

Brachiopod macrofaunal distribution through the upper Volkhov – lower Kunda (Lower Ordovician) rocks, Lynna River, St. Petersburg region

JESPER HANSEN & DAVID A.T. HARPER



Hansen, J. & Harper, D.A.T. 2003–04–30: Brachiopod macrofaunal distribution through the upper Volkhov – lower Kunda (Lower Ordovician) rocks, Lynna River, St. Petersburg region. *Bulletin of the Geological Society of Denmark*, vol. 50, pp. 45–53, Copenhagen. © 2003 by Geological Society of Denmark. ISSN 0011–6297.

The ranges of 27 brachiopod species, through the upper Volkhov-lower Kunda interval of the Lynna River section, are presented on the basis of over 17,500 specimens. Three depth-related ecological associations are recognized within the succession of alternating limestones and marls forming part of an array of nearshore to mid-shelf communities in an intracratonic setting. Faunal diversity is relatively stable throughout the section with little evidence for abrupt local extinctions or originations. The dominant orthoid and clitambonitoid assemblages, however, form the basis of the distinctive Baltic brachiopod province developed during this time interval.

Key words: Brachiopods, Volkhov, Kunda, Lynna River, biodiversity, brachiopod assemblages.

Jesper Hansen, Geological Museum, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark (Present address: Tromsø University Museum, NO-9037 Tromsø, Norway) & David A.T. Harper [dharper@savik.geomus.ku.dk], Geological Museum, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark. 2 January 2002.

The Ordovician rocks of the St. Petersburg region (Fig. 1) have, for nearly 200 years, been the focus for intensive palaeontological and stratigraphical studies. Although Kutorga published the first detailed geological map of the region in 1852 following initial overviews by Murchison and others, it was Schmidt (1881) who first developed a stratigraphical scheme for the Lower Palaeozoic rocks of the greater region; this, in a modified form, is the basis for modern correlation and interpretation of the succession (Bruton *et al.* 1997). Schmidt's scheme was enhanced and modified by Lamansky (1905) and his units have helped define the regional stages, developed by Männil (1966) and others (e.g. Männil & Meidla 1994), that are currently in use. Nevertheless many of these units are based on a confusing mixture of litho- and biostratigraphy and to date have not been formally defined in type sections in the Baltoscandian palaeobasin. Moreover their use outside the East Baltic region is restricted, where, for example, the development of siliciclastics and deeper-water facies limit their recognition. These units have, however, been used in this study together with the recognised lithostratigraphy because the Lynna River in fact falls within the type area for Lamansky's units. These Ordovician units are typically character-

ized by abundant, diverse and well-preserved shelly faunas, which not only have formed the subject of much monographic research, but also are providing data to frame and test models for biodiversification in the region. The Lower Ordovician successions are exposed along the Baltic-Ladoga Klint line in a series of quarries and river sections. The Lynna River provides near complete and accessible exposure through the Lower Ordovician succession within Lamansky's (1905) type area.

Geological Setting

The St. Petersburg region is located between the continuation of the Baltic palaeobasin to the west (and northwest) and the Moscow palaeobasin to the southeast (Fig. 1); the successions are dominated by condensed carbonates. Ordovician successions were deposited in the eastern part of a relatively shallow, epicontinental sea, characterized by very slow rates of sedimentation (Lindström 1963, 1984; Männil 1966). Carbonate sources in the eastern part of the palaeobasin may have competed with siliciclastic sources to

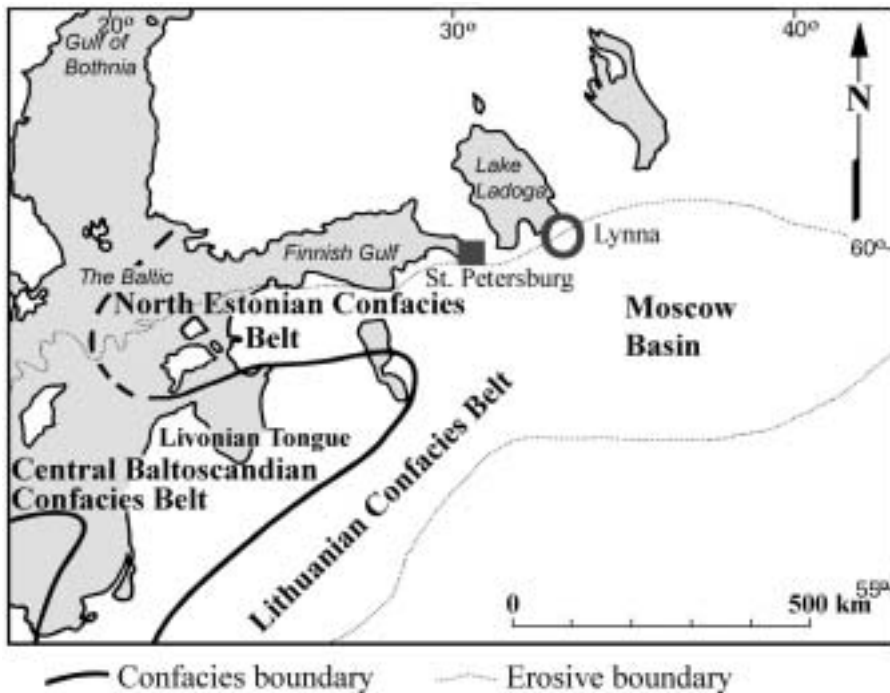


Fig. 1. Location of the study area in the Lynna River section together with the track of the Baltoscandian confacies belts (Jannusson 1976).

the west (Jannusson 1973) associated with the developing Caledonide mountain belt (Bruton & Harper 1988). During the early Ordovician Baltica probably lay at relatively high latitudes; faunal and sedimentological data together with palaeomagnetic studies suggest the Baltic craton moved from high to low latitudes, rotating in an anticlockwise direction (Torsvik *et al.* 1991; Torsvik 1998). During the Ordovician Period the composition and style of carbonate deposition changed from cool to warm-water carbonates (Lindström 1984), the Volkhov–Kunda stages being mainly dominated by cool-water limestones and marls. This interval, however, also marked the development of the distinctive Baltic province following the deeper and cooler-water assemblages of the Billingen (Egerquist 1999), with Gondwanan links; the first influxes of Laurentian marginal taxa occurred later during the Keila–Oandu (upper Middle Ordovician) transition (Harper & Hints 2001).

Stratigraphy and methodology

A complete section from the middle of the Volkhov regional stage to the top of the Kunda regional stage is exposed along the Lynna River (Fig. 1), where in ascending order, the Volkhov (Volkhov Regional Stage), Lynna, Sillaoru and Obukhovo (Kunda Regional Stage) formations crop out. These rocks have been correlated with the Arenig and Llanvirn series

of the British succession. The boundaries between Lamansky's stratigraphical units have previously been recognized and correlated on first occurrence of *Asaphus lepidurus* for the base of $B_{II}\gamma$ and *Asaphus raniceps sensu stricto* for the base of $B_{III}\alpha$ (see Hansen & Nielsen 2003). *Asaphus expansus*, a key taxon for $B_{III}\alpha$, appears in bed L30A above the $B_{II}\gamma$ – $B_{III}\alpha$ boundary (Fig. 2). The lithostratigraphy follows that of Dronov (1997), Dronov & Holmer (1999) and references therein. The bed numbers in the figures follow those established by Dronov (personal communication, May 2000; see also Hansen & Nielsen 2003). In practice Lamansky's units $B_{II}\beta$, $B_{II}\gamma$ and $B_{III}\alpha$ correspond to the Jeltjaki and Frizy members of the Volkhov Formation and the Lynna Formation, respectively.

A section through the upper part of the Volkhov Formation into the lowest part of the Lynna Formation was collected in detail. Over 17,500 brachiopods have been collected and registered from this section. The marl beds were investigated at three levels (see Fig. 6); brachiopods were extracted by washing and sieving using conventional methods (Hansen 2002) and collected as three size fractions [>1 mm, between 1 and 0.5 mm, and between 0.5 and 0.063 mm]. Where possible the specimens have been identified to species level and the material will form the basis for a revision of key taxa of clitambonitoid and orthoid brachiopods. A detailed range chart of all macrobrachiopod species is presented for the first time through this interval. The most dominant brachiopod genus *Ranorthis* has a very chaotic and variable distribution,

and does not apparently follow any of the recognized assemblages. Because of this variability, its distribution strongly influenced the calculated percentages of the other brachiopods. For this reason it was necessary to remove this genus from the dataset before patterns in the variations of the assemblages could be discerned. The bed-by-bed data from over 30 horizons were input into PAST (Hammer, Harper & Ryan 2001; see also <http://folk.uio.no/ohammer/past>) and the data manipulated and analysed for changing diversity patterns through the sequence.

Brachiopod distribution

The detailed sampling of the Lynna River section has permitted, for the first time, an accurate analysis of the ranges of all the brachiopod taxa occurring in this interval. The brachiopod fauna through the Middle to Upper Volkhov and Lower Kunda regional stages in the Lynna River section includes at least 27 genera (Fig. 3). The turnover of genera and species is, nevertheless, remarkably continuous; no abrupt faunal changes such as regional extinction or origination events are apparent. The brachiopod fauna is mainly dominated by *Paurorthis parva* Pander, *Ranorthis* spp., *Apomatella ingraca* (Pahlen), *Antigonambonites planus* (Pander) and linguloidean spp. *Ranorthis* is apparently represented exclusively by *Ranorthis norvegica* Öpik, but many valves are too poorly preserved to be identified to species level.

The upper part of the B_{II}β, investigated here, contains two characteristic, but sporadically distributed species: *Productorthis obtusa* Pander and *Paurorthis valida* Rubel (Rubel 1961). *Productorthis obtusa* occurs across the boundary between B_{II}β and B_{II}γ. The oldest recorded specimen of the clitambonitoid *Lacunarites* occurs in the upper bed of B_{II}β. Earlier records of the species suggest it was restricted the B_{III}β-γ units, essentially the Kundan (Öpik 1934; Rubel & Wright 2000). The base of B_{II}γ is, however, marked by the first appearance of *Platystrophia* cf. *putilovoensis* Zuykov and *Raunites venusta* Öpik. Of these *Platystrophia* cf. *putilovoensis* is of the most interest, because it is frequent in the overlying beds. *Nothorthis* sp. occurs in B_{II}β at a number of other localities (Egerquist 1999; Rubel 1961). The genus *Raunites* is represented by all four known species, but is mostly confined to the lower half of B_{II}γ, where it is abundant. *Raunites strophomenoides* Öpik, however, reappears in the upper Volkhov (Arenig) in Estonia (Rubel & Wright 2000). The other genera and species, which appear in the lower part of B_{II}γ are sporadic in their distributions. They include the strophomenoid *Inversella* repre-

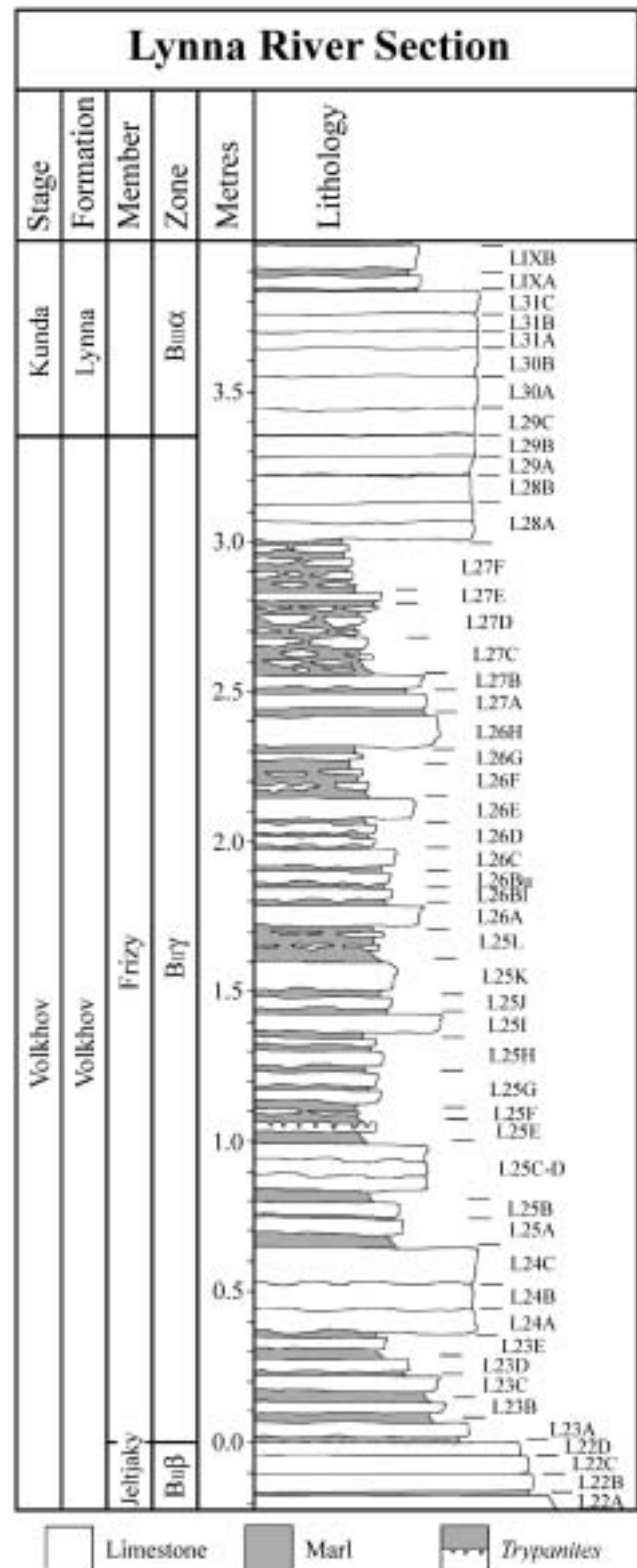


Fig. 2. Detailed bed-by-bed stratigraphy of the investigated part of the Lynna River section. Bed notation is based on the system employed by Russian researchers (Dronov, personal communication 2000; see also Hansen & Nielsen 2003).

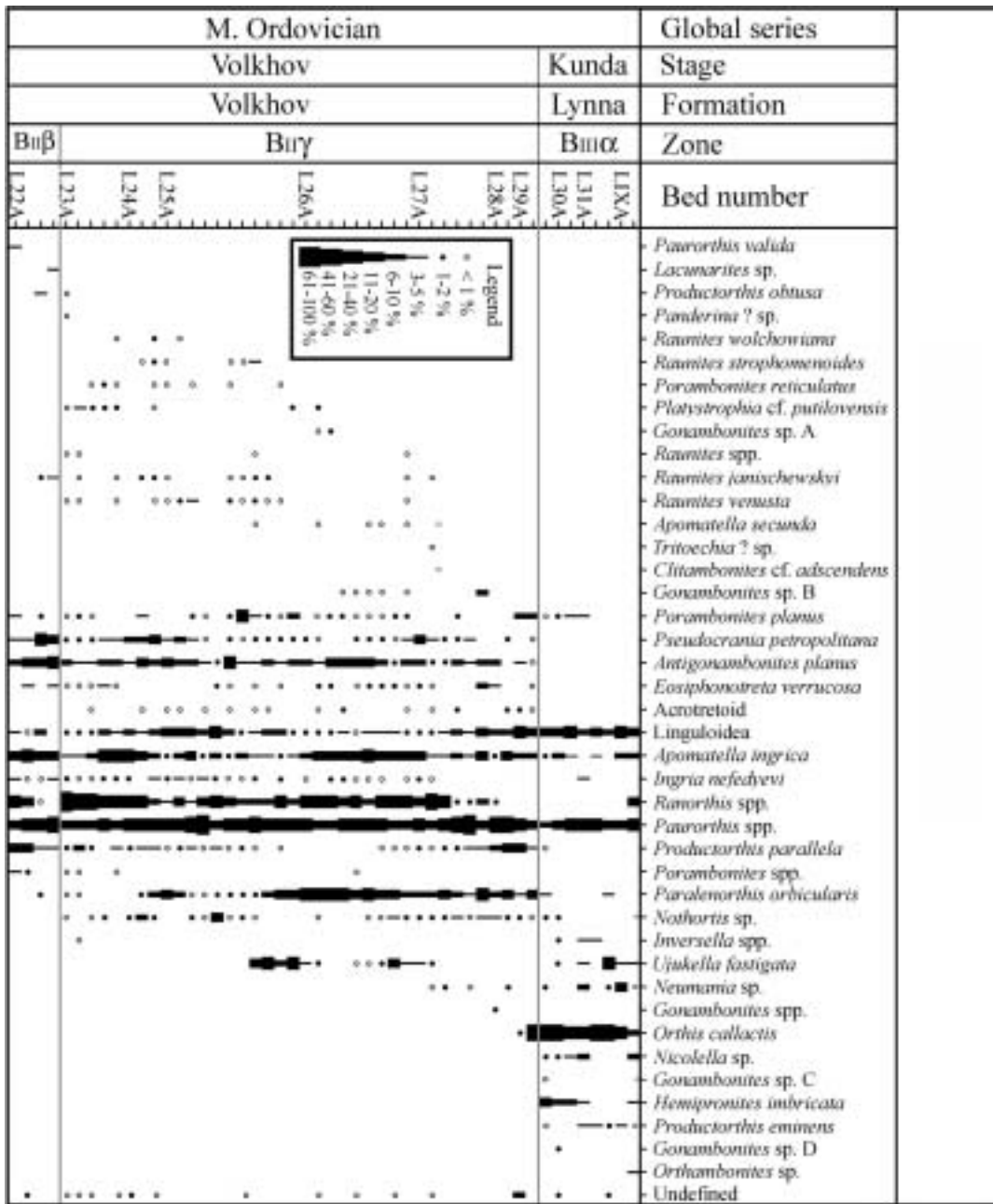
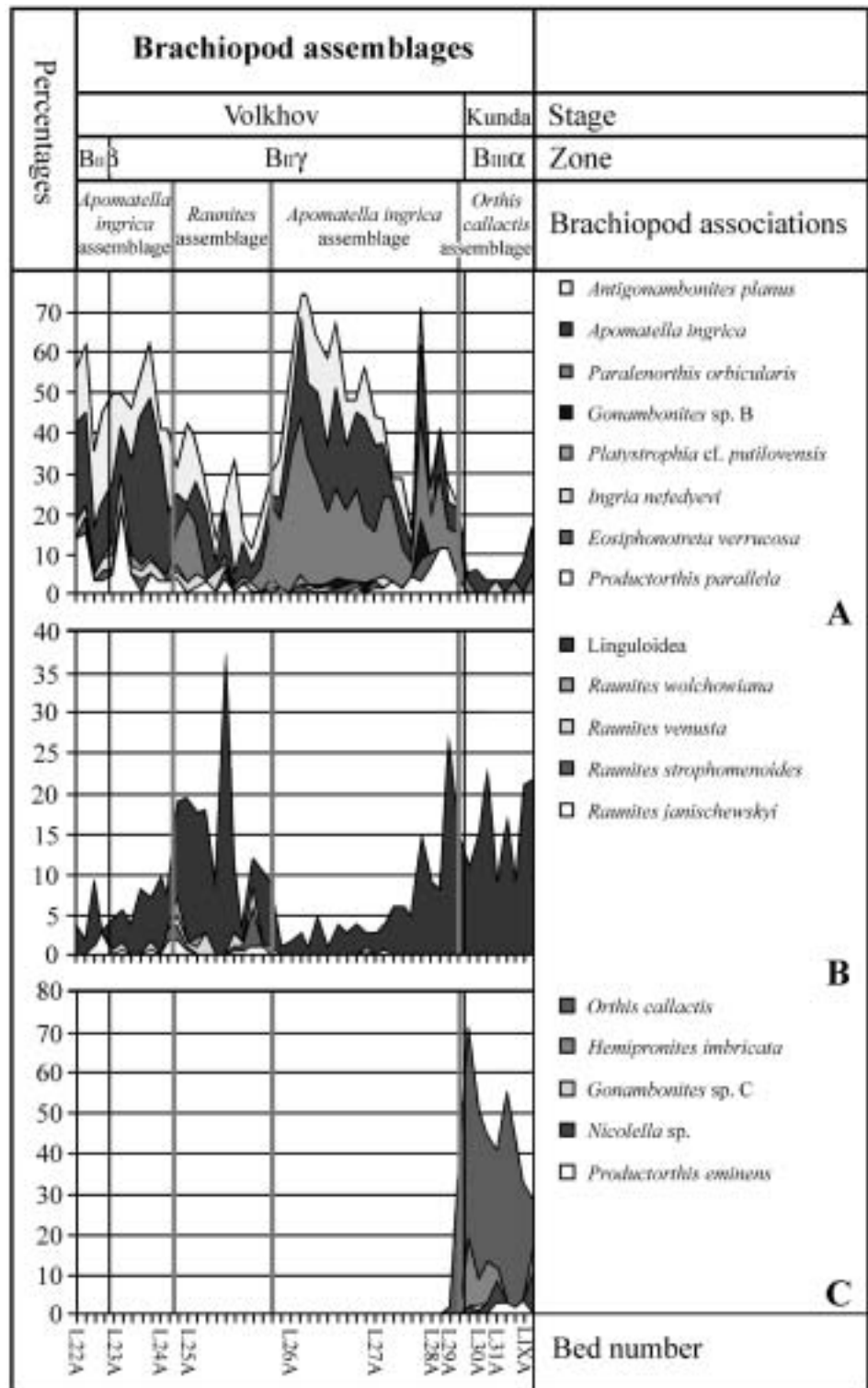


Fig. 3. Stratigraphical occurrence of brachiopods through part of the Volkhov–Kunda interval in the River Lynna section (east of St. Petersburg). Relative abundances of the brachiopods are indicated against the stratigraphy.

sented by one juvenile ventral valve in B_{II}γ. This is the first record of *Inversella* below the B_{III} units of the Kunda Stage. The valve, nevertheless, differs from specimens in B_{III}α. The middle part of B_{II}γ is characterised by the first occurrence of *Ujukella fastigata* (Rubel) and two successive species of *Gonambonites*. The plectambonitoid *Ujukella fastigata* appears suddenly and in great numbers. The two species of *Gonambonites* are succeeded by two quite different

species in B_{III}α. *Platystrophia cf. putilovoensis* disappears in the middle part of B_{II}γ at Lynna. The upper part of B_{II}γ is characterised by the first occurrence of *Orthis callactis* Dalman, *Neumania* sp., *Clitambonites cf. adscendens* Pander and *Tritoechia?* sp. The last three are rare and *Clitambonites cf. adscendens* is represented by a single dorsal valve from the interbedded marl. *Neumania* sp. resembles the new but un-named species from the B_{II}β-zone mentioned and figured by Tol-

Fig. 4. The three brachiopod assemblages from the base to the top of the section: *Apomatella ingriva* assemblage, *Raunites* assemblage and *Orthis callactis* assemblage. Bed numbers are based on the system employed by Russian researchers (Dronov, personal communication 2000; see also Hansen & Nielsen 2003).



macheva, Fedorov & Egerquist (2003); both are probably conspecific. *Orthis callactis* was originally a key taxon for the lower part of the Kunda Stage (Rubel 1961), but it is one of the dominant species in the upper bed of B_{II}γ. *Apomatella secunda* Öpik, which is sporadically distributed in the middle part of B_{II}γ, constitutes well below 10% of the representatives of the genus in the section. The boundary between B_{II}γ and B_{III}α is marked by the last occurrences of *Antigonambonites planus* (Pander), *Pseudocrania petropolitana* Pander, *Eosiphonotreta verrucosa* (Eichwald) and a distinctive acrotretoid in this section. Both *Pseudocrania petropolitana* [syn.= *Pseudocrania antiquissima* (Eichwald)] and *Antigonambonites planus* have, nevertheless, been recorded from higher strata (Lamansky 1905; Öpik 1934). The base of B_{III}α is associated with the first appearances of the two characteristic genera *Hemipronites* and *Nicolella* and the characteristic species *Productorthis eminens* (Pander). *Hemipronites imbricata* (Öpik) is moderately abundant, whereas the other two occur more sporadically through the section. *Productorthis parallela* (Pander), which has a last occurrence in the lower bed of B_{III}α apparently was previously restricted to the Volkhov Stage (Rubel 1961).

Porambonites spp. includes mainly *P. planus* Pander, which occurs through the whole range of the genus. One valve from L22B is questionably assigned to *Porambonites triangularis* Pander, while others are too fragmentary to classify to species level.

Brachiopod assemblages

The brachiopod fauna at Lynna comprises three statistically-recognizable assemblages (Fig. 4). The three assemblages have been identified on the basis of Principal Component Analysis (PCA); details of these results are presented elsewhere (Hansen 2002). The first two, the *Apomatella ingrlica* and *Raunites* assemblages, are by no means mutually exclusive in terms of their constituent taxa, but differ mainly in the dominance of key taxa. The *Orthis callactis* assemblage appears in the uppermost bed of B_{II}γ, where *Asaphus expansus* appears for the first time, and dominates the remaining part of the section. This assemblage is most closely related to the *Raunites* assemblage, but occupied a more nearshore position.

The *Apomatella ingrlica* assemblage, consists of at least eight species: *Antigonambonites planus*, *Apomatella ingrlica*, *Gonambonites* sp. B, *Platystrophia* cf. *putilovoensis*, *Productorthis parallela*, *Paralenorthis orbicularis*, *Ingria nefedyevi* and *Eosiphonotreta verrucosa*. The domi-

nant species in the upper part of the assemblage are *Apomatella ingrlica*, *Antigonambonites planus* and *Paralenorthis orbicularis*. *Paralenorthis orbicularis* apparently migrated into the area during the last part of the first diversity peak and becomes the most dominant species at the second maximum. The *Raunites* assemblage consists of mainly linguloideans and *Raunites*. The *Orthis callactis* assemblage consisting of *Orthis callactis*, *Hemipronites imbricata*, *Gonambonites* sp. C, *Nicolella* sp. and *Productorthis eminens* is dominated by *Orthis callactis* and *Hemipronites imbricata*. Linguloideans are abundant again in the *Orthis callactis* assemblage, where the *Raunites* is, however, absent.

Paurorthis parva and *Ranorthis* are the two most abundant brachiopods in the section, but do not follow any recognizable distributional patterns. The *Apomatella ingrlica* assemblage is most dominant in sections with a relatively low content of glauconite, which according to Tolmacheva *et al.* (1999) indicates high stands of sea level. The *Raunites* assemblage is associated with glauconitic limestones, while the *Orthis callactis* assemblage coincides with the most glauconitic limestone in the section. This suggests that the *Orthis callactis* assemblage is a shallow-water fauna, while the *Raunites* assemblage belongs to slightly deeper water. Nevertheless the spectrum of water depth throughout the Volkhov – early Kunda interval was probably not great, probably within the range of Benthic Assemblage Zone 2 to low Benthic Assemblage Zone 3 (see Brett *et al.* 1993; Brenchley & Harper 1998). The communities probably occupied a position on the outer mid ramp beneath fair-weather wave base.

Substrate relationships

Thirteen marl beds have been compared with the surrounding limestone units to help clarify which, if any, species were substrate related. As a rule, the fauna is slightly but consistently less diverse in the marls than in the corresponding limestones (Fig. 4), but the relative abundance of most species does not change significantly between the two sedimentary types. Those with a clear preference for the limestone are linguloideans, *Pseudocrania petropolitana*, *Porambonites* and *Productorthis parallela*. *Pseudocrania petropolitana* seems to be restricted to the limestone. *Ranorthis* is the only genus, which relative to the others is clearly more abundant in the marl. The distribution of the following species, *Antigonambonites planus*, *Paralenorthis orbicularis*, *Paurorthis parva* and *Ujukella fastigata* seems to be independent of the substrate type. The remaining species are rare or do not show a clear pattern.

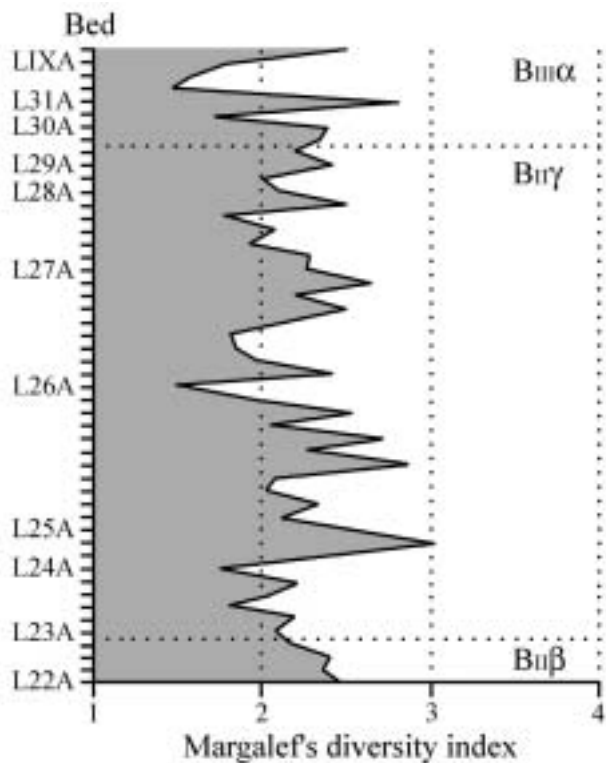


Fig. 5. Diversity changes amongst the brachiopods through the sections measured by the Margalef index.

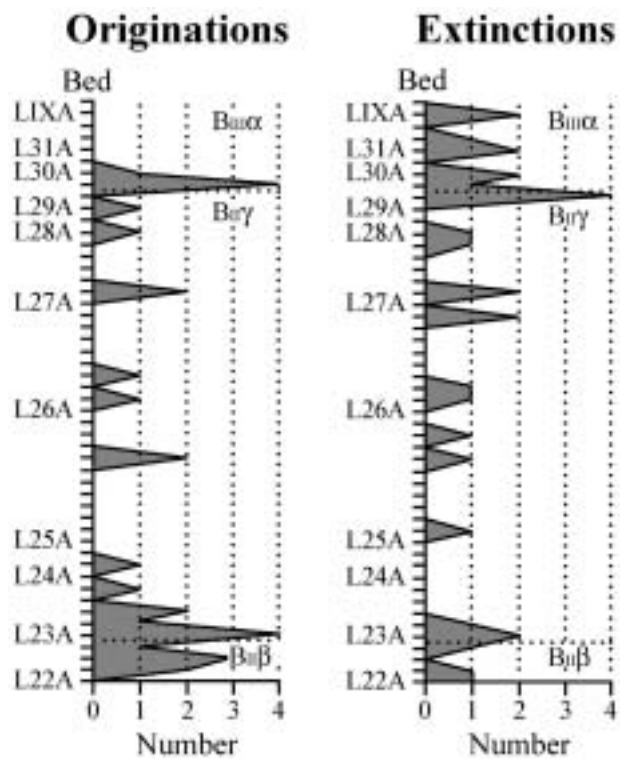


Fig. 7. Dynamics of local originations and extinctions within the brachiopod fauna through the section.

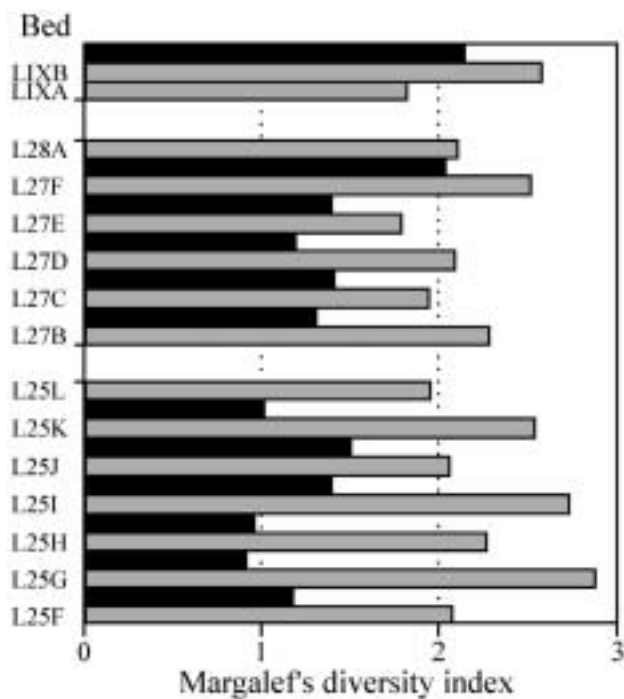


Fig. 6. Relative diversity of the brachiopod fauna (measured by the Margalef index) in limestones and marls through the section.

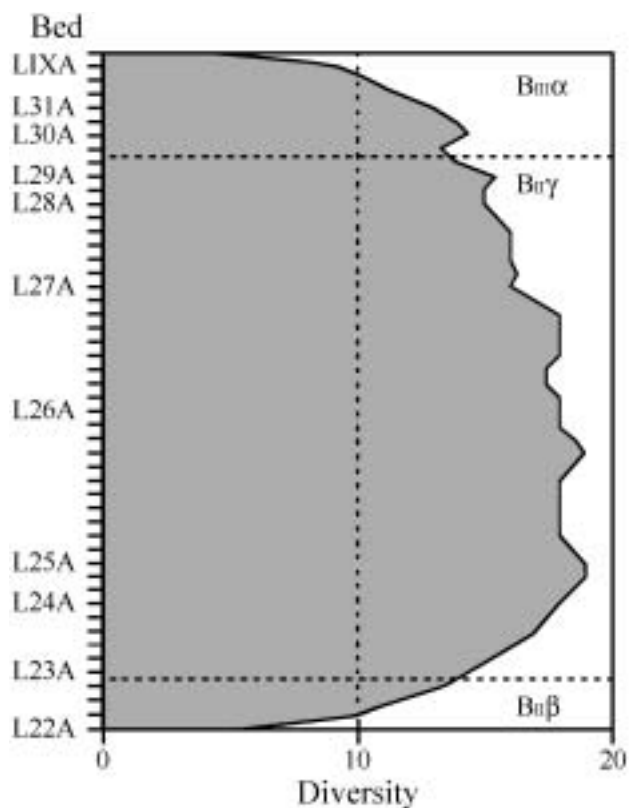


Fig. 8. A corrected standing diversity curve (see text) for the section.

The fauna in the marl consists mainly of juvenile specimens, in contrast to the limestone, where the fauna is dominated by more mature specimens. The difference is not only due to differential preservation and the fact that large specimens are easier to find in limestone than small shells. Sorting due to storms is also unlikely because the composition of the faunas in the two sedimentary types should be markedly different from each other. Possibly the deposition of the marl took place in a more restricted environment (see Tolmacheva *et al.*, this volume) or the lithologies and faunas are responding to the physical and chemical effects of Milankovitch cyclicity within the section.

Brachiopod biodiversity

Brachiopod diversity, measured by the Margalef index (see Brenchley & Harper 1998), fluctuates between 1.5 and 3, through the section (Fig. 5). Moreover the differences in diversity (using the Margalef index) have been calculated for a number of limestone and marl samples (Fig. 6); diversities are consistently lower for the marl samples. The main trends, however, are clearer when the raw data is displayed graphically. Local originations and extinctions suggest the largest faunal turnover occurs near the top of the section with the arrival of the *Orthis callactis* fauna (Fig. 7). The 'endpoint correction' inserts the value of 0.5 for a FAD (First Appearance Datum) or LAD (Last Appearance Datum) in a given sample whereas a value of 0.33 is inserted for the occurrence of both a FAD and LAD. Diversity shows a steep rise until bed L25 where a plateau at about 20 species is reached (Fig. 8). A gradual decline is initiated after sample bed L30 with some minor fluctuations. Although local originations and extinctions occur through the succession, the most striking horizons are Bed L23A [the first bed above the $B_{II\beta} / B_{II\gamma}$ junction] (four appearances) and Bed 29C [at the base of the Kunda] (four appearances) together with Bed L29B (4 disappearances). Two main events are clear within the section: First, the disappearance of the species of the genus *Raunites* during the late Volkhov, that underwent a radiation during the mid-Volkhov, and second, the appearance of a number of new taxa at or just under the base of the Kunda. Both faunal shifts are probably due to slight changes in facies, probably promoted by sea level fluctuations, rather than immigrations into this part of the palaeobasin.

Conclusions

The distribution of 27 brachiopod species, investigated through the upper Volkhov-lower Kunda interval of the Lynna River section based on over 17,500 specimens suggest three depth-related ecological associations. The assemblages formed part of an array of nearshore to mid-shelf communities in an intracratonic setting; minor sea-level changes may have effected the local migrations of taxa within this part of the Baltic palaeobasin. The dominant orthoid and clitambonitoid assemblages, however, form the basis of the distinctive Baltic province during the early Ordovician (Harper & Hints 2001), contrasting with coeval faunas around Gondwana and Laurentia at this time. Faunal diversity, however, was relatively stable throughout the section with little evidence for abrupt local extinctions or originations while diversity was apparently lower in the marl facies compared to assemblages within limestones.

Acknowledgements

We thank the Carlsberg Foundation for financial support, together with Thomas Hansen and Arne Thors-høj Nielsen for useful discussion and partnership in the field. Andrei Dronov (St. Petersburg State University) has given much academic guidance and logistic support during our field campaigns in the St. Petersburg district. Linda Hints (Tallinn) and Eva Egerquist (Uppsala) reviewed the manuscript. This paper is a contribution to IGCP project 410, 'The Great Ordovician Biodiversification'.

References

- Brenchley, P.J. & Harper, D.A.T. 1998: Palaeoecology: Ecosystems, Environments and Evolution. 402 pp. London: Chapman & Hall.
- Brett, C.E., Boucot, A.J. & Jones, B. 1993: Absolute depths of Silurian benthic assemblages. *Lethaia* 26, 25–40.
- Bruton, D.L., Hoel, O.A., Beyene, L.T. & Ivantsov, A. 1997: Catalogue of the trilobites figured in Friedrich Schmidt's "Revision of the ostbaltischen silurischen Trilobiten" (1881–1907). Contributions from the Paleontological Museum, University of Oslo 403, 117 pp.
- Bruton, D.L. & Harper, D.A.T. 1988: Arenig–Llandovery stratigraphy and faunas across the Scandinavian Caledonides. Special Publication of the Geological Society, London 38, 247–268.
- Dronov, A. 1997: Russian and International Bryozoan Conference "Bryozoa of the World". Field Excursion Guide, St. Petersburg, 1997 (unpaginated).

- Dronov, A. & Holmer, L.E. 1999: Depositional sequences in the Ordovician of Baltoscandia. In: Kraft, P. & Fatka, O. (eds): Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System. Acta Universitatis Carolinae, Geologica 43, 133–136.
- Egerquist, E. 1999: Early Ordovician (Billingen–Volkhov stages) Brachiopod Faunas from the NW Russia. In: Kraft, P. & Fatka, O. (eds): Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System. Acta Universitatis Carolinae, Geologica 43, 341–343.
- Hammer, Ø., Harper, D.A.T. & Ryan, P.D. 2001: PAST: Paleontological Statistics Software: Package for Education and Data Analysis. *Palaeontologia Electronica* 4, 9pp.
- Hansen, J. 2002. Nedre Mellem Ordovicium ved Lynna Floden, Volhov, Rusland: biofacies og palæoøkologi baseret på armfodder. 95 pp. Unpublished Cand. Scient. Thesis, University of Copenhagen.
- Hansen, T. & Nielsen, A.T. 2003: Upper Arenig trilobite biostratigraphy and sea-level variations at Lynna River, east of Petersburg, Russia. *Bulletin of the Geological Society of Denmark* 50, 105–113.
- Harper, D.A.T. & Hints, L. 2001: Distribution and diversity of Ordovician articulated brachiopods in the east Baltic. In: Brunton, C.H.C., Cocks, L.R.M. & Long, S.L. (eds): Brachiopods past and present. Systematics Association Special Volume Series 63, 315–326. London & New York: Taylor & Francis.
- Jaanusson, V. 1973: Aspects of carbonate sedimentation in the Ordovician of Baltoscandia. *Lethaia*, 6, 11–34.
- Jaanusson, V. 1982: Introduction to the Ordovician of Sweden. In: Bruton, D.L. & Williams, S.H. (eds): Field Excursion Guide, 1–9. IV International Symposium on the Ordovician System. *Palaeontological Contributions from the University of Oslo* 279. Oslo: Universitetsforlaget.
- Lamansky, W. 1905: Die ältesten silurischen Schichten Russlands (Etage 8). *Mémoires Comité Géologique, Nouvelle Série* 20, 223 pp.
- Lindström, M. 1963: Sedimentary folds and the development of limestone in an early Ordovician sea. *Sedimentology* 2, 243–275.
- Lindström, M. 1984: The Ordovician climate based on the study of carbonate rocks. In: Bruton, D.L. (ed.): *Aspects of the Ordovician System*, 81–88. *Palaeontological Contributions from the University of Oslo*, 295. Oslo: Universitetsforlaget.
- Männil, R. 1966: [Development of the Baltic Basin during the Ordovician]. 201 pp. Tallinn: Valgus (in Russian).
- Männil, R. & Meidla, T. 1994: The Ordovician System of the East European Platform (Estonia, Latvia, Lithuania, Byelorussia, parts of Russia, the Ukraine and Moldova). *International Union of Geological Sciences* 28, 52 pp.
- Öpik, A. 1934: Über Klitamboniten. *Universitatis Tartuens (Dorpatensis), Acta et Commentationes (Series A)* 26, 1–239.
- Rubel, M. 1961: [Lower-Ordovician Brachiopods of the Superfamilies Orthacea, Dalmanellacea and Syntrophiacea of Eastern Baltic.] *Ensv Teaduste Akadeemia Geoloogia Instituudi Uurimused* 4, 141–226 (in Russian).
- Rubel, M. & Wright, A.D. 2000: Suborder Clitambonitidina. In: Kaesler, R. L. (ed.): *Treatise on invertebrate paleontology. Part H. Brachiopoda, Volume 3 (Revised)*, 692–708. The University of Kansas and Geological Society of America, Boulder, Colorado and Lawrence, Kansas.
- Schmidt, F. 1881: Revision der ostbaltischen silurischen Trilobiten nebst geognostischer Übersicht des ostbaltischen Silurgebiet Abteilung I. Phacopiden, Cheiruriden und Encrinuriden. *Mémoires de l'Académie Impériale des Sciences de St.-Petersbourg, VII^e Série* 33, 127 pp.
- Tolmacheva, T.Y., Fedorov, P. & Egerquist, E. 2003: Conodonts and brachiopods from the Volkhov Stage (Middle Ordovician) microbial mud mound at Putilovo Quarry, north-western Russia. *Bulletin of the Geological Society of Denmark* 50, 63–74.
- Tolmacheva, T.Y., Holmer, L.E., Dronov, A., Egerquist, E., Fedorov, P. & Popov, L.E. 1999: Early Ordovician (Hunneberg–Volkhov) facial and faunal changes in the East Baltic. In: Kraft, P. & Fatka, O. (eds): Quo vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System. Acta Universitatis Carolinae, Geologica 43, 467–470.
- Torsvik, T.H. 1998: Palaeozoic palaeogeography: a North Atlantic viewpoint. *GFF* 120, 109–118.
- Torsvik, T., Ryan, P.D., Trench, A. & Harper, D.A.T. 1991: Cambrian–Ordovician palaeogeography of Baltica. *Geology* 19, 7–10.