material is insufficiently or badly preserved and the ornamentation is hardly visible. Some of these forms are represented

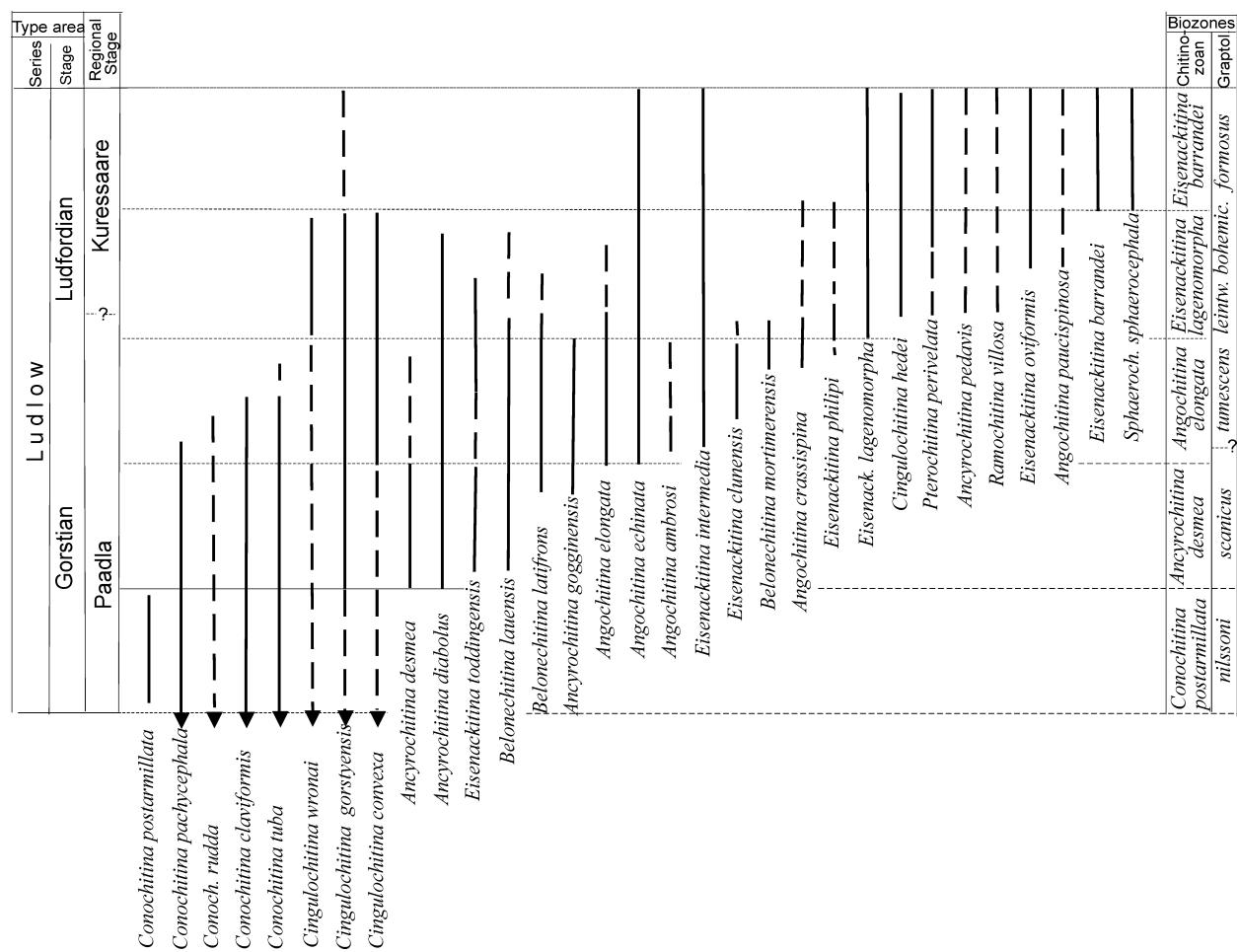


Fig. 7. Distribution of selected chitinozoan species in the Ludlow sequence of the East Baltic, including those already described in Nestor (2007).

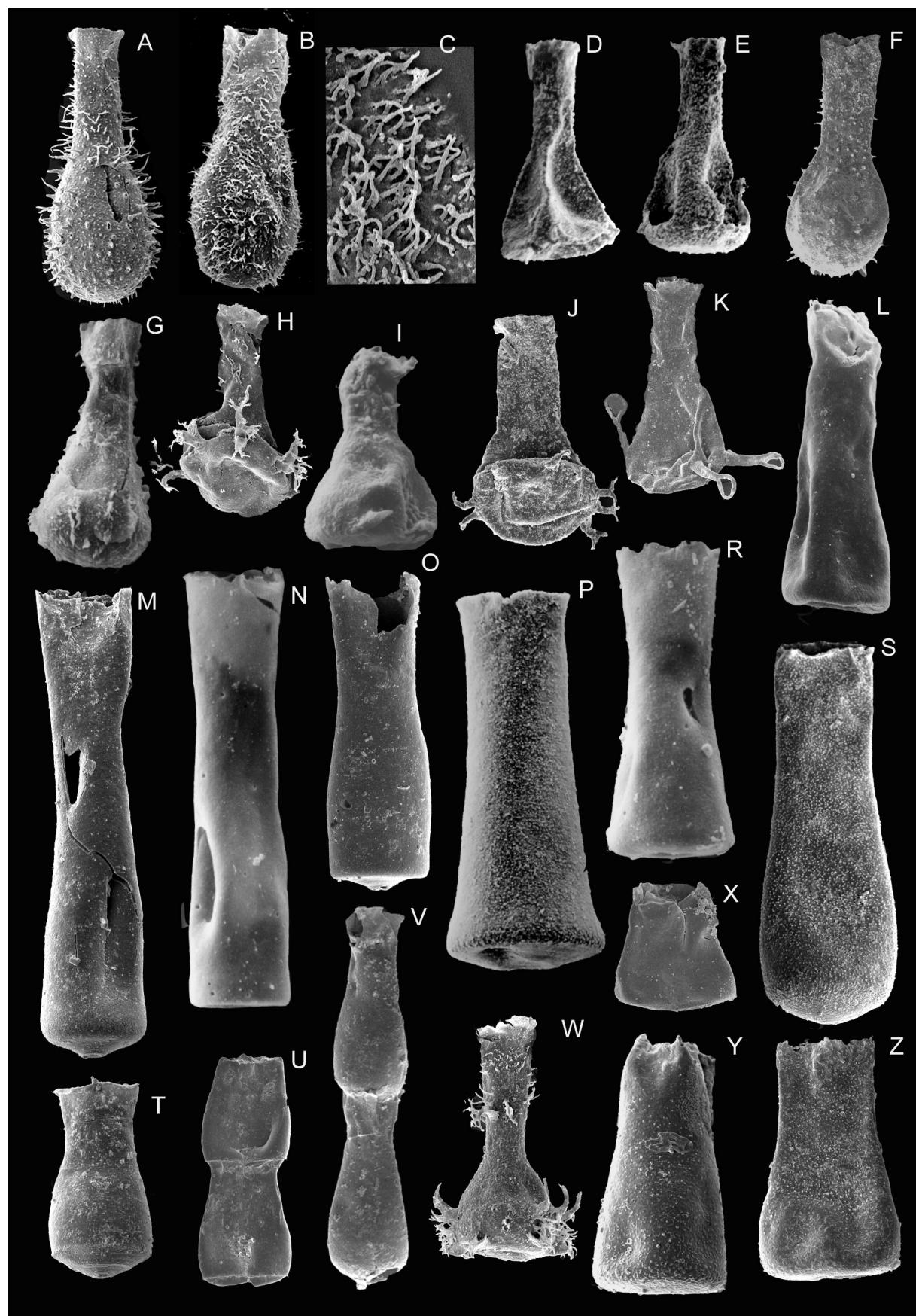
in Figs 9 and 10. The *Angochitina elongata* Biozone includes *Eisenackitina* sp. 1 (Fig. 9C), *Eisenackitina* sp. 2 (Fig. 9D), and *Sphaerochitina* sp. (Fig. 9L) in the Pavilosta core and *Ramochitina?* sp. 1 (Fig. 9N) and *Ramochitina* sp. 2 (Fig. 9T) in the Ventspils core.

The chitinozoan succession in the Ohesaare core (Fig. 3) is interrupted by many barren intervals, where chitinozoans are missing, referring to unfavourable conditions for these microfossils (regression?) or their preservation. In the Ventspils core (Fig. 4) two intervals of chitinozoan extinctions can be recognized in the *Angochitina elongata* Biozone, one in the upper part of the Dubysa Formation (564–568 m) and the other step by step disappearance of species in the lower-middle part of the Engure Formation (527–546 m). Six species disappear in the uppermost Dubysa Formation in the Pavilosta core (742–752 m) (Fig. 5).

The *Eisenackitina lagenomorpha* Biozone

Verniers et al. (1995) distinguished the global *E. philipi* Biozone in the middle-upper Ludlow. In the present paper, as *E. philipi* is rare in the East Baltic sections, we used the regional *E. lagenomorpha* Biozone instead of the *E. lagenomorpha*–*E. philipi* Biozone, which has been published earlier by V. Nestor (1990, 1997).

In the Pavilosta core *Eisenackitina philipi* Laufeld (Fig. 9H) ranges for only about 10 m in the lowermost Ludfordian, i.e., in the upper part of the Dubysa Formation. It is rare in about 50 m at the boundary interval of the Engure and Mituva formations in the Ventspils core and is missing from the Dubovskoye core. *Eisenackitina lagenomorpha* (Eisenack) (Fig. 9G) is well represented in all studied sections, except for the upper part of this zone in the Dubovskoye core.



According to Dorning (1981), *E. lagenomorpha* and *E. philipi* appear together in the Lower Leintwardine Formation in the Welsh Basin. In the sections of the Ludlow area *E. lagenomorpha?* was identified in the uppermost part of the Bringewood Formation (Sutherland 1994). Actually this taxon is rather similar to *E. lagenomorpha* in the East Baltic cores. In the Pavilosta and Dubovskoye cores different *Cingulochitina* species occur abundantly throughout the biozone: *Cingulochitina wronai* Paris & Kříž (Fig. 9M), *C. hedei* Laufeld (Fig. 9V), *Cingulochitina* sp. 1 (Fig. 9S) as well as *C. gorstyensis* and *C. convexa*. The facies control on *Cingulochitina* species is obvious, as they are completely missing in the Ohesaare core and occur only sparsely in the Ventspils core. The chitinozoan assemblage of this biozone is better represented in the Pavilosta and Dubovskoye cores. *Ancyrochitina pedavis* Laufeld (Fig. 9U), *Ramochitina villosa* Laufeld (Fig. 9P), and *Pterochitina perivelata* Eisenack (Fig. 10E) appear in the lowermost part of the Pagegai Formation in the Pavilosta core. The same species are present in the Hamra Formation on Gotland, also including *Eisenackitina oviformis* Eisenack (Fig. 10D), which appears in a somewhat higher level in Pavilosta. *Angochitina paucispinosa* Miller, Sutherland & Dorning (Fig. 10B, C) is known from the Ludfordian of the Clun area, Shropshire (Miller et al. 1997). It occurs in the Ohesaare, Dubovskoye, and Pavilosta cores within the overlying *Eisenackitina barrandei* Biozone. *Angochitina crassispina* Eisenack (Fig. 10A) is found only sporadically. Atypical specimens of *Eisenackitina elongata* Eisenack (Fig. 9R) are represented in the Pavilosta and Dubovskoye cores, *Calpichitina squamosa* (Laufeld) (Fig. 9E) and

Angochitina aff. *echinata* Eisenack (which has spines with wide bases) (Fig. 9I) have been identified in the Dubovskoye core, and *Sphaerochitina acanthifera* Eisenack (Fig. 9F) is found only in the Pavilosta core. The last two species are characteristic of the Eke Formation of Gotland.

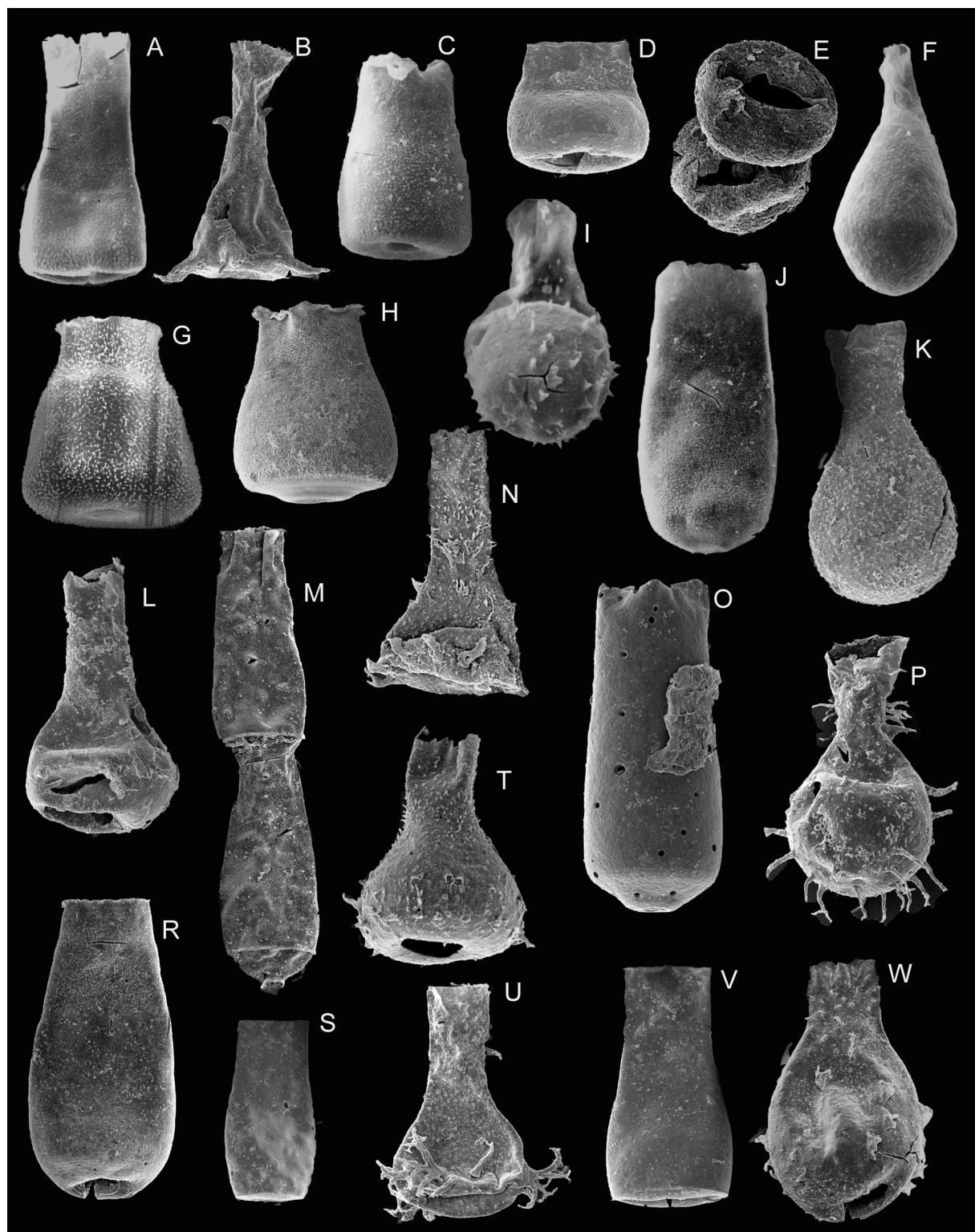
In addition, some species kept in open nomenclature are also identified from the *E. lagenomorpha* Biozone: *Belonechitina* sp. 1 (Fig. 9J), *Sphaerochitina* sp. (Fig. 9K), *Belonechitina* sp. 2 (Fig. 9O), *Ramochitina* sp. (Fig. 9W), and *Plectochitina* sp. (Fig. 10F).

The *Eisenackitina barrandei* Biozone

The index species, *Eisenackitina barrandei* Paris & Kříž (Fig. 10G) has been described from the uppermost Ludlow of the Prague Basin (Paris & Kříž 1984). In the East Baltic this species is best represented in deep-water silt- and mudstones of the Pavilosta and Dubovskoye cores, in the upper parts of the Pagegai and Uljanov formations, respectively.

The assemblage of chitinozoans in the *E. barrandei* Biozone in its type area (Kříž et al. 1986) is similar to the corresponding assemblage in the East Baltic upper Ludlow sections. *Angochitina echinata* occurs in all studied drill cores, *Ancyrochitina pedavis* in Pavilosta. *Sphaerochitina sphaerocephala* (Eisenack) (Fig. 10M) is best represented in the upper part of the biozone in the Pavilosta and Ohesaare cores. *Eisenackitina intermedia*, *E. oviformis* (Eisenack) (Fig. 10D), and *E. lagenomorpha* occur in all studied sections, but more abundantly in the Pavilosta core. These species are also found in the Hamra and Sundre formations of Gotland

Fig. 8. Selected chitinozoan species. **A**, *Angochitina elongata* Eisenack 1931, GIT 576-1, Ventspils core, depth 536 m, Engure Formation, $\times 220$. **B**, **C**, *Angochitina ambrosi* Schweineberg 1987; B, GIT 576-2, Ohesaare core, depth 117.05–117.15 m, Paadla Stage, $\times 310$; C, surface detail of GIT 576-3, Ventspils core, depth 560 m, $\times 1400$. **D**, *Ancyrochitina brevispinosa* Eisenack 1968, GIT 576-4, Ohesaare core, depth 118 m, Paadla Stage, $\times 200$. **E**, *Sphaerochitina impia* Laufeld 1974, GIT 576-5, Ohesaare core, depth 118 m, Paadla Stage, $\times 200$. **F**, *Angochitina echinata* Eisenack 1931, GIT 576-6, Pavilosta core, depth 750.30–750.60 m, $\times 240$. **G**, *Ramochitina spinipes* (Eisenack 1964), GIT 576-7, Pavilosta core, depth 796–796.40 m, $\times 250$. **H**, *Ancyrochitina desmea* Eisenack 1964, GIT 576-8, Ventspils core, depth 573 m, Dubysa Formation, $\times 270$. **I**, *Ancyrochitina diabolus* (Eisenack 1937), GIT 576-9, Ohesaare core, depth 112.60–112.70 m, $\times 350$. **J**, *Ancyrochitina gogginensis* Sutherland 1994, GIT 576-10, Pavilosta core, depth 771–771.30 m, $\times 230$. **K**, *Ancyrochitina brevis* Taugourdeau & de Jekhowsky 1960, GIT 576-11, Ventspils core, depth 532 m, $\times 275$. **L**, *Conochitina rudda* Sutherland 1994, GIT 576-12, Ohesaare core, depth 118 m, $\times 220$. **M**, *Conochitina pachycephala* Eisenack 1964, GIT 576-13, Pavilosta core, depth 821–821.40 m, $\times 195$. **N**, *Conochitina claviformis* Eisenack 1931, GIT 576-14, Pavilosta core, depth 804.30–804.60 m, $\times 200$. **O**, *Conochitina tuba* Eisenack 1932, GIT 576-15, Pavilosta core, depth 821–821.40 m, $\times 230$. **P**, *Belonechitina latifrons* (Eisenack 1964), GIT 576-16, Ohesaare core, depth 110.44 m, $\times 300$. **R**, *Belonechitina lauensis* (Laufeld 1974), GIT 576-17, Pavilosta core, depth 804.30–804.60 m, $\times 230$. **S**, *Belonechitina mortimerensis* Sutherland 1994, GIT 576-18, Pavilosta core, 749–749.30 m, $\times 120$. **T**, *Cingulochitina convexa* (Laufeld 1974), GIT 576-19, Pavilosta core, depth 733.30–733.40 m, $\times 250$. **U**, *Cingulochitina gorstyensis* Sutherland 1994, GIT 576-20, Pavilosta core, depth 796–796.40 m, $\times 190$. **V**, *Linochitina erratica* (Eisenack 1931), GIT 576-21, Pavilosta core, depth 821–821.40 m, $\times 235$. **W**, *Ramochitina swifti* (Sutherland 1994), GIT 576-22, Ventspils core, depth 536 m, $\times 255$. **X**, *Eisenackitina kerria* Miller, Sutherland & Dorning 1997, GIT 576-23, Pavilosta core, depth 775–775.30 m, $\times 185$. **Y**, *Eisenackitina intermedia* (Eisenack 1955), GIT 576-24, Pavilosta core, depth 804.30–804.60 m, $\times 280$. **Z**, *Eisenackitina toddingensis* Sutherland, GIT 576-25, Pavilosta core, depth 758–758.30 m, $\times 220$.



(Laufeld 1974). *Calpichitina gregaria* Paris & Kříž (Fig. 10P) has been identified in the Dubovskoye core. Atypical specimens of *Ancyrochitina ansarviensis* Laufeld (Fig. 10J) are recorded in the Pavilosta core and *Belonechitina?* cf. *granosa* (Laufeld) (Fig. 10L) is present in all studied cores, except the Dubovskoye core. Some taxa with open nomenclature are also identified in the *E. barrandei* Biozone, mainly in the Pavilosta core: *Plectochitina* sp. (Fig. 10H), *Ramochitina* sp. 2 (Fig. 10I), *Eisenackitina* sp. 3 (Fig. 10R), *Eisenackitina* sp. 4 (Fig. 10O), and *Belonechitina* sp. 3 (Fig. 10N) in the Ventspils core.

The lower boundary of the *E. barrandei* Biozone is fixed by the appearance of the index species. V. Nestor (1990) and Grahn (1996) distinguished the *Sphaerochitina sphaerocephala* Biozone in the topmost Ludlow. This zone can be traced in the Ohesaare and Pavilosta cores, but not in the other studied sections.

In the Ventspils core the Lau Event, related to intense extinction of chitinozoans, has been established in the topmost Mituva Formation (Kaljo et al. 1998), roughly in the depth interval 460–470 m (Fig. 4). It coincides with the lowermost part of the *E. barrandei* Biozone and is characterized by the disappearance of 14 chitinozoan species. Above the layers barren of chitinozoans at the boundary of the Mituva and Ventspils formations, only three species reappeared. In general, chitinozoans are scarce in the whole of the Ventspils Formation. In the Ohesaare core a stratigraphic gap corresponds to the Lau Event (Kaljo et al. 1997).

RELATIONS BETWEEN CHITINOZOAN, MICROVERTEBRATE, AND CONODONT OCCURRENCES IN THE OHESAARE CORE

Vertebrate microfossils (scales), conodonts, and chitinozoans have been studied in the same East Baltic

cores, permitting comparison of their ranges. The distribution of all three microfossil groups is facies controlled, as was proved by the integrated study of the Ohesaare, Ventspils, and Pavilosta cores (Kaljo et al. 1986). Although many samples lack chitinozoans in the Ludlow strata of the Ohesaare core, this section still offers the best opportunity for comparison of the zonal successions of vertebrates (Märss 1986; Märss & Miller 2004), conodonts (Viira 1982; Viira & Aldridge 1998), and chitinozoans (Fig. 11).

According to Märss (1986, fig. 41), the lowermost Ludlow strata (113.40–124.4 m) are barren or contain only scarce fragments of vertebrates. Upwards the zonal species appear successively: *Phlebolepis ornata*, *P. elegans*, *Andreolepis hedei*, *Thelodus sculptilis*, and *T. admirabilis*. In the Ohesaare core two zonal boundaries of vertebrates coincide with those of chitinozoans: (1) *Andreolepis hedei*, appearing at 99.50 m, correlates with the *Eisenackitina lagenomorpha* Biozone boundary and (2) *T. admirabilis*, appearing at 83.10 m, correlates with the *Eisenackitina barrandei* Biozone boundary. The richest assemblage of vertebrates occurs in the lower part of the Kuressaare Formation, whereas the chitinozoan assemblages are the most diverse and abundant in the lower part of the Torgu Formation.

The succession of conodonts in the Ohesaare core was published by Viira (1982). Later, Viira & Aldridge (1998, figs 5, 6) provided more precise distribution of conodont species in the Ludlow of the Ohesaare core. In the Paadla Stage they established the *Ozarkodina snajdri snajdri* and *O. crispa* biozones, and the *O. snajdri parasnajdri* Biozone in the Kuressaare Stage. No direct criteria for correlation of chitinozoan and conodont biostratigraphical units have been observed. The zonal species of conodonts and vertebrates appear more closely tied in the Ohesaare core: *O. s. parasnajdri* (at 93.40 m) and *Thelodus sculptilis* (95.15 m), as well as *Phlebolepis ornata* (112.25 m) and *O. s. snajdri* (113.35 m).

Fig. 9. Selected chitinozoan species. A, *Eisenackitina clunensis* Miller, Sutherland & Dorning 1997, GIT 576-26, Pavilosta core, depth 779 m, $\times 270$. B, *Plectochitina* sp., GIT 576-27, Ventspils core, depth 484.50 m, $\times 245$. C, *Eisenackitina* sp. 1, GIT 576-28, Pavilosta core, depth 775 m, $\times 230$. D, *Eisenackitina* sp. 2, GIT 576-29, Pavilosta core, depth 767–767.30 m, $\times 260$. E, *Calpichitina squamosa* (Laufeld 1974), GIT 576-30, Dubovskoye core, depth 1304.40 m, $\times 270$. F, *Sphaerochitina acanthifera* Eisenack 1955, GIT 576-31, Pavilosta core, depth 739 m, $\times 270$. G, *Eisenackitina lagenomorpha* (Eisenack 1931), GIT 576-32, Ohesaare core, depth 89.30 m, $\times 330$. H, *Eisenackitina philipi* Laufeld 1974, GIT 576-33, Pavilosta core, depth 746.70–747 m, $\times 220$. I, *Angochitina aff. echinata* Eisenack 1931, GIT 576-34, Dubovskoye core, depth 1299 m, $\times 280$. J, *Belonechitina* sp. 1, GIT 576-35, Pavilosta core, depth 779 m, $\times 310$. K, *Sphaerochitina* sp., GIT 576-36, Dubovskoye core, depth 1284 m, $\times 315$. L, *Sphaerochitina* sp., GIT 576-37, Pavilosta core, depth 796–796.40 m, $\times 350$. M, *Cingulochitina wronai* Paris & Kříž 1984, GIT 576-38, Dubovskoye core, depth 1311.20–1311.50 m, $\times 280$. N, *Ramochitina?* sp. 1, GIT 576-39, Ventspils core, depth 532 m, $\times 295$. O, *Belonechitina* sp. 2, GIT 576-40, Ventspils core, depth 516 m, $\times 365$. P, *Ramochitina villosa* (Laufeld 1974), GIT 576-41, Pavilosta core, depth 736–736.50 m, $\times 360$. R, *Eisenackitina elongata* Eisenack 1972, GIT 576-42, Pavilosta core, depth 711–711.30 m, $\times 215$. S, *Cingulochitina* sp. 1, GIT 576-43, Dubovskoye core, depth 1296 m, $\times 275$. T, *Ramochitina* sp. 2, GIT 576-44, Ventspils core, depth 521.30 m, $\times 315$. U, *Ancyrochitina pedavis* Laufeld 1974, GIT 576-45, Pavilosta core, depth 650.60–651 m, $\times 205$. V, *Cingulochitina hedei* Laufeld 1974, GIT 576-46, Dubovskoye core, depth 1299 m, $\times 265$. W, *Ramochitina* sp., GIT 576-47, Dubovskoye core, depth 1296 m, $\times 260$.

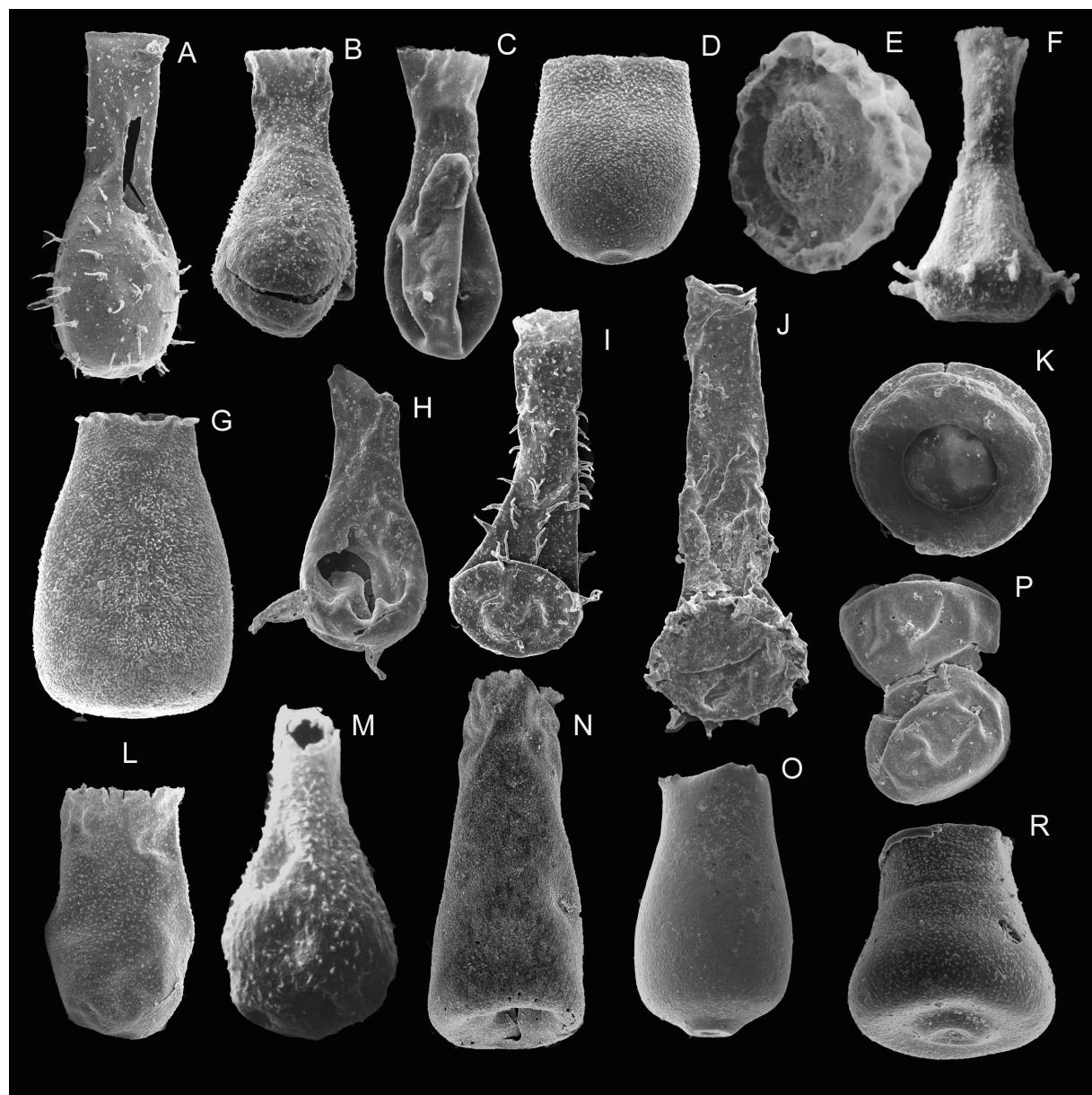


Fig. 10. Selected chitinozoan species. **A**, *Angochitina crassispina* Eisenack 1964, GIT 576-48, Ventspils core, depth 476.7 m, $\times 290$. **B**, **C**, *Angochitina paucispinosa* Miller, Sutherland & Dorning 1997, B, GIT 576-49, Pavilosta core, depth 620.20–620.50 m, $\times 310$; C, GIT 576-50, Ohesaare core, depth 86.30 m, $\times 320$. **D**, *Eisenackitina oviformis* (Eisenack 1972), GIT 576-51, Pavilosta core, 676.40–676.80 m, $\times 370$. **E**, *Pterochitina perivelata* (Eisenack 1937), GIT 576-52, Dubovskoye core, depth 1257 m, $\times 330$. **F**, *Plectochitina* sp., GIT 576-53, Dubovskoye core, depth 1257 m, $\times 280$. **G**, *Eisenackitina barrandei* Paris & Kříž 1984, GIT 576-54, Pavilosta core, depth 695–695.50 m, $\times 260$. **H**, *Plectochitina* sp., GIT 576-55, Pavilosta core, depth 684.30–684.60 m, $\times 250$. **I**, *Ramochitina* sp. 2, GIT 576-56, Pavilosta core, depth 653–653.40 m, $\times 190$. **J**, *Ancyrochitina ansarviensis* Laufeld 1974 (*sensu* Sutherland), GIT 576-57, Pavilosta core, depth 644.60–645 m, $\times 220$. **K**, *Calpichitina cf. hemsiensis* (Laufeld 1974), GIT 576-58, Pavilosta core, depth 641.20–641.50 m, $\times 300$. **L**, *Belonechitina?* cf. *granosa* (Laufeld 1974), GIT 576-59, Ventspils core, depth 476.70 m, $\times 325$. **M**, *Sphaerochitina sphaerocephala* (Eisenack 1932), GIT 576-60, Ohesaare core, depth 72.95–73 m, $\times 300$. **N**, *Belonechitina* sp. 3, GIT 576-61, Ventspils core, depth 472 m, $\times 275$. **O**, *Eisenackitina* sp. 4, GIT 576-62, Pavilosta core, depth 623.20–623.50 m, $\times 250$. **P**, *Calpichitina gregaria* Paris & Kříž 1984, GIT 576-63, Dubovskoye core, depth 1246.60 m, $\times 300$. **R**, *Eisenackitina* sp. 3, GIT 576-64, Pavilosta core, depth 626.20–626.40 m, $\times 300$.

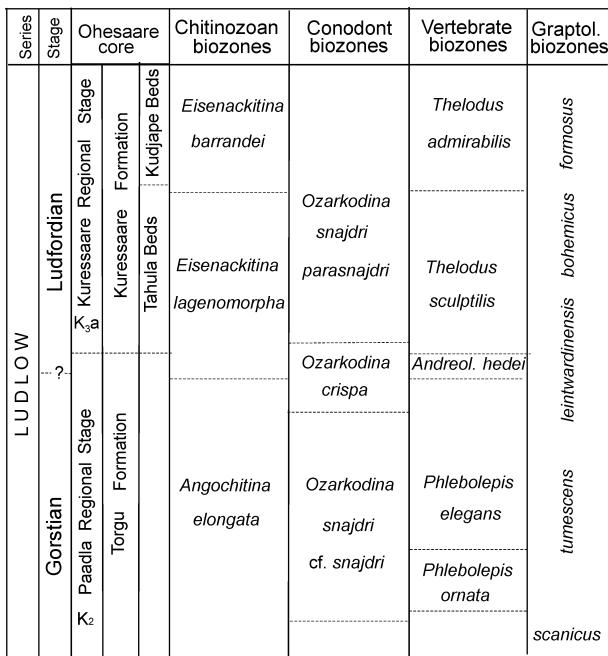


Fig. 11. Correlation chart of the chitinozoan, conodont, and vertebrate biozones in the Ludlow of the Ohesaare drill core.

CONCLUSIONS

1. Chitinozoans are well represented in the studied core sections with the highest diversity in the deepest-water Pavilosta core (57 species).
2. In most sections the Wenlock species range into the *Angochitina elongata* Biozone, except in the Ohesaare core, where a sedimentation gap exists in the early Ludlow.
3. Many chitinozoan species, previously known only from Avalonia (Welsh Basin) and Gondwana (Prague Basin, Palencia), were for the first time identified in Baltic sections.
4. *Pterochitina perivelata* has its first appearance in the *E. lagenomorpha* Biozone earlier than previously supposed (Verniers et al. 1995).
5. The Lau Event, recognized in the uppermost part of the Mituva Formation in the Ventspils core (Kaljo et al. 1998), coincides with the lowermost part of the *E. barrandei* Biozone, characterized by the disappearance of 14 chitinozoan species.
6. Several chitinozoan and vertebrate zonal boundaries coincide in the Ludlow of the Ohesaare core.

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REFERENCES

- Calner, M. & Eriksson, M. J. 2006. Evidence for rapid environmental changes in low latitudes during the Late Silurian Lau Event: the Burgen-1 drillcore, Gotland, Sweden. *Geological Magazine*, **143**, 15–24.
- Dorning, K. J. 1981. Silurian Chitinozoa from the type Wenlock and Ludlow of Shropshire, England. *Review of Palaeobotany and Palynology*, **34**, 205–208.
- Eisenack, A. 1931. Neue Mikrofossilien des baltischen Silurs I. *Palaeontologische Zeitschrift*, **13**, 74–118.
- Eisenack, A. 1964. Mikrofossilien aus dem Silur Gotlands. Chitinozoen. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **120**, 308–342.
- Eisenack, A. 1970. Mikrofossilien aus dem Silur Estlands und der Insel Ösel. *GFF*, **92**, 302–322.
- Gailite, L., Ulst, R. & Yakovleva, V. 1987. *Stratotipicheskie i tipovye razrezy silura Latvii [Stratotype and type sections of the Silurian of Latvia]*. Zinatne, Riga, 182 pp. [in Russian].
- Grahn, Y. 1996. Upper Silurian (Upper Wenlock–Lower Pridoli) Chitinozoa and biostratigraphy of Skåne, southern Sweden. *GFF*, **118**, 237–250.
- Grahn, Y. 2005. Silurian and Lower Devonian chitinozoan taxonomy and biostratigraphy of the Trombetas Group, Amazonas Basin, northern Brazil. *Bulletin of Geosciences*, **80**, 245–276.
- Jaglin, J. C. & Paris, F. 2002. Biostratigraphy, biodiversity and palaeogeography of late Silurian chitinozoans from A1-61 borehole (north-western Libya). *Review of Palaeobotany and Palynology*, **118**, 335–358.
- Jeppsson, L. & Aldridge, R. J. 2000. Ludlow (late Silurian) oceanic episodes and events. *Journal of Geological Society*, **157**, 1137–1148.
- Jeppsson, L., Viira, V. & Männik, P. 1994. Silurian conodont-based correlation between Gotland (Sweden) and Saaremaa (Estonia). *Geological Magazine*, **131**, 201–218.
- Kaljo, D. & Martma, T. 2006. Application of carbon isotope stratigraphy to dating the Baltic Silurian rocks. *GFF*, **128**, 123–129.
- Kaljo, D. & Paškevičius, J. 1993. Practice of biozonal stratigraphy in the East Baltic. *Geologija (Vilnius)*, **14**, 34–44 [in Russian, with English summary].
- Kaljo, D. & Sarv, L. 1976. Stratigraphy of the upper Silurian section of the Dubovskoje boring (Kaliningrad region). *Eesti NSV Teaduste Akadeemia Toimetised, Keemia, Geoloogia*, **25**, 325–333 [in Russian, with English summary].
- Kaljo, D., Viira, V., Märss, T. & Nestor, V. 1986. The nekton, nektobenthic and planktic communities (fishes, agnathans, conodonts, graptolites, chitinozoans) of the East Baltic Silurian. In *Theory and Practice of Ecostratigraphy* (Kaljo, D. & Klaamann, E., eds), pp. 127–136. Valgus, Tallinn [in Russian, with English summary].
- Kaljo, D., Kiipli, T. & Martma, T. 1997. Carbon isotope event markers through the Wenlock–Pridoli sequence at Ohesaare (Estonia) and Priekule (Latvia). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **132**, 211–223.

- Kaljo, D., Kiipli, T. & Martma, T. 1998. Correlation of carbon isotope events and environmental cyclicity in the East Baltic Silurian. In *Silurian Cycles – Linkages of Dynamic Stratigraphy with Atmospheric, Oceanic and Tectonic Changes* (Landing, E. & Johnson, M., eds), *New York State Museum Bulletin*, **491**, 297–312.
- Koren, T. N. & Suyarkova, A. A. 2007. Silurian graptolite biostratigraphy of the Kaliningrad district, northwest Russia. *Acta Palaeontologica Sinica*, **46**, 232–235.
- Kříž, J., Jaeger, H., Paris, F. & Schönlau, H. P. 1986. Pridoli – the fourth subdivision of the Silurian System. *Jahrbuch der Geologischen Bundesanstalt*, **129**, 291–360.
- Laufeld, S. 1974. Silurian Chitinozoa from Gotland. *Fossils and Strata*, **5**, 1–130.
- Männil, R. 1982. Wenlock and Late Silurian trilobite associations of the East Baltic area and their stratigraphical value. In *Ecostratigraphy of the East Baltic Silurian* (Kaljo, D. & Klaamann, E., eds), pp. 63–69. Academy of Sciences of the Estonian SSR, Tallinn.
- Märss, T. 1986. *Silurian Vertebrates of Estonia and West Latvia*. Valgus, Tallinn, 104 pp. [in Russian, with English summary].
- Märss, T. & Miller, C. G. 2004. Thelodonts and distribution of associated conodonts from the Llandovery–lowermost Lochkovian of the Welsh Borderland. *Palaeontology*, **47**, 1211–1265.
- Martma, T., Brazauskas, A., Kaljo, D., Kaminskas, D. & Musteikis, P. 2005. The Wenlock–Ludlow carbon isotope trend in the Vidukle core, Lithuania, and its relations with oceanic events. *Geological Quarterly*, **49**, 223–234.
- Miller, C. G., Sutherland, J. E. & Dorning, K. J. 1997. Late Silurian (Ludlow–Pridoli) microfossils and sedimentation in the Welsh Basin near Clun, Shropshire. *Geological Journal*, **32**, 69–83.
- Morávek, R. 2007. Late Ludlovian Chitinozoa from the locality Na Požárech (Silurian, Prague Basin, Barrandian area, Czech Republic). *Review of Palaeobotany & Palynology*, **148**, 124–135.
- Nestor, H. 1990. Some aspects of lithology of the Ordovician and Silurian rocks. In *Field Meeting, Estonia. An Excursion Guidebook* (Kaljo, D. & Nestor, H., eds), pp. 27–32. Institute of Geology, Estonian Academy of Sciences, Tallinn.
- Nestor, H. 1995. Comments to the modernized Silurian correlation chart of Estonia and Latvia. *Geologija (Vilnius)*, **17**, 88–95.
- Nestor, V. 1982. Correlation of the East Baltic and Gotland Silurian by chitinozoans. In *Ecostratigraphy of the East Baltic Silurian* (Kaljo, D. & Klaamann, E., eds), pp. 89–96. Academy of Sciences of the Estonian SSR, Tallinn.
- Nestor, V. 1990. Silurian chitinozoans. In *Field Meeting, Estonia. An Excursion Guidebook* (Kaljo, D. & Nestor, H., eds), pp. 80–83. Institute of Geology, Estonian Academy of Sciences, Tallinn.
- Nestor, V. 1997. Silurian chitinozoans. In *Geology and Mineral Resources of Estonia* (Raukas, A. & Teedumäe, A., eds), pp. 212–213. Estonian Academy Publishers, Tallinn.
- Nestor, V. 2003. Distribution of Silurian chitinozoans. In *Ruhnu (500) Drill Core* (Pöldvere, A., ed.), *Estonian Geological Sections*, **5**, 13–14.
- Nestor, V. 2007. Chitinozoans in the Wenlock–Ludlow boundary beds of the East Baltic. *Estonian Journal of Earth Sciences*, **56**, 109–128.
- Paris, F. & Kříž, J. 1984. Nouvelles espèces de Chitinozoaires à la limite Ludlow/Pridoli en Tchécoslovaquie. *Review of Palaeobotany and Palynology*, **43**, 155–177.
- Sarv, L. 1982. On ostracode zonation of the East Baltic Upper Silurian. In *Ecostratigraphy of the East Baltic Silurian* (Kaljo, D. & Klaamann, E., eds), pp. 71–77. Academy of Sciences of the Estonian SSR, Tallinn.
- Schweineberg, J. 1987. Silurische Chitinozoen aus der Provinz Palencia (Kantabrisches Gebirge, N-Spanien). *Göttinger Arbeiten zur Geologie und Paläontologie*, **33**, 1–94.
- Sutherland, S. J. E. 1994. Ludlow chitinozoans from the type area and adjacent regions. *Palaeontographical Society Monograph*, **591**, 1–104.
- Verniers, J., Nestor, V., Paris, F., Dufka, P., Sutherland, S. & Van Grootel, G. 1995. A global Chitinozoa biozonation for the Silurian. *Geological Magazine*, **132**, 651–666.
- Verniers, J., Van Grootel, G., Louwye, S. & Diependaele, B. 2002. The chitinozoan biostratigraphy of the Silurian of the Ronquières-Monstreux area (Brabant Massif, Belgium). *Review of Palaeobotany and Palynology*, **118**, 287–322.
- Viira, V. 1982. Late Silurian shallow and deep water conodonts. In *Ecostratigraphy of the East Baltic Silurian* (Kaljo, D. & Klaamann, E., eds), pp. 79–87. Academy of Sciences of the Estonian SSR, Tallinn.
- Viira, V. & Aldridge, J. 1998. Upper Wenlock to Lower Pridoli (Silurian) conodont biostratigraphy of Saaremaa, Estonia, and a correlation with Britain. *Journal of Micropalaeontology*, **17**, 33–50.
- Viira, V. & Einasto, R. 2003. Wenlock–Ludlow boundary beds and conodonts of Saaremaa Island, Estonia. *Proceedings of the Estonian Academy of Sciences, Geology*, **52**, 213–238.

Ludlow' kitiinikute biostratigraafia Ida-Balti puuraukudes

Viiu Nestor

Kitiiniku liikide levik ja biotsoonid on kindlaks tehtud neljas Ida-Balti puuraugu Ludlow' vanusega kivimites. Lisaks varem kirjeldatud Alam-Ludlow' biotsoonidele (Nestor 2007) on selles artiklis eristatud kitiinikute *Angochitina elongata*, *Eisenackitina lagenomorpha* ja *E. barrandei* biotsoonid, neist viimane esmakordsest kogu Balti regioonis. On rööbistatud kitiinikute, konodontide ja vertebralate biotsoonid Ohesaare puuraugus.