

## Hulterstad brachiopods and associated faunas in the Vormsi Stage (Upper Ordovician, Katian) of the Lelle core, Central Estonia

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**Abstract.** Integrated palaeontological and sedimentological study of the Upper Ordovician Vormsi Stage in the Lelle drill core section, Central Estonia, revealed an association of shelly fauna containing the endemic saukrodictyid brachiopod *Hulterstadia cor* (Wiman), which is otherwise known only from erratic boulders close to Hulterstad in the southeastern area of the Island of Öland, Sweden. In the Lelle core this fauna occurs in the uppermost *Fungochitina spinifera* chitinozoan Biozone of mid-Vormsi age. Cyclic changes in the content of siliciclastic material in the carbonate section, and in the predominance of shallower- and deeper-water scolecodonts in the interval of the distribution range of *H. cor*, suggest sea-level oscillations during mid-Vormsi time. Upper Vormsi strata, corresponding to the *Tanuchitina bergstroemi* chitinozoan Biozone, including the *Acanthochitina barbata* Subzone, are characterized by common occurrence of sponge remains. Lithologies of the uppermost part of the Lelle section indicate sedimentation in channel environments. Taxonomic composition of the macrofauna in the core differs considerably from that of North Estonia, but has some similarity with the deeper-water Ashgill faunas in other regions (e.g. Fosse Formation of Belgium and Portrane Limestone of Ireland). The Estonian specimens of *Hulterstadia cor* are described.

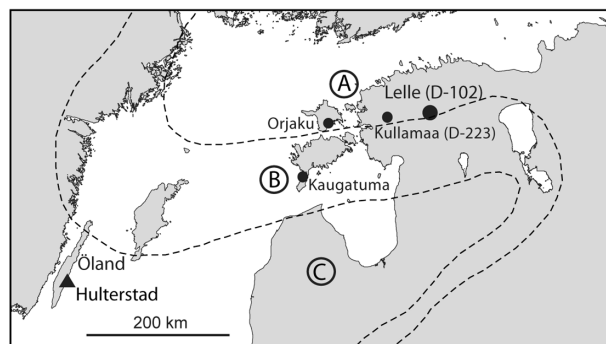
**Key words:** Hulterstad brachiopods, chitinozoans, scolecodonts, Vormsi Stage, Ordovician, Estonia.

### INTRODUCTION

Study of the Lelle (D-102) drill core section, Central Estonia (Fig. 1), has revealed two new faunal associations in the middle and upper parts of the Upper Ordovician Vormsi Stage (upper Katian). The middle, most argillaceous part of the Vormsi Stage contains the endemic saukrodictyid brachiopod *Hulterstadia cor* (Wiman), known previously only from erratic boulders on the Island of Öland (Sweden) (Wiman 1907; Harper 2000). In the present study, *H. cor* is used as an index fossil for the mid-Vormsi brachiopod association, which in the core contains several brachiopod species common with the fauna from Öland (Hulterstad Fauna as named by Jaanusson 1982). The late Vormsi faunal association is conspicuous for the frequency of sponges (remains of spicules and root-tufts) in association with several other brachiopods, among them *Saukrodictya* and *Foliomena*?

The Island of Öland in the Baltic Sea is one of the areas containing erratic boulders of Ordovician rocks, transported from continental and submarine outcrop areas by Pleistocene glaciers. A Late Ordovician (Keila to Pirgu) age has been suggested for these boulders, based mainly on macrofossils (Jaanusson 1982). In 1907, Carl Wiman published data on more than 30 genera of different groups of fossils in 155 erratic boulders of the

“West Baltic *Leptaena* limestone” close to Hulterstad in the southeastern part of Öland (Fig. 1). He compared the silicified faunas from the chert-bearing limestones of the boulders with those of the *Leptaena* Limestone in



**Fig. 1.** Location of the sections and distribution of main lithofacies of Vormsi Age. The dashed line marks the boundary between lithofacies (Männil 1966; Harris et al. 2004). A, mixed facies of the Estonian shelf (bioclastic carbonate deposits of the Kõrgessaare Formation); B, mixed and mud-supported facies of the transitional belt (carbonate marls with argillaceous limestone interlayers of the Tudulinna Formation, with variable content of glauconite grains); C, black shales (Fjäckå Formation) of the Livonia Basin. Black circle – drill core locations; black triangle – location of the erratic boulders.

Dalarna (= Upper Leptaena Limestone of Warburg 1925; = Boda Limestone of Jaanusson 1982) and the “Borkholmer Schicht” (Schmidt 1881; = Porkuni Stage) in Estonia and concluded that, in spite of some common taxa, these faunas are different on the basis of facies variation. On the basis of dominant fossils, the boulders (blocks) can be subdivided into three groups: (1) blocks (Nos 6, 7, and 9 of Wiman 1907) rich in ostracods together with some pentameride brachiopods (identified by Wiman as *Meristella?* sp. and *Camerella salteri* Davidson; a total of over 80 specimens in different blocks), and, in block No. 6, also abundant sponge remains; (2) blocks (Nos 16–22, 30, 34, and others in Wiman’s table) containing specimens of leptaenids in association with dalmanellids; (3) blocks (Nos 1, 4, and 10) with the most diverse association of brachiopods comprising mainly *Hulterstadia cor* (Wiman), *Sulevorthis lyckholmiensis* (Wysogórski), *Skenidioides oelandica* (Wiman), and *Ogmoplecia plicata* (Wiman), and some dalmanellids (identified by Wiman as *Orthis argentea* Hisinger and *O. wysogorskii* Wiman). The variation in the faunal composition of the erratic blocks possibly indicates associations of different age. Some species, e.g. *Sulevorthis lyckholmiensis*, described first from the erratics, are well known in Late Ordovician brachiopod associations (Jaanusson & Bassett 1993).

This integrated study on the distribution of shelly faunas and microfossils in the Vormsi Stage of the continuous Ordovician section in the Lelle drill core provides new data on the brachiopod fauna containing *Hulterstadia cor* and allows us to establish its age in relation to chitinozoan biozonation. Data on the carbonate shelly fauna (preservation, distribution, diversity) and polychaetes (scolecodonts) are compared and analysed briefly with regard to environmental conditions during mid- and late-Vormsi time. New palaeontological and lithological data provide more reliable criteria for defining the boundary between the Vormsi and Pirgu stages in Estonia, and allow some conclusions for supra-regional correlation. Data from core contribute to the identification of the boundary between the Kohila and Atla regional subseries (Nölvak et al. 2006), within the upper part of the Katian Global Stage.

Macrofossils were studied in 67 samples. The specimens were mostly washed out of marly interbeds by processing the samples with hydrogen peroxide. Organic-walled microfossils, collected by washing or

acid digestion, were studied in 34 samples. The lithological description of the section is based on polished surfaces and thin sections; chemical carbonate analysis was undertaken on selected samples. The drill core and the palaeontological collections studied are housed at the Institute of Geology at Tallinn University of Technology (abbreviated GIT).

## LOCALITY AND ROCKS

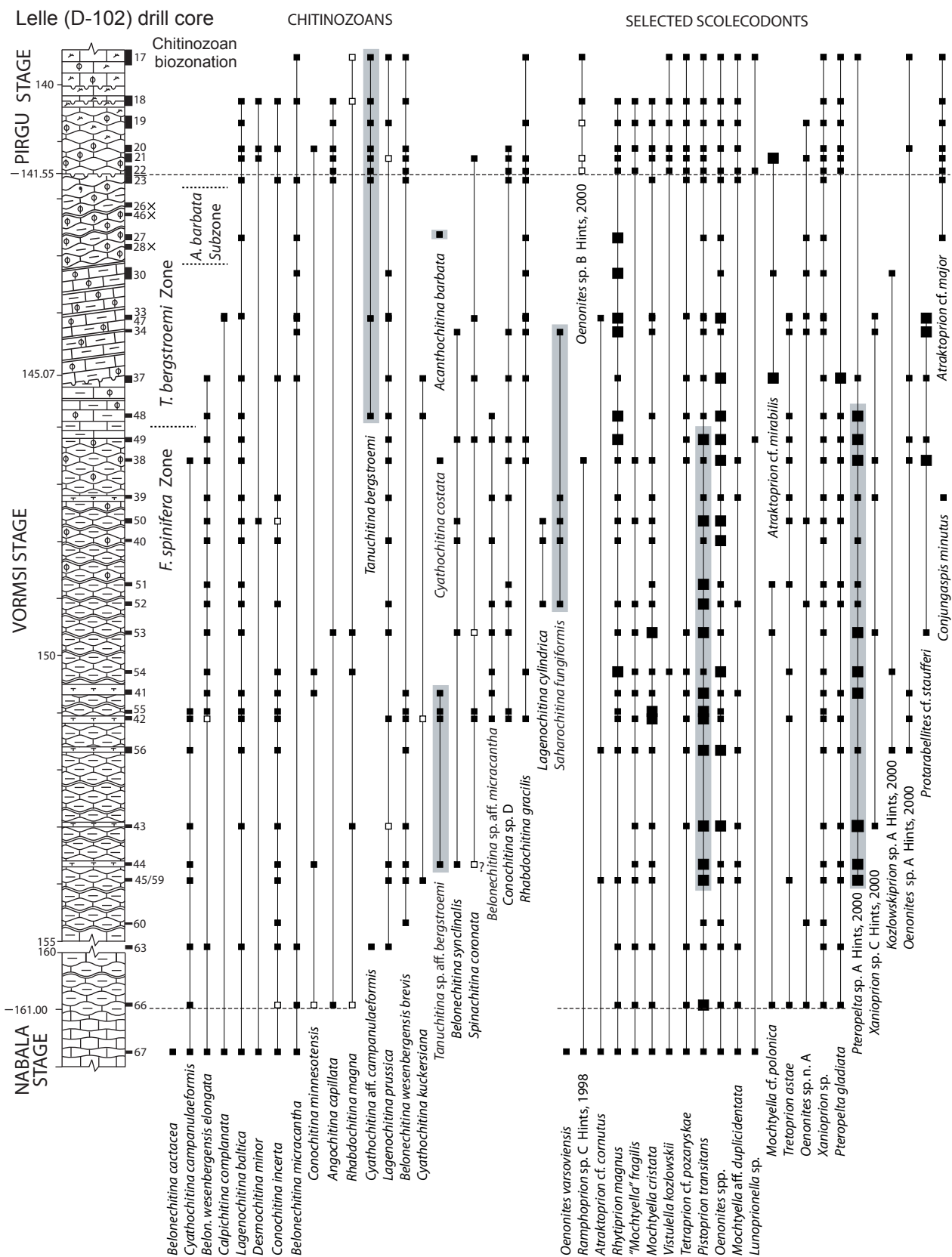
The Lelle (D-102) drilling site (Lat. 58.84°N, Long. 24.98°E) is located close to Lelle settlement in Central Estonia (Fig. 1). The Vormsi age sediments in this area were deposited in conditions transitional from shallow to deeper shelf. In the core, the mixed and mud-supported carbonate rocks of the Vormsi Stage are underlain by carbonate mudstones (micritic limestones) of the Saunja Formation within the Nabala Stage (contact at a depth of 161 m; Fig. 2), and overlain (contact at 141.55 m) by grain- and mud-supported limestones and dolostones with bioclasts of the alga *Palaeoporella* within the Moe Formation of the Pirgu Stage (Männil & Meidla 1994; Harris et al. 2004).

This paper focuses on the middle and upper parts of the Vormsi Stage in the Lelle drill core. *Hulterstadia cor* has not been found in the lower part of the stage, below 153.8 m depth, although there are some brachiopods (*Skenidioides*, *Laticrura*) and microfossils that range into the younger beds.

The middle part of the Vormsi Stage (interval 155.00–145.07 m; Figs 2 and 3) comprises grey to greenish-grey, semi-nodular to nodular argillaceous bioclastic limestones intercalating with marl interlayers of 1–3 cm, in some levels up to 10 cm thick. The content of insoluble residue in these interlayers reaches 60%. The limestone/marl contacts become less sharp upwards in the section. Silicification (up to a depth of about 149 m) and dolomitization of the rocks are weakly developed. The average content of dolomite is 13.8%. The top of the described interval is marked by an uneven discontinuity surface, dipping at about 10° and containing *Trypanites*-type burrows and phosphatic (?) impregnation reaching up to 5 cm below the surface.

The uppermost part of the Vormsi Stage (interval 145.07–141.55 m) is characterized by dipping bedding planes and patchy silicification of bioclastic limestones

**Fig. 2.** Range chart of chitinozoans and selected scolecodonts in the Lelle (D-102) drill core. Sample numbers marked with an x denote those devoid of organic-walled microfossils. Open squares mark identifications as cf. the particular species. Chitinozoan zonations follow Nölvak et al. (2006). Larger squares denote higher relative frequency of scolecodonts; grey shading marks biozonal and biostratigraphically important species of chitinozoans and two polychaete species that distinguish the Hulterstad Fauna interval. Sample No. 63 comes from 157.6 m depth – that part of the section is not shown because of space constraints. For lithological legend see Fig. 3.



intercalating with up to 20 cm thick layers of carbonate marl, which are laminated at some levels. The content of dolomite (up to 35%) exceeds that of the under- and overlying intervals, but the content of siliciclastic material (18–56%) varies similar to the remaining part of the studied interval. The content of bioclasts (commonly less than 1 mm in diameter) varies from 3 to 39% (on average 22%). Thin-section analysis demonstrated that bioclasts are represented mainly by fragments of echinoderms (on average 49%), and in some intervals also by bryozoans. In one thin section (sample 30) siliceous sponge spicules form 55% of bioclasts. Fragments of several other fossils (trilobites, brachiopods, and ostracods) are less common and form no more than 5% similar to other sections in northern Estonia (Oraspõld 1991; Hints et al. 2005).

The 30 cm thick bed at the top of the Vormsi Stage includes at least four pyritized discontinuity surfaces. The uppermost discontinuity at a depth of 141.55 m is taken here as the boundary between the Vormsi and Pirgu stages. Just above this level, in the lowermost beds of the Moe Formation of the Pirgu Stage, flat pebbles with *Trypanites*-type borings occur. In the lowermost part of the Pirgu Stage, fragments of the alga *Palaeoporella* become dominant in the composition of bioclasts, forming algal-limestone interlayers at some levels (Hints et al. 2005). The bedding planes at 15 cm below the discontinuities dip at about 30° within an interval of about 25 cm (sample No. 24). This is the steepest inclination within the otherwise almost horizontal bedding of marl interlayers in the middle of the Vormsi Stage.

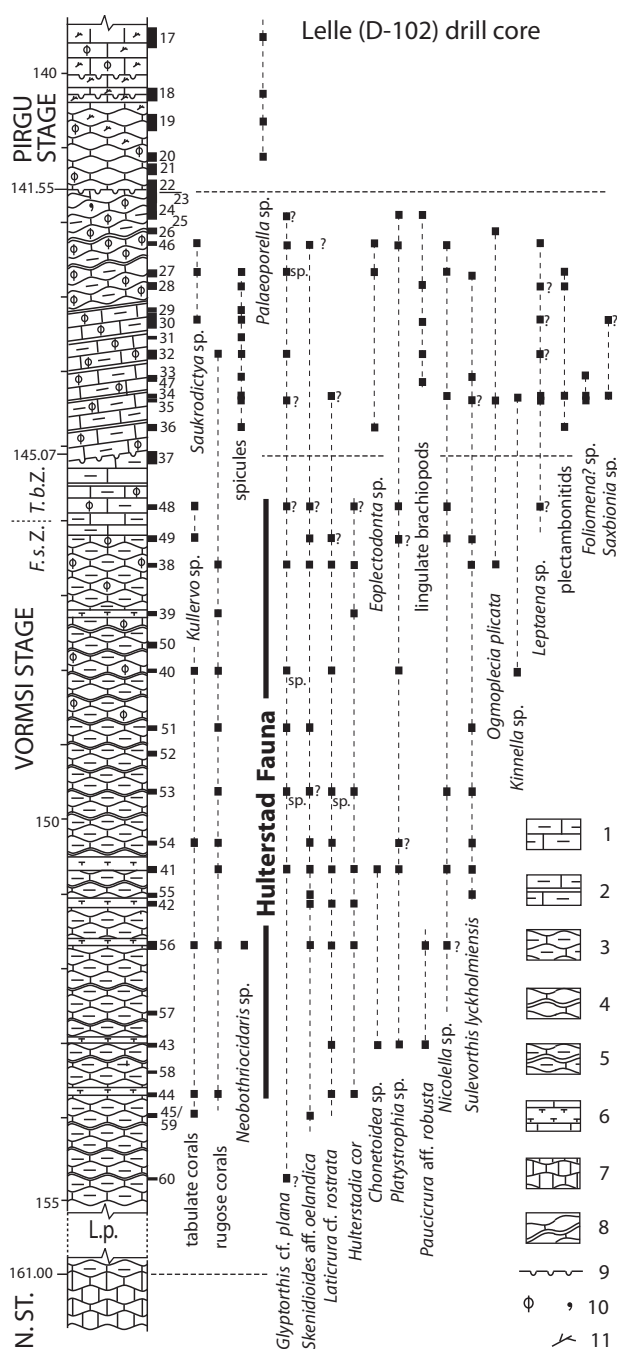
In terms of lithostratigraphical units, the lower part of the Vormsi Stage (up to a depth of about 155 m) corresponds to the Kõrgessaare Formation, which forms the whole stage in northern and northwestern Estonia (Oraspõld & Kala 1982; Männil & Rõõmusoks 1984; Männil & Meidla 1994). The interval of the Vormsi Stage discussed in this paper evidently represents the Tudulinna Formation, characterized by a relatively high content of siliciclastic material. However, in the southernmost (offshore) sections the Tudulinna Formation consists mainly of carbonate and clayey marls, but in our section common and thick (up to 10–20 cm) marl interlayers intercalate with limestone beds. In the easternmost sections, argillaceous limestones and marls contain glauconite grains and the grey colour of rocks is replaced by mottled colours (Oraspõld & Kala 1982). In the deepest part of the basin (Central East Baltic, including southeastern Estonia), the Vormsi Stage is represented by black shales of the Fjäckä Formation (Männil & Meidla 1994; Hints & Meidla 1997) (Fig. 1), which formed during maximum deepening before the sea-level fall associated with the Gondwana glaciation at the end of the Ordovician (Harris et al. 2004).

## BIOSTRATIGRAPHY

The Upper Ordovician rocks in the Lelle core are dated and correlated in detail by chitinozoans, comparing the data from this section with those from previously studied East Baltic sections (Nõlvak 1980, 1984, 1987, 1988). The studied stratigraphical interval from the uppermost Nabala Stage up to the lower part of the Pirgu Stage belongs within two chitinozoan biozones – the *Fungochitina spinifera* and *Tanuchitina bergstroemi* zones (Fig. 2). In the Lelle section, the *F. spinifera* Zone is represented by its upper part (above the *Armoricochitina reticulifera* Subzone; Nõlvak et al. 2006), and the *T. bergstroemi* Zone by its lower half, including the *Acanthochitina barbata* Subzone. The boundary between these biozones is within the upper half of the Vormsi Stage, fairly close to the level of the disappearance of the brachiopod *H. cor* and to changes in the composition of scolecodonts. The *F. spinifera* Biozone is identified by the occurrence of *Saharochitina fungiformis*, which was previously included within the complex species *Fungochitina fungiformis* (Nõlvak & Grahn 1993; revised in Nõlvak et al. 2006). In the Lelle core, *S. fungiformis* is not found in the lower half of the Vormsi Stage, but it appears in the lower half of the Upper Ordovician (in the Oandu Stage of the Valga core; Nõlvak 2001).

The assemblage of chitinozoans is not particularly rich (only 25 taxa have been identified) in the Lelle section but, nevertheless, some changes are observed in their succession. In addition to the first appearance of the zonal species, *T. bergstroemi*, at a depth of 145.8 m (sample No. 48), two more stratigraphically useful levels are recognized: (1) the appearance of *Belonechitina* sp. aff. *micracantha* and *Conochitina* sp. D at a depth of 151.2 m (sample No. 42) in the limits of the *Fungochitina spinifera* Zone (in the middle part of the Vormsi Stage) and (2) the appearance of the subzonal *Acanthochitina barbata* (found, however, only in sample No. 27; Fig. 2). Because of strong silicification of the topmost beds of the Vormsi Stage (interval 141.7–142.9 m), some samples (Nos 28, 46, and 26) were barren and no acid-resistant microfossils were found. The lower boundary of the *A. barbata* Subzone is drawn tentatively above the uppermost productive sample (No. 30 at a depth of 143.0 m) below the occurrences of zonal taxa (Fig. 2).

A similar pattern in the distribution of chitinozoans has been identified in some previously studied sections of Central Estonia (Nõlvak 1984, figs 13, 20), where the Vormsi Stage is more than 15 m thick (see the map in Hints & Meidla 1997, fig. 55). The most essential differences in the thickness of the Vormsi Stage in western and Central Estonia depend, according to the



**Fig. 3.** Range chart of selected brachiopods in the Lelle (D-102) drill core. The possible occurrence of taxa is marked by “?” and “sp.” marks the identification of fossils at the genus level. N. ST., Nabala Stage; L.p., lower part of the Vormsi Stage, which is not discussed in the paper. F.s.Z. and T.b.Z., *Fungochitina spinifera* Biozone and *Tanuchitina bergstroemi* Biozone. Lithological legend: 1, argillaceous limestone; 2, argillaceous limestone with marl interlayers; 3, nodular argillaceous limestone; 4, nodular limestone with a marl interlayer; 5, nodular argillaceous limestone with a marl interlayer; 6, marl interlayer; 7, seminodular aphanitic limestone (carbonate mudstone); 8, tilted beds; 9, discontinuity surface; 10, silicification, glauconite grain; 11, biotritus of algae.

chitinozoan data, on the thickness of the middle part of the stage (interval 146.2–154.0 m in the Lelle core), corresponding to the uppermost *F. spinifera* Zone. In the Orjaku core (Island of Hiiumaa), this part is only about 2 m thick, but is completely absent in many other sections of northern and southwestern Estonia (e.g. Hullo, Are, Eikla, Ruhnu in Nölvak 1984, 2003).

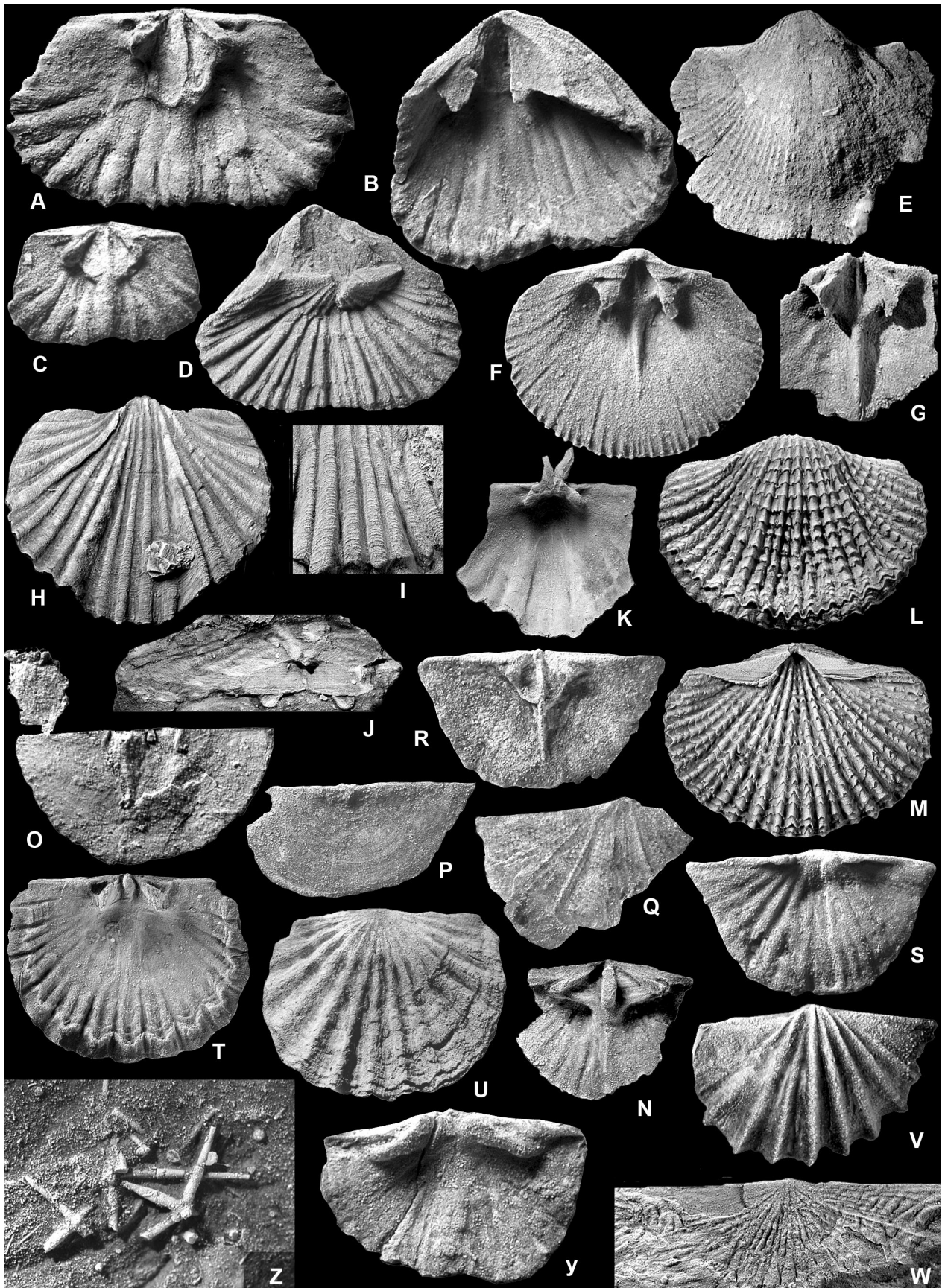
A particular feature of the studied section is the occurrence of *Tanuchitina* sp. aff. *bergstroemi*, a morphologically transitional species between *Conochitina incerta* and typical *Tanuchitina bergstroemi*, in the interval of 150.6–153.6 m. The occurrence of such transitional forms sometimes complicates precise determination of the ranges of stratigraphically valuable taxa, in this case evidently indicating that these beds were previously unknown. It is interesting to note that transitional forms (having an unusually conical base and, for *Tanuchitina*, a very weak membranous carina on the margin) similar to *Tanuchitina* sp. aff. *bergstroemi* have been described from the Ashgill Fosses Formation, Belgium (Vanmeirhaeghe & Verniers 2004, pl. II, figs a, b, j).

### THE HULTERSTAD BRACHIOPODS AND ASSOCIATED FOSSILS

Associations of shelly faunas in the Lelle core comprise brachiopods, bryozoans, echinoderms (predominantly stem ossicles), corals, and some other fossils (Figs 3 and 4). Many shells and skeletons are either deformed or fractured. Brachiopods with relatively large, mature shells (e.g. *Nicolella*, *Platystrophia*, *Laticrura*, *Leptaena*, *Saxbionia*) are mostly represented by incomplete valves (Fig. 4G, K, N) or juvenile specimens (Fig. 4V), which are often insufficient for the precise identification of the species. Small brachiopods of the genera *Hulterstadia*, *Skenidioides* (Fig. 4) and some others (mainly dalmanellids) are represented by complete valves.

*Hulterstadia cor* and associated taxa, common in the Hulterstad Fauna of the erratic boulders on Öland, or related to it, occur in the Lelle section in the *Fungochitina spinifera* chitinozoan Zone, in the middle part of the Vormsi Stage. An exception is one poorly preserved specimen of *H. cor* in sample No. 48, at the appearance level of *Tanuchitina bergstroemi*, indicative of the succeeding biozone. In the Lelle core, *H. cor* occurs in the interval of 145.77–153.67 m (between samples 48 and 44), where it is associated with the brachiopods *Sulevorthis lyckholmiensis*, *Laticrura* cf. *rostrata*, *Glyptorthis* cf. *plana*, *Skenidioides* sp., *Kullervo* sp., *Ogmoplecia plicata*, and some others (Figs 3 and 4). Numerous stem ossicles and fragments of bryozoans,





and rugose and tabulate (heliolitids) corals occur in the same interval. The first appearance of *H. cor* in the Lelle section coincides with that of the chitinozoan *Tanuchitina* sp. aff. *bergstroemi* (sample No. 44). Both appear in the *F. spinifera* Biozone. Some brachiopods, for example *Laticrura*, *Platystrophia*, *Nicolella*, represented by incomplete valves, were probably transported into the area from shallower environments (north of Lelle) with higher water energy. *Hulterstadia cor*, and some small-shelled brachiopods such as *Skenidioides*, *Chonetoidea?* and dalmanellids, are represented in some samples by valves of different sizes (juvenile and mature specimens), which indicates their almost autochthonous location. The uppermost occurrence of *H. cor*, in the top of the *F. spinifera* chitinozoan Zone, are associated with *Ogmoplecia plicata* and *Kullervo* sp. These two brachiopods also occur in the erratic boulders on Öland, but in smaller numbers than *H. cor* (Wiman 1907). Trilobites are rare in the Hulterstad Fauna on Öland and also in the Lelle section, but halysitids, which co-occur with *H. cor* in the Lelle section, also occur in the boulders where this brachiopod is missing. Several brachiopods in erratics of Öland (*Orthis argenta* Hisinger, *Strophomena rhomboidalis* Wilkens, *Camerella salteri* Davidson), listed by Wiman (1907), and also the strophomenids and dalmanellids of the Lelle section are in need of taxonomic revision before more detailed comparison of the Öland and Estonian faunas can be completed. Nevertheless, on the basis of similar faunas, among them *H. cor*, we can date at least part of the erratic boulders on Öland with great probability as being of Vormsi age. These boulders are evidently derived from submarine rock outcrops west of the Estonian coast. The Vormsi age of the Hulterstad erratics is supported also by the rugose corals in the boulders (Webby et al. 2004).

Changes in faunal composition – the disappearance of *H. cor* and *Kullervo* sp. and the appearance of several new strophomenids (*Eoplectodonta* sp., *Saxbionia* sp., *Foliomena?* sp.) and of the zonal chitinozoan *Tanuchitina bergstroemi* – take place in the interval between samples Nos 36 and 48. In this interval, there is a discontinuity surface at a depth of 145.2 m (sample No. 37; Fig. 3). The occurrence of *Foliomena?* (two badly preserved specimens; Fig. 4O, P) suggests probable connection of the late Vormsi brachiopod fauna in the Lelle core with the relatively deep-water *Foliomena* Fauna described from several Ordovician basins (Harper 1980; Sheehan 1987; Cocks & Rong 1988; Neuman 1994; Rong & Zhan 1996; Harper et al. 1999; Villas et al. 2002; Zhan & Jin 2005).

Ten samples (Nos 27–36; Fig. 3) from the uppermost part of the Vormsi Stage contain abundant siliceous sponge spicules and root-tufts (Fig. 4Z). Possible oversaturation of sea-water by silica due to volcanic activity (Botting 2005) at the end of Vormsi time, led to widespread distribution of siliceous sponges. In Estonia, Vormsi age K-bentonite layers have been identified in a few sections (Männil 1966, fig. 27; Nõlvak 1987). The common occurrence of sponge remains in one erratic boulder (No. 6; Wiman 1907) on Öland suggests that the rocks in the source area of erratics were somewhat similar to those in the Lelle section.

In addition to those from the Lelle core, only three specimens of *H. cor* have been found in Estonia: two from the Kullamaa (D-223) core and one from the Kaugatuma core (Fig. 1), all three from marl interlayers. The Vormsi Stage has a similar lithology and thickness in the Kullamaa and Lelle sections, which are located in the same facies zone (Fig. 1). Thus new finds of *H. cor* could be expected in the former section. The

**Fig. 4.** Selected fossils in the middle and upper parts of the Vormsi Stage in the Lelle drill core section. **A–D**, *Hulterstadia cor* (Wiman). A, GIT 509-1, dorsal valve interior; B, GIT 509-2, ventral valve interior; C, GIT 509-5, dorsal valve interior; D, GIT 509-4, dorsal view of complete shell; depth 150.60–150.70 m (sample 41),  $\times 9$ . **E–G**, *Laticrura rostrata* Hints. E, GIT 509-12, ventral valve exterior, depth 150.60–150.70 m (sample 41),  $\times 5.3$ ; F, GIT 509-15, dorsal valve interior, depth 151.07–151.13 m (sample 42),  $\times 8.1$ ; G, GIT 509-14, fragment of dorsal valve with cardinalia, depth 150.60–150.70 m (sample 41),  $\times 5.5$ . **H–K**, *Ogmoplecia plicata* Wright. H, GIT 509-31, ventral valve exterior, depth 144.35–144.40 m (sample 35),  $\times 2.5$ ; I, GIT 509-32, external sculpture of dorsal valve,  $\times 7$ ; J, GIT 509-30, posterior view of ventral valve, depth 144.35–144.40 m (sample 35),  $\times 3.5$ ; K, GIT 509-29, fragment of dorsal valve, depth 146.55–146.60 m (sample 38),  $\times 2.5$ . **L–N**, *Glyptorthis* cf. *plana* Rõdmusoks. L, M, GIT 509-39, exteriors of dorsal and ventral valves,  $\times 3$ ; N, GIT 509-40, fragment of dorsal valve,  $\times 5.7$ ; depth 146.55–146.60 m (sample 38). **O, P**, *Foliomena?* sp. O, GIT 509-43, exterior of dorsal valve with loose reversed fragment of the same specimen showing the cardinal process,  $\times 5$ ; P, GIT 509-44, exterior of dorsal valve,  $\times 5$ ; depth 144.30–144.35 m (sample 34). **Q**, *Saukrodictya* sp. GIT 509-10, ventral exterior of incomplete valve, depth 142.63–142.73 m (sample 27),  $\times 5.8$ . **R, S**, *Skenidioides* aff. *oelandica* Wiman. R, GIT 509-21, dorsal valve interior, depth 146.55–146.60 m (sample 38),  $\times 10$ ; S, GIT 509-22, dorsal valve exterior, depth 150.60–150.70 m (sample 41),  $\times 9$ . **T, U**, *Sulevorthis lyckholmiensis* (Wiman), GIT 509-18, interior and exterior of dorsal valve, depth 146.55–146.60 m (sample 38),  $\times 5$ . **V**, *Nicolella* sp., GIT 509-25, ventral valve exterior, depth 150.60–150.70 m (sample 41),  $\times 8$ . **W**, *Saxbionia* sp., GIT 509-50, exterior of incomplete dorsal valve, depth 144.30–144.35 m (sample 34),  $\times 2.5$ . **Y**, *Kullervo* sp., GIT 509-11, dorsal valve interior, depth 146.55–146.60 m (sample 38),  $\times 10$ . **Z**, bedding plane with fragments of sponge spicules, depth 144.30–144.35 m (sample 34),  $\times 12$ .

Kaugatuma core, where the thickness of the Vormsi Stage is restricted (2.3 m; Oraspõld & Kala 1982), possibly marks the southern limit of the distribution area of *H. cor*.

Scolecodonts (polychaete jaws) in the Lelle section comprise 43 species, about ten of which are abundant (Fig. 3). There is a distinct polychaete association co-occurring with *H. cor*. In particular, *Pteropelta* sp. A *sensu* Hints, 2000, which has been recorded in abundance only in the Vormsi Stage of a few sections (Hints 2000), appears at a depth of 154 m (sample 59) and is common up to about 146 m (sample 48). Within this range, the species displays three acmes that coincide with the occurrences of *H. cor* (Fig. 3). Since similar fluctuations are not known from other localities, it is impossible to ascertain whether they are time constrained or reflect interfingering biofacies.

*Pistoprion transitans* Kielan-Jaworowska, 1966, a common and stratigraphically widespread species, has its maximum relative frequencies approximately in the same interval as *Pteropelta* sp. A. Its frequency fluctuations, however, seem not to correlate exactly with those of *Pteropelta* sp. A. Generally, the genus *Pistoprion* is regarded as characteristic of relatively shallow-water facies (Hints 2000; Nõlvak et al. 2006). *Pteropelta* sp. A, on the other hand, has been found abundantly only in deeper-water or transitional settings (Laeva drill core in Central Estonia and Mielnik drill core in NE Poland), whereas more on-shore settings are characterized instead by high frequencies of *Pteropelta gladiata*. The mentioned species may indicate the transitional nature of the deposits of the Vormsi Stage in the Lelle section.

In the uppermost part of the Vormsi Stage, above sample No. 48 containing the last *Hulterstedia cor*, the scolecodonts *Rhytiprion magnus* and *Oeonites* are dominant. This level coincides also with the appearance of the zonal chitinozoan *T. bergstroemi*. At some levels in the uppermost Vormsi Stage, *Atraktoprion* and *Protarabellites* also make up a significant part of the scolecodont assemblage. The polychaete fauna of the lowermost Pirgu Stage is notably more diverse, containing several species not present or rare in the underlying strata (e.g. *Oeonites* sp. B *sensu* Hints, 2000, *Atraktoprion* cf. *major*, and *Vistulella kozlowskii*).

The faunal change described above occurs close to the discontinuity surface at the 145.07 m level. The inclined bedding planes and pebbles above the discontinuity indicate a significant event in the depositional regime and faunal association. The common occurrence of sponge spicules and the strongest silicification of the rocks in the sequence characterize the uppermost Vormsi strata.

## DISCUSSION AND CONCLUSIONS

Two faunal associations within the Tudulinna Formation of the Lelle drill core section correspond to the middle and upper parts of the Vormsi Stage, respectively. New data, although from only one section, show that the general model of biofacies successions along an onshore–offshore transect is more complicated than presumed earlier (Hints & Meidla 1997). Although previous data on the macrofauna of the Tudulinna Formation (Rõõmusoks 1966; Hints & Meidla 1997) are quite scarce, they still indicate essential differences from the faunas of the Kõrgessaare Formation (Jaanusson 1956; Rõõmusoks 1960, 1966; Männil 1966; Hints & Meidla 1997).

In the Lelle section, the lower 8 m interval of the Tudulinna Formation is characterized by transitional lithologies, a faunal association with *H. cor*, and alternating dominance of the scolecodonts *Pistoprion transitans* and *Pteropelta* sp. A. This part of the section belongs to the *Fungochitina spinifera* chitinozoan Biozone. According to the chitinozoans, the strata corresponding to this interval have very restricted thicknesses or are completely missing in many other sections in northern and Central Estonia. However, the occurrence of *H. cor* in erratics on the Island of Öland and two other sections in Estonia signify an originally wider distribution of that species.

On the basis of chitinozoans (the zonal species *Tanuchitina bergstroemi* and subzonal species *Acanthochitina barbata*), the uppermost part of the Tudulinna Formation, represented in the Lelle core by atypical lithologies of the Tudulinna Formation, can be correlated fairly precisely with the uppermost part of the Vormsi Stage in some sections of northwesternmost Estonia, where the whole of the Vormsi Stage is represented by the Kõrgessaare Formation (Hullo and Eikla drill core sections; Nõlvak 1984; Oraspõld & Kala 1982). According to this correlation, the diverse fauna of the latter formation, comprising large-shelled brachiopods, gastropods, cephalopods, different tabulate and rugose corals, trilobites, and bryozoans (Jaanusson 1956; Rõõmusoks 1960, 1966; Männil 1966), has been replaced by the fauna described in the uppermost part of the Vormsi Stage in the Lelle section about 30 km in an offshore direction. The Saxby, Paluküla, and Moe outcrops are good examples to demonstrate where the diverse shelly fauna of the Kõrgessaare Formation corresponds to the *A. barbata* Subzone (Rõõmusoks 1966; Nõlvak 1984).

The Lelle section is located in the offshore part of the Estonian Shelf (Harris et al. 2004), where the mixed shallow to middle shelf (Kõrgessaare Formation) and deeper shelf mud-supported (Tudulinna Formation)



facies interfinger. Different preservation of shelly fossils due to sorting and some transportation of skeletal remains, and the co-occurrence of shallow- and deeper-water habitants among scolecodonts indicate changeable environmental conditions and oscillation of sea level during the transgressive stage of basin development (Nestor & Einasto 1997; Kaljo et al. 2004).

The inclined bedding planes in the upper part of the Vormsi Stage in the Lelle core mark changes in sea floor relief. The study area possibly represents a channel-like depression, similar to those established by shallow marine seismic reflection profiling in the Baltic Sea between the islands of Gotland and Saaremaa (Tuuling & Flodén 2000). According to these authors, such depressions formed during the erosional period before the deposition of the Vormsi Stage. In our case these structures were developed in late-Vormsi time, presumably close to the slope area. The variation in the thickness of the Vormsi Stage in northernmost and Central Estonia (Nölvak 1987; Flodén et al. 1994; Hints & Meidla 1997) indicates the probable occurrence of other similar depressions.

Outside Estonia, brachiopod faunas similar to that discussed above have been described from the Portrane Limestone, Ireland (Wright 1963, 1964) and the Fosse Formation, Belgium (Sheehan 1987). The silicified brachiopods of the Portrane Limestone were collected from a few metre thick interval containing also barren beds. Comparison of the assemblages of the Portrane Limestone and the Vormsi Stage (Popov et al. 1994) revealed a possibility that the former brachiopods belong to two different associations. The Portrane Limestone, within the Cautleyan Stage (Wright in Williams et al. 1972; Holland 1981), is correlated with the uppermost *complanatus* and lower half of the *anceps* graptolite biozones (Fortey et al. 1995). The Vormsi Stage is correlated traditionally with the uppermost *linearis* biozone (Nölvak et al. 2006). The age difference between the Estonian and Irish brachiopod faunas may be a result of a facies and faunal shift, but it may also suggest a somewhat older age for the Portrane Limestone than presumed earlier.

The Ashgill brachiopod fauna described by Sheehan (1987) from Belgium contains 16 of the 18 orthid genera recorded from the Portrane Limestone. Several of these, for example *Skenidioides*, *Ogmoplecia*, *Kullervo*, *Laticrura*, and *Saukrodictya*, occur also in Estonia. Sheehan (1987) was correct in supposing that the brachiopod faunas of North Estonia and Belgium differ in community ecology, but at that time only very few palaeontological data had been published on contemporaneous faunas from the offshore facies

in Central Estonia (Männil 1966; Ulst et al. 1982). Our data from the Lelle and some other Estonian sections, and also from other regions, demonstrate that early Ashgill (late Katian) brachiopod faunas, of fairly similar taxonomic composition and ecological type (predominantly small-shelled specimens), are widely distributed in the offshore facies of the North European Faunal Province.

## SYSTEMATIC PALAEOLOGY

Genus *Hulterstadia* Wright, 1993

*Hulterstadia cor* (Wiman, 1907)

Figure 4A–D

*Lectotype.* Conjoined valves, Naturhistoriska Riksmuseet in Stockholm, Br. 4405, figured by Wiman 1907, pl. 1, figs 13, 13a, Block 4. Hulterstad, Öland.

*Diagnosis.* See Wright 1993, p. 74.

*Description of Estonian specimens.* Shell plano-convex, slightly cordate in outline, varying from subquadrate in small shells to suboval in adults (Fig. 4A–D). The width of the valves reaches 8.3 mm, the length of the largest ventral valve 5 mm, and of the dorsal valve 4.0 mm; the hinge line is about half the maximum width of the shell. The ornament consists of 12–14 costae appearing close to the umbo, increasing to 30 by branching along the margins. The rib density in 1 mm at 2 mm from the umbo is up to 5. The shell surface is covered by net-like ornament, which is denser in the rib interspaces. The valve is relatively thick in some specimens with pores having white (silicified?) infillings.

The pedicle interarea is slightly curved, apsacline, up to 1.5 mm long and with open triangular delthyrium. The dorsal interarea is low and flat. The interior of the pedicle valve is known only from a few incomplete or deformed specimens (Fig. 4B). For 1/3 of the length of the ventral valve, the muscle field is raised above the valve floor and is bounded by the dental plates of triangular teeth. The dorsal valve has brachiophores that are triangular in lateral view, tapering ventrally; brachiophore bases turn to form subtriangular to elongately oval or trapezoidal sessile septalium reaching up to the middle of the valve. Fulcral plates on the lateral sides of brachiophores are weakly developed, with dental sockets supported anteriorly by secondary shell material. A low ridge-like cardinal process divides the septalium, reaching to the slightly elevated anterior septalium margin. The myophore is developed as a

small knob on the posterior end of the cardinal process. The dorsal adductor field is weakly developed, with posterior triangular scars located lateral to the septalium; anterior subrounded scars extend anteriorly to 4/5 of the valve length. Anterior and antero-lateral parts of the interiors have strong crenulation reaching up to the adductor field.

*Comparison.* The Estonian specimens are somewhat larger than the paralectotypes figured by Wright (1993), among which the largest ventral valve is 5.7 mm wide and 5.2 mm long. The obtuse form of the brachiophore processes in Estonian specimens is probably due to poorer preservation; the specimens from Öland have long, spike-like brachiophores. Quite often silicified brachiopods, such as those from Öland, are excellently preserved. The exterior of incomplete valves of *H. cor* may bear some similarity with the exterior of *Saukrodictya*, which is also present in the uppermost Vormsi Stage of the Lelle core. Main differences between *Hulterstadia* and *Saukrodictya* are described by Wright (1993). A few specimens of *Saukrodictya* sp. in the Lelle core have a laterally elongate outline, with acute cardinal extremities and wide interarea corresponding to the maximum width of the shell. The net-like sculpture on the exterior surface of *Saukrodictya* sp. (Fig. 4Q) is more than three times coarser and the number of costae is about half of that in *Hulterstadia*.

*Occurrence.* Lelle (D-102) drill core, depth 146.55–153.67 m – 1 shell, 2 incomplete dorsal valves and 1 ventral valve; 147.38–147.60 m – 3 dorsal valves and 1 ventral valve; 150.48–150.54 m – 1 dorsal valve and 32 incomplete valves; 151.07–151.13 m – 1 incomplete ventral valve; 153.62–153.67 m – 1 shell and 1 incomplete ventral valve. Kaugatuma drill core, depth 386.7 m – 1 deformed shell; Kullamaa (D-223) drill core, depth 104.60–104.67 m – 1 dorsal valve and 1 shell.

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## Vormsi lademe (Ülem-Ordoviitsium, Katian) Hulterstadi brahhiopoodid ja kaasnev fauna Lelle puursüdamikus Kesk-Eestis

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Lelle puursüdamiku paleontoloogiliste ja sedimentoloogiliste uuringutega on välja selgitatud omapärase faunakoosluse esinemine Vormsi lademes. Selle fauna üheks iseloomulikuks esindajaks on brahhiopood *Hulterstadia cor* (Wiman), mis senini oli teada rändkividest Ölandi saarel. *H. cor* esineb Lelle läbilõikes Vormsi lademe keskmises osas, mis vastab kitiiniku *Fungochitina spinifera* biotsooni ülemisele poolele. Sellest tulenevalt võib järeldada, et Ölandi rändkivid, mis sisaldavad brahhiopoodi *H. cor* kivistisi, pärinevad Vormsi, mitte Pirgu lademest, nagu varem oletati. Terrigeense materjali tsükliline esinemine lademe keskmises osas ja sügavama- ning madalamaveeliste faatsiistele iseloomulike polüheetide vahelduv esinemine viitavad meretaseme korduvatele muutustele. Vormsi lademe ülemine osa, mis vastab *Acanthochitina barbata* alamtsoonile, sisaldab uusi, vanemates kihtides puuduvaid liike. Märkimist väärib käsnade toesefragmentide rohke esinemine. Sedimentoloogiliste ja paleontoloogiliste tunnuste põhjal võib oletada, et Lelle piirkonnas esines Vormsi ea teisel poolel kanalitaoline struktuur, kuhu kuhjus rohkem setteid kui naaberaladel. Lelle puursüdamiku brahhiopoodifauna sisaldab ühiseid liike Portrane'i lubjakiviga Iirimaal ja Fosse kihistu faunaga Belgias.