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THE BALTIC MIDDLE SILURIAN STROMATOPOROID SUCCESSION

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Although a remarkable number of regional taxonomical and biostratigraphical papers has been published on the Silurian stromatoporoids during last decades, there does not still exist a formal zonal stromatoporoid standard for any region. The Baltic area offers good opportunities for elaborating such a standard for stromatoporoid stratigraphy due to relatively detailed researches covering Silurian outcrop areas on both sides of the Baltic Sea (Рябинин, 1951; Нестор, 1964, 1966, 1970; Nestor, 1979; Mori, 1968, 1969, 1970, 1978).

The aim of the present paper is to summarize the existing data on the distribution of stromatoporoids in the Baltic middle Silurian (Wenlock). The main attention is paid to the species distributed both in the East Baltic and Gotland sequences.

General remarks on the stromatoporoid distribution

Due to their relatively narrow ecological ranges stromatoporoids are distributed in Silurian rocks rather unevenly. The richest and the most diverse stromatoporoid assemblage occurs in the sparitic, biomicritic and argillaceous limestones of shallow water genesis, distributed in the border areas of the Baltic Silurian sedimentary basin. According to the generalized facies-sedimentary model of the basin (Нестор, Эйнасто, 1977) these rocks formed in the high energy shoal environments and in the moderate to low-energy open-shelf environments (Nestor, 1977). In the territory of Gotland and Estonian outcrop areas such conditions prevailed almost throughout the whole Silurian period. These areas offer the best possibilities for following the succession of stromatoporoid faunas in the shallow water optimal conditions. As for the Estonian sequence its stromatoporoid succession is not so complete as in the Gotland sequence. There are several gaps in the stratigraphical distribution of stromatoporoids caused by the presence of tongues of lagoonal or restricted-shelf deposits (various dolomitic sediments) in which stromatoporoids are lacking. The latter are more common for the Wenlock-Ludlow boundary beds, i.e. for the Jaagarahu, Rootsiküla and Paadla Formations. In the Gotland area Silurian sediments accumulated almost without exception in the normal-marine environments and therefore they contain a very rich stromatoporoid fauna.

Towards the centre of the Baltic Basin biomicritic nodular limestones of the open shelf are replaced with marlstones, considered as deposits of a relatively gentle basin slope (Нестор, Эйнасто, 1977) and the latter, in turn, with graptolite bearing mudstones and shales of the axial depression of the gulf-like basin. As a rule, the latter facies do not contain stromatoporoids. Therefore stromatoporoids are lacking in the middle Silurian of Latvia, West Lithuania and Scania. The transition belt from the shelf limestones to the slope mudstones is characterized by improverished fauna of comparatively long-range species of stromatoporoids, giving a specific succession of deeper water assemblages. Such lateral differentiation of stromatoporoid fauna was earlier mentioned by K. Mori (1970), who noticed that in western Gotland marls and marly limestones include only a few species of stromatoporoids, which all belong to the comparatively long-ranging ones, while the rich and diverse stromatoporoid fauna in

massive reef limestones and in surrounding stratified limestones of eastern Gotland changes more rapidly. In the present paper two parallel successions of zonal assemblages have been distinguished (Table 1): one for shallow water, another for deeper water deposits. Actually there does not exist any distinct boundary between these contemporaneous lateral assemblages and partly deeper water species occur also together with the shallow water ones, gradually replacing each other.

Composition of the zonal standard

The most wide-spread species of stromatoporoids were preferred for outworking of the zonal standard, given in Table 1. The medium column of the table lists all species common for the corresponding stratigraphical units of the Estonian and Gotland sequences, presented in the left and right columns of the table, correspondingly.

According to the recent stratigraphical scheme regional stages of Estonia are subdivided into beds or formations (Аалоэ и др., 1976). It enables a more detailed correlation of sequences than earlier. Unfortunately in Estonian sections stromatoporoids occur and are studied rather unevenly. The names of the stratigraphical units which are not characterized by stromatoporoids yet, have been shown in Table 1 in square brackets. Species are distributed in sections rather sparsely and mostly they do not offer any possibility for tracing exact boundaries between the stromatoporoid biozones. Conventionally the latter are considered coincidental with the boundaries of the local topostratigraphical units. If the unfit of the boundary is obvious or if its position is very obscure, it is shown in Table 1 by the broken line. If in the table the column of the shallow water zonal assemblages is divided into two parts by double line then on such stratigraphical levels there do not exist stromatoporoid species common for both the East Baltic and Gotland areas and the species listed on both sides of the double line occur only in the corresponding area.

Table 1

The Baltic middle Silurian stromatoporoid communities and species common for Estonia and Gotland

Estonia		Communities and common species: Shallow water	Communities and common species: Deeper water		Gotland
Jaagarahu	[Soeginina Vesiku]	*Araneosustroma stelliparratum*	*Parallelostroma tenellum*	*Densastroma densum* / *Clathrodictyon vaivarensis*	*Klinteberg*
Jaagarahu	Rootsiküla: Kuusnõmme				
Jaagarahu	Rootsiküla: Viita				
Jaagarahu	[Tagavere]	not studied	*Labechia conferta*, *Stelodictyon striatellum*, *Clathrodictyon vesiculosum*	*„Pycnodictyon" densum* / *Actinostromella aff. vaivarensis*	*Halla*
Jaagarahu	Maasi	*Ecclimadictyon astrolaxum*, *E. macrotuberculatum*, *Simplexodictyon validum*		*Densastroma pexisum* / *Clathrodictyon simplex*	*Slite*
Jaagarahu	Vilsandi	*Vikingia tenuis*, *V. vikingi*, *Syringostromella yavorskyi*			*Tofta*, *Högklint*
Jaani	[Ninase] Paramaja	*Stromatopora impexa*, *„Pseudolabechia" hesslandi*, *Clathrodictyon linnarssoni*			*U. Visby*

Mulde

Succession of stromatoporoid communities

Detailed data on the distribution of stromatoporoid species in localities of Gotland and Estonia have been presented in the special papers (Mori, 1968, 1970; Нестор, 1966, 1970; Nestor, 1979) and they are not repeated here. Additional data are commented below if necessary.

The *Stromatopora impexa* Community

On Gotland the earliest stromatoporoids hitherto known are these of the Upper Visby Marls. It is remarkable that almost all the Upper Visby species occur also in similar nodular limestones and marls of the Estonian Jaani Formation, exposed in the cliffs of the northern coast of Saaremaa (Liiva, Panga, Suuriku) immediately below the lower boundary of the Ninase Member. Some of these species such as *"Pseudolabechia" hesslandi* and *Clathrodictyon linnarssoni* have not been described in the author's earlier paper (Нестор, 1966) due to some taxonomical difficulties. Now their presence is well established in the Estonian sequence.

Actually the most common stromatoporoid species in the Upper Visby Beds and Jaani Formation are *Densastroma pexisum* and *Clathrodictyon simplex*, but these species have a wider stratigraphical and ecological range, and are considered here as the main representatives of the Lower Wenlock deeper water stromatoporoid assemblage (p. 44). At the same time such rather wide-spread species as *Stromatopora impexa*, *Clathrodictyon linnarssoni* and *"Pseudolabechia" hesslandi* are mostly confined to the Upper Visby and Jaani levels and could be treated as the zonal assemblage of a more shallow-water faunal succession. A few specimens of these species have also been reported from the basal part of the Högklint Beds. Therefore the upper boundary of the *Stromatopora impexa* Zone may actually lay within the limits of the Högklint Beds and may coincide with the boundary between its "a" and "b" or even "b" and "c" units. In the Estonian sequence the boundary probably coincides with the base of the Jaagarahu Stage.

Hitherto species typical of the *Stromatopora impexa* Community have not been reported from the other regions.

The *Vikingia tenuis* Community

Vikingia tenuis is the most common species in the Högklint and Tofta Beds of Gotland, particularly in the massive reef limestones of the former and in the Spongiostroma Limestone of the latter. In Estonia the same species occurs abundantly in reef limestones and associated rocks in the Vilsandi Beds of the early Jaagarahu age. In places *Vikingia tenuis* is accompanied by *Vikingia vikingi* and *Syringostromella yavorskyi*. In Estonia the latter species was not earlier separated from *Vikingia tenuis* but as the latter examination of the collection has confirmed, it definitely occurs in Jaagarahu locality besides *V. tenuis*. On Gotland a few specimens of *Vikingia tenuis* have also been recorded from the uppermost part of the Visby Beds and from the lower part of the Slite Beds (Mori, 1968). Thus there is a certain overlap of the stratigraphical ranges of the zonal stromatoporoid species and the both boundaries of the *Vikingia tenuis* Zone could be fitted with the boundaries of the topostratigraphical units only conventionally.

The *Vikingia tenuis* Community is apparently rather specialized ecologically and it is mainly restricted to the reef facies. At the same time it has a rather narrow stratigraphical range, as it has not been recorded neither from the small Upper Visby patch reefs below, nor from the reefs of the Slite Group higher in the sequence. Therefore the opinion about different age of the *Vikingia tenuis* Community in Gotland and Estonian sequences, expressed earlier by Kaljo (Кальо, 1970, p. 198) on the basis of the indirect correlations of the outcrop sections, does not evidently have enough ground. The data obtained through the investigation of tabulate corals (Клааманн, 1977) and chitinozoans (V. Nestor, 1982) confirm the same.

The elements of the fauna with *Vikingia tenuis* have not been recorded from other regions. Some similar species (*Vikingia demshynensis*, *"Pseudolabechia" nikiforovae*) occur in the Restevo and Demsha Beds of the Kitaigorod Stage of Podolia (Большакова,

1973), which are roughly contemporaneous to the *Vikingia tenuis* Zone but are represented by different lithofacies.

The *Ecclimadictyon astrolaxum* Community

Rather thick and variable Slite Group of Gotland contains diverse stromatoporoid fauna. Unfortunately most of the stromatoporoid species in the Slite Group occur in a single or in very few localities and therefore are not of interest as zonal forms. Only such species as *Stromatopora* cf. *pseudotuberculata*, *Ecclimadictyon astrolaxum*, *E. macrotuberculatum*, *Densastroma podolicum*, *D. pexisum*, *Simplexodictyon simplex* are more wide-spread. The latter four are of rather wide stratigraphical range and are therefore of less interest. Therefore *Ecclimadictyon astrolaxum* is the most characteristic species for the stratigraphical interval considered. In Estonia it is rather abundant in some outcrops (Tõre, Sepise) of the Maasi Beds of middle Jaagarahu age.

According to the data by K. Mori (1968) *Ecclimadictyon astrolaxum* occurs both in the lower and in the upper parts of the Slite Group while many other species are restricted to one of the parts. Unfortunately at the present time the data are too scanty for a more detailed subdivision of the Slite Group by stromatoporoids.

Besides *Ecclimadictyon astrolaxum* there are some other species common for the Slite and Maasi Beds. *Ecclimadictyon macrotuberculatum* and *Simplexodictyon validum* are more notable. Evidently specimens of the latter species were described by K. Mori (1968) as representatives of *Clathrodictyon* cf. *argutulum* and *Diplostroma yavorskyi*. Both stratigraphical units contain also *Densastroma pexisum* and *Simplexodictyon simplex* of wide stratigraphical range.

One of the characteristic features of the stratigraphical interval considered is very diverse fauna of the representatives of *Ecclimadictyon* and some related genera. The same phenomenon has been observed in many other regions, particularly in the Arctic areas, the Urals, Siberia, Central Asia where the so-called "Wenlockian fauna" of stromatoporoids contains abundantly representatives of *Ecclimadictyon*, *Neobeatricea* and *Actinodictyon*. Obviously the middle Wenlock was one of the ages of nearly cosmopolitic distribution of certain stromatoporoid species. Unfortunately identification of the species of *Ecclimadictyon* and related genera is very difficult and they are of less correlative significance than many other stromatoporoids.

The *Densastroma pexisum* Community

In many parts of the Upper Visby and Slite Beds the most common stromatoporoid species are *Densastroma pexisum* and *Simplexodictyon simplex*. A few specimens of these species occur also in the Högklint Beds. In the Upper Visby Marls these species occur partly together with the representatives of the *Stromatopora impexa* Community (Snäckgardsbaden, Vattenfallet, Kneippbyn, Högklint). In Slite Marls in the western part of Gotland (Westergarn, Klinteby) these species are the only representatives of stromatoporoids. In the Lerberget Marls of Stora Karlsö *D. pexisum* and *Clathrodictyon simplex* have been met together with the specific forms *Ferestromatopora insularis* and *Plumatalinia densa*. It is reasonable to suppose that *Densastroma pexisum* and *Clathrodictyon simplex* inhabited the most deep water marginal areas of stromatoporoid settlement during the whole early Wenlock time. Towards the shore stromatoporoid fauna gradually enriched with more short-range species, while the role of deeper water elements decreased respectively. Consequently, the fauna with *Densastroma pexisum* may be treated as a deeper water equivalent of the shallower water *Stromatopora impexa* - *Vikingia tenuis* - *Ecclimadictyon astrolaxum* succession.

In Podolian sequence *Densastroma pexisum* has been mentioned from the Chercha Beds

of the Kitaigorod Stage (Богоявленская, 1976). In the same beds and lower, in the Demsha Beds *Clathrodictyon microstriatellum* occurs, which is very similar and even may be conspecific with *Clathrodictyon simplex*. Presumably the major part of the Kitaigorod Stage roughly coincides with the range of the *Densastroma pexisum* Community and is also ecologically comparable.

The *Labechia conferta* Community

In the East-Baltic area stromatoporoids are insufficiently known from the upper part of the Wenlock (*nassa/ludensis* Zones of the graptolite succession). Hitherto there are no data on their occurrence in the Tagavere Beds (upper Jaagarahu) and very few evidence in the Viita Beds (lower Rootsiküla). In the shallow water sequence of Gotland the stromatoporoid succession is more complete. Here the fauna with *Ecclimadictyon astrolaxum* is directly followed by the *Labechia conferta* Community, which occurs in the Halla Beds. Stromatoporoids of this stratigraphical level mostly occur in coral and reef limestones and are even partly connected with oolitic limestones. *Labechia conferta* is the most common species in the Halla Beds. *Clathrodictyon striatellum* (= *Stelodictyon* Bogoyavlenskaya, 1969), *Clathrodictyon vesiculosum* and *Stromatopora antiqua* are the other species, typical of that part of the sequence.

Although some of the Halla species also occur in the sequence lower (*Ecclimadictyon macrotuberculatum* in the Slite Beds) and higher (*Stelodictyon striatellum* in the Klinteberg Beds at Klinte), as the whole, the *Labechia conferta* Community is comparatively distinct.

It is remarkable that all the most common species of the Halla Beds (*L. conferta, Cl. vesiculosum, S. striatellum*) have been described by H. Nicholson (1886-1891) from the Wenlock Limestone of the Welsh borderland (Dudley, Ironbridge, Much Wenlock, Dormington). Thus the correlation of the Halla Beds and the Wenlock Limestone is well supported by stromatoporoids. More difficult is the question whether the *Labechia conferta* Zone corresponds to the whole extent of the Wenlock Limestone section or only to some part of it. Relying merely upon the scanty stromatoporoid data the first possibility seems more likely as the known stromatoporoid fauna of the Wenlock Limestone looks rather unitary and does not contain typical representatives of neither Slite nor Klinteberg faunas of Gotland.

In Podolian sequence *Labechia conferta* is common in the Muksha Beds (Богоявленская, 1976 and author's data). On the same stratigraphical level I have identified *Stelodictyon striatellum* (loc. Bagoviza).

Consequently, *Labechia conferta* Zone is discernable in different regions of Europe and it roughly coincides with the Halla Beds in Gotland, the Wenlock Limestone in Britain and the Muksha Beds in Podolia.

The *Parallelostroma tenellum* Community

On Gotland the *Labechia conferta* Community is succeeded by those of the *Parallelostroma tenellum*. Taxonomical content and distribution of the fauna with *Parallelostroma tenellum* are rather badly delimited. *P. tenellum* itself is distributed in the middle and upper parts of the Klinteberg Beds and occurs in the outcrops of the middle part of the island. Some other species specific to the Klinteberg Beds (*Plumatalinia balticivaga, Actinostroma botvaldavikense*) have been known by a few specimens from a limited number of localities. Quite a lot of the Klinteberg species pass over into above laying limestones of the Hemse Group. Those are *Syringostromella borealis, Stromatopora venukovi, Parallelostroma typicum, Stromatopora carteri, Clathrodictyon convictum, Ecclimadictyon robustum*, suggesting great affinity of the Klinteberg stromatoporoid fauna to

the succeeding Ludlovian ones. True enough, *Stromatopora carteri* is one of the species erected on the basis of the material from the Wenlock Limestone of the Welsh borderland, but exact identification of that species is extremely complicated as very similar forms are distributed from Wenlock to Givet.

The *Araneosustroma stelliparratum* Community

In Estonian sequence *Parallelostroma tenellum* has not been found yet. In the local stromatoporoid succession his position is probably occupied by the *Araneosustroma stelliparratum* Community. The latter species itself, earlier described as *Clathrodictyon ? stelliparratum* is most common in the Kuusnõmme Beds of the Rootsiküla Stage, but a few specimens have also been found from the Paadla Stage (Нестор, 1966). The fauna with *Araneosustroma stelliparratum* is scanty. Besides *A. stelliparratum* it only contains *Ecclinadictyon robustum* and *Densastroma podolicum* of a comparatively wide stratigraphical range.

It seems that the *Araneosustroma stelliparratum* Community is a lateral equivalent of the *Parallelostroma tenellum* Community and it probably inhabited a more restricted, near-shore part of the sea. Such opinion is supported by new data concerning the distribution of stromatoporoids in a section of the Southern part of Novaya Zemlya (Нестор, 1982, in press). There, in the section of peninsula Khatanzei *Parallelostroma tenellum* and *Araneosustroma* ex gr. *stelliparratum* have been found together in the upper part of the Klenov Formation, represented by interlayering lagoonal and normal-marine carbonate deposits.

The *"Pycnodictyon" densum* Community

The *Labechia conferta* and *Parallelostroma tenellum* Community were treated as succeeding shallow water stromatoporoid communities. Their lateral, deeper water analogue may be the *"Pycnodictyon" densum* Community (probably synonym of *Densastroma*), which occurs in the Mulde Marls of Gotland and also passes over into the Hemse Marls. Besides *"Pycnodictyon" densum* *Actinostromella* aff. *vaiverensis* is another common species for Mulde and Hemse Marls. These two fine-reticulate stromatoporoids are most frequent in outcrops of the western part of Gotland, whereas other species are found there in a very few specimens.

In the deeper water succession the *"Pycnodictyon" densum* Community replaces the *Densastroma pexisum* Community stratigraphically. Both have rather wide stratigraphical range corresponding to three or more stromatoporoid zones in the shallow water succession.

The distinction of the fine-reticulate species of *Densastroma pexisum* and *"Pycnodictyon" densum* Community is rather complicated, especially when the material is recrystallized. Therefore in Estonian sequence *"Pycnodictyon" densum* was not distinguished. Probably specimens of this species were earlier linked with the species *Densastroma podolicum*.

Summary

The present paper distinguishes five successive stromatoporoid communities spread in the shallow water sections of the Baltic Silurian Basin, in the stratigraphical interval corresponding to the Wenlock Series by now accepted correlations. In the ascending order they are: *Stromatopora impexa*, *Vikingia tenuis*, *Ecclimadictyon astrolaxum*, *Labechia conferta* and *Parallelostroma tenellum* Communities. However, there is a possibility that the last community already belongs to the lowermost Ludlow. Potentially these communities may serve as a basis for a zonal stromatoporoid standard of the Baltic and adjacent regions. In the same stratigraphical interval in deeper water, marginal areas of the distribution of stromatoporoids two communities - *Densastroma pexisum* and *"Pycnodictyon" densum* are distinguished.

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ПОСЛЕДОВАТЕЛЬНОСТЬ СТРОМАТОПОРАТ В СРЕДНЕМ СИЛУРЕ БАЛТИКИ

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В мелководных разрезах Балтийского силурийского бассейна в стратиграфическом интервале по принятой в настоящее время корреляции соответствующем венлоку, выделено пять последовательных сообществ строматопорат. Снизу вверх это сообщества *Stromatopora impexa*, *Vikingia tenuis*, *Ecclimadictyon astrolaxum*, *Labechia conferta*, *Parallelostroma tenellum*. Не исключено, что последнее из них имеет уже раннелудловский возраст. Потенциально эти сообщества могут служить основой для зонального стандарта строматопорат в Балтийском и соседних регионах.

В более глубоководных разрезах распространяются сообщества *Densastroma pexisum* и *"Pycnodictyon" densum*, причем первое из них соответствует зонам *S. impexa*, *V. tenuis* и *E. astrolaxum*, вторая - зонам *L. conferta* и *P. tenellum* в мелководной последовательности.