

Upper Arenig trilobite biostratigraphy and sea-level changes at Lynna River near Volkhov, Russia

THOMAS HANSEN & ARNE THORSHØJ NIELSEN



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Over 5000 trilobites have been collected from Lower Ordovician rocks exposed at the Lynna River in the Volkhov region, east of St. Petersburg, Russia. Bed-by-bed sampling has been carried out through the upper part of Volkhov Formation (top of Jeltiaki Member and the entire Frizy Member), the Lynna Formation and the basal part of the Obukhovo Formation. This interval, which is 7.5 metres thick, correlates with the upper part of the Arenig Series, and presumably even ranges into the very base of the Llanvirn. A preliminary biostratigraphical investigation of top Jeltiaki Member ($B_{II}\beta$), Frizy Member ($B_{II}\gamma$) and basal Lynna Formation ($B_{III}\alpha$) reveals a rather continuous faunal turnover lacking sharp boundaries, and the biostratigraphical zonation ($B_{II}\beta$ – $B_{III}\alpha$) is primarily defined by the index trilobite taxa. The trilobite ranges are generally in agreement with the pattern described by Schmidt in 1907. The abundance ratio between *Asaphus* and the ptychopygids seems to be related to changes in relative sea level with *Asaphus* preferring the most shallow water conditions. A tentative interpretation of sea-level changes suggests an initial drowning at the base of $B_{II}\gamma$, immediately followed by a lowstand that in turn was succeeded by a moderate sea-level rise and then a significant fall. The last marks the $B_{II}\gamma$ / $B_{III}\alpha$ boundary. Correlation with sections in Scandinavia suggests that the basal part of $B_{II}\gamma$ is strongly condensed.

Keywords: Biostratigraphy, trilobites, Arenig, Volkhov–Kunda boundary, Lynna River, East Baltic, sea-level variations.

T. Hansen, Geological Museum, Øster Voldgade 5–7, DK-1350 Copenhagen K, Denmark (Present address: Palaeontological Museum, Sars gate 1, Oslo 5, Norway). A.T. Nielsen [arnet@savik.geomus.ku.dk], Geological Museum, University of Copenhagen, Øster Voldgade 5–7, DK-1350 Copenhagen, Denmark. 30 November 2001.

The current project focussing on the upper Lower Ordovician stratigraphy in western Russia was initiated at the end of the twentieth century between the St. Petersburg State University, the University of Copenhagen and the Geological Survey of Denmark and Greenland. It targets the taxonomy and biostratigraphic distribution of various trilobite and brachiopod groups but also aims to reconstruct palaeoenvironmental changes, notably oscillations in the palaeo-sea level. It is hoped that ecostratigraphy may eventually improve the stratigraphical correlation between Scandinavia and Russia. To date only two Russian localities have been sampled in detail. One of these is located on the banks of the Lynna River about 150 km east of St. Petersburg, Russia. This is within the Volkhov area, where Lamansky (1905) established his biostratigraphical zonation. In the present context his stratigraphical units are considered to function as

biozones, although to date they lack formal definition.

The Ordovician trilobite fauna of the East Baltic area was described in a number of classic monographs by Schmidt (1881, 1885, 1886, 1894, 1898, 1901, 1904, 1906, 1907). Some taxonomic and nomenclatural revisions have been published, for example by Balashova (1953, 1976) and Bruton *et al.* (1997), and the preliminary biostratigraphical subdivision established by Schmidt (1881) was refined by Lamansky (1905). This is basically still in use and the current biostratigraphical resolution is generally not higher than that of a typical biozone, which makes it difficult to correlate high frequency sea-level changes (compare Nielsen 1992, 1995). The section at Lynna, which totals 10.4 metres, was sampled systematically bed-by-bed from the top of Jeltiaki Member (Volkhov Formation) and up into the basal part of the Obukhovo Forma-

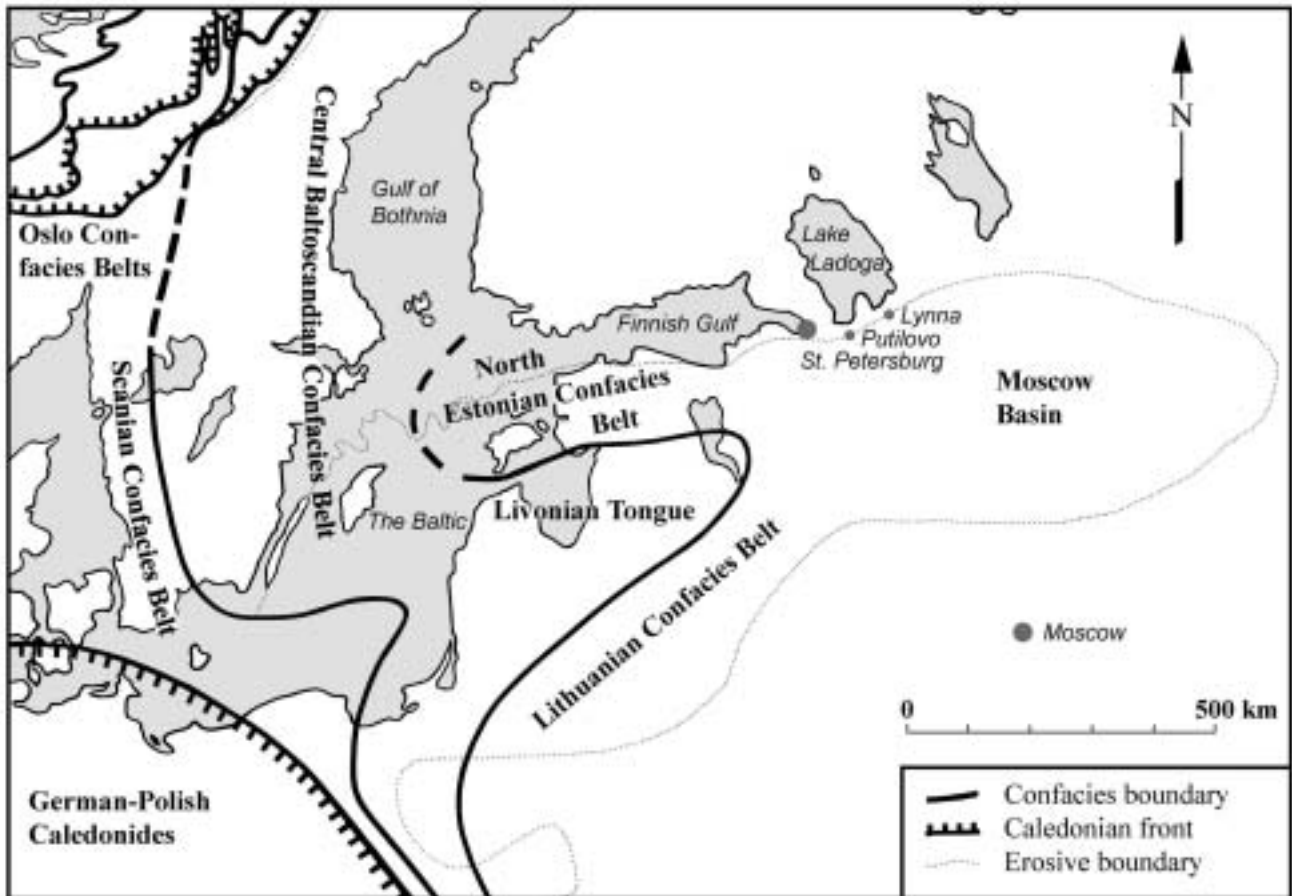


Fig. 1. Map showing the approximate boundaries between the Ordovician confacies belts in Baltoscandia. The positions of the Russian localities mentioned in the text are indicated. Modified after Jaanusson (1995) and Nielsen (1995).

tion. This interval comprises the lower 7.5 metres of the section. For the moment only the lowermost 4.5 metres corresponding to the interval from the top of Jeltiaki Member and up into the base of the Lynna Formation has been studied for trilobites. From here nearly 4000 specimens representing around 30 genera have been collected.

The purpose of this paper is to present preliminary biostratigraphic results and compare them with those of earlier studies. Furthermore some comments are made on the sea-level oscillations indicated in the section at Lynna.

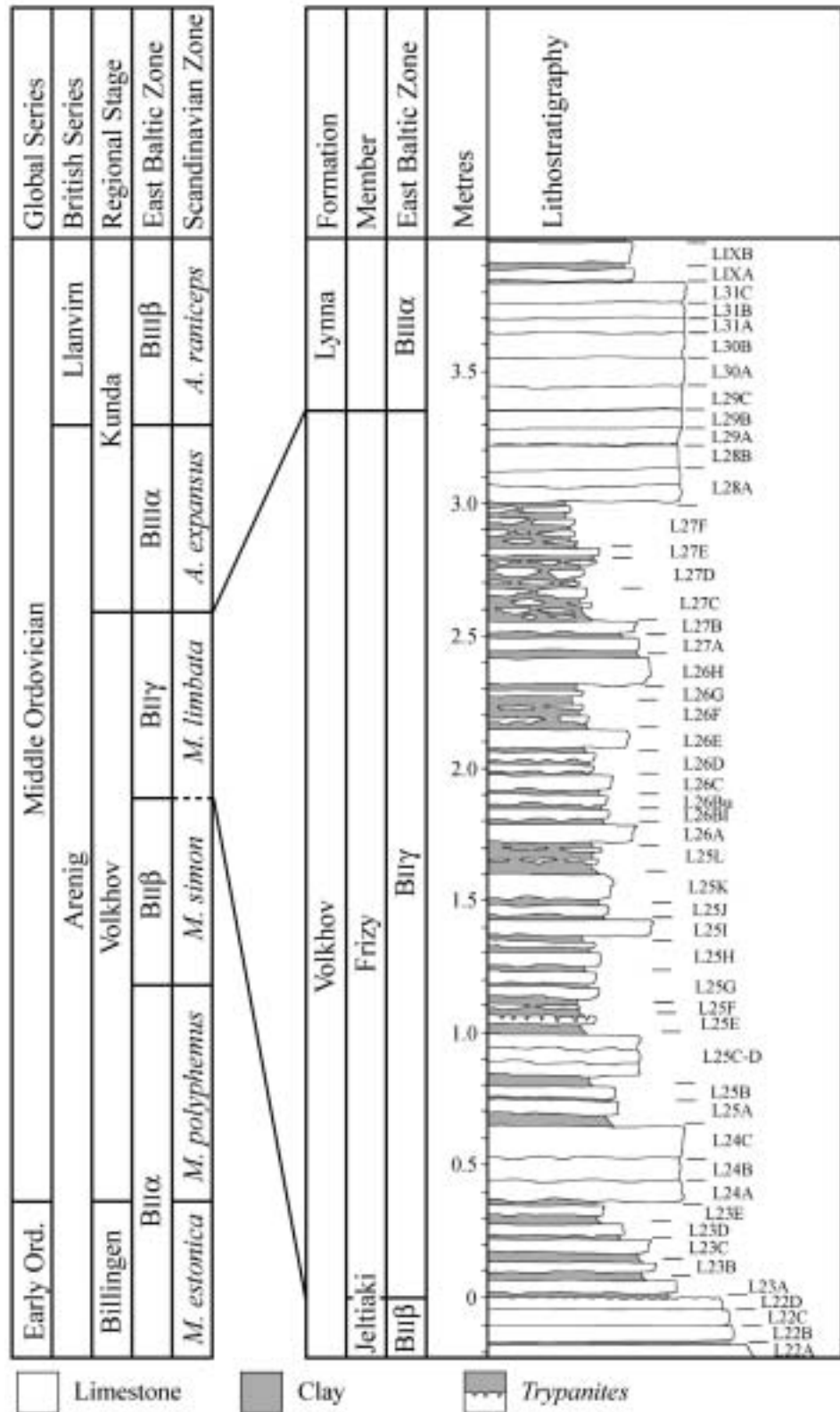
Geological setting

At the beginning of the late Arenig (here taken at the base of the Volkhov Regional Stage) a significant part of Baltoscandia was covered by a shallow epicontinental sea (Fig. 1). An extremely low clastic input in

combination with a very flat sea bottom topography resulted in widespread limestone deposition in eastern Scandinavia and the Baltic area (Jaanusson 1982).

The upper Arenig succession of the St. Petersburg area consists of alternating carbonate and clay beds (Fig. 2) deposited in an environment dominated by storms. The limestone beds are interpreted as tempestites, whereas the silty clay beds may represent background deposition (Tolmacheva *et al.* 1999). Smaller sea-level changes during the Arenig resulted in slight lithological variations indicated by an increase in glauconite content and a coarsening of the sediments during sea-level lowstands (Tolmacheva *et al.* 1999). There is a general agreement that the overall sea-level dropped through $B_{III}\gamma$ ending in a significant lowstand at the boundary between the Volkhov and Kunda stages (Lamansky 1905; Nordlund 1989; Nielsen 1995; Tolmacheva *et al.* 1999). However, this event is marked only by a rather indistinct unconformity at Lynna. The sea level was relatively low during the $B_{III}\alpha$ zone and in Russia the interval is well-

Fig. 2. Lithological log for the Lynna section drawn to show schematically the profiles of the beds. Bed numbers are listed on the right. Modified from data made available by Andrei Dronov.



represented only in the Volkhov region. Farther east the zone is represented by a condensed oolite bed (the Sillaoru Formation) and it correlates with a hiatus in northern Estonia (e.g. Lamansky 1905).

Methods

In order to facilitate sampling, all beds were numbered as shown on Figure 2. The limestone beds were then systematically sampled, whereas the clay intercalations were not investigated for trilobites. Each bed was sampled for about two hours or until the material collected was deemed large enough (i.e. >30 specimens) to give an impression of the approximate proportions between the most common species present.

In terms of palaeoecology it is well-known that one disarticulated trilobite may be represented by several skeletal parts in the fossil material. To circumvent this problem each librigena was given the value of one; cranidia and pygidia two; cephalae four and whole specimens six. Thoracic segments and hypostomes were not counted. The relative abundances of trilobites were then calculated for each bed.

The glauconite content was assessed in the laboratory on a scale from zero (no glauconite) to five (limestone rich in glauconite) by comparison with six standard samples chosen initially. This relative classification provides a good general indication of the variations occurring through the section.

Stratigraphy

The interval that has been examined in detail so far represents biostratigraphically the top of $B_{II}\beta$, the whole of $B_{II}\gamma$ and the lower part of $B_{III}\alpha$ in the sense of Lamansky (1905). The trilobite fauna is dominated by representatives of *Megistaspis*, *Asaphus* and ptychopygids, but is otherwise very diverse with more than 15 genera co-occurring at some levels. The faunal turnover is remarkably continuous and the biozones are largely defined only by their index species (Fig. 3). The gradual faunal turnover thus broadly corresponds to the pattern observed in coeval successions within Scandinavia (Nielsen 1995; Tjernvik & Johansson 1980) although the faunal composition is different.

The base of $B_{II}\gamma$ is defined by the first occurrence of *Asaphus* (*Asaphus*) *lepidurus* Nieszkowski, 1859, *Megistaspis* (*Rhinoferus*) *gibba* (Schmidt, 1906) and *Harpides plautini* Schmidt, 1894 (Fig. 3). *Pliomera fischeri* (Eichwald, 1825), which is very abundant in the up-

per part of $B_{II}\beta$, disappears shortly above the boundary. None of the index species of $B_{II}\beta$ (*Asaphus broeggeri* and *Onchometopus volborthi*) has been found in the Lynna section, but only the uppermost bed of the zone has been sampled. The $B_{II}\beta/B_{II}\gamma$ boundary corresponds to the lithostratigraphic boundary between the Jeltiaki and Frizy members. The lower half of $B_{II}\gamma$ is characterised by *Megistaspis* (*Rhinoferus*) *hyorrhina* (Leuchtenberg, 1843), *Remopleurides* sp., *Pterygometus sclerops* (Dalman, 1827) and *Asaphus* (*A.*) *lepidurus*. The last of these species is rare in the lowermost eight beds (L23A–E, L24A–C), but then becomes extremely common. From level L25A and up to L26 B_u it completely dominates the trilobite assemblage (Fig. 4B). *Dysplanus acutigenia* subsp. Jaanusson, 1957, geragnostids, *Agerina woehrmanni* (Schmidt, 1907) and *Nieszkowskia tumida gibba* (Angelin, 1854) are more patchy in occurrence, but they are still good indicators for the lower part of $B_{II}\gamma$. A few incomplete cranidia of *Hemisphaerocoryphe* have been found in the lower part of $B_{II}\gamma$. They seem to represent the earliest known representative of that genus.

The upper half of $B_{II}\gamma$ is dominated by *Megistaspis* (*Megistaspidella*) *acuticauda* (Angelin, 1854) and a ptychopygid, probably *Metaptychopyge truncata* (Nieszkowski, 1859). Other species such as *Bornholmispis* sp., *Ingriops intermedius* (Schmidt, 1881) and *Nieszkowskia tumida tumida* (Angelin, 1854) are also indicative of this biostratigraphical level. *Cyrtometopus clavifrons* (Dalman, 1827) is only found at the base and top of $B_{II}\gamma$, where it is one of the more common species.

Based on the index species *Asaphus* (*A.*) *expansus* (Wahlenberg, 1821) the boundary between $B_{II}\gamma$ and $B_{III}\alpha$ should be placed between bed L29C and L30A. This is, however, not in accordance with the interpretation of Lamansky (1905), who placed the boundary at an erosive unconformity marking a shift in the fauna. A rather indistinct unconformity was noted between bed L29B and L29C, above which *Asaphus* (*A.*) *fallax* Angelin, 1854 appears. *A.* (*A.*) *fallax* was formerly classified as *A.* (*A.*) *raniceps sensu stricto* (Dalman, 1827) by Tjernvik & Johansson (1980) and Nielsen (1995). New investigations indicate that *A.* (*A.*) *raniceps 'sensu stricto'* is identical to *A.* (*A.*) *fallax*, whereas *A.* (*A.*) *'raniceps' sensu Jaanusson* (1953) in fact represents the true *A. raniceps* (Bergström *et al.* 2003). Within Scandinavia *A.* (*A.*) *fallax* occurs only in the *A. expansus* Zone (Tjernvik & Johansson 1980; Nielsen 1995). Based on these data the lower boundary of the *A. expansus* Zone ($B_{III}\alpha$) is placed at the unconformity between bed L29B and L29C, corresponding to the boundary between the Volkhov and Lynna formations. It may actually prove that the East Baltic *A. lamanskii* Schmidt, 1901, used as a second index-

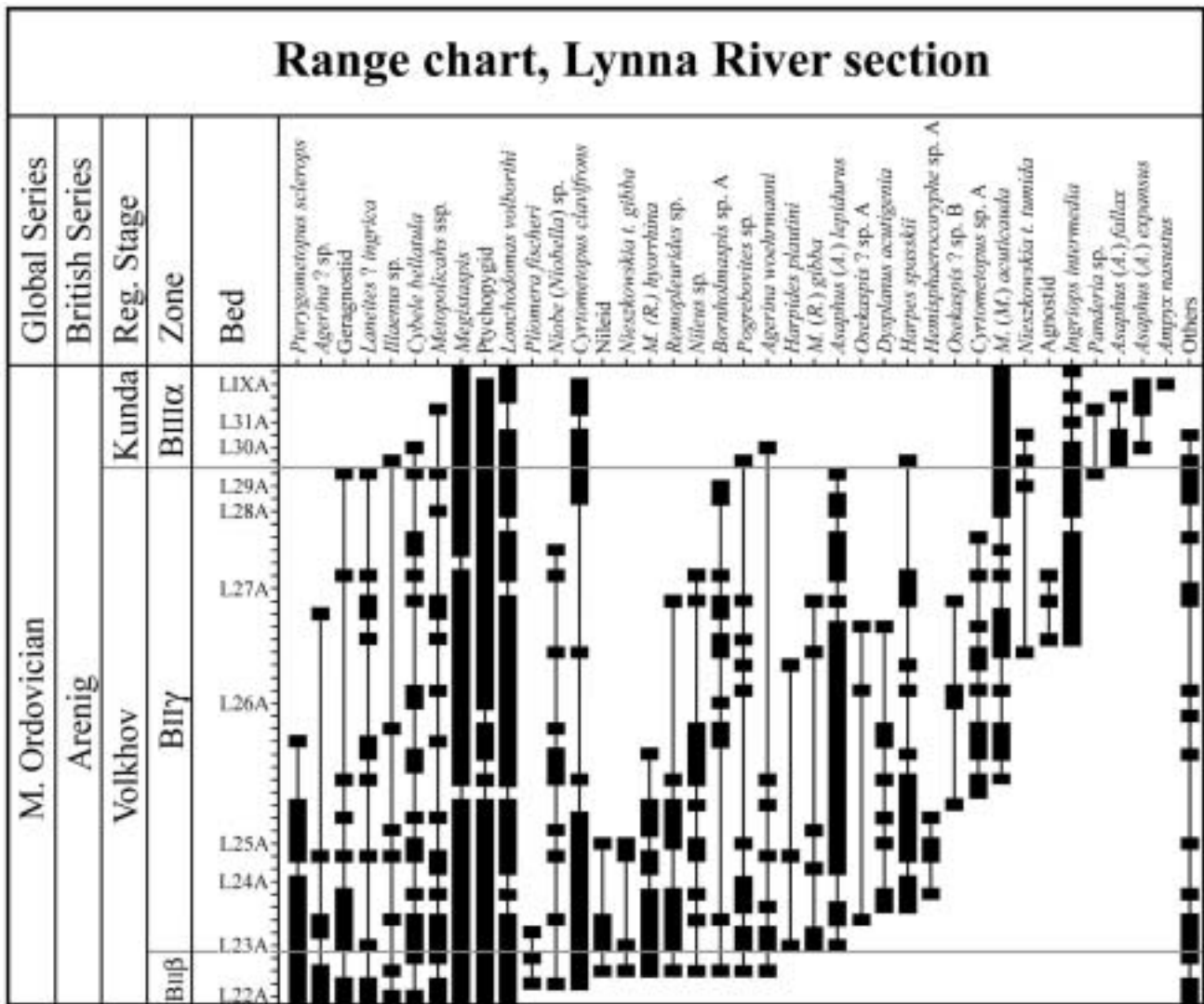


Fig. 3. Range chart showing the occurrences of trilobites in the Lynna section. Only the A-beds of each numbered unit are listed (compare Fig. 2).

species for B_{III}α by Lamansky (1905), turns out to represent yet another synonym of *A. fallax*, but this needs further examination to be confirmed. *Ampyx nasutus* (Dalman, 1827) turns up in bed LIXA; this species is a characteristic constituent of the *A. expansus* Zone fauna all over Baltoscandia (Nielsen 1995). The basal B_{III}α boundary seems to mark the last occurrence of geragnostids, *Metopolichas verrucosus* (Eichwald, 1842), *Laneites? ingrica* (Schmidt, 1881) and *Asaphus (A.) lepidurus*. However, it is stressed that only the lower part of B_{III}α has been studied so far and some of these taxa may prove to extend farther up when the entire material is examined. Regarding *A. lepidurus*, it cannot entirely be ruled out that it also occurs in the basal part of the B_{III}α zone. A large proportion of the available asaphid pygidia has not been identi-

fied at the species level as yet and may include late representatives of *A. (A.) lepidurus*.

The examined lower part of B_{III}α contains only a few taxa and trilobites are generally less abundant than in B_{II}γ.

Biostratigraphical discussion

The occurrence of trilobites in western Russia has been documented by Lamansky (1905), Schmidt (1881–1907) and Balashova (1953, 1976) amongst others. These authors assigned the known trilobites to biozones, but the exact occurrences have never been documented in terms of range charts for specific lo-

calities. In combination with taxonomic uncertainties, the absence of detailed occurrence data has made it difficult to correlate between Scandinavia and the Baltic area (e.g. Tjernvik 1972; Nielsen 1995). Compared with previous investigations the new data deviate from previous work with regard to a number of details:

Lamansky (1905) did not record *Lonchodomas volborthi* outside $B_{III}\alpha$. At Lynna the species occurs all the way down into the top of $B_{II}\beta$, corresponding to the pattern known from Scandinavia (see Nielsen 1995; Stouge & Nielsen 2003). *Cyrtometopus clavifrons* and *Nieszkowskia tumida tumida* were not reported to occur higher than $B_{II}\gamma$ by Lamansky (1905). At Lynna they enter $B_{III}\alpha$. *Nieszkowskia tumida gibba* has only been mentioned from $B_{II}\beta$, but it also occurs in $B_{II}\gamma$. *Cybele bellatula* ranges from $B_{II}\beta$ to $B_{III}\alpha$, whereas *Laneites? ingrlica* occurs in $B_{II}\beta$ and $B_{II}\gamma$. Lamansky (1905) indicated a lower boundary for *Cybele bellatula* somewhere in $B_{II}\gamma$ and a first appearance of *Laneites? ingrlica* in $B_{III}\beta$. The trilobite ranges listed by Schmidt (1907) are basically confirmed by the new data. However, *Harpes spasskii* (Eichwald, 1840) was reported to occur in both B_3 and C_1 (Schmidt 1907, p. 63) but it occurs as low as $B_{II}\gamma$ (corresponding to part of the B_{2b} zone *sensu* Schmidt). *Metopolichas celorrhin* (Angelin, 1854) was indicated to have a last occurrence in the studied interval, where it is succeeded by *Metopolichas verrucosus* (Eichwald, 1842). Schmidt (1885) indicated a strong resemblance between those two species and it is therefore very likely that both are represented in the material temporarily assigned to *Metopolichas* spp. *Onchometopus volborthi* Schmidt, 1898, and *Ptychometopus volborthi* (Schmidt, 1894) should both continue up into $B_{II}\gamma$ according to Schmidt, but neither were found in the Lynna section. Likewise *Ceraurina ornatus* (Dalman 1827) does not seem to range downwards into the lowermost part of $B_{III}\alpha$.

For the moment the correlation of the Volkhov zonation between Scandinavia and the East Baltic area is uncertain. The Volkhov part of $B_{II}\alpha$ seems to match the *Megistaspis polyphemus* Zone (Fig. 2). Nielsen (1995) suggested that the $B_{II}\beta$ zone matches the *M. simon* Zone plus the lower part of the *M. limbata* Zone, whereas the $B_{II}\gamma$ zone correlates only with the upper part of the *M. limbata* Zone. However, the new data raise doubt about this conclusion, as the lower part of the $B_{II}\gamma$ zone with sporadic occurrence of *Asaphus lepidurus* may turn out to correlate with the lower part of the *M. limbata* Zone. A more detailed ecostratigraphical analysis may clarify this problem. As it appears from the discussion of sea-level changes below, we are inclined to believe that $B_{II}\gamma$ in fact is equivalent to the whole *M. limbata* Zone.

Palaeoecology

Some lithological investigations were made in order to get an impression of whether the lithological changes had any bearing on the distribution of the trilobites. Variations in the relative thickness of individual limestone and clay beds do not match the distribution of the common genera or species, whereas variations in the relative glauconite content seem in better agreement. The limestone beds are especially rich in glauconite at two intervals (Fig. 4A), namely from L23D to L25K and again from L29A to LIXA (depending on interpretation the upper interval may already start in bed L27C). A frequency diagram for two of the most common genera is shown in Figure 4B. The abundance of *Asaphus* increases when the ptychopygids are less frequent and vice versa. Note that these abundance calculations are based on the entire trilobite material, and not only on *Asaphus*/ptychopygids. A comparison with the glauconite content shows a crude but out of phase correlation between the two *Asaphus* peaks and high glauconite content. The abundance pattern thus appears to be influenced by the same factor(s) that controlled the glauconite content. The lack of an '*Asaphus* signal' at the smaller glauconite peak around L27C corresponds to a similar general lack in response in the remaining fauna. No changes are seen in brachiopod-assemblages between the two larger glauconite peaks (cf. Hansen & Harper 2003). The lack of response may reflect small scale and short duration of the environmental change influencing the glauconite content.

In Putilovo quarry 70 km east of St. Petersburg (Fig. 1) glauconite-rich layers with vertical *Trypanites* borings were found to indicate shallow water (Tolmacheva *et al.* 1999). The same authors suggested that commonly the more fine-grained sediments poor in glauconite indicated deeper water. This assumption is supported by the location of two distinct unconformities at the top of beds L22D and L25E (Fig. 2) at Lynna. The first one occurs together with a glauconite minimum. The other one is found slightly above the following glauconite peak and is characterised by *Trypanites*. They should thus correspond to a relative sea-level highstand and a sea-level lowstand, respectively. According to such an interpretation *Asaphus* is abundant during lowstands and initial transgressions, whereas ptychopygids are related to high-stands and initial regressions. This general pattern is in accordance with observations made from Scandinavia (Nielsen 1995, p. 70), where both groups were found to prefer more shallow water, but more so for *Asaphus* than for the ptychopygids. The inference that *Asaphus* preferred shallow water is also in accordance with the earlier occurrence of this genus in the East Baltic

area compared to Scandinavia. Concerning the other genera and species found at Lynna, *Pandera* sp., *Dysplanus acutigenia* and *Hemisphaerocoryphe* sp. occur in intervals deposited in shallow water environments, whereas *Agerina?* sp., *Pliomera fischeri*, *Osekaspis?* sp. A and agnostids seem to have preferred relatively deeper water environments. Because of the general sparse occurrence of these species and a general lack of data from other localities the proposed preferences must be taken with caution awaiting further investigations of the fauna as well as analyses of the large collection of trilobites from the Putilovo quarry.

Sea-level variations

The preliminary lithological interpretation in combination with the trilobite abundance pattern suggests a deepening in the basal part of $B_{II}\gamma$ (levels 23A–L23C), compared to $B_{II}\beta$. This relative highstand was quickly succeeded by a lowstand during which beds L23D–L25K were deposited. These are rich in glauconite and *Asaphus lepidurus* is very common. A moderate relative sea-level rise, comprising levels L25L–L27B, during which *Asaphus* became less abundant and the glauconite content dropped, was followed by a new lowstand, marking the boundary between zones $B_{II}\gamma$ – $B_{III}\alpha$. The investigated lower part of $B_{III}\alpha$ is characterized by common *Asaphus* and low numbers of ptychopygids (Fig. 4B).

This pattern may match the Scandinavian sea-level rise, marking the *M. simon*/*M. limbata* shift, followed by a shallowing marking the boundary between lower/upper *M. limbata* Zone *sensu* Nielsen (1995) that in turn was followed by a drowning/pronounced shallowing couplet in the upper part of the *M. limbata* Zone/base of *A. expansus* Zone (compare Nielsen 1995). If this tentative correlation is correct, it follows that the basal part of the $B_{II}\gamma$ zone is highly condensed compared to Scandinavia. This implication will be further explored in the section sampled at Putilovo.

Conclusion

A preliminary investigation of trilobites from the upper Arenig at Lynna River east of St. Petersburg yielded the following results: 1) The boundary between the $B_{III}\beta$ and $B_{II}\gamma$ zones is signalled by the first occurrence of *Asaphus* (*Asaphus lepidurus*, *Megistaspis* (*Rhinoferus*) *gibba* and *Harpides plautini*). 2) The boundary between $B_{II}\gamma$ and $B_{III}\alpha$ is marked by the first

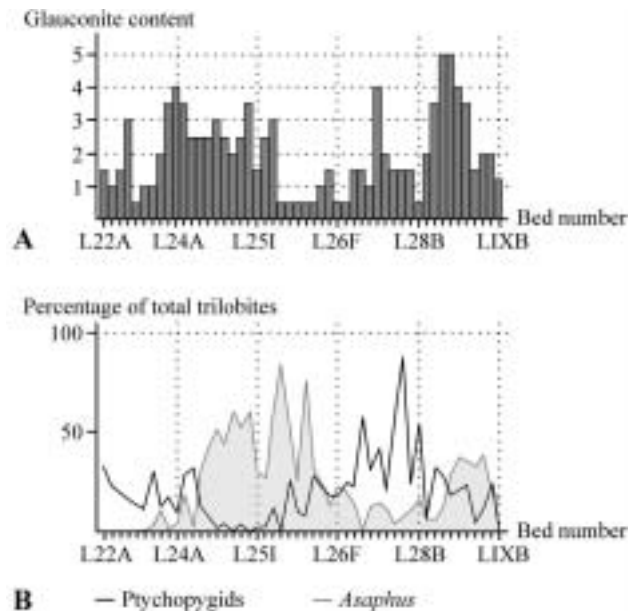


Fig. 4. A. The glauconite content in the section at Lynna, determined on a relative scale from zero (no glauconite) to five (very abundant glauconite). B. The relative frequency of *Asaphus* and ptychopygids through the investigated section. Note the overall correlations between glauconite content and abundance/scarcity of the two genera. Every tenth bed is listed.

occurrence of *Asaphus* (*A.*) *fallax* and the last occurrence of geragnostids, *Metopolichas* spp., *Laneites? ingraca* and presumably also by *Asaphus* (*A.*) *lepidurus*. *A. expansus* turns up slightly above the base of $B_{III}\alpha$. 3) Lamansky's zonal boundaries at Lynna do not show signs of a significant faunal turnover and they probably represent only short time-gaps. However, it is for other suspected reasons that the basal part of $B_{II}\gamma$ is strongly condensed.

Tentative investigations concerning sea-level variations suggest: 1) *Asaphus* and ptychopygids succeed each other as the most or one of the most dominating genera through the section. 2) The shifts between the two are largely coincident, although slightly out of phase with changes in glauconite content, indicating a direct or indirect influence from variations in sea-level. 3) *Asaphus* seems to have preferred an environment corresponding to lowstands and initial transgressions, whereas the ptychopygids are found in highstands and initial regression intervals. 4) The succession is suggested to reflect an initial drowning at the base of $B_{II}\gamma$, followed by a lowstand, moderate drowning and a new, more profound lowstand, the latter corresponding to the boundary between B_{II} and B_{III} .

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