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APPLICATION OF SHELF AND SLOPE CONCEPTS TO THE SILURIAN BALTIC BASIN

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Shelf, slope and depression serve as the basic concepts in oceanography and marine geology. However, unambiguous application of these concepts to the basins of geological past is somewhat complicated. Firstly, it is due to the diversity of situations at recent continental margins. Secondly,it should be considered that present-day situations may prove unrepresentative for the geological past. Particularly great difficulties arise in connection with the application of actualistic concepts to such a distant past as Early Paleozoic. Last years disagreements have been arisen with regards to defining the shelf and slope in the Silurian Baltic Basin. This basin was situated at the western margin of the East European Craton and included North Poland, East Baltic, Gotland and the areas of the present Baltic Sea. The basin was directly connected with the Central-European Hercynian Geosynclinal Basin, the origin of which is still disputable. Some investigators (Berry and Boucot, 1967; Krebs and Wachendorf, 1973; Matthews, Chauvel, Robardet, 1980 and others) supposed that the Mid-European Paleozoic marine basin developed wholly on the continental crust due to intraplate tectonics and the existence of a real ocean in this area, at least during the Early Paleozoic, is fairly problematic. Others (Burrett, 1972; McKerrow, Ziegler, 1972; Johnson, 1973; Ziegler et al., 1977; Tomczyk and Tomczykowa, 1979; Cogne and Wright, 1980; Bard, Burg, Matte, Ribeiro, 1980) assume the presence of a Paleozoic ocean (Rheic, proto-Tethys or paleo-Tethys) in Middle Europe that closed during the Hercynian Orogeny. The last point of view seems quite acceptable for us and we consider the Baltic Basin in Silurian as a marginal sea of this ocean with clearly distinguished shelf, slope and depression environments.

In 1977 the authors of the present paper published a facies-sedimentary model of the Silurian Baltic Basin (Нестор, Эйнасто, 1977).

According to the model, the Baltic Basin was characterized by the lateral succession of 5 macrofacies belts which we have interpreted as follows: 1) littoral-lagoonal belt with argillaceous dolomitic sediments; 2) inshore shoal belt with various sparitic calcarenites, sometimes including reefs; 3) open shelf with nodular micritic calcarenites and thin argillaceous intercalations; 4) basin slope with calcareous mudstones, argillaceous calcilutites or clays; 5) central depression of the basin with graptolitic mudstones. At that predominantly carbonate sediments of the first three facies belts were regarded as shelf deposits, whereas fine-clastic deposits of the fourth and fifth belts distributed mainly within the boundaries of the Baltic Syneclise were already taken for bathyal deposits. More common is the opinion that the shelf included the whole cratonic Baltic Basin up to the Törnquist Line, and the continental slope, if it existed, started from the Törnquist Line. This approach is based on the argument that the phenomena characteristic of the continental slope (gravity slides, slumps, breccias and turbidites) are not established within the boundaries of the Baltic Basin.

However, it seems to us that this approach makes the shelf too wide and it does not coincide with the actualistic shelf conception. According to the fundamental handbook of marine geology by F. P. Shepard (Шепард, 1976) the shelf stretches up to the first clear break in the gradient of the sea bottom profile. The average width of present day shelves is about 75 km, the average depth of their flat part about 60 m, the depth of the shelf edge ranges from 20 to 600 m, being 130 m on an average. Continental slope may be rather wide and within it several terraces may occur. In this case only the uppermost break in the bottom gradient serves as the boundary between the shelf and slope, whereas the other terraces are included to the continental slope. At places the continents may be edged by deeply subsided blocks of continental crust, e.g. Blake Plateau at the eastern coast of Florida, its width is up to 300 km, depth 750-1,000 m. In a wider sense these plateaus are considered as a part of the continental slope, not of the shelf. As a rule, slopes are covered by finer-grain deposits than shelves. Sands are typical of the present-day shelves, muds prevail on slopes. The accumulation of deposits is highly dependent upon the gradient of the slope (Stanley and Unrug, 1972). On a steep slope deposits may be entirely lacking, the thickest deposits are concentrated on the continental rise. Gravity slides, slumps and turbidites are characteristic namely of such slopes. If the bottom is gently sloping the deposits may accumulate in great thickness already on the slope itself as a result of which the slope progrades offshore direction. Deposits are often lacking at shelf edges and on the upper slope.

Let us try to estimate the position of shelf and slope in the Silurian Baltic Basin in the light of these data, starting with the most offshore member of the facies succession, the graptolitic mudstones of the fifth facies belt. Silurian graptolitic shales and mudstones are prevailingly geosynclinal deposits which reach only as tongues to the craton margins. It is reasonable to suppose that typical graptolitic shales represent the main Silurian oceanic deposits. It could be well seen from the schematic geological section compiled by H. Jaeger (1976, Fig. 6) from Sweden through Paleotethys to the Sahara. It shows that at the time when more than 1,000 m of carbonate and clastic sediments accumulated at the margins of Fenno-Sarmatia and Gondwana cratons, the thickness of the complete Silurian sequence was only 50-70 m of monotonous graptolitic shales and "ockerkalk" within Paleotethys from Thyringia to Sardinia (see also Fig. 1B in the present work). It permits to make a conclusion that these were obviously deposits of abyssal plain. On continental margins within the boundaries of continental rise and bathyal the thickness of graptolitic sediments considerably increases in connection with the growing intensity of the accumulation of fine-clastic material towards the source area, however, the basic type of the sediment remains the same. Since graptolitic mudstones accumulated within the boundaries of the Baltic Syneclise on a wide area and during most of Silurian (about 30 million years) we obviously have not to deal with a closed shelf depression, but most likely it was a deep-water continental margin plateau immediately connected with the Gentral European oceanic basin.

Evidently the Paleo-Baltic Basin formed in Early Paleozoic as a result of an incomplete development of rifting in the course of the opening of the Paleotethys (Rheic) Ocean. In this respect the schemes by E. and H. Tomczyk (1979, Figs 2, 3, 4) on the development of the Prototethys Ocean are of interest. According to the first scheme corresponding to the Caradocian the Baltic Basin laid on the extension of the opening Prototethys Ocean and was probably originated by prerift downwarping. Its development probably stopped while a side rift was formed later in the Silurian (see also Fig. 1A in the present work).

The bathyal origin of the axial part of the Baltic Basin is also proved by the history of its development. From North Poland to West Latvia the thickness of the Lower and Middle Llandovery dark graptolitic shales is only 5-15 m while in Central and South Estonia the marginal area of the basin, the thickness of contemporaneous carbonate sediments is up to 10 times greater (see Fig. 1B, 1C and 2). It shows that a depression where subsiding was not compensated with the sediment loading developed here at the initial stage of the Silurian transgression. In the Late Silurian in the course of fulfilling of the depression in North Poland depositea very thick (up to 1,500 m) flysh-

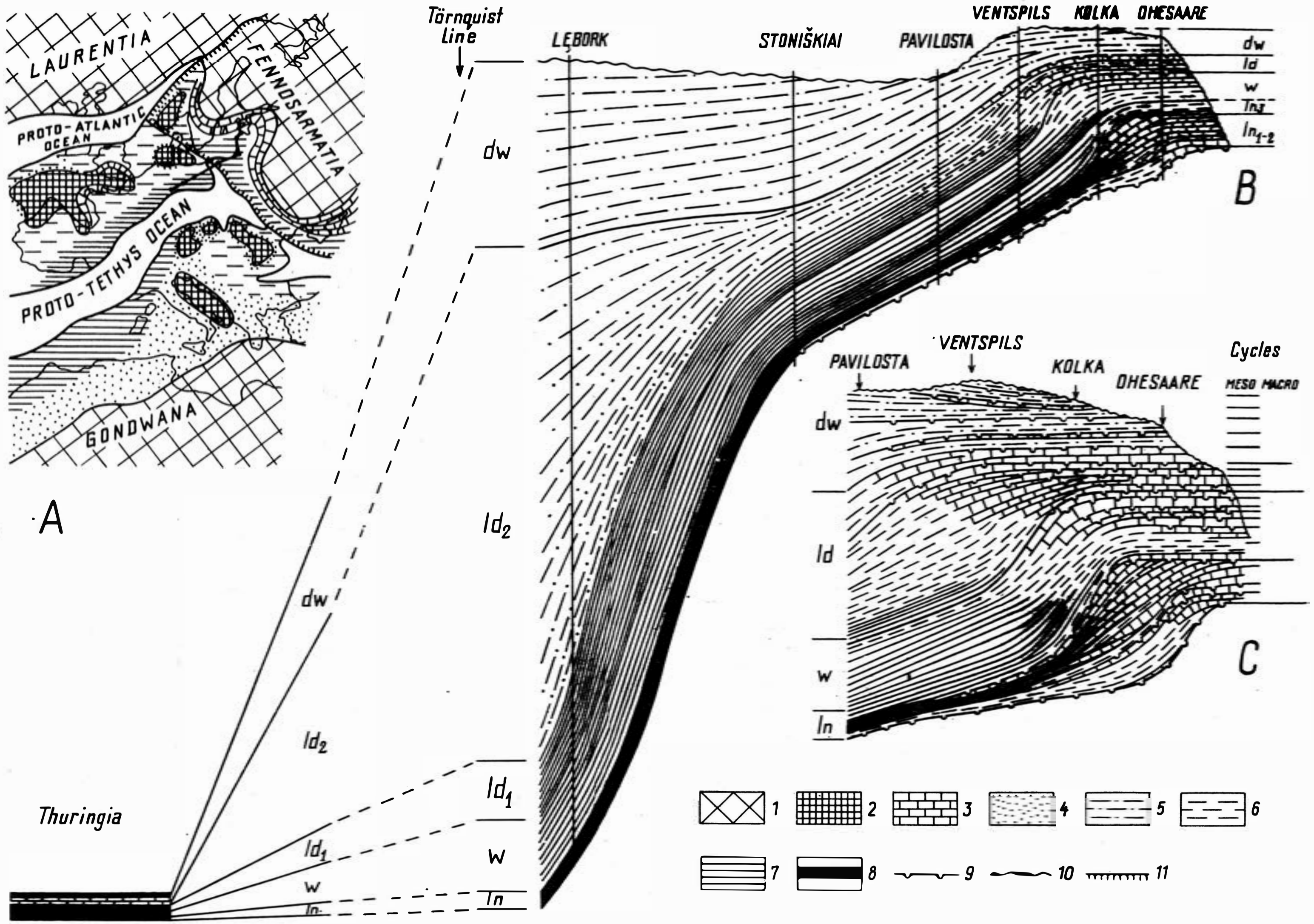

Fig. 1. Middle Silurian paleogeographical situation in Europe after Tomczyk and Tomczykowa (1979) (A) and generalized section across the pericontinental Baltic Basin into Central European Geosynclinal Basin (B, C).
1-cratonic lowland; 2-inter-geosynclinal massifs (microcontinents); 3-carbonate shelf deposits; 4-terrigenous shelf deposits; 5-silty muds of the basin filling phase; 6-pellitic deposits of the slope; 7-graptolitic muds of the depression; 8-shaly graptolitic deposits; 9-hardgrounds; 10-post-Silurian errosion surface; 11-Törnquist Line.

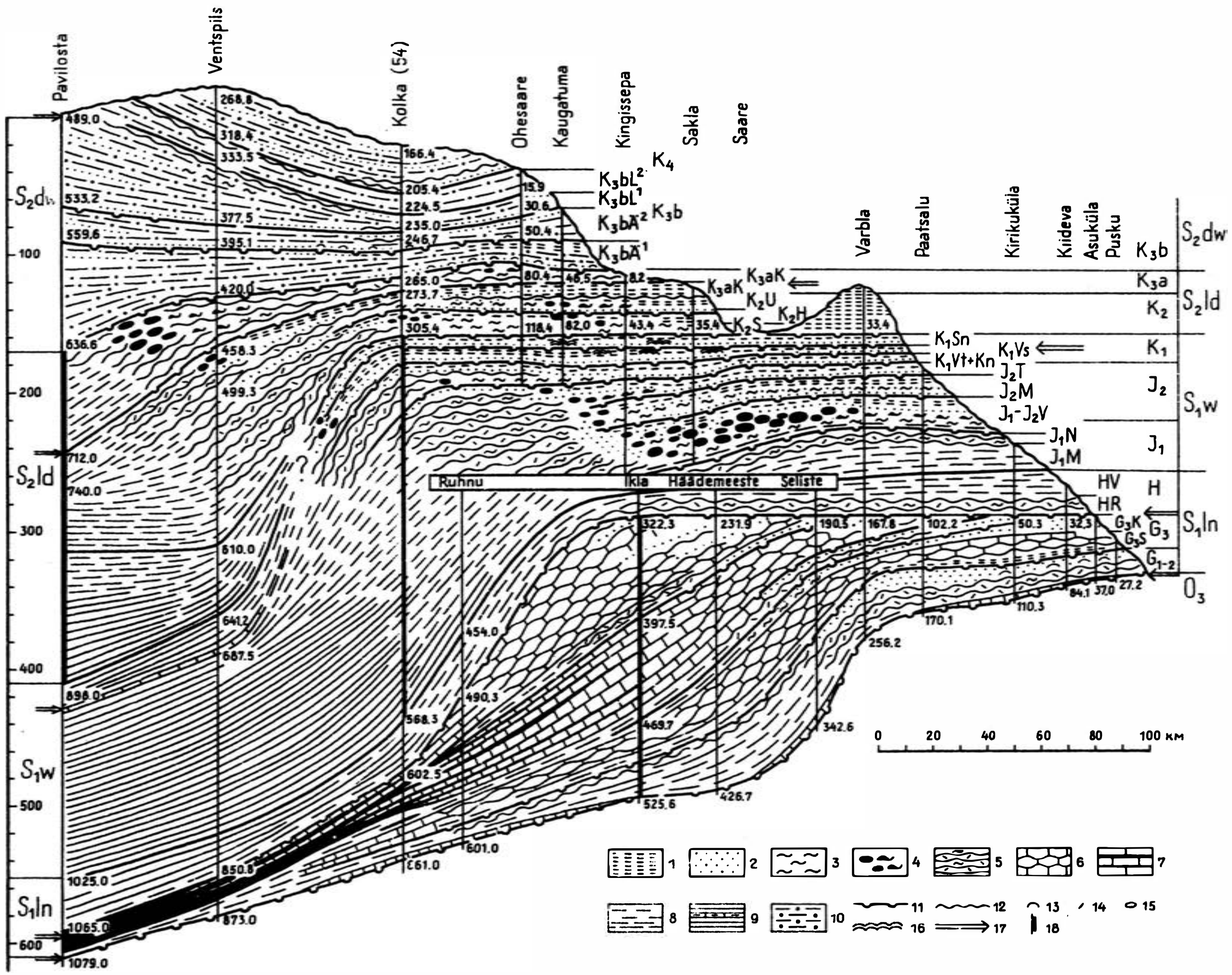

Fig. 2. Cross section of the Silurian facies on the northern flank of the Baltic Basin from West Estonia (right) to Kurzeme Peninsula in Latvia.
1-littoral-lagoonal argillaceous dolomites; 2-sparitic calcarenites of the shoal belt; 3-bioturbated argillaceous-calcareous restricted shelf sediments; 4-organic buildups with back-reef sediments; 5-nodular micritic calcarenites of the open shelf; 6-nodular calcilutites of the open shelf; 7-intercalating calcilutites and graptolitic mudstones of the slope; 8-calcareous mudstones of the slope; 9-graptolitic mudstones of the depression; 10-silty mudstones of the basin filling phase; 11-hardgrounds; 12-post-Silurian errosional surface; 13-brachiopod banks; 14-skeleton detritus; 15-conglomerate; 16-stromatolite layers; 17-boundaries of macrocycles; 18-sections with the maximum thickness of series.

like interlayering graptolitic mudstones and siltstones of Siedlce series that could be interpreted as marginal turbidites.

Thus, the development of the axial part of the Baltic Basin in the Silurian period includes the elements typical of the development of a depression and it can be considered as a tongue of the North European miogeosynclinal depression which extends far into the area of the East European Craton. Regarding this area of the basin as a part of the shelf would be evidently misleading.

On the other hand, the I-III facies belts (lagoons, shoals and open shelf) of our model, forming carbonate platform, could be beyond doubt referred to the shelf. In geological papers the distribution of the shelf is often restricted to the area of carbonate deposits rich in shelly fauna. Interesting parallels can be drawn between the distribution of sediments in the Silurian Baltic Basin and in the north-western part of the present Black Sea. The flat relief of the surrounding area and wide extension of the lagoonal coast, where muds are the prevailing deposits, prevents the transport of terrigenous material to the open shelf of north-western Black Sea. For these purposes the latter is mainly covered with carbonate deposits, 30-80 % of which form shells and their debris (Щербаков и др., 1978). The content of shells decreases abruptly on the continental slope that begins at the depth of 100 m on an average and is covered with argillaceouscoccolite muds. The distribution of skeletal material is more or less similar in the Silurian Baltic Basin, the first - lagoonal belt is relatively poor in it, in the second and third facies belts it plays an important role and in the fourth belt its amount decreases abruptly. F. Shepard (Шепард, 1976), J. Stanley, R. Unrug (1972) and others have also shown that the amount of coarse- and medium-grained material, among this skeltal sand, decreases abruptly with the transition from shelf to slope. The same phenomenon is typical of the eastern coast of the Caspian Sea (Алексина, 1962; Лебедев и др., 1973).

The results obtained through the analyses of the thicknesses of deposits lead to the same conclusion. In the Baltic Basin the thickness of the deposits of the three onshore facies belts grows rather evenly with the depth. A more abrupt increase of thickness takes place on the transition to carbonate-terrigenous muds of the fourth belt. We connect it with the change in the sea bottom gradient at the shelf edge. In favour of the above interpretation speaks the fact that in the onshore sections of the basin the rocks of the I-III facies belts are interbedding rather frequently, whereas the sections of its central part with deposits of the fourth and especially of the fifth facies belt are much more monotonous. This is well known from the section of Wenlock and Ludlow deposits at the northern margin of the Baltic Basin which shows a distinct cyclic change of carbonate facies in Estonian sections as far as Ohesaare boring (Fig. 2). At the same time relatively monotonous argillaceous deposits of the fifth and fourt facies belts accumulated in West Latvia. To our mind it enables to differentiate the northern part of the section as the shelf platform on which the comparatively minor changes in water level gave rise to an extensive facies oscillation that is not reflected in bathyal sections in the central part of the basin due to the relatively abrupt increase in depth.

In the same section, given more generalized in Fig. 1 of the present paper, it becomes evident that the belt of the greatest thicknesses which coincides with the distribution of marls and argillaceous calcilutites of the fourth facies belt migrates gradually towards the basin centre. Evidently it is a reflection of the lenticular deposition of hemipelagic sediments on the flat basin slope that results in the progradation of the slope and migration of the shelf edge towards the central part of the basin.

In favour of the location of the shelf edge between the third and fourth facies belts also speak the evidences obtained through the analyses of the distribution of benthic organisms. If the second and third facies belts are inhabited by a diverse bottom fauna and benthic algae, then in the fourth belt colonial corals, stromatoporoids, algae, bryozoans - all potential reef-building organisms are practically lacking. The disappearance of benthic algae shows that the boundary between the third and fourth facies belts is close to that of the photic zone and thus its absolute depth approaches to the average values of the outer edge of the recent shelves.

These were the most essential considerations that made us restrict the shelf in the Silurian Baltic Basin to the I-III facies belts where the carbonate sedimentation was prevailing.

The concept of the continental slope is not as clear as that of shelf. From the tectonical point of view the continental slope includes the whole subsided part of the continental crust that remains beyond the shelf edge. In these cases when the deep-subsided plateau is situated at the continental margin, continental slope as a purely geomorphological element is actually divided into two independent parts, one of which remains between the shelf and marginal plateau or represents the inner slope of the continental margin sea, while the other lies between the marginal plateau and ocean floor and forms the outer slope of the marginal sea.

It is quite possible that such a complicated situation with two-stage slope was also characteristic of the Silurian Baltic Basin where the first stage roughly coincides with the boundary of the Baltic Syneclise, the other with the Törnquist Line. Speaking of the slope of the Baltic Basin in a narrow sense, we keep in view the first one coinciding with our fourth facies belt. The existence of the second slope behind the Törnquist Line is yet to be proved as there are cases (e.g. the present-day Zambesi-Mosambique Channel Basin - Scrutton, Dingle, 1976) when the marginal block of the continent has subsided to the level of the ocean bottom and the topographical slope is practically lacking between the marginal plateau and ocean floor.

Summarizing the analysis above one may conclude that according to the strict shelf definition of the recent oceanography, that fits the shelf edge with the first clear break in the gradient of the sea bottom profile, it is reasonable to restrict the shelf in the Silurian Baltic Basin with the belt of shelly carbonate sediments in the marginal part of the basin. The central part of the basin within the Baltic Syneclise, where graptolitic mudstones accumulated, has been treated here as a tongue of the North European miogeosynclinal depression. Probably the slope between the shelf and depression had a very low gradient and it was hardly comparable to the continental slopes of the recent oceans. The reason could be the extremely low relief of the Silurian continents and much less depth of the oceans comparing with nowadays.

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ПРИМЕНЕНИЕ КОНЦЕПЦИИ ШЕЛЬФА И СКЛОНА К СИЛУРИЙСКОМУ БАЛТИЙСКОМУ БАССЕЙНУ

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Силурийский Балтийский бассейн располагался на пассивной окрайне континента и открывался непосредственно в Центрально-Европейский геосинклинальный бассейн океанической природы. Такая позиция позволяет интерпретировать Балтийский бассейн в силуре как периконтинентальное море с обособленным шельфом и материковым склоном. Мы считаем, что шельф мог скорее всего совпадать с поясом в основном карбонатной седиментации, который прилегал к пенепленизированному Фенно-Сарматскому материку. Осевая часть Балтийского бассейна с граптолитосодержащими сланцами и аргиллитами может быть рассмотрена как глубоко опущенный блок материковой окрайны, который тектонически относился к материковому склону, но седиментологически представил с собой язык крупной североевропейской некомпенсированной депрессии, проникающей в северо-восточном направлении внутрь Восточноевропейской платформы. Склон бассейна в его более узком, геоморфологическом понимании, вероятно, охватывал пояс седиментации известкого-глинистых илов между шельфовыми карбонатными и граптолитовыми пелитовыми осадками центральной депрессии бассейна. Эррозионные каналы, турбидиты и другие явления, характерные крутым материковым склонам, в Балтийском силурийском бассейне отсутствовали из-за относительно пологого наклона морского дна.