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Facies and depositional environment of the Pridoli carbonate ramp in the Silurian Baltic Basin, Lithuania

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The present study focuses on the Pridoli succession in the Lithuanian part of the Silurian Baltic Basin. Seven main microfacies are distinguished, based on the carbonate classification system of Dunham (1962): marly shale, mudstone, brachiopod-crinoid wackestone, crinoid-brachiopod packstone, crinoid grainstone, stromatoporoid-crinoid or coral-crinoid float-rudstone and dolomudstone. These microfacies are arranged in five major lateral depositional facies belts. From proximal to distal, the following facies can be distinguished: Sabkha, Inner-shallow ramp, Mid ramp, Outer ramp, Lower ramp slope – deep basin. There was no evidence found of reefs or reef belts in the system, and the central facies belt with abundant stromatoporoid rudstones and floatstones is interpreted as a biostrome. Based on the microfacies and lithofacies distribution, instead of the common platform interpretation, a ramp model is appropriate for the Pridoli succession in Lithuania.

Key words: carbonates, depositional environment, biostrome, ramp, Silurian Baltic Basin, Pridoli

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INTRODUCTION

Nowadays, energy supply is one of the most important political points, and this will become more important when the growing economies of China and India, amongst others, will strain the energy market with their increasing demands. Oil prices are high, but it is questionable if the production levels can be increased or even kept at the same level to meet the increasing demands. Oil production is getting inadequate to meet the demand, and scientists are desperate about finding the way out of the impasse. Oil is crucial for energy supply in modern society, and to maintain the present production levels we either need to find new oil reservoirs, new techniques to improve oil extraction from the present reservoirs, or to substitute oil by other energy resources.

Most of the well-known giant and large oil reservoirs are close to or maybe have already passed their peak production (Deffeys, 2001; Abdullah, 2005; Heinberg, 2005). A number of giant and large oilfields on which a significant part of oil production depends occur in Palaeozoic carbonates. For maintaining the production rates and optimizing recovery percentages, it is crucial to have adequate geological models of predicting the lithology and petrophysical properties. Palaeozoic carbonates are fundamentally different from Mesozoic and Cainozoic ones because of the different carbonate factories. Since the arrival of scleractinian corals, carbonate platform deposits rimmed by reefs are common. Palaeozoic carbonate factories are different since they are often dominated by stromatoporoid, tabulate or rugose coral and microbial-algal associations. The study of analogous outcrops can lead to improvement, but also core-based subsurface studies are relevant. The Silurian carbonates in the Lithuanian part of the Baltic Basin offer a good opportunity to perform such a subsurface study because abundant core material is present, which represents the carbonate system from the near-coast shallow depositional environments to the deeper basinal parts.

The available computing power now allows for a relatively easy construction of three-dimensional facies models, and this has in particular been done for siliciclastic sediments. The question 'why is it important to model facies?' is therefore appropriate to ask. In case of siliciclastic sediment, it is obvious that the initial grain-size distribution and sorting as a result of depositional processes is directly related to the depositional porosity and permeability distribution. However, after diagenesis, this relationship may not be as straightforward as initially. For carbonates, the relationships between texture in the sense of grain-size distribution and sorting are not as direct as for siliciclastic deposits. The carbonate particles are in the first instance produced within the basin and often accumulate more or less *in situ*. The main part of the carbonate particles is produced by organic activity, as skeletal parts, and their size, shape and sorting are thus first of all a function of the biota producing it. Sorting based on tractive transport processes is less important for grain-size distribution than the assemblage of species producing carbonate as a result of metabolic processes or by other organisms producing fine-grained material through bioerosion of the primary skeletal or also non-skeletal particles. The sediment texture is thus more related to environmental factors such as nutrient availability, water depth and light penetration, and substrate type than to water energy. These environmental factors probably have changed in relative importance through the evolution of the carbonate-producing fauna and flora and may not be the same for the Palaeozoic, making direct comparative studies with present-day carbonate environments difficult.

The distribution of reservoir properties in carbonate may thus be more complex than in siliciclastic sediments. Nevertheless, one may hypothesise that carbonate facies are indeed important because their primary porosity and permeability distribution is related to the fabric of the sediment, i.e. grain- or matrix-supported fabric, and the content of carbonate mud. The temporal development of these properties is most likely related to the initial mineralogical composition of the sediment. The susceptibility for diagenetic processes depends largely on the mineralogy, but also on the texture of the particles (i.e. specific surface area). The changes in depositional porosity may thus still be related to depositional facies since each facies has a different diagenetic susceptibility and thus may follow a different pathway for diagenesis.

OBJECT OF STUDY

It is often stated that Silurian carbonates form an excellent target for hydrocarbon exploration. This statement is based on the fact that Silurian shales are the source rock for the economic hydrocarbon reservoirs in the underlying Cambrian sandstones, and some oil spots or bitumen have been found in Silurian as well as in Ordovician core material. Also, the literature has suggested that good porosity and permeability could be found in Silurian carbonates. Since production from Cambrian reservoirs is decreasing in the last years, the attention is thus changing towards the Ordovician and Silurian carbonates. As the demands are still rising, potential reservoirs in the Silurian would be welcome.

To further test the possibility of reservoir occurrences in the Silurian, the present study focused on the description of lithofacies and their petrophysical properties.

The Minija regional stage (Pridoli) carbonates in the Silurian Baltic Basin (Fig. 1) are a good example of a carbonate ramp system with a stromatoporoid-crinoid-brachiopod dominated carbonate factory. The Silurian Baltic Basin is located at the margin of the Baltic craton, which was in the tropical climate a belt just south from the equator during the Silurian (Cocks, Torsvic, 2005).

The Silurian stratigraphy has been studied for decades, resulting in the availability of a good stratigraphic framework (Paškevičius, 1997; Brazauskas, 2005) (Fig. 2). The carbonates are extensively drilled and cored in the eastern part of the basin for hydrocarbon exploration and production of oilfields in the Middle Cambrian siliciclastic sandstones in Lithuania, Kaliningrad Region and Poland. Silurian shales are one of the source rocks for much of that oil (Zdanavičiūtė, Lazauskienė, 2004). Current interest exists in Ordovician and Silurian carbonates because of the oil shows in Gotland and in Lithuania (Paškevičius, 1997; Zdanavičiūtė, Bojesen-Koefoed, 1997; Lapinskas, 2000; Stentoft et al., 2003 Sivhed et al. 2004).

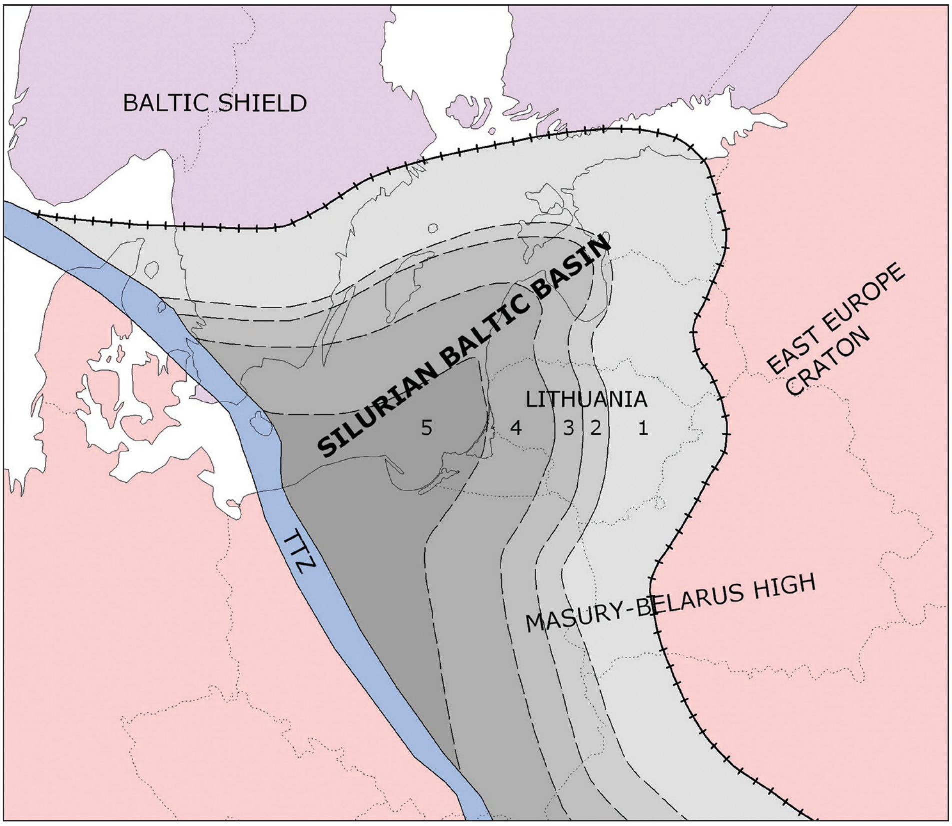


Fig. 1. The main facies belts of the Pridolian ramp in the Baltic Basin. *1* – Sabkha; *2* – Inner-shallow ramp; *3* – mid ramp; *4* – outer ramp; *5* – lower ramp slope – deep basin. TTZ – Tornquist–Teisseyre zone

1 pav. Pagrindinės facijų zonos Baltijos sedimentacinio baseino pržidolio rampoje: *1* – sabka; *2* – vidinė sekli rampa; *3* – vidurinė rampa; *4* – išorinė rampa; *5* – žemesnis rampos šlaitas – gilus baseinas. TTZ – Tornkvisto–Teizerio zona

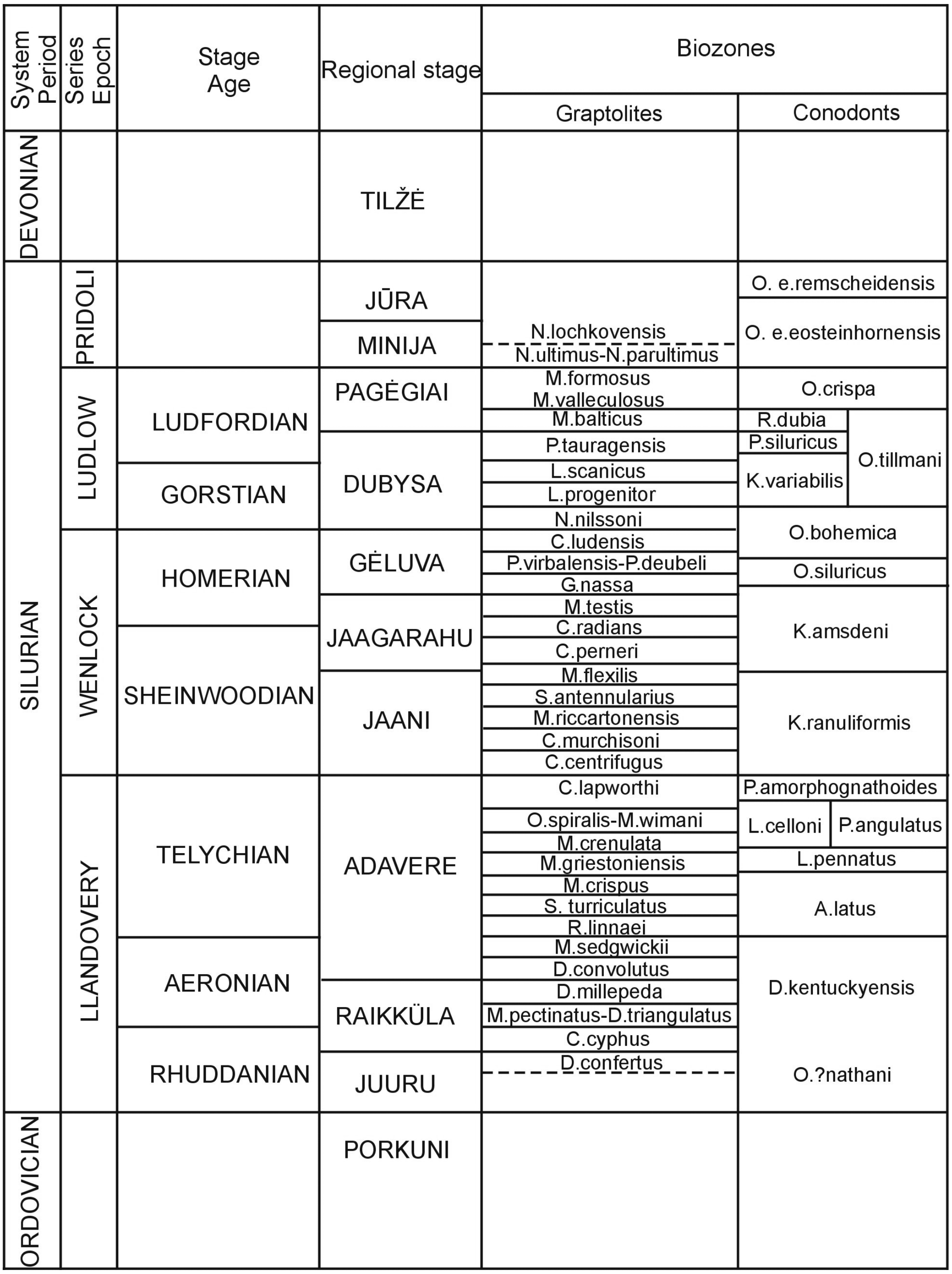


Fig. 2. The Silurian biostratigraphic scheme according to J. Paškevičius (1997)

2 pav. Silūro biostratigrafinė schema pagal J. Paškevičių (1997)

MATERIALS AND METHODS

742 core samples from 43 wells were studied (Fig. 3). Geophysical logs from 17 wells were available for investigations. In total, 313 thin sections (20 µm thick) from 36 wells were prepared for petrographic analysis. Some of the thin sections were selected for scanning electron microscopy (SEM). The sediments were classified using the Dunham (1962) classification system expanded by Embry and Klovan (1971). This system classifies carbonate sediments mainly according to their depositional texture, i.e. mud-supported or grain-supported, and the abundance of detrital grains. The texture as such is linked to the initial type of pores. A standard industry helium porosimeter was used for collecting porosity data (N = 503), which were done by the authors at the Technical University of Denmark. Industry reports from deep drilling projects provided additional data on porosity (N = 254).

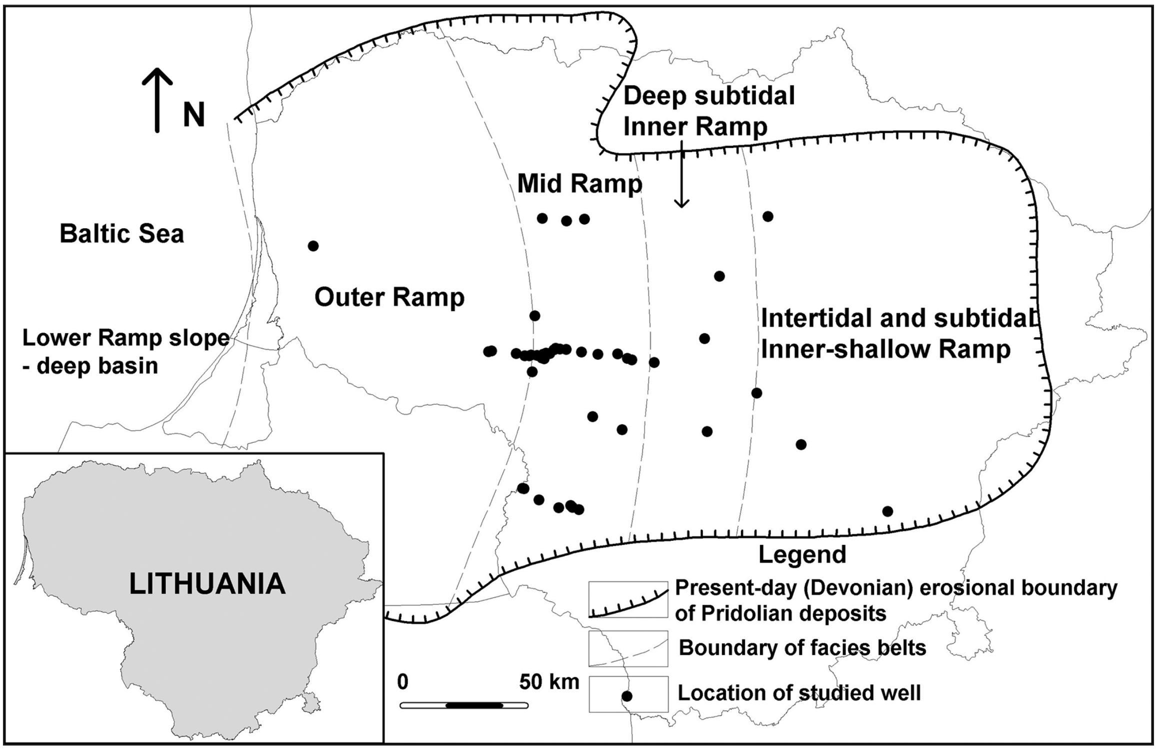


Fig. 3. Location of wells and study cores with the main depositional environments of the carbonate ramp in Lithuania and the erosional outlines of Pridoli deposits
3 pav. Gręžiniai, iš kurių tirtas kernas, pagrindinės karbonatinės rampos sedimentacinės aplinkos Lietuvos teritorijoje ir pržidolio uolienų dabartinis paplitimas

Geological setting

This study is concentrated on the Minija regional stage, which forms the lower sequence of the Pridoli (Paškevičius, 1997) (Fig. 2). The carbonates studied represent depositional environments ranging from proximal, shallow marine in East Lithuania to distal marine in West Lithuania. Tectonic activity was minor due to deposition along the passive cratonic margin. During the Caledonian Orogeny, the Baltica continent collided with Laurentia in the west and with Avalonia in the south. This collision led to the closure of the Iapetus Ocean in the early Devonian. This explains the progressive increase in subsidence and accommodation during the late Silurian. The most proximal facies in the eastern part of the basin are partly lacking due to the post-depositional uplift and denudation (lower Devonian) (Lapinskas, 2000). The Minija regional stage succession consists of parallel facies belts ranking from dolostones in the east, passing into marine bioclastic limestones with variable dolomite content and with increasing numbers and thickness of marl or sometimes marly shale interbeds towards the western part of the basin; bioclastic limestones change into nodular limestone. Shales and black shales occur in the deepest part of the basin.

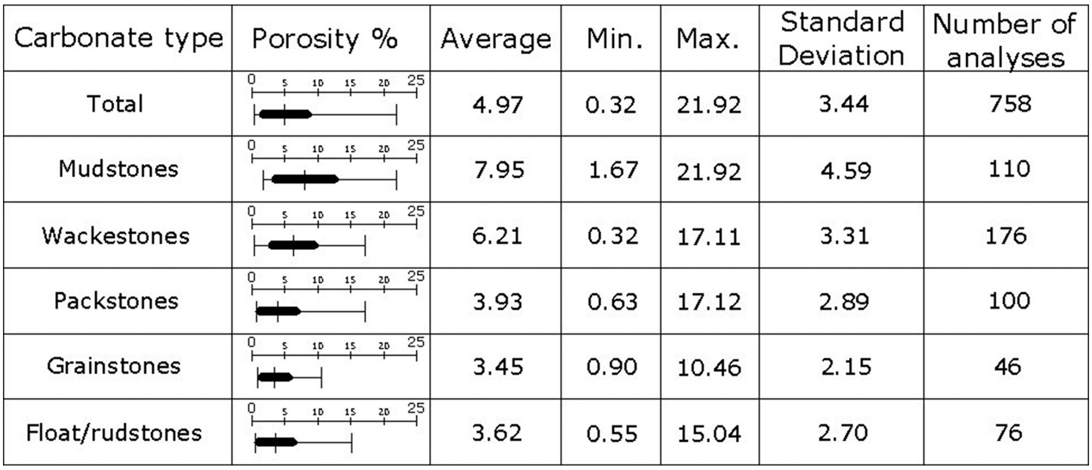
Petrophysical properties in the Minija regional stage

The main petrophysical properties determining the hydrocarbon reservoir quality are porosity and permeability. Usually, in oil reservoirs these properties have a positive correlation: the higher the porosity the higher the permeability. This rule does not hold in this case. The porosity data distribution related to microfacies is presented in Fig. 4. The critical point is that most of the carbonates are impermeable and show permeability below the detection limit of the equipment. Permeability data are presented in Fig. 5.

Contrary to expectations and contrasting with siliciclastic deposits, the finer grained carbonates are most porous, although their porosity in general is very low. The better reservoir properties are found in the dolomudstones that have slightly higher average porosity than other carbonates (Fig. 4). Most of the pores in dolomudstones are micro-intercrystalline and moldic, but some of them could be interpreted as fenestral, too. In general, all carbonate types have inter- and intra-particle, mouldic and intercrystalline pores. Fractures which temporally increased porosity were filled with calcite and dolomite cement. A similar scenario happened to all pores, most diagenetic processes led to the reduction of porosity mostly by mechanical and chemical compaction which further evoked precipitation of burial calcite and dolomite cements. Diagenesis overprints the primary porosity patterns largely and reduces porosity regardless of the depositional facies. Comparing the porosity values across the various depositional facies, it is evident that postdepositional processes (diagenesis) reduced the depositional porosity, but further discussion of diagenesis is beyond the scope of this paper.

DISCUSSION AND PALAEOENVIRONMENTS

It appears that most of the microfacies are mud-dominated and have a matrix-supported fabric. Microporosity is dominant in such sediments, and permeability is thus low. Only grainstones and, to a lesser degree, packstones had larger-sized interparticle pores and thus an initially appreciable permeability.



Carbonate type	Porosity %	Average	Min.	Max.	Standard Deviation	Number of analyses
Total		4.97	0.32	21.92	3.44	758
Mudstones		7.95	1.67	21.92	4.59	110
Wackestones		6.21	0.32	17.11	3.31	176
Packstones		3.93	0.63	17.12	2.89	100
Grainstones		3.45	0.90	10.46	2.15	46
Float/rudstones		3.62	0.55	15.04	2.70	76

Fig. 4. The distribution of porosity values in different types of carbonate rocks. Note that mudstone includes both lime- and dolomudstones. To determine the analytical accuracy, two samples with distinctly different porosities (around 2% and 22%) were measured 100 times each. For the porosity values of 2% and 22%, standard deviations of 0.061% and 0.209%, respectively, were obtained, indicating a high accuracy of the equipment

4 pav. Poringumo reikšmių pasiskirstymas skirtinguose karbonatinių uolienų tipuose. Pažymėtina, kad mikritinis tipas jungia tiek kalcitinę, tiek ir dolomitinę dalį. Nustatant analitinio tyrimo tikslumą buvo pasirinkti du skirtingo poringumo reikšmių (apie 2 ir 22%) mėginiai ir tų pačių mėginių poringumas buvo matuojamas po 100 kartų. Nustatytas standartinis šių mėginių nuokrypis (atitinkamai 0,061 ir 0,209%) patvirtina instrumento tikslumą

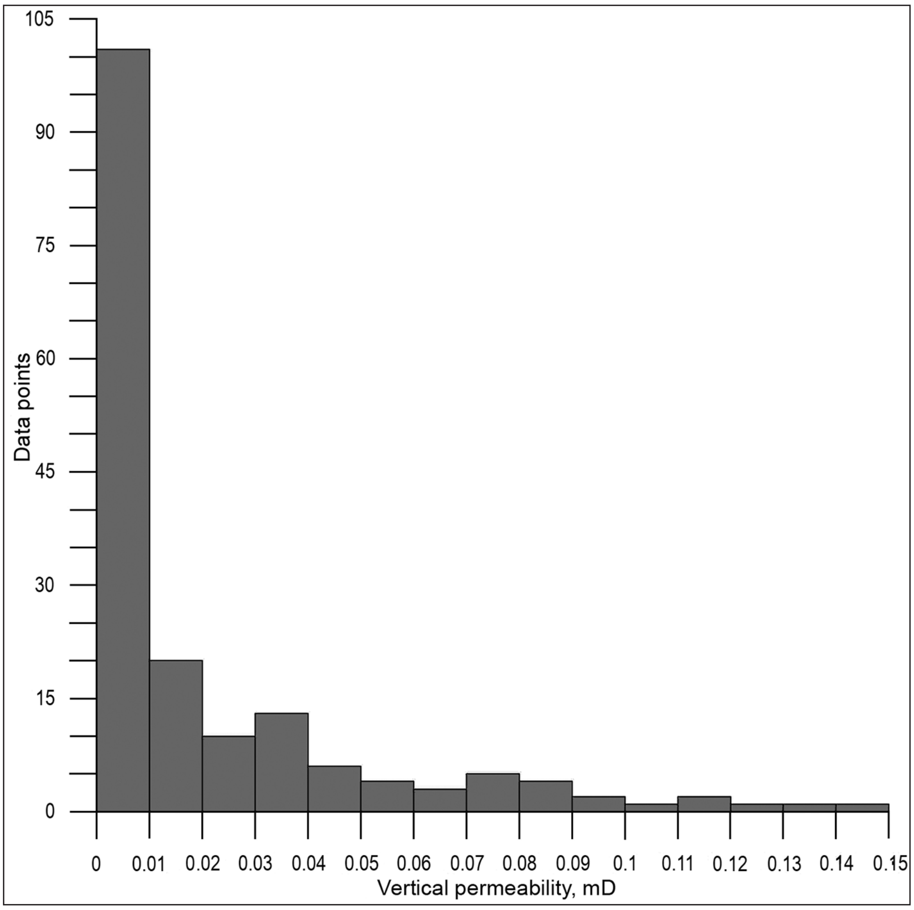


Fig. 5. A histogram showing the permeability values of the carbonates of the Minija regional stage. The permeability values have a lognormal distribution in a single population. Most of the measured permeability values are below 0.1 mD. Note that more samples have been measured, but most of the samples showed permeability below the detection limit of the equipment

5 pav. Karbonatinių uolienų iš Minijos regioninio aukšto skvarbumo reikšmių histograma. Skvarbumo reikšmės rodo lognormalų pasiskirstymą vienoje populiacijoje. Dauguma išmatuotų skvarbumo reikšmių yra mažesnės negu 0,1 mD

The proximal dolostones are probably the resultant of early dolomitization processes related to the depositional environment and as such show an appreciable mouldic porosity from dissolved shells, in addition to intercrystalline porosity.

So far, the Silurian Baltic Basin has usually been interpreted as a carbonate platform (Kaljo, 1977; Lapinskas, 2000; Stentoft et al., 2003) with a central reef belt. Most of the platforms in the Palaeozoic are apparently accompanied by reef belts. The critical point here is what exactly is meant by a 'reef'. From the sedimentological point of view, a reef can be defined as a structure having a stable and thus interconnected framework of sessile carbonate fossils, which distinctly arises above the sea floor, is early marine-cemented and thus able to resist the action of waves and currents. This kind of structure should be accompanied by talus deposits in the front and back of the reef. In the study area, no such structures have been observed either in outcrops, cores or thin sections. In platforms, as a result of the presence of reef barriers, lagoons develop behind the reefs with a more or less restricted water circulation. In the lagoons, the salinity therefore tends to be higher than normal marine, which results in decreased bioturbation and reduced or less diverse biota and biogenic activity. Lagoonal sediments, therefore, may be laminated and often contain evaporitic minerals like gypsum, anhydrite, or halite.

In a lagoon depositional environment, there should be some depositional features indicating low-energy depositional environments with (semi)closed connection with the open sea, but no such features were found. In all facies, apart from the most proximal dolomudstones, bioturbation is abundant, and usually sedimentary structures resulting from tractive transport are absent. Evaporitic minerals or laminated structures indicating a lack of oxygen or reduced open marine circulation are also absent. More importantly, there was no physical barrier that could close off the lagoons from the open sea. A lagoon, therefore, was absent. Only the dolomudstone facies had laminated structures, indicating the stromatolitic origin of the laminae with inter- to supratidal conditions.

Petrographic studies of rock samples and thin sections revealed seven main microfacies based on the Dunham system (1962): marly shale, mudstone, brachiopod-crinoid wackestone, crinoid-brachiopod packstone, crinoid grainstone, stromatoporoid-crinoid or coral-crinoid float rudstone and dolomudstone. These microfacies are summarised in Table 1 and shown in Figs. 6 and 7.

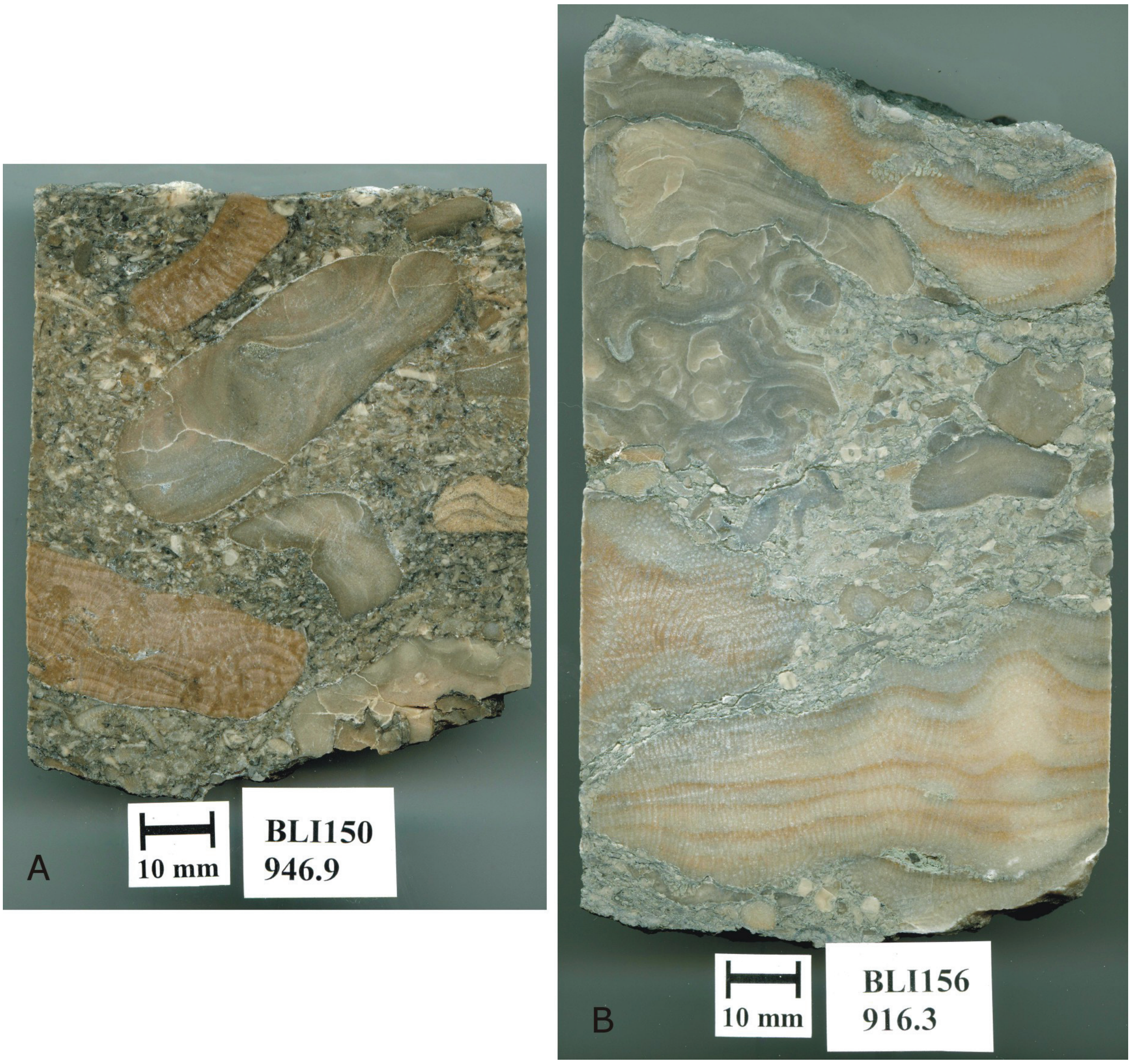


Fig. 6. Photographs of polished core samples. *A* – stromatoporoid-crinoid floatstone (limestone) with dm-sized stromatoporoids typical of the central facies belt; *B* – coral-crinoid rudstone (limestone) with small tabulate coral colonies

6 pav. Antšlifių nuotraukos. *A* – stromatoporoidinė-krinoidinė stambiaporfyrinė (*floatstone*) klintis su dm dydžio stromatoporoidėjomis iš centrinės facijinės zonos, *B* – koralinė-krinoidinė stambiarašmeninė (*rudstone*) klintis su nedidelėmis sluoksniuotų koralų kolonijomis

Table 1. **Carbonate microfacies description in the Minija regional stage (Pridoli) of Lithuania based on the Dunham carbonates classification system (1962)**

1 lentelė. **Minijos regioninio aukšto (pržidolis) karbonatinių mikrofacijų aprašymas Lietuvos teritorijoje remiantis Dunham karbonatų klasifikacijos sistema (1962)**

Microfacies	Grains	Grain size	Matrix	Fauna
Marly shale	Non or few bioclasts	<2 mm	Dominated by carbonate mud (micrite) and terrigenic siliciclastic material	Brachiopods
Mudstone	Non or few bioclasts	<2 mm	Dominant carbonate mud (micrite)	Crinoids, brachiopods, ostracods, bivalves
Crinoid wackestone	Bioclasts	<2 mm	Dominated by carbonate mud (micrite) composed of calcite	Crinoids, brachiopods, trilobites, ostracods, bryozoans, gastropods, bivalves, pellets
Crinoid-brachiopod packstone	Bioclasts	<2mm	Minor admixture of carbonate mud (micrite)	Crinoids, brachiopods, trilobites, ostracods, bryozoa, pellets
Crinoid grainstone	Usually well rounded bioclasts	<2 mm	Non	Crinoids, brachiopods, trilobites, ostracods, bryozoans
Stromatoporoid-crinoid or coral-crinoid rudstone	Different bioclast shapes from well rounded to angular	Dominated by >2 mm, but smaller ones also occur	Minor admixture of carbonate mud (micrite)	Stromatoporoids, tabulate and rugose corals, crinoids, brachiopods, bryozoa
Stromatoporoid-crinoid or coral-crinoid floatstone	Different bioclast shapes from well rounded to angular	Variable size	Dominated by carbonate mud (micrite)	Stromatoporoids, tabulate and rugose corals, crinoids, brachiopods, bryozoa
Dolomudstone	Non or few badly preserved	<2 mm	Dominated by carbonate mud (micrite) composed of dolomite	Bivalves, gastropods, algae

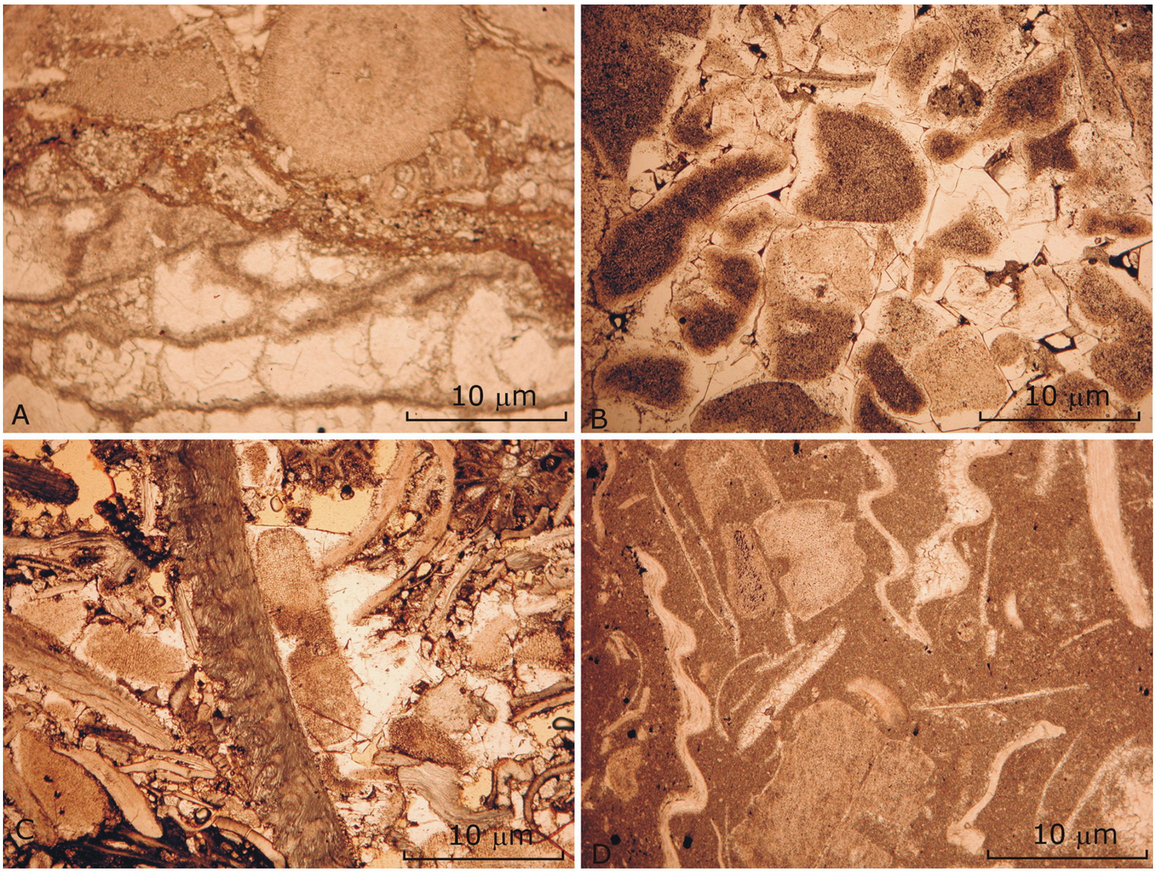


Fig. 7. Thin section microphotographs of different microfacies. *A* – coral-crinoid rudstone (limestone) dominated by coarse-grained tabulate colonies and crinoids from the central facies belt (note stylolites among the grains); *B* – crinoid grainstone (limestone) from the central facies belt, consisting almost entirely of crinoid grains overgrown with syntaxial cement; *C* – brachiopod-crinoid packstone (limestone) from the central facies belt consisting of brachiopod and crinoid grains; *D* – Brachiopod-crinoid wackestone (limestone) from the outer ramp with a matrix supported fabric

7 pav. Skirtingų mikrofacijų šlifų nuotraukos. *A* – koralinė-krinoidinė stambiarašmeninė (*rudstone*) klintis iš centrinės facijinės zonos, kurioje vyrauja stambianuolaužinės koralų kolonijos ir krinoidėjos (nuotraukoje tarp dalelių taip pat matomas stilolitas); *B* – krinoidinė grūdėta (*grainstone*) klintis iš centrinės facijinės zonos, susidedanti beveik vien tik iš krinoidėjų, kurių dalelės apaugusios sintaksiniu cementu; *C* – brachiopodinė-krinoidinė rašmeninė (*packstone*) klintis iš centrinės facijinės zonos, daugiausia susidedanti iš brachiopodų ir krinoidėjų dalelių; *D* – brachiopodinė-krinoidinė porfyrinė (*wackestone*) klintis iš išorinės rampos, kuriame vyrauja mikritas

Based on microfacies, lithofacies and faunal distribution, a depositional ramp model in Pridoli carbonates was constructed (Fig. 8). The ramp system can be subdivided into five major, parallel depositional facies belts with typical lithofacies associations (Fig. 3). From the proximal, near coastal to the distal, central basin these are: 1 – a near-coastal facies of dolomudstones with intertidal and shallow subtidal features (intertidal-subtidal inner-shallow ramp); 2 – a shallow facies above the wave base with wackestones and mudstones with some coarser bioclastic coarse-grained packstones, grainstones or rud- and floatstones. The fauna consists of bivalves, ostracods, gastropods, crinoids and brachiopods (Inner-shallow ramp); 3 – a central facies with coarse-grained bioclastic stromatoporoid – coral biostromal and crinoid deposits ranking from grainstones to rudstones (mid-ramp); 4 – a deeper slope, a fine-grained muddy facies belt with some coarser-grained bioclastic packstones (outer ramp); 5 – a deepest ramp slope facies with marl-shales and black shales (lower ramp slope – deep basin). The depositional environments are briefly summarised in Table 2. Basically, in a ramp, the major control factor on the facies is water energy, i. e. the depth of the fair-weather wave base and storm-wave base, variations in topography and depositional slope, and material transport by storms, waves and tides (e. g., Pomar, 2001; Flügel, 2004).

Table 2. **The main features of sediments in the various depositional facies belt**

2 lentelė. **Skirtingų sedimentacinių facijinių zonų pagrindiniai bruožai**

Lithofacies	Microfacies	Dominant fauna	Structures	Depositional environment	Ramp facies belt
dolostones	dolomudstones, dolowackestones	ostracods, bivalves	laminated-bedded	intertidal to shallow subtidal deposition	sabkha
limestones, some dolostones	mudstones, wackestones, packstones	crinoids, ostracods, bivalves, brachiopods, gastropods	bioturbated, bedded to thin bedded	subtidal, well oxygenated	inner-shallow ramp
limestones	rudstones, floatstones, grainstones, packstones	stromatoporoids, tabulate and rugose corals, crinoids, bryozoans, brachiopods, trilobites	bioturbated, bedded, interbedded	below wave base, below photic zone, above fair weather storm base, biostromes, storm reworking	mid ramp
limestones, marls, shales	mudstones, wackestones, packstones	crinoids, brachiopods, gastropods, graptolites	bioturbated, nodular bedded, interbedded	low energy, below wave base, pelagic and storm deposition	outer ramp
shales, marls	mudstones, wackestones	graptolites	bedded-laminated	occasional distal storm deposition, siliciclastic low energy deposition	lower ramp slope – deep basin

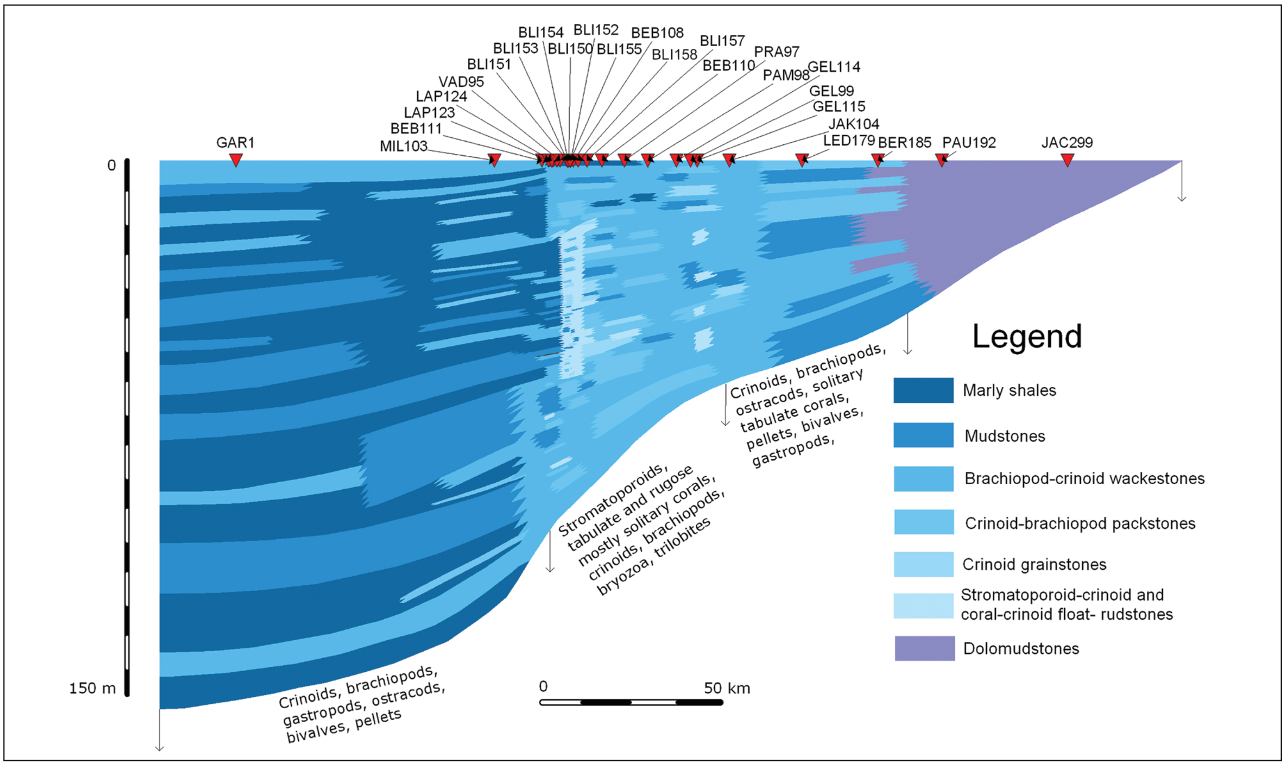


Fig. 8. Lithological cross section of the Minija regional stage deposits in the Lithuanian part of the Silurian Baltic

8 pav. Baltijos baseino silūro Minijos regioninio aukšto nuogulų litologinis pjūvis Lietuvos teritorijoje

The central facies belt is richest in fauna with respect to its quantity and diversity. It is difficult to assess the exact proportions in carbonate production in the various facies throughout the ramp, but it is probable that the central facies belt in the basin was the main carbonate factory in the system. The correct identification of this facies belt is of particular importance for interpreting the whole system and can lead to a misunderstanding of the carbonate system in the Silurian Baltic Basin. This is the case not only for this region, but also all over the world. The presence of the central facies belt with particular fauna (e. g., stromatoporoids, crinoids, bryozoa and tabulate or rugosa corals) almost spontaneously leads to identification of reefs and thus the interpretation of the pertinent system as a carbonate platform. However, this facies is composed mainly of floatstones and rudstones associated to biostromes instead of reefs as earlier defined. Small reefs, usually some decimeters to a metre in size, have been described from Gotland, but these are evidently a minor part of the system occurring behind the biostromes and thus better should be called patchreefs.

Of course, it is difficult to assess the exact shape of stromatoporoids from core samples and particularly from thin sections, but it is possible to determine that most of the stromatoporoids are relatively small, flat to bulbous or domical-shaped and more rarely laminar. Most of the stromatoporoids were not *in situ* but turned over and / or displaced (Fig. 9). They were overturned or broken by waves and currents which were probably caused by storms. The angular shape of many of the stromatoporoids suggests that they were transported for short distances, whereas well-rounded shapes indicate transportation over longer distances. Moreover, no stromatoporoids were encountered attached to hard substrates, but instead appeared to have grown on soft substrates, i. e. muddy, fine-grained sediments. They were thus not bound together and did not build a rigid, stable framework. Recent research has provided evidence that stromatoporoids alone are not able to produce a stable framework. Evidence that stromatoporoids and Palaeozoic corals alone are not capable to build a framework was presented, e. g., by Nose et al. (2006). For a stable framework, encrusting stromatoporoids, microbialites, calcimicrobes or calcareous red algae are needed (Meyer, Price, 1993; Nose et al., 2006). However, it may be difficult to determine whether or not the fossils are indeed in place and undisturbed, especially if the fauna did not build a framework (Sandström, Kershaw, 2002). Sandström and Kershaw (2002) argue that stromatoporoids did not fixate themselves to a hard substrate at all. Large ones are unstable and easily turned over, smaller and flat ones being more stable but potentially mobile. Kershaw (1998) and Sandström and Kershaw (2002) presented experimental evidence that currents could move stromatoporoids without overturning them. In the study area, indeed, no framework has been observed.

Most of the modern scleractinian corals that build reefs are colonial, fixed to hard substrates or shelly carbonate sands, and are prone to build rigid and stable frameworks through interconnected colonies. In contrast, Silurian corals like tabulates or rugosa are mostly solitary and occur in mud-rich sediments, i.e. they grew on soft substrates similar to stromatoporoids. Colonial tabulates do occur, but are a minor component, except of some deposits described on Gotland. Some researchers (e. g., Scrutton, 1998, 1999) inferred that rugosa and tabulate corals lived, at least partly, on soft sediments. Thus, all the above-mentioned features suggest that the Minija regional stage does not contain any reefs or even a barrier reef, but stromatoporoid and coral carbonate production gave rise to biostromal shaped bodies. Most of the described stromatoporoid-rich sediments in Gotland lack talus deposits and thus lack a relief (Manten, 1971).

Fig. 9. A typical stromatoporoidal rudstone (limestone) with coarse, unsorted and random oriented remains of stromatoporoids from the central facies belt
9 pav. Tipinė stromatoporoidinė stambiarašmeninė (*rudstone*) klintis su stambianuolaužinėmis nerūšiuotomis ir be tvarkos orientuotomis stromatoporoidėjomis iš centrinės facijinės zonos

Although carbonate mud is abundant throughout the system, grainstones are common in the mid ramp. These grainstones usually are rich in crinoid remains and also contain disarticulated brachiopod shells. The well-sorted nature and the absence of micrite in some layers suggest an environment with occasionally well-agitated water and / or a high local grain (mostly crinoid) productivity which had a great influence on the sediment structures. Postdepositional matrix accumulation either by infiltration or through bioturbation or infaunal activity, turned part of these grainstones into packstones.

CONCLUSIONS

The Pridoli sediments from the Minija regional stage in the Silurian Baltic Basin are interpreted as a ramp system. According to the lithofacies distribution, the ramp can be subdivided into five major parts: intertidal-subtidal inner-shallow ramp; inner-shallow ramp; mid-ramp; outer ramp; lower ramp slope – deep basin.

The systematic variation in lithofacies in each part of the ramp enabled to interpret the depositional environments ranging from shallowest (intertidal) dolomudstones along the basin margin in the east to the deepest part of the ramp in the west with dominant shales and marls.

The assemblages of coarse bioclasts in the mid-ramp in rudstones or floatstones are interpreted as biostromal deposits. Although the biostromes occur within a narrow facies belt, they are neither reefs nor a reef belt.

The best petrophysical properties are found in dolomudstones that occur in several facies belts. Diagenesis is evidently the main factor determining the eventual reservoir properties, obliterating largely the original differences in properties of the various lithologies.

Depositional facies models are thus important for modelling the petrophysical properties of carbonate systems, but apparently less important than in case of siliciclastic deposits. Primary porosity patterns may be reversed by diagenesis.

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PRŽIDOLIO KARBONATINĖS RAMPOS FACIJOS IR SEDIMENTACINĖ APLINKA SILŪRO SEDIMENTACINIAME BASEINE (LIETUVA)

Santrauka

Šiandien nafta yra svarbiausias energijos šaltinis, tačiau jos atsargos nepaliaujamai senka, ir mokslininkai stengiasi atrasti išeitį iš tokios situacijos. Norint išlaikyti bent šiandieninį naftos išgavimo lygį, būtina atrasti naujus naftos telkinius, sukurti metodiką, kuri padėtų kuo daugiau išgauti naftos iš tų pačių telkinių, arba pakeisti ją alternatyviais energijos šaltiniais.

Keliolika milžiniškų naftos telkinių yra dislokuota paleozojaus karbonatinėse uolienose. Norint išlaikyti tą patį gavybos lygį ir optimizuoti gavybą, ypač svarbu turėti tinkamą geologinį modelį, kuris leistų tiksliau apibrėžti telkinių litologines ir petrofizines savybes. Dėl skirtingos karbonatinės medžiagos kaupimosi paleozojaus karbonatai yra visiškai kitokie negu mezozojaus ir kainozojaus. Tam pagrindinę įtaką turėjo skleraktininių koralų įsivyravimas nuo mezozojaus, kurie dažnai karbonatinės platformos profiliui suteikia išgaubimą, vadinamą rifu. Paleozojaus karbonatinė medžiaga kaupėsi nevienodai, nes joje daugiausia stromatoporoidėjų, dugnelinių ir keturspindulinių koralų bei dumblių asociacijų. Lietuvos Baltijos baseino silūro karbonatai labai tinka tokiems tyrimams, nes gausi gręžinių kerno medžiaga reprezentuoja karbonatinę sistemą nuo seklios iki gilios sedimentacinės aplinkos.

Šis tyrimas stratigrafine prasme apima Lietuvos Baltijos baseino silūro apatinę pržidolio dalį. Remiantis Dunham (1962) karbonatinių uolienų klasifikacija, buvo išskirtos šios pagrindinės mikrofacijos: molingų mergelių, mikritų (*mudstone*), brachiopodinė-krinoidinė-porfyrinė (*wackestone*), krinoidinė-brachiopodinė-rašmeninė (*packstone*), krinoidinė grūdėta (*grainstone*), stromatoporoidinė-krinoidinė arba koralinė-krinoidinė-stambiaporfyrinė (*floatstone*), arba stambiarašmeninė (*rudstone*) ir dolomikritų (*dolomudstone*). Minėtos mikrofacijos yra paplitusios lateraliai išsidėsčiusiose sedimentacinėse facinėse zonose. Nuo seklių iki giliavandenių šios zonos gali būti įvardytos kaip sabka, vidinė sekli rampa, vidurinė rampa, išorinė rampa, žemesnis rampos šlaitas – gilus baseinas.

Гедрюс Бичкаускас, Николаас Моленаар

ФАЦИИ И СЕДИМЕНТАЦИОННЫЕ ОБСТАНОВКИ КАРБОНАТНОЙ РАМПЫ ПРЖИДОЛИЯ В СИЛУРИЙСКОМ СЕДИМЕНТАЦИОННОМ БАССЕЙНЕ ЛИТВЫ

Резюме

Неоспоримо, что нефть является главным источником энергии. Однако её запасы постепенно уменьшаются, и ученые стараются найти выход из создавшейся ситуации. Для сохранения нефтедобычи на прежнем уровне существует несколько путей: открыть новые месторождения, создать методику, позволяющую извлечь больше нефти из месторождений, заменить нефть альтернативными источниками энергии.

Множество крупных и очень крупных месторождений нефти обнаружены в палеозойских карбонатных породах. В целях оптимизации и поддержания нефтедобычи из карбонатных пород на прежнем уровне важно иметь подходящую геологическую модель, которая позволила бы точнее определить литологические и петрофизические свойства месторождения. Из-за различий образования известковистого материала карбонаты палеозойские отличаются от мезозойских и кайнозойских. В двух последних основную роль играли рифообразующие склерактиновые кораллы, которые часто в профиле карбонатных платформ образуют выпуклость, называемую рифом. В карбонатных образованиях палеозоя преобладают строматопроидеи, табуляты и ругозовые кораллы, а также ассоциации водорослей. Карбонатные породы силурийского седиментационного бассейна Литвы создают прекрасную возможность проведения исследований благодаря обильному материалу керна из буровых скважин, который представляет карбонатную систему от мелко- до глубоководных седиментационных обстановок. Данные исследования в стратиграфическом отношении охватывают нижнюю часть пржидольского яруса силурийского седиментационного бассейна Литвы.

На основе классификации карбонатных пород Р. И. Данхама (Dunham, 1962) выделены основные микрофации: глинистые мергели, микриты (*mudstone*), брахиоподово-криноидные порфиры (*wackestone*), криноидно-брахиоподные узоры (*packstone*), криноидные зерна (*grainstone*), строматопорово-криноидные или кораллово-криноидные крупнопорфиры или крупноузоры (*float-rudstone*) и доломикриты (*dolomudstone*).

Вышеназванные микрофации распространены в расположенных параллельно седиментационных фациальных зонах (от береговой линии к морю), которые можно определить следующим образом: себха, внутренняя мелководная рампа, средняя рампа, внешняя рампа, нижний склон рампы – глубокая часть бассейна.