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CHITINOZOANS AT THE LLANDOVERY—WENLOCK TRANSITION IN THE JAAGARAHU CORE, ESTONIA

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Abstract. The lower part of the Jaagarahu core, including the Llandovery—Wenlock transition, contains chitinozoans in high diversity and abundance. Some species, particularly *Gotlandochitina magnifica*, occurring in the basal Wenlock in the East Baltic sections and probably also in the Llandovery—Wenlock boundary stratotype near Leasows are regarded as potential biomarkers for establishing this boundary in the carbonate sections. A comparison of the taxonomic composition and diversity of coeval chitinozoan assemblages from the Jaagarahu core and Vattenfallet section in Gotland permits to conclude that at Jaagarahu the lowermost Wenlock sediments accumulated in deeper-water conditions than the Upper Visby marls at Vattenfallet. Later, however, more open-marine conditions endured there longer than at Jaagarahu.

Key words: Chitinozoa, basal Wenlock, Estonia.

INTRODUCTION

The Jaagarahu borehole is located in an abandoned stratotypical quarry of the mid-Wenlockian Jaagarahu Regional Stage (Fig. 1). It was drilled in order to establish the precise position of the stratotype section in the whole sequence of the Jaagarahu Stage. The lithological column is given mainly after Einasto (Эйнасто, 1981). The Jaagarahu Stage is here represented by its basalmost Vilsandi Beds (0.3—8.7 m, see Fig. 2) and is mostly characterized by lagoonal, coral, and biohermal limestones. The lower-lying Jaani Regional Stage is represented by reef limestones and dolomites of the Ninase Member (8.7—28.0 m), by calcitic and argillaceous marlstones, and argillaceous nodular limestones of the Mustjala Member (28.0—55.3 m). The basal part of the section shows argillaceous marlstones and calcareous mudstones of the Upper Llandovery Adavere Regional Stage (55.3—61.6 m).

The core was sampled at regular 1 m intervals from which conodonts (by P. Männik and V. Viira) and chitinozoans were identified. Conodonts occur throughout the section, chitinozoans were recorded only from its lower part, whereas lagoonal and coral limestones of the uppermost part of the section are devoid of chitinozoans.

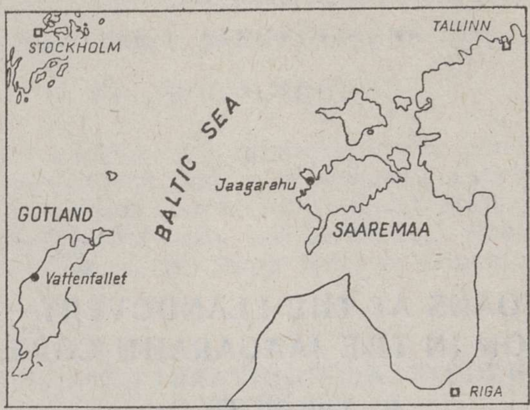

Fig. 1. Location of the Jaagarahu borehole and Vattenfallet section.

In the paper the chitinozoan assemblage in the Llandovery—Wenlock transition is characterized in order to find out some new biomarkers for establishing this boundary in the carbonate sections, but also for pointing out a considerable decrease in the chitinozoan diversity in the basal Wenlock, which represents one of the most important chitinozoan extinction events in the Silurian (Nestor, 1992). Some parallels are drawn between the Jaagarahu section and the Vattenfallet section of Sweden (Laufeld, 1979).

DISTRIBUTION OF CHITINOZOANS

The total number of samples taken from the Jaagarahu core for the study was 59, but only 35 yielded chitinozoans. They represent without exception the lower 33 m thick marly part of the section, mostly characterized by argillaceous marlstones and comprising the boundary beds of the Adavere and Jaani stages. In this interval the species diversity and abundance of chitinozoans are high. The dominant species is here *Conochitina proboscifera*, but also *Ancyrochitina primitiva*, *Angochitina longicollis*, *Gotlandochitina ruhnuensis*, *Conochitina acuminata*, and *C.* cf. *visbyensis* occur abundantly (see Pls. I and II). The base of the Jaagarahu core section, lying at a depth of 61.6 m, has yielded representatives of the genus *Anthochitina*, so far known from the Lower Silurian sediments only in the uppermost Llandovery of the Viki core (Saaremaa Island). Similar forms have also been found in the Jupiter Formation of the Anticosti section, identified there as *Clathrochitina*? sp. 2 (Achab, 1981).

According to the East-Baltic chitinozoan biozonation the appearance of *Conochitina proboscifera* in the upper part of the Adavere Stage marks the last biozone in the uppermost Llandovery and the co-occurrence of *Angochitina longicollis* and *Margachitina margaritana* in the lowermost Jaani Stage marks the first chitinozoan biozone in the basal Wenlock. In the Jaagarahu core the thickness of the latter zone is about 20 m, decreasing eastwards and southwards to 6—8 m. The disappearance level of *Angochitina longicollis* and several other chitinozoan species (*Conochitina acuminata*, *C. emmastensis*, *Gotlandochitina ruhnuensis*, *Desmochitina opaca*, etc.) is a good correlative level in all sections studied. This level can also be traced in several other regions of the world, for example in the middle of the Upper Visby Beds on Gotland Island (Laufeld, 1974, 1979) and in the topmost part of the subunit

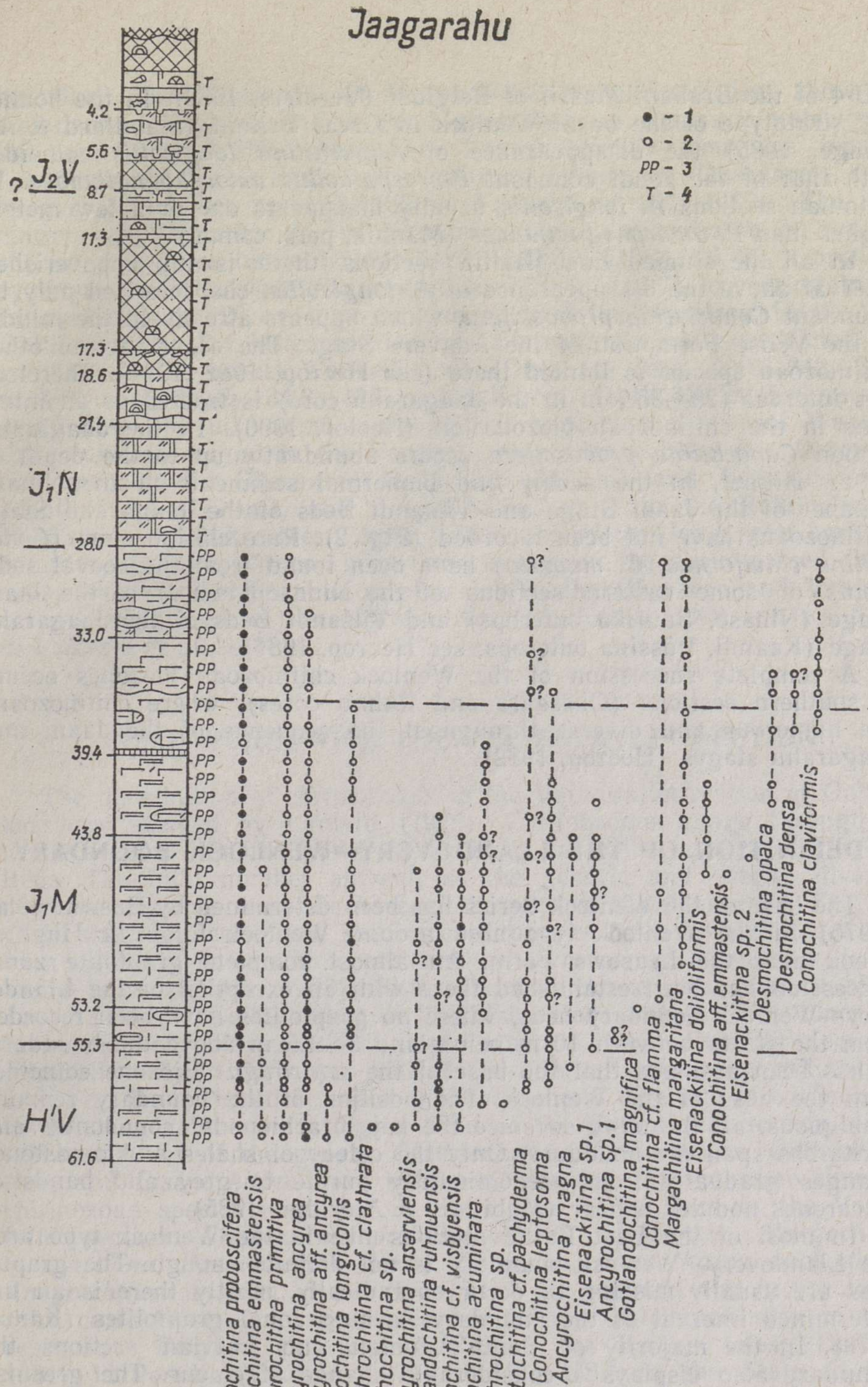

Fig. 2. Distribution of chitinozoans in the Jaagarahu section: *1* — abundant occurrence of the species; *2* — occurrence of the species; *3* — chitinozoans predominating over other acid-resistant microfossils; *4* — chitinozoans and other acid-resistant microfossils are missing.
H'V — Velise Formation of the Adavere Stage (Llandovery); J_1M — Mustjala Member of the Jaani Stage (Wenlock); J_1N — Ninase Member of the Jaani Stage; J_2V — Vilsandi Beds of the Jaagarahu Stage.

MB-4 of the Brabant Massif of Belgium (Verniers, 1982). In the boundary stratotype of the basal Wenlock in Great Britain (Mabillard & Aldridge, 1985) the disappearance of *Angochitina longicollis* coincides with that of the zonal conodont *Pterospathodus amorphognathoides*. In Estonian sections *A. longicollis* usually disappears one or a few meters higher than *P. amorphognathoides* (Männik, pers. comm.).

In all the studied East Baltic sections there is an impoverished interval above the disappearance of *A. longicollis*, characterized only by abundant *Conochitina proboscifera*, which appears already in the middle of the Velise Formation of the Adavere Stage. The occurrence of other chitinozoan species is limited there (see Нестор, 1982, 1984). Therefore this interval (28—36.7 m in the Jaagarahu core) is treated as an interzone in the chitinozoan biozonation (Nestor, 1990). In the Jaagarahu section *Conochitina proboscifera* occurs abundantly up to the depth of 28 m. Higher, in the shoaly and biohermal sediments of the Ninase Member of the Jaani Stage and Vilsandi Beds of the Jaagarahu Stage chitinozoans have not been recorded (Fig. 2). Rare chitinozoans (*Conochitina claviformis, C. mamilla*) have been found from the coeval sediments of some eastern sections of the Ninase Member of the Jaani Stage (Ninase, Suuriku outcrops) and Vilsandi Beds of the Jaagarahu Stage (Kaandi, Püssina outcrops; see Нестор, 1984).

A complete succession of the Wenlock chitinozoan biozones occurs in southern sections (Ohesaare and Ruhnu cores), where chitinozoans are numerous and diverse throughout the sequence of the Jaani and Jaagarahu stages (Нестор, 1982).

DEFINITION OF THE LLANDOVERY—WENLOCK BOUNDARY

The base of the Wenlock Series has been determined by Bassett et al. (1975) in the Wenlock type area around Wenlock Edge in Hughley Brook near the Leasows Farm. An almost complete graptolite zonal succession has been established there with an exception of the Llandovery—Wenlock boundary beds, where no graptolites have been recorded from the strata between 10 m below and 3—4.5 m above the boundary. It has been assumed that the base of the *centrifugus* Biozone coincides with the base of the Wenlock. The position of the boundary remains ambiguous, all the more so since the key brachiopods, conodonts, and acritarchs span the boundary. Only the colour of shales and mudstones changes gradually from predominantly purple to grey and bands of calcareous nodules appear (Mabillard & Aldridge, 1985).

In most of the East Baltic sections like in the Wenlock type area the Llandovery—Wenlock boundary is not definite enough. The graptolites are usually missing or occur sporadically, mostly there is an undetermined interval at the boundary, lacking zonal graptolites (Кальо, 1970). In the majority of South-Estonian and Latvian sections the boundary also displays a considerable change of colour. The greenish mudstones of the uppermost Llandovery are replaced by dark grey or brownish mudstones in the basal Wenlock. However, in most of the territory this boundary is lithologically indistinct and characterized by a predominantly transitional fauna (Аалоэ, 1970).

In the boundary stratotype section in the Wenlock type area and in a parallel section near Domas chitinozoans occur sporadically, missing in the lowermost part of the section, represented mainly by maroon mudstones of the Purple Shales (Mabillard, 1981; Mabillard & Aldridge, 1985). Most of the chitinozoan species are stratigraphically long-ranging (*Ancyrochitina primitiva*, etc.) and span the Llandovery—Wenlock boundary. The appearance of *Margachitina margaritana* just above the boundary at Leasows and in the highest beds at Domas is noteworthy, but rare finds of this species are known already from the topmost Llandovery in some East Baltic sections (Ventspils, Ohesaare), dated by graptolites (see pp. 125—132 in Гайлите et al., 1987). The best chitinozoan biomarker in the boundary stratotype seems to be *Ancyrochitina* cf. *gutnica* Laufeld (Mabillard, 1981, Pl. 6, figs. 6, 7), a probable synonym of *Gotlandochitina magnifica* (Pl. I, fig. 7), occurring in the interval of about 20 cm, just on both sides of the boundary. In the East Baltic sections the latter species has a stratigraphically restricted distribution in the lowest Wenlock beds (Ohesaare core, depth 342—345.7 m; Viki core, depth 134.8—135 m; Nagli core, depth 612 m; Ruhnu core, depth 454—456 m). Some more species appear in the basal Wenlock: *Ancyrochitina magna* in the Ventspils core (depth 792.2 m), *Desmochitina opaca* in the Ohesaare (depth 338—342 m) and Ventspils cores (depth 792.2—779 m), and *Ancyrochitina* sp. 1 in the Ruhnu (depth 454.65 m) and Viki cores (depth 144.5 m). In the Jaagarahu core this boundary (see Fig. 2) has been fixed basing on the above-named chitinozoan species, the distribution of which in the Ohesaare and Ventspils cores is controlled by zonal graptolites (see Кальо, 1970 and pp. 5—28 in Гайлите et al., 1987).

COMPARISON WITH THE VATTENFALLET SECTION

The distribution of chitinozoans in the Vattenfallet section of Gotland has been studied by Laufeld (1979). Chitinozoans range through the whole section from the Lower Visby Beds up to the uppermost Högklint Beds. The total number as well as the generic and species diversity decrease upwards from the base of the section (Laufeld, 1979, Fig. 22).

In the Jaagarahu core section chitinozoans have been recorded only from its lower half, which presumably corresponds completely to the Visby Beds (Nestor, 1982). Although in thickness this interval of the Jaagarahu core exceeds that of the Visby Beds almost three times, the abundance of chitinozoans is high, whereas their diversity decreases gradually only in the upper half of the interval containing chitinozoans (see Fig. 2). It should be noted that the general diversity of chitinozoans in the Jaagarahu core is higher than in the Vattenfallet section, where representatives of the genera *Clathrochitina*, *Anthochitina*, *Gotlandochitina*, and *Eisenackitina* have not been recorded. At the same time, all chitinozoan species identified in the Upper Visby Beds in the Vattenfallet section (*Conochitina proboscifera*, *C. visbyensis*, *Margachitina margaritana*, *Desmochitina densa*, *D. opaca*, *Plectochitina pachyderma*, *Ancyrochitina ancyrea*, *A. primitiva*, etc.) are common also in the Jaagarahu core. Most of these species are widely distributed also in other regions: in Belgium (Verniers, 1982), on the British Isles (Dorning, 1981), in Podolia (Laufeld, 1971), in the USA in the State of Ohio (Grahn, 1985), etc. Therefore the concept of restricted provinciality of these taxa as earlier supposed by Laufeld (1979, p. 73) should be treated with some doubt.

The abrupt decrease in the species diversity in the middle of the Mustjala Member of the Jaani Stage is expressed in the Vattenfallet section by the disappearance of *Angochitina longicollis* and *Desmochitina opaca* in a short interval in the middle part of the Upper Visby Beds. As the disappearance of the same species took place also in the deeper water sections of the Tõlla Member of the Jaani Stage (Ohesaare, Ruhnu, Ventspils cores), it could not possibly have been evoked by facies changes. The abrupt decrease in the faunal diversity is probably related to the changes in certain other ecological factors, such as water temperature, chemistry or something else, occurring simultaneously over a large area. The presence of an abundant high-diversity chitinozoan assemblage including taxa with a coarse and complicated ornamentation (*Ancyrochitina magna*, *A.* sp. 1, *Clathrochitina* cf. *clathrata*, *Gotlandochitina magnifica*, *G. ruhnuensis*, *Anthochitina* sp.) in the lowermost part of the Jaagarahu section gives evidence of the favourable living conditions in the low-energy environments, which existed mainly in the deep shelf or transitional facies belt of the basin. In the Vattenfallet section the corresponding part is characterized by the chitinozoan assemblage lacking species of a complicated ornamentation. A possible explanation of such a peculiarity might be differences in the depth of local sedimentation. According to Jaanusson (1979), the presence of calcareous algae in the whole Vattenfallet section shows that the sedimentation took place entirely in the photic zone of the sea. Stromatoporoids, which have been recorded in the whole Upper Visby Beds of the Vattenfallet section (H. Nestor, 1979), occur also only in the photic zone up to the depth of 70 m (H. Nestor, 1984). In the Mustjala Member only the topmost part of the section has yielded stromatoporoids (H. Nestor, pers. comm.). It shows that at Jaagarahu in the northwestern part of Saaremaa Island the topmost Llandovery and lowermost Wenlock sediments accumulated probably in deeper-water conditions than Upper Visby marls in the vicinity of Vattenfallet on Gotland Island.

However, the absence of this very rich basal Mustjala assemblage of chitinozoan taxa in the Vattenfallet section and elsewhere on Gotland (see Laufeld, 1974) could also be explained by the lack of the corresponding sediments, which may be denudated or not exposed there. Unfortunately, no published data on the distribution of chitinozoans in the subsurface of Gotland are available.

The upper part of the Mustjala Member in the Jaagarahu section shows gradual decrease in the diversity of chitinozoans. At the end of Mustjala time the shallowing of the basin was abrupt and no chitinozoans usually characteristic of the succeeding Ninase Member (*Conochitina mamilla*, abundant *C. claviformis*) occur in the following complex of grainstones and biohermal sediments, completely barren of chitinozoans. In the coeval part of the Vattenfallet section the abundance and diversity of chitinozoan taxa fluctuate greatly, but notwithstanding

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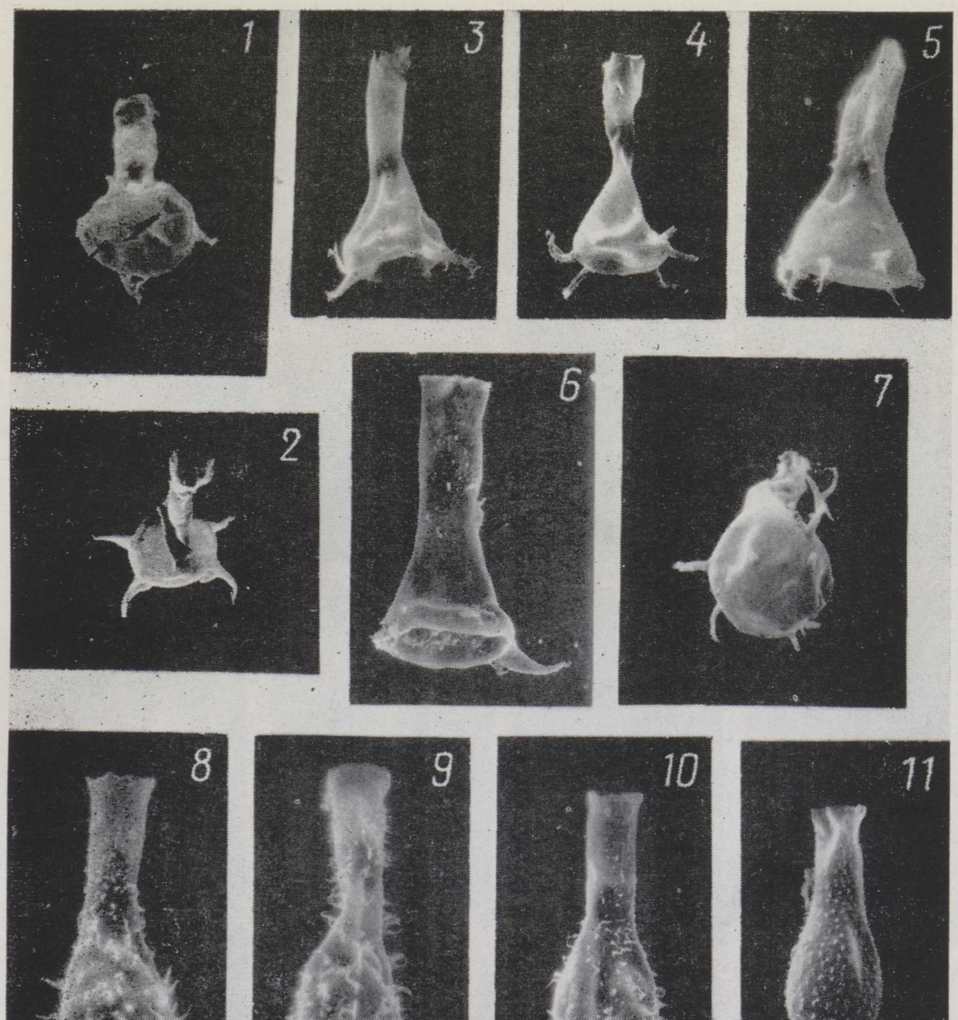
PLATE I

(All figured chitinozoans are from the Jaagarahu core.)

Figs. 1—2. *Plectochitina pachyderma* (Laufeld, 1974), 1 — Ch 446/10676, ×220, depth 35.7 m; 2 — Ch 447/10651, ×250, depth 60.1 m. Fig. 3. *Ancyrochitina ancyrea* (Eisenack, 1931), Ch 448/10676, ×250, depth 35.7 m. Fig. 4. *Ancyrochitina primitiva* Eisenack, 1964, Ch 449/10676, ×250, depth 35.7 m. Fig. 5. *Ancyrochitina* sp. 1, Ch 450/9202, ×250, depth 54.75 m. Fig. 6. *Ancyrochitina magna* Nestor, 1982, Ch 473/10654, ×225, depth 56.1 m. Fig. 7. *Gotlandochitina magnifica* Nestor, 1982, Ch 469/9202, ×250, depth 54.75 m. Figs. 8—10. *Gotlandochitina ruhnuensis* Nestor, 1982; 8 — Ch 465/10662, ×240; 9 — Ch 478/10662, ×250, depth 48.5 m; 10 — Ch 466/10669, ×250, depth 42.6 m. Fig. 11. *Angochitina longicollis* Eisenack, 1959, Ch 468/10661, ×250, depth 49.5 m. Figs. 12—13. *Clathrochitina* cf. *clathrata* Eisenack, 1959, ×250, depth 59.6 m; 12 — Ch 452/9199, 13 — Ch 453/9199. Fig. 14. *Anthochitina* sp., Ch 451/9199, ×250, depth 59.6 m.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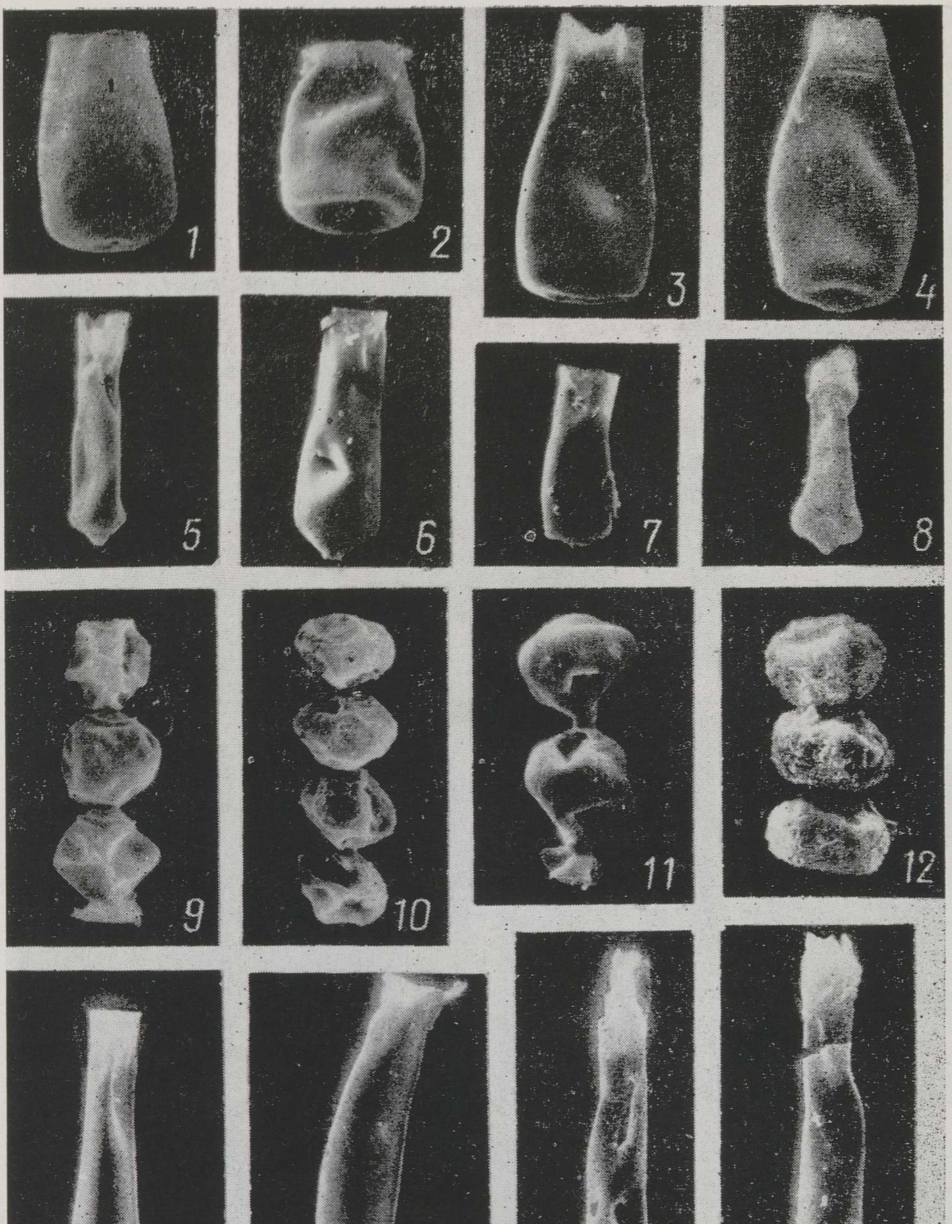
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the general decreasing upward trend, chitinozoans occur up to the top of the Högklint Beds (Laufeld, 1979). This shows that more open-marine conditions endured considerably longer at the Vattenfallet area than at Jaagarahu.

The appearance of *Desmochitina acollaris* in the Högklint "c" in the Vattenfallet section and elsewhere on Gotland in the marly SW Högklint facies (Laufeld, 1979) supports the correlation of these beds with Paramaja marls, which in most of the studied sections occur in the uppermost Jaani Stage (Нестор, 1984), but at least in the Jaagarahu area are replaced by the biohermal sediments.

CONCLUSIONS

(1) The Llandovery—Wenlock boundary beds along with the Mustjala Member of the Jaani Stage are characterized in the Jaagarahu core by a rich assemblage of chitinozoans, widely distributed in many regions.

(2) The appearance of chitinozoan species *Gotlandochitina magnifica*, *Desmochitina opaca*, *Ancyrochitina* sp. 1, and *A. magna* in the basal Wenlock (the last species may appear in the topmost Llandovery) besides *Margachitina margaritana* may serve as a criterion for establishing the Llandovery—Wenlock boundary in the carbonate sections.

(3) The disappearance of *Angochitina longicollis*, but also of many other chitinozoan species taking place in a short interval in lower Wenlock constitutes a good biostratigraphical marker, probably of global significance.

(4) Considering the distribution of certain chitinozoan taxa in the Mustjala Member of the Jaagarahu core and Upper Visby Beds in the Vattenfallet section of Gotland Island (Laufeld, 1979) and also the data on the occurrence of stromatoporoids and calcareous algae, we may presume that the lowermost Wenlock sedimentation in the Vattenfallet area took place in a rather shallow-water environment of the open shelf, while at Jaagarahu it proceeded in deeper water conditions of the transitional facies belt.

PLATE II

(All figured chitinozoans are from the Jaagarahu core.)
Fig. 1. *Eisenackitina dolioliformis* Umnova, 1976, Ch 454/10670, ×250, depth 41.7 m. Fig. 2. *Eisenackitina* sp. 1, Ch 455/10670, ×250, depth 41.7 m. Figs. 3—4. *Conochitina emmastensis* Nestor, 1982, ×175, depth 45.5 m; 3 — Ch 456/10666; 4 — Ch 479/10666. Fig. 5. *Conochitina flamma* Laufeld, 1974, Ch 457/10700, ×175, depth 28.6 m. Fig. 6. *Conochitina* cf. *flamma* Laufeld, 1974, Ch 458/10665, ×250, depth 46.4 m. Fig. 7. *Conochitina visbyensis* Laufeld, 1974, Ch 459/10665, ×250, depth 46.4 m. Fig. 8. *Conochitina acuminata* Eisenack, 1959, Ch 460/10666, ×250, depth 45.5 m. Fig. 9. *Desmochitina densa* Eisenack, 1959, Ch 470/10676, ×250, depth 35.7 m. Figs. 10—11. *Margachitina margaritana* (Eisenack, 1937), ×250; 10 — Ch 480/10666, depth 45.5 m; 11 — Ch 472/10699, depth 29.4 m. Fig. 12. *Desmochitina opaca* Laufeld, 1974, Ch 471/10676, ×250, depth 35.7 m. Figs. 13—14. *Conochitina proboscifera* Eisenack, 1937; 13 — Ch 464/10676, ×100, depth 35.7 m; 14 — Ch 463/10667, ×150, depth 44.6 m. Fig. 15. *Conochitina claviformis* Eisenack, 1931, Ch 460/10666, ×150, depth 35.7 m. Fig. 16. *Conochitina* cf. *leptosoma* Laufeld, 1974, Ch 462/10676, ×150, depth 35.7 m.

(5) By the end of the formation of the Mustjala Member and Upper Visby Beds the facies conditions became similar in both areas discussed. Differences reappeared after the shallowing of the basin when the formation of the Ninase Member (Saaremaa) and Högklint Beds (Gotland) started. In the Jaagarahu area the shallowing was abrupt, therefore the succeeding complex of grainstones and biohermal sediments accumulated already in the shoal facies belt. In the Visby area (Vattenfallet), however, somewhat more open-marine conditions preserved, evidenced also by the distribution of the microfossil groups studied.

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KITINOZOAD JAAGARAHU PUURSÜDAMIKU LLANDOVERY—WENLOCKI PIIRIKIHTIDES

Viiu NESTOR

Jaagarahu stratotüüpse läbilõike (puursüdamiku) alumises osas — Adavere—Jaani lademe piirikihtides ning Mustjala kihistikus esineb arvukalt kitinozoasid, millest Jaani lademe alumisel piiril ilmuvaid liike (*Gotlandochitina magnifica* jt.) võiks kasutada Llandovery—Wenlocki piiri määramisel karbonaatsetes läbilõigetes. Kitinozoade sisalduse ja taksonoomilise koosseisu võrdlus Jaagarahu ja samavanuselises Vattenfalleti läbilõikes Gotlandil (Laufeld, 1979) lubab järeldada, et Wenlocki alguses valitsesid Jaagarahus tõenäoliselt süvaveelisemad olud kui Vattenfalletis, hiljem aga kestsid avamerelised tingimused Vattenfalleti ümbruses kauem kui Jaagarahu piirkonnas.

ХИТИНОЗОИ В ПОГРАНИЧНЫХ СЛОЯХ ЛЛАНДОВЕРИ И ВЕНЛОКА РАЗРЕЗА ЯАГАРАХУ (ЭСТОНИЯ)

Вийу НЕСТОР

В пограничных слоях адавереского и яаниского горизонтов нижней части яагарахуского стратотипического бурового разреза и в мустъялаской пачке встречается разнообразный комплекс хитинозой. Некоторые виды (*Gotlandochitina magnifica* и др.), появляющиеся в базальной части яаниского горизонта, рассматриваются в качестве потенциальных биомаркеров при определении нижней границы венлока в карбонатных разрезах. Сравнение таксономического состава и разнообразия одновозрастных комплексов хитинозой в разрезах Яагараху и Ваттенфаллет о-ва Готланд (Laufeld, 1979) позволяет предполагать, что в начале венлока морской бассейн в районе Яагараху был более глубоководным, чем около Ваттенфаллета. Позднее картина изменилась на противоположную: открыто-морская зона в окрестностях Ваттенфаллета существовала дольше, чем в Яагараху.