

## The Early Ordovician trilobite distribution and zonation of the East Baltic

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Received 7 November 2005, in revised form 6 December 2005



**Abstract.** Biozones of the East Baltic Early Ordovician trilobites were studied based on the trilobite distribution in northwestern Russia, Estonia, and Sweden. New data on trilobite distribution reveal the diachroneity of the lowest calcareous sediments of the Mäeküla Member, which forms the upper part of the Leetse Formation in the East Baltic. Trilobites of the Tremadoc *Apatokephalus serratus* and *Megistaspis (Ekeraspis) armata* biozones are missing in the East Baltic, in contradiction to the suggestion of Balashova (*Vopr. Paleontol.*, 1966, **5**, 3–22). Some poorly preserved specimens probably belonging to *Megistaspis (Paramegistaspis) planilimbata* (Angelin) and also records of *Pliomerops? linnarssoni* (Wiman) indicate that the Arenig *Megistaspis (P.) planilimbata* Biozone of the Hunneberg Stage may be represented in some localities. The final delimitation of biozones in the Mäeküla and Päite members should improve when the ontogenetic and phylogenetic variation of the *M. (Paramegistaspis)* lineage has been fully documented. Until then the *Evropeites lamanskii* Biozone is used in the East Baltic following Balashova, as indicated by the appearance of that taxon in most studied localities, marking the beginning of the Billingen Age. The succeeding *Megalaspides (Megalaspides) dalecarlicus* Biozone is represented by the occurrence of at least its upper part in the Vassilkovo Beds in the St. Petersburg region, where *Megalaspides paliformis* Tjernvik occurs together with the index taxon (these taxa co-occur in the upper part of this zone in Sweden). The Päite Member in the East Baltic is correlated with the *Megistaspis (P.) estonica* Biozone of the upper part of the Billingen Stage in Sweden.

**Key words:** trilobites, biozonation, Hunneberg, Billingen, Lower Ordovician, Baltoscandia.

### INTRODUCTION

The aim of this study was to investigate the distribution of the trilobites of the lowest part of the Ordovician limestone succession in the East Baltic and to observe their zonation in comparison with Scandinavian trilobite biozones. In the studied area trilobites are very rare in the lowest calcareous sediments of the

Ordovician succession. Fewer than 60 specimens assigned to 18 species were previously recorded from the calcareous glauconitic sandstone of the Mäeküla Member (Schmidt 1904, 1907; Lamansky 1905; Öpik 1937; Balashova 1961, 1966). Most of this material was revised by Balashova (1966). Subsequent revision showed that only 15 species of the above 18 are valid (Pärnaste 2003). The majority of specimens came from the Popovka River district close to Pavlovsk, the remainder from localities along the banks of the Tosna, Izhora, Luga, Lava, and Volkhov rivers of northwestern Russia, and only seven were from northern Estonia (NE: Päite, Toila, and Lügänuše; NW: Mäeküla and Paldiski; Fig. 1).

The trilobite distribution and zonation were used in chronostratigraphic subdivision by Lamansky (1905). He subdivided the Series B in the East Baltic into three subseries (B<sub>I</sub>, B<sub>II</sub>, and B<sub>III</sub>) and these in their turn into several stages. Two stages, B<sub>I</sub>β and B<sub>II</sub>α, include the lowermost calcareous part of the section and are treated in this paper (Fig. 2). According to Lamansky (1905), the calcareous Glauconite Sandstone (B<sub>I</sub>β) contains trilobites of the *Megalaspides* Zone and is a correlative roughly of the *Phyllograptus*-skiffer in Sweden and Norway. The overlying stage (B<sub>II</sub>α) of glauconitic limestone is characterized by the occurrence of *Megistaspis planilimbata*, *M. limbata*, and *Asaphus priscus* and is thus a correlative of the Planilimbata- and Limbatakalk in Sweden and Norway (Lamansky 1905, p. 104, table). Öpik (1937, p. 103) correlated B<sub>I</sub>β with the somewhat older Ceratopyge Limestone, and Tjernvik (1956, p. 184) suggested that B<sub>I</sub>β together with B<sub>I</sub>γ, which was established by Jaanusson (1951), may correspond to the *Megalaspides dalecarlicus* Biozone established by him in Sweden. Balashova (1966) distinguished six local trilobite zones in the East Baltic, five in B<sub>II</sub>α and one in B<sub>I</sub>β. The last was correlated with the Tremadoc *Apatokephalus serratus* Biozone. Her assumption was based on several erroneous identifications discussed below. The latest studies on trilobites suggest that the lowest part of the Ordovician calcareous succession in the East Baltic is of Billingen or partly of Hunneberg age (Pärnaste 2004a, b; Fig. 2).

The boundary between the Hunneberg and Billingen “groups” (later referred to as stages, substages or series) was placed between the *Megistaspis* (*Paramegistaspis*) *planilimbata* and *Megalaspides dalecarlicus* trilobite biozones when established



**Fig. 1.** Map of North Estonian and St. Petersburg regions showing sampled localities. The names of the sections sampled bed by bed are written in bold. The dotted line shows the Baltic-Ladoga Klint (escarpment).

Global series		East Baltic chrono- and lithostratigraphy				Trilobite zonation			Other Baltoscandian biozones		
British series		Stage	Substage	Estonia W	Ingria E	Lamansky 1905	Tjernvik 1956, 1980	Balashova 1966	Present paper	Conodonts	Graptolites
Middle	Arenig	Volkhov	B <sub>1</sub> α	Tollia Fm.	Saka Mb.	<i>Asaphus priscus</i> <i>Megalaspis limbata</i>	<i>Megistaspis (M.) lata</i>	<i>Megistaspis limbata</i>	<i>Megistaspis (M.) polyphemus</i>	<i>Baitoniodus navis</i> <i>Baitoniodus triangularis</i>	<i>Didymograptus hirundo</i>
		Volkhov	B <sub>1</sub> γ	Päite Mb.	Volkhov Fm.	<i>Megalaspis planilimbata</i>	<i>Megistaspis (V) estonica</i>	<i>Plesiomegalaspis estonica</i> <i>M. (M.) dalecarlicus balticus</i> <i>Plesiom. planilimbata rossica</i> <i>Plesiomegalaspis (E.) armata</i>	<i>Megistaspis (P.) estonica</i>	<i>Ospikodus evae</i>	
Lower Ordovician	Arenig	Billingen	B <sub>2</sub> β	Mäeküla Mb.	Vassilkovo Beds	<i>Megalaspides</i>	<i>Megalaspides (M.) dalecarlicus</i>	<i>Apatokephalus serratus</i> <i>Megalaspides (P.) schmidti</i> (with <i>Euloma ornatum</i> , <i>Pilomeroides primigenus</i> var. <i>lamanskii</i> )	<i>Megalaspides (M.) dalecarlicus</i>	<i>Prioniodus elegans</i>	<i>Phyllograptus densus</i>
		Hunneberg	B <sub>2</sub> α	Joa Mb.	Leetse Formation		<i>Megistaspis (V) aff. estonica</i>		<i>Evropeites lamanskii</i>	<i>Prioniodus elegans</i>	<i>Didymograptus balticus</i>
Tremadoc	Tremadoc	Hunneberg	B <sub>3</sub> α	Joa Mb.	Lakity Beds		<i>Megistaspis (V) planilimbata</i>		<i>Megistaspis (P.) planilimbata</i>	<i>Paroistodus proteus</i>	<i>Tetragraptus phylograptoides</i>
		Hunneberg	B <sub>3</sub> α	Joa Mb.	Lakity Beds		<i>Megistaspis (E.) armata</i>				<i>Hunnegraptus copiosus</i>
							<i>Apatokephalus serratus</i>				

**Fig. 2.** East Baltic upper Tremadoc and lower Arenig chrono- and lithostratigraphy correlated with Baltoscandian biozones. Traditional substages: a, after Lamansky (1905) and Orviku (1960); b, after Männil (1966) and Mägi et al. (1989); B<sub>1</sub>γ is used according to Jaanusson (1951) instead of B<sub>1</sub>b<sub>2</sub>P of Männil (1966). The history of the trilobite zonation in the East Baltic is shown in correlation with chrono- and lithostratigraphy and with biozones in Sweden. The dotted lines ending in an arrow show the correlation by Balashova (1966) including the Mäeküla Beds into the Tremadoc.

(Tjernvik 1956), coinciding with the lower boundary of the *Phyllograptus densus* graptolite Biozone. Later, Tjernvik (Tjernvik & Johansson 1980) agreed with Lindström (1957) that the uppermost strata of the *M. (P.) planilimbata* Biozone with a diverse fauna should be correlated with the *Didymograptus balticus* Biozone, since in several sections this “Transitional Bed” still contains some survivors from the lower succession but also the first representatives of an “*estonica* sequence”. Thus the boundary between Hunneberg and Billingen was brought down to the lower limit of a new trilobite biozone, the *Megistaspis (P.) aff. estonica* Biozone (Tjernvik & Johansson 1980). The last version is followed herein and in my earlier works (Pärnaste 2001a, b, 2003, etc.). However, Lindholm (1991b, p. 287) recommended that the Hunneberg (Series) is better used in its original extent suggested by Tjernvik in 1956, as the unit filling, in Sweden, a hiatus which occurs between Tremadoc and Arenig rocks of the type area (Wales). Since then, both versions have been used, or alternately the inclusive Latorp Stage (established by Jaanusson 1960), which amalgamates those (sub)stages.

Many relevant conodont studies are available from the study area (Mägi & Viira 1976; Mägi 1984; Bergström 1988; Mägi et al. 1989; Dronov et al. 1995, 1997a, p. 15, 1997b, p. 22; Viira et al. 2001). Correlation of Baltoscandian conodont zones with those of trilobites (Tjernvik 1956; Tjernvik & Johansson 1980) and graptolites (Cooper & Lindholm 1990; Lindholm 1991a) is mainly in agreement with Löfgren (1996). However, there are two exceptions (Fig. 2). First, the lower boundary of the *Prioniodus elegans* Biozone is slightly shifted upwards relative to that of the *M. (P.) aff. estonica* Biozone and to that of the upper subzone of the *Tetragraptus phyllograptoides* Biozone (see Löfgren 1993, 1994, 1997). This interpretation is based on the evidence of the first appearance of *Prioniodus elegans* Pander somewhat higher in sections (cf. Maletz et al. 1996, figs 4, 5). Second, the *Baltoniodus navis*–*Baltoniodus triangularis* Biozone is somewhat lowered in position with respect to the Billingen–Volkhov boundary. This follows from the evidence in sections at Ontika (Mägi 1990, fig. 38) and Aseri (Mägi 1984, fig. 1) in northeastern Estonia. Here, *B. triangularis* (Lindström), co-occurring with the zonal trilobite *M. (P.) estonica* (Tjernvik), has been identified below the “Püstakkiht” (a specific discontinuity layer with deep borings), together with *Stolodus stola* (Lindström) above the last appearance of *Oepikodus evae* Lindström and below the first appearance of *B. navis* (Lindström). However, as the conodonts may have been redeposited, this assumption should be taken with some caution.

## GEOLOGICAL SETTING

Palaeomagnetic data place the Baltica Palaeocontinent at the temperate southern latitudes in the Early Ordovician, on the eastern side of the Iapetus Ocean. The northwestern part of Baltica was influenced by the Palaeotethys Ocean and the southern part by the Tornquist Sea (Scotese & McKerrow 1990; Torsvik 1998). The Baltoscandian Palaeobasin was a cool epicontinental sea at

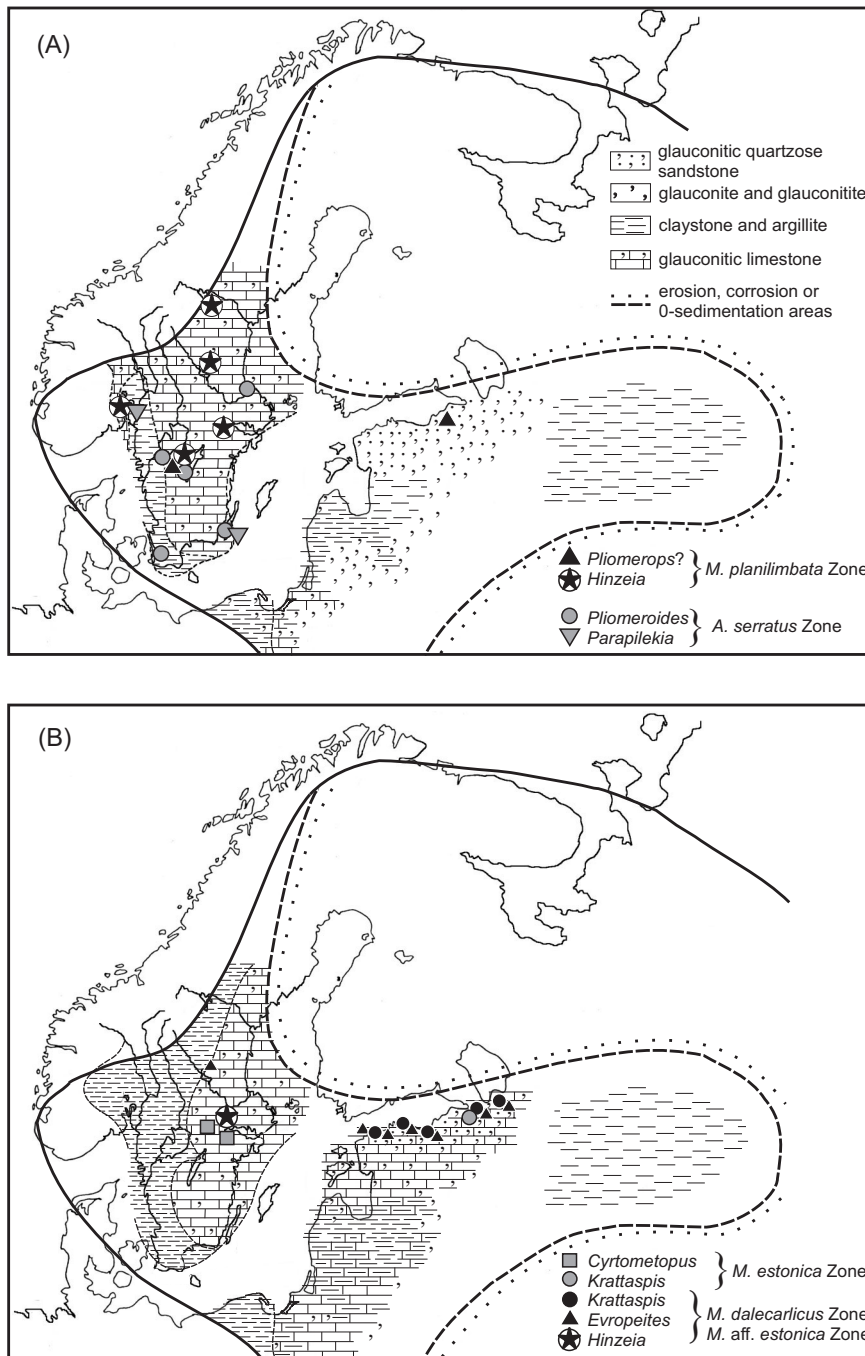
the margin of the Iapetus. Sediments of the Baltoscandian epicontinental sea show rather low rates of deposition, namely 1–3 mm/1000 years (Lindström 1971; Jaanusson 1976, 1982). Usually the Ordovician succession is less than 200 m thick, and is nearly horizontally settled. The deposits are rhythmically bedded, possessing regionally numerous breaks caused by repeated fluctuation of the sea depth, by the occurrence of submarine non-deposition or by denudation. In spite of these factors, the deposits are continuous basinwide (Jaanusson 1982). Beds are undisturbed tectonically except those in the Oslo Region, where they are folded, cleaved and thrust, reaching 500 m in thickness (Owen et al. 1990). In addition, the sparsely distributed allochthonous deposits follow the 1800 km long Caledonian front (Bruton et al. 1985). The studied area, northern Estonia and Ingria (the old province of the St. Petersburg region between the Narva and Syas rivers), constituted the shallowest part of the basin. During Hunneberg and early Billingen time, terrigenous sediments were settling in the east (Estonia and Ingria), whereas limestones, mudstones, and shales were deposited to the west (Sweden and the Oslo Region; Fig. 3).

In Estonia the Lower Ordovician succession is represented by quartzose sandstones of the Kallavere Formation, dark laminated graptolite argillites of the Türisalu Formation, and light claystone of the Varangu Formation of the Tremadoc Age, followed by glauconitic silts, sands or calcareous sandstones of the Leetse Formation, and glauconitic limestones of the Toila Formation of the Arenig Age (Männil & Meidla 1994). The earliest Ordovician trilobites occur in the Mäeküla Member, the most carbonaceous upper part of the Leetse Formation.

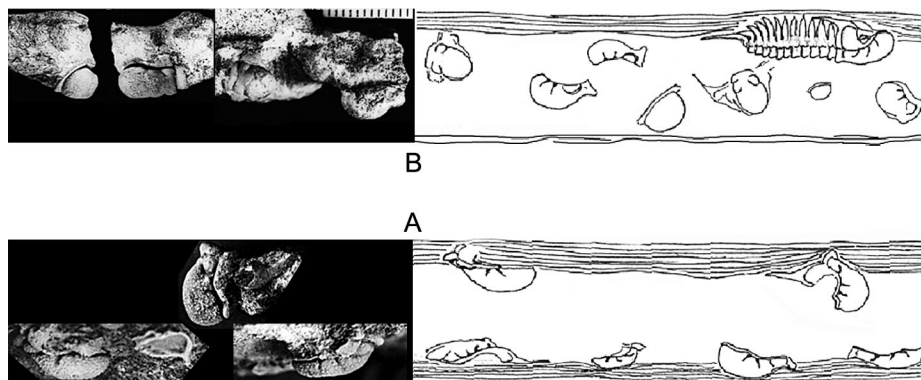
## LITHOLOGY AND TAPHONOMY

### Mäeküla Member

The Mäeküla Member consists of alternating variously dolomitized glauconitic sandstone, calcareous sandstone, and glauconitic sandy limestone, with clay laminae or layers often covering discontinuity surfaces. The common thickness of the member in outcrops is about 0.4 m. Disarticulated skeletal parts of trilobites are often preserved on the upper or lower surface of sandstone layers or nodules (at Jägala, Nõmmeveski, and Saka) covered by clay. The clay probably protected fossils from dolomitization and dissolution, which is seen elsewhere in sandy beds containing rare badly preserved moulds of asaphid fragments. Most of the testiferous cranidia of the cheirurid *Krattaspis* Öpik discovered on the surfaces (Pärnaste 2003) occur upside down and are tilted forwards, lying on the anterior glabellar lobes, or backwards, lying on the posterior glabellar lobes (Fig. 4A); often they are also tilted sideways onto the fixed cheek, probably the most stable attitude for these trilobite sclerites. This, however, is the reverse of the results of the experiment described for *Flexicalymene* Shirley (cf. Lask 1993, p. 222), in which the elements were not preserved inverted. Cephalae of *Krattaspis* are also flattened



**Fig. 3.** Facies distribution of the Baltoscandian palaeobasin (modified after Erdtmann 1965; Männil 1966; Laškovas 1968; Modlinski 1976; Erdtmann & Paalits 1994) showing cheirurin data: (A) during the Hunneberg, for comparison the Tremadoc cheirurins from the *A. serratus* Biozone are shown (grey filling); (B) during the Billingen (Pärnaste 2004b).



**Fig. 4.** Orientation of trilobites on the example of *Krattaspis*: (A) in the Mäeküla Member skeletal parts are mostly oriented upside down and lie on their anteriormost lobes (LA and L3) or on their posteriormost lobes (L2, L1, and L0) on the clayey surface; (B) in the Vassilkovo Beds the skeletal parts are non-oriented and occur throughout the entire layer (Pärnaste 2004b).

and the glabella and furrows are deformed or even distorted (see Pärnaste 2003, text-fig. 6). The deformation was probably a result of compression by relatively large sand bodies deposited during the heavy storms. The clay laminae and layers were formed during quiet periods at a very low rate of sedimentation, when the sediment was reworked by soft-bodied fauna, leaving horizontal and flattened burrows filled with clay. Some thin soft clay layers contain three-dimensional well-preserved trilobites; in claystone they are usually strongly deformed.

### Vassilkovo Beds

The trilobite sclerites are randomly orientated and occur throughout the unit (Fig. 4B), in the argillaceous glauconitic limestones of the Vassilkovo Beds (e.g. Lava section; Figs 1, 5), indicating rapid burial conditions or bioturbation (cf. Speyer 1987). The skeletal remains, varying in size, are better preserved probably due to the lower degree of dissolution within this somewhat finer-grained sediment with a higher clay content.

### Päite Member

The dolomitized limestone unit of the Päite Member is mostly 0.3–0.4 m thick in Estonia (Orviku 1958, 1960) but exceptionally thick (1.13 m) at Tõrvajõe (Orviku 1960, p. 56). The average thickness of the unit in the outcrops of Ingria is about 0.7 m (Dronov et al. 1997a, p. 15; Popov et al. 1997, p. 5; Pushkin & Popov 1999). Disarticulated sclerites of the isotelines are very abundant throughout the

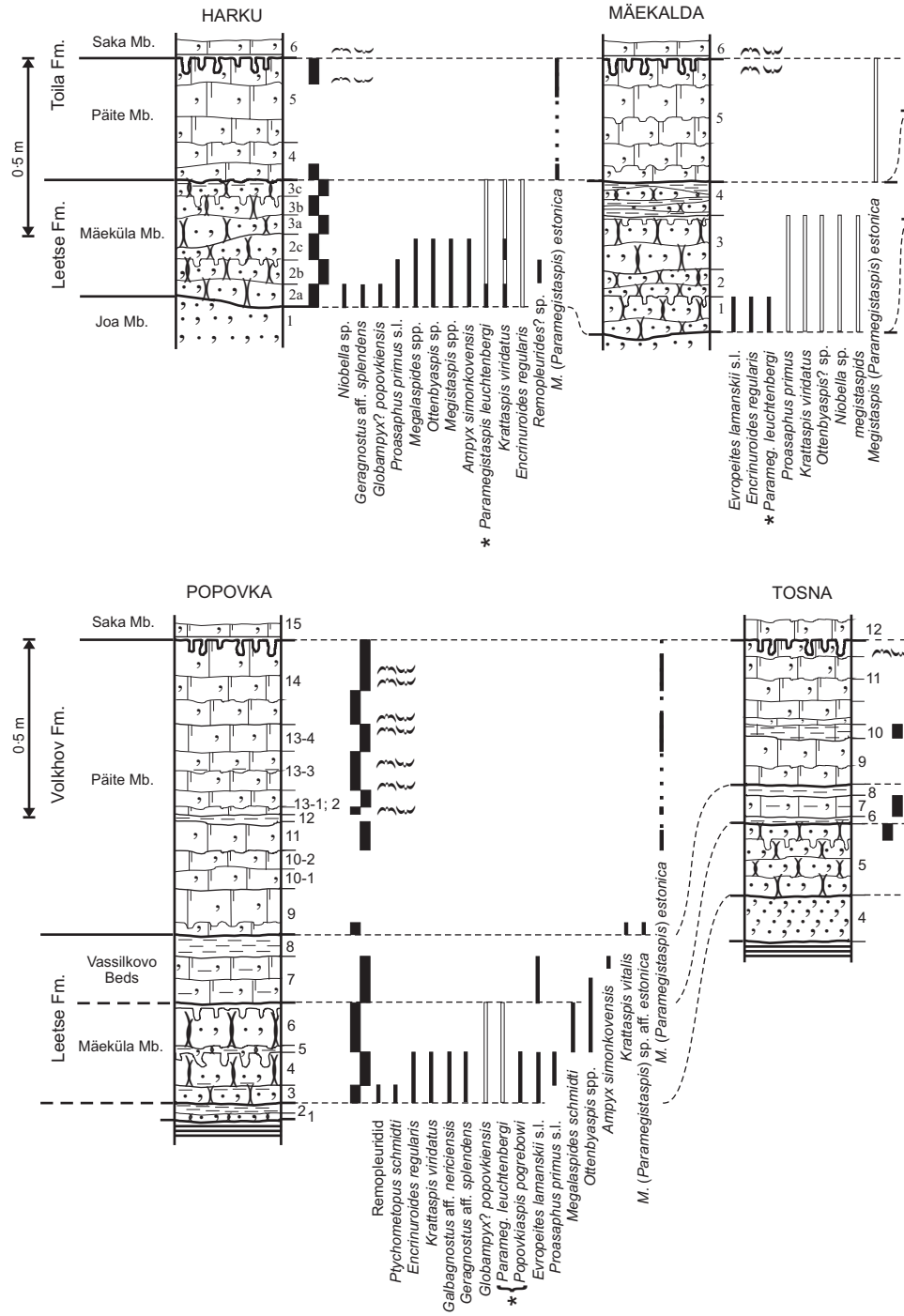


Fig. 5. Trilobite distribution in the sections studied bed by bed. Bed numbers are indicated on the right-hand side of the columns.



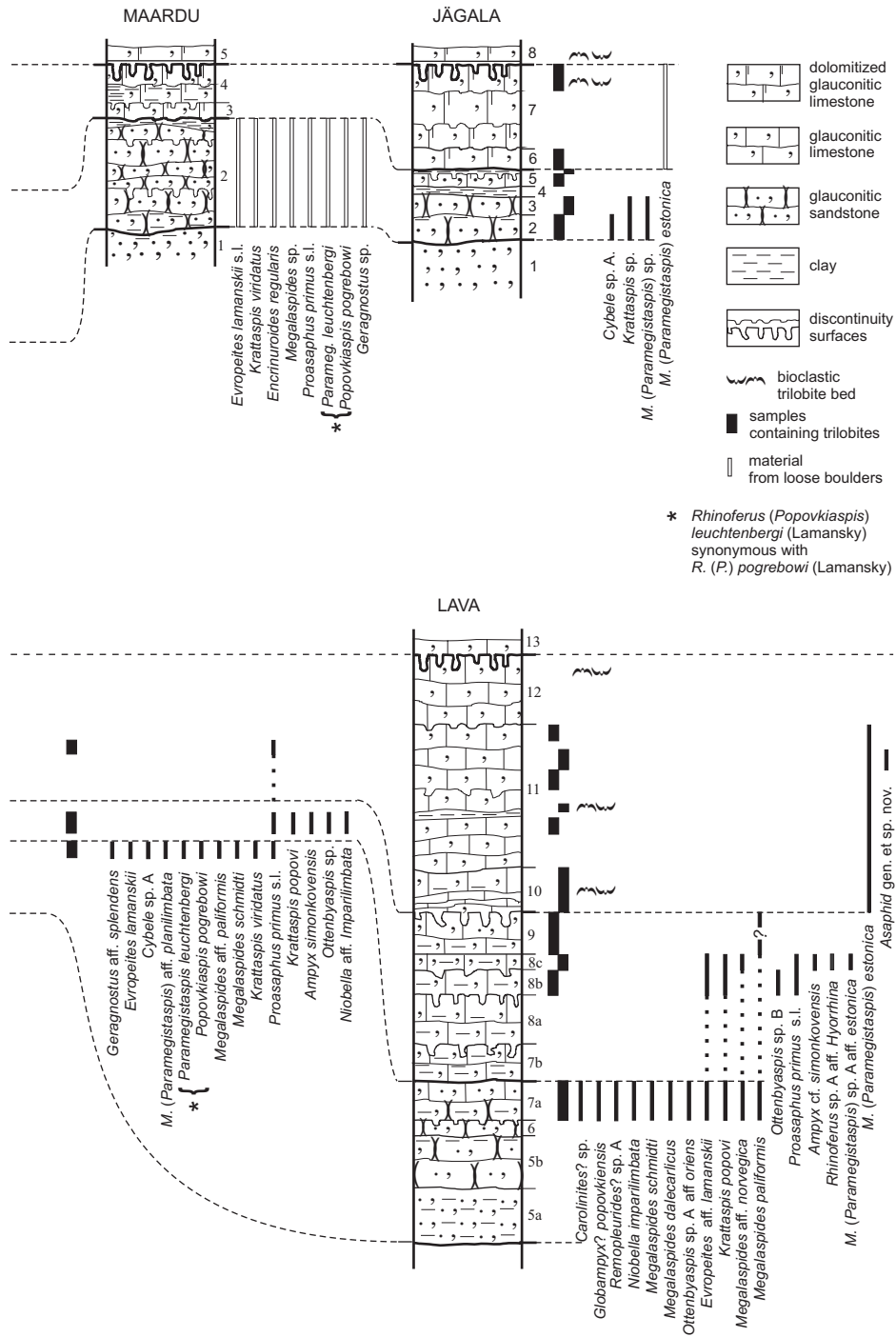


Fig. 5. Continued.

member, producing so-called trilobite cemeteries, similar to the lowest beds of the overlying Saka Member. Most commonly, the pygidia are preserved arranged horizontally, being generally oriented upside down, showing some degree of sorting processes.

## MATERIAL AND METHODS

This study was initiated by Dr Leonid Popov who kindly gave me his trilobite collection from Ingria. I collected additional material during two expeditions to Ingria in 1986–1987, and numerous spells of fieldwork in Estonia. The new collections contain about 200 cheirurine specimens published earlier (Pärnaste 2002, 2003, 2004b, 2006) as well as over 500 non-cheirurins (Aru 1990; Pärnaste 2001b), a very large number of megistaspids from the bioclastic beds of the Päite Member excluded. The trilobites were mostly collected by bed-by-bed sampling of strata in all studied localities (Fig. 1).

The thickness of the sampled beds varied from 1 to 10 cm (rarely to 15 cm; Fig. 5). The slabs of sandstone covered by clay films were brushed clean in river- or seawater to reveal the specimens exposed on top. The slabs were then mechanically broken into small pieces to recover the specimens inside. Samples from thin soft clay layers were washed through a 1-mm sieve to remove the clay, and the residue was examined under the microscope in the laboratory. Some layers were barren but some contained a rich variety of skeletal elements (trilobites, brachiopods, ostracods, bryozoans, echinoderms, and conodonts). In addition, exoskeletons of trilobites exposed by weathering were found on loose boulders at the localities where trilobites of the Mäeküla Member were preserved on the outer surface of the particular beds. As the lithology of the different beds of these thin members is easily recognizable, it was possible to estimate roughly the stratigraphic level of these slabs.

## TRILOBITE DISTRIBUTION

The East Baltic trilobite assemblage of the Mäeküla Member is slightly more diverse near its base than higher and in the Vassilkovo Beds, but is considerably diverse compared to the almost monospecific association of the overlying Päite Member (Fig. 5). However, the latter member is also far less studied. In contrast, the number of specimens increases upwards. A similar trend is described also for the Hagastrand Member limestones of the Hunneberg Stage in the Oslo Region (Hoel 1999).

Compared to the contemporaneous trilobite association in Norway and Sweden several newcomers appear in the East Baltic in addition to the genera spread over the basin. The near-shore environment favoured the appearance of the following

taxa: the encrinurids *Encrinuroides* Reed and *Cybele* Loven, a cheirurid *Krattaspis*, a pilekiid *Evropeites* Balashova, and a pharostomatid *Ptychometopus* Schmidt. Of those, *Encrinuroides regularis* Pärnaste is the earliest representative of the Encrinurinae: the lineage, which disappeared from Baltoscandia shortly after Billingen time and reappeared not before Oandu time (Pärnaste 2004b, 2006). Also *Krattaspis* is a stem-group for the Cyrtometopinae Öpik, 1937 (Pärnaste 2003), which evolves in Baltoscandia up to the Keila Age (Pärnaste 2004a). *Krattaspis viridatus* Öpik occurs usually in the lowest beds of the Mäeküla Member, but *K. popovi* Pärnaste appears in a slightly finer-grained sediment above it (see the Tosna section, Fig. 5). The latter occurs in both the Mäeküla and Vassilkovo beds in the Lava section, where the grain size of the Mäeküla beds is somewhat finer as compared to that in the Popovka or Mäekalda sections; the difference in grain-size hints at the possibility that *K. popovi* might be a facies-related species. However, ontogenetic study reveals evolutionary trends, showing the ancestry of *K. viridatus*. Evolution continues towards *K. vitalis* Pärnaste in the lowest part of the Päite Member and more extensively towards *Cyrtometopus priscus* Tjernvik, which ranges in the upper part of the Billingen Stage in Sweden. *Cyrtometopus Angelin* occurs in the Volkhov and Kunda stages, as well as *Cybele*. The pilekiid *Evropeites lamanskii* (Schmidt) is quite common in the lowest beds of the Mäeküla Member. A slightly different form of it is found from the same member in the Lava section. *Evropeites* itself is very rare elsewhere in Baltoscandia. Only one specimen of *Evropeites toernquisti* (Holm) has been reported from the Billingen Stage in Sweden (Holm 1882) and there are no other records from younger beds or from outside Baltoscandia. Another rare taxon known from the lowest part of the Mäeküla Member is a pharostomatid, *Ptychometopus schmidtii* Balashova, which is closely related to *Ptychometopus volborthi* Schmidt of the Volkhov Stage. The earliest pharostomatids occur in the Tremadoc of Avalonia, Gondwana, and Southern China (Peng 1990, pp. 72, 117). Two other obscure taxa, the Hunnebergian *Celmus? insolita* (Tjernvik) from Sweden and the Volkhovian *Celmus? longifrons* Poulsen from Bornholm, Denmark, deserve further attention as they resemble *Ptychometopus*. Unfortunately, these taxa are only known from their cranidia, which allows no confident assessment.

One fragmentary cranidium of the globally distributed pelagic *Carolinites* Ross was collected in the Lava section in addition to the specimen in Popovka (Balashova 1961). Another representative of the pelagic realm, a remopleuridid, occurs in the lowest trilobite beds of the same localities.

A few rare agnostids (*Arthrorhachis* Hawle & Corda, *Galbagnostus* Whittington, and *Geragnostus* Howell) were also collected from the lowest beds of the Mäeküla Member. These show some affinities with the material described from the shale and limestone beds in the western part of the basin (Tjernvik 1956; Ahlberg 1992). The agnostids and the following groups are under taxonomic revision and are mentioned here as preliminary records. Raphiophorids are relatively

common; at most localities *Globampyx? popovkiensis* Balashova appears first, followed by *Ampyx simonkovensis* Balashova, which much resembles *Lonchodomas* Angelin. The endemic asaphid *Proasaphus* Balashova is of similar frequency to raphiophorids, ranging from the Mäeküla to Vassilkovo beds, and has also been collected in Sweden (figured as genera et species indet. by Tjernvik 1956, pl. 10, figs 7, 8). *Proasaphus* is possibly the ancestor of *Asaphus* Brongniart (Tjernvik 1956, p. 259) and also of *Onchometopus* Schmidt, both occurring in the Toila/Volkhov formations just above the Leetse Formation. *Proasaphus* also resembles *Aulacoparia* Hintze & Jaanusson from the Fillmore Formation of Utah (Tjernvik 1956, p. 259), and somewhat *Norasaphus* Fortey & Shergold from the Nora Formation in Australia, both from the Lower Ordovician.

Two isoteline taxa, one previously described as *Megalaspis leuchtenbergi* Lamansky and the other as *Megalaspis pogrebovi* Lamansky (1905), co-occur in the lowest nodular beds of several localities (Maardu, Nõmmeveski, Popovka, and Tosna; Fig. 5). The former species was later assigned to *Paramegistaspis* Balashova and the latter to *Rhinoferus? (Popovkiaspis)* Balashova (1976). Apparently they are conspecific and belong to *Rhinoferus* Balashova, differing from its younger relatives in having, analogously to all other Hunnebergian–Billingenian isotelines, ill-defined furrows on the posterior parts of the glabella. Of the more common species, *Megalaspides paliformis* Tjernvik and *M. dalecarlicus* (Holm) are known from the upper part of the Mäeküla and in the Vassilkovo beds, but usually absent from the lowermost part of the former unit; other rare *Megalaspides* species are found in the lowest beds. *Megistaspis (Paramegistaspis)* ranges through the studied section, being very sparse at the beginning, but very common in the top. Additionally, some other poorly preserved, obscure isotelines were described by Balashova in 1966 as *M. (P.) planilimbata rossica*, *M. (P.) putilovensis*, *M. (P.) popovkiensis*, and *Megalaspides (Lannacus) popovkiensis*. The species *M. (P.) popovkiensis* and *M. (P.?) scutata* Tjernvik show several similarities to *Megistaspis (Megistaspis)* Jaanusson, being likely ancestors of the latter. Similarly, *Megalaspides (L.) popovkiensis* is the possible ancestor of *Rhinoferus (Lawiaspis)* Balashova, and is rather different from *Megalaspides* itself. Also *Megalaspides (M.) dalecarlicus balticus* Balashova apparently belongs to *Protoptychopyge* Balashova, bringing down the first appearance of that group. In addition, I have recorded a few rare raphiophorids, niobinids, cheirurids, and cybelines from the Päite Member.

### TRILOBITE BIOZONATION

Correlating the Lower Ordovician rocks of northwestern Russia and Estonia with those of Scandinavia, Lamansky (1905) recognized the Scandinavian *Megalaspis limbata* and *Megalaspis planilimbata* zones in the lowest limestone unit (B<sub>II</sub>α) and established the *Megalaspides* Zone in the underlying calcareous Glauconite

Sandstone (B<sub>1</sub>β; Fig. 2). Balashova (1966) recognized five local trilobite zones within the interval now interpreted as the Billingen Stage. Her lowest zone was correlated with the upper Tremadoc and the following zones with the lower Arenig. Unfortunately, her correlation (dotted lines with an arrow in Fig. 2) of the Mäeküla sandstones with the ***Apatokephalus serratus* Biozone** was based on several erroneous identifications. The first of these is the fragment she named *A. serratus* (Boeck), which actually belongs to *Remopleurides* Portlock (Pärnaste 2004a, b). Second, a very tiny and poorly preserved fragmentary cranidium referred to *Euloma ornatum* Angelin (Balashova 1966, pl. 1, fig. 1) most probably belongs to *Ptychometopus schmidtii*. Third, the new subspecies of *Pliomeroides primigenus* (Angelin) was recorded as indicating the *A. serratus* Biozone. However, the taxon *Pliomeroides (Evropeites) primigenus lamanskii* (Schmidt) is rather different and has been variously considered as an independent genus (Fortey 1980, p. 86), as well as a taxon of species rank – namely *Evropeites lamanskii* (Tjernvik 1956, p. 184; Aru 1990, p. 72; Ebbestad 1999, p. 107). Lamansky (1905, p. 6, pl. 1, fig. 1) mistakenly identified a fragment of the latter species as the Tremadocian *Triarthrus angelini* Linnarsson. Also, a fragmentary pygidium attributed to the index species of the succeeding ***Megistaspis (Ekeraspis) armata* Biozone** (Balashova 1966, p. 16, pl. 2, fig. 12) is too poorly preserved to allow a confident identification, and judging by the original, it appears that the retouching and cutting of the figure is rather subjective. This leaves no evidence therefore, which confirms that any of these (*A. serratus* and *M. (E.) armata*) Scandinavian trilobite zones can be recognized in the East Baltic.

Determination of the succeeding Swedish zones in the East Baltic is somewhat complicated. In particular, during the holaspid period, the isotelines (the index trilobites) vary considerably in their diagnostic characters (e.g. the number of pleural segments and length/width ratios of the axis or cephalon and pygidia in general; Nielsen 1995). The width of the pygidium and number of its pleurae increase on *Megistaspis (Paramegistaspis)* during the holaspid period. The same tendency is observed in the phylogenetic lineage *M. (P.) planilimbata*–aff. *estonica*–*estonica*. The relatively narrow pygidium of *M. (P.) planilimbata* has six pleural ribs, and that of the stratigraphically younger *M. (P.) estonica* eight ribs, being also slightly wider. Unfortunately, the hitherto published material of *M. (Paramegistaspis)* does not allow adequate comparison of species and a study of growth variation is needed. However, some dubiously identified pygidia of *M. (P.) planilimbata* from the Tosna River locality indicate probable occurrence of the eponymous zone in the eastern Baltic. *Pliomerops? linnarssoni* known from the ***Megistaspis planilimbata* Biozone** in Skultrop, Västergötland (Wiman 1906; Tjernvik 1956, p. 128), has also been identified from Lamoshka (Fig. 3), which further supports that sign. Trilobites indicative of the ***Megistaspis (P.) aff. estonica* Biozone** in Sweden, such as *Pricyclopyge gallica* (Tjernvik) and *Raymondaspis brevicauda* Tjernvik, have not been recorded eastwards. However, there is a potential to use for correlation

some undescribed taxa mentioned by Tjernvik (1956), belonging to the genera such as *Geragnostus*, *Symphysurus* Goldfuss, and *Megalaspides* Brøgger.

At most of the studied localities the trilobite assemblage of the lowest part of the Mäeküla Member contains *Evropeites lamanskii*. Until further study proves the applicability of Scandinavian isoteline zonation in the East Baltic, the earlier established ***Evropeites lamanskii* Biozone** (see Popov et al. 1997, fig. 2, after Balashova 1966) is temporarily accepted for that assemblage, which is correlated with the *Megistaspis* (*P.*) aff. *estonica* Biozone in Sweden. However, this species is closely related to *Evropeites toernquisti* (Pärnaste 2002, 2004b), known only from the type specimen from the *Megalaspides dalecarlicus* Biozone in Dalarna (Tjernvik & Johansson 1980, p. 187). If the appearance of this particular genus in the Baltoscandian palaeobasin was synchronous basinwards, this association containing *E. lamanskii* could be correlated with the ***Megalaspides* (*M.*) *dalecarlicus* Biozone**. However, as *Evropeites* is possibly a descendant of the Tremadoc *Anacheirurus* Reed from Avalonia, or *Pliomeroides* Harrington & Leanza from Argentina and Baltica, then during the early Arenig it could first evolve in the near-shore area (Estonia, Ingria) and afterwards migrate further offshore (Sweden), being represented in both the *Megistaspis planilimbata* and *Megalaspides dalecarlicus* biozones.

Agnostids, pliomerids, and encrinurids are lacking in the trilobite association of the clay-rich Vassilkovo Beds, where both *Megalaspides* (*M.*) *dalecarlicus* and *Megalaspides paliformis* are common. The latter is an index species for the **upper part of the *Megalaspides* (*M.*) *dalecarlicus* Biozone** in Sweden. In addition, *Krattaspis*, *Proasaphus*, and *Ottenbyaspis* Bruton are rather common, but *Rhinoferus*? (*Popovkiaspis*) is rare.

A new, almost monospecific association comprising ***Megistaspis* (*Para-megistaspis*) *estonica*** appears in the Päite Member, and characterizes the eponymous zone, which can be correlated across Baltoscandia. The appearance of *Megistaspis* (*Megistaspis*) Jaanusson just above the discontinuity surface of the “Püstakkiht” marks the Billingen–Volkhov boundary. Both the index trilobite ***Megistaspis* (*Megistaspis*) *polyphemus*** (Brøgger) [= *M. lata* (Törnquist) synonymized by Nielsen 1995] and *M. (M.) limbata baltica* Balashova are very abundant in the overlying Saka Member of the Volkhov Stage.

## CONCLUSIONS

The study of the Lower Ordovician trilobites in the Mäeküla and Päite members of Estonia and northwestern Russia shows that most previous correlations with Scandinavian trilobite zones are in error because of misidentification of stratigraphically significant species. In contrast to the conclusions of Balashova (1966), there is no sound evidence of the occurrence of the trilobites of the *Apatokephalus*

*serratus* and *Megistaspis* (*Ekeraspis*) *armata* biozones in the East Baltic, whilst there is evidence of the occurrence of the *Megistaspis* (*Paramegistaspis*) *planilimbata* and *M. (P.)* aff. *estonica* biozones at some localities. The *Megalaspides dalecarlicus* Biozone is represented in Estonia and Ingria, especially by its upper part indicated by the appearance of *Megalaspides paliformis*, observed in the Vassilkovo Beds in Ingria just below the *M. (P.) estonica* Biozone. The latter is the lithologically homogeneous interval traced on the glauconitic limestone succession throughout Baltoscandia, containing skeletons of the index trilobite settled as the “trilobite cemeteries”. Consequently, this study shows that the faunal association of different beds of the Mäeküla Member varies by locality, indicating diachrony of the lowest calcareous beds of Estonia and Ingria (Pärnaste 2003).

### ACKNOWLEDGEMENTS

I am grateful to Dr Leonid Popov (Cardiff), who kindly gave me the collection of trilobites from the St. Petersburg Region, and to Dr Ivar Puura, who read the first draft of the manuscript and improved its language. My sincere thanks are addressed to the referees Dr Philip D. Lane from Keele University and Prof. Dimitri Kaljo from the Institute of Geology at Tallinn University of Technology for their helpful reviews and detailed corrections. Vivianne Berg-Madsen, a curator of the Museum of Evolution, Uppsala University, is thanked for loan of Tjernvik’s originals. Financial support of the Estonian Science Foundation (grants Nos 5922 and 6127) is acknowledged. This investigation is a contribution to the International Geological Correlation Program Project No. 503 “Ordovician Palaeogeography and Palaeoclimate”.

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## **Ida-Balti Vara-Ordoviitsiumi trilobiitide levik ja tsonaalsus**

Helje Pärnaste

On vaadeldud Kirde-Venemaa ja Põhja-Eesti Vara-Ordoviitsiumi trilobiitide levikut ning tsonaalsust ja võrreldud seda Rootsi läbilõikega, mida 1956. aastal kirjeldas põhjalikult Tjernvik. Ida-Balti läbilõigete biostratigraafilisel liigestamisel on trilobiitide tsonaalne levik olnud üheks oluliseks argumendiks alates juba 1905. aastast, mil Lamansky kirjeldas kuus biostratigraafilist üksust. Neist kaks alumist vastavad artiklis käsitletud Mäeküla ja Päite kihistikele (Hunnebergi/Billingeni lademed), ulatudes lasuvasse Saka kihistikku (Volhovi lade).

On selgitatud, et paljud varasemad korrelatsioonid Skandinaavia trilobiiditsoonidega on olnud ekslikud ja seda peamiselt stratigraafiliselt tähtsate liikide (*Apatokephalus serratus*, *Ceratopyge forficula*, *Euloma ornatum*, *Pliomeroides primigenus*, *Triarthrus angelini*) vale identifitseerimise tõttu. Sellest tulenevalt on Mäeküla kihistikku peetud Tremadoki-ealiseks, kuid revisjoni alusel on tege- mist nooremate ehk Arenigi-ealiste kihtidega. Erinevalt Rootsi aladest puudu-

vad Põhja-Eestis ja Loode-Venemaal trilobiidid biotsoonidest nagu *A. serratus* (Varangu lade) ja *Megistaspis (Ekeraspis) armata* (Hunnebergi lade), kuid kohati on esindatud (esialgse määratluse järgi) *Megistaspis (Paramegistaspis) planilimbata* ja *M. (P.)* aff. *estonica* biotsoonid. Neist viimane tsoon oli Tjernviku esialgse määratluse järgi loetud Hunnebergi-ealiseks, kuid hiljem Billingeni-ealiseks (seda viimast on järgitud kõigis siinse autori töödes). Järgmine biotsoon ehk *Megalaspides dalecarlicus* on esindatud nii Eestis kui ka Loode-Venemaal ja selle tsooni ülemine osa, mida tähistab indeksliigi esinemine koos *Megalaspides paliformis*'ega, on jälgitav Vassilkovo kihtides. *Megistaspis (P.) estonica* biotsoon esineb Päite kihistikus, kus esineb hästi sorteeritud skeletitasemeid, nn trilobiidisurnuaedu, mis on moodustunud enamasti indeksliigist. Kokkuvõtteks näitab trilobiitide levik, et Mäeküla kihistiku formeerumise ehk karbonaatse sedimentatsiooni algus on erinevate paljandite lõikes erinev.