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CYCLICITY, LITHOFACIAL FEATURES AND SEDIMENTARY ENVIRONMENTS OF EIFELIAN DEPOSITS OF DOBRUDJA FOREDEEP

Purpose. Demonstration of the lithofacial structure and reconstruction of the sedimentation conditions of the Eifelian deposits of the Biloliskyy block of the Dobrudja foredeep in the aspect of the formation of productive horizons and the localization of perspective objects. **Methods.** The complex of lithological, paleo-oceanographic, lithophysica, and well logging explorations. **Results.** Five sedimentary cyclites of regressive nature, which are traced throughout the study area, were identified in the section of the Eifelian deposits of the Biloliskyy block of the Dobrudja foredeep. Cyclites have a two-membered structure: the lower part is represented by carbonate or terri-genous-carbonate rocks, the upper part is represented by marl- sulphate and sulphate (anhydrites). Characteristic changes in the content of the main lithological differences of cycles in space and time and the rhythmic nature of their sedimentation conditions have been determined. The sedimentation features of the development of biostromic bodies during the Eifelian age were reconstructed. The study localized the areas of their maximum development which tend to the slopes of the Skhidnosaratske and Zhovtoyarske uplifts. The features of the lithophysical structure of the Skhidnosaratske deposit are clarified. The main reservoirs (anticlinal and lithological types) of all the five identified productive horizons of the deposit were discovered to tend not to the modern arch of the structure, but to its south-western pericline. Based on the lithological and facial features of the region's Eifelian sediments, prospects for lithological-type traps within the southern, eastern, and northern slopes of the Zhovtoyarska structure are highly estimated. **Scientific novelty.** The construction of lithological, paleo-oceanographic, lithophysical models made it possible to determine the peculiarities of the spatial-temporal heterogeneity of the Eifelian deposits lithological structure of the Biloliskyy block of the Dobrudja foredeep and to correct the current estimation of their oil and gas prospects. **Practical significance.** The study of the features of the lithological structure of the strata, the creation of lithological, lithophysical, and paleo-oceanographic models will help to clarify the nature of the spatial-temporal development of sedimentary solids of various composition and genesis. All this will serve as a lithological basis for a more reasonable forecast of the distribution of oil and gas prospective objects.

Key words: lithologic structure, cyclicity, Eifelian deposits, Biloliskyy block, Dobrudja foredeep, oil and gas bearing.

Introduction

The Devonian deposits of the Dobrudja foredeep are one of the promising complexes of the Black Sea-Crimean oil and gas region. Thus, Skhidnosaratske and Zhovtoyarske oil deposits were discovered in the sul-phate-carbonate deposits of the Middle Devonian. In addition, insignificant oil inflows at the Biloliska and Saryyarska structures were obtained. Besides, the indu-strial gas inflow from the Lower Devonian terrigenous rocks in the borehole Zhovtoyarska-1 was found.

However, the Dobrudja foredeep remains the region studied the least by seismic exploration and drilling [Hozhyk, et al., 2007]. Certain points in stratigraphy, spatial-age distribution, and structural-material composition of Devonian deposits were considered in the works [Grishchenko, et al., 1986; Polukhtovich, et al., 1971; et al.].

On the other hand, sedimentary layers of the Devonian age are covered rather fragmentarily by complex lithological and facial studies. In this aspect, only the works by [Skachedub, 1998; Hnidets, 2003] can be mentioned. However, these works focus only on regional paleo-oceanographic aspects. Conducting detailed lithofacial and sedimentological studies is important because the lithological features and conditions of sedimentation control the structure, conditions of formation, placement, and quality of natural reservoirs and fluid cap rocks. This allows predicting the development sites of traps, including oil and gas bearing basins not covered by drilling.

In the Middle Devonian, the Dobrudja foredeep was located in the pre-equatorial zone on the northeastern end of Lavraziya, along which a number of carbonate platforms were formed with the development of carbonate-sulphate sediments in isolated lagoons [Garland, 1997]. According to [Skachedub, 1998], the Dobrudja basin was a shallow shelf which was bounded by a system of barrier reefs at the marginal part. This led to the widespread development of sulphate-carbonate sedimentation conditions. A characteristic feature of the deposits structure of the latter is the different rank cyclicity. It is revealed both in the recurrence of powerful packs (macrocycles) and in the thin interlayer of rocks (microcycles). Such a structure is characterized by sulfate-carbonate deposits of various ages, including the early Paleozoic [Schröder, Schreiber, Amthor, Matter, 2003]

As a rule, hydrocarbon traps (HC) in such deposits have a small capacity, a complex contour of wedging out or substitution [Obrovets, Yashin, 2018]. They are currently not detectable by field geophysics methods because they may be beyond their resolution. In this regard, the detailed study of the lithofacial composition and conditions of sediment accumulation (namely lithological criteria of the forecast) is a top priority in the process of forecasting prospective areas.

Purpose of work

To study the lithological structure, lithofacial features of deposits of individual cyclites of the Eifelian age of the Biloliskyy block of the Dobrudja foredeep and reconstruct the conditions of their accumulation in the aspect of the formation of productive horizons and the localization of oil-gas-prospective objects.

Method

Creating lithological models and the conditional reconstruction of sedimentation environments are further complicated by the uneven exploration of the territory. It was caused by the traditional orientation of geological exploration to search primarily for anticlinal structures and proper traps of HC. In this regard, the following points were considered in the course of the studies. Firstly, the research distinguished the structural scheme of the region [Skachedub, 1998] with a number of depressions and uplifts (Fig. 1), whose consedimentation character was confirmed by lithofacial data [Hnidets, Hryhorchuk, Polukhtovych, Fedyshyn, 2003; Hnidets, Hryhorchuk, Koshil, Yakovenko, 2018]. Secondly, the scientifically based ideas [Saraev, 2015; Strahov, 1962; Obrovets, & Yashin, 2018; Becker, & Bechstädt, 2006] on paleogeomorphological levelling of the basin bed during the regression (formation of sulphate formations in supralitoral conditions) made it possible to assume the sub-horizontal character of the bed part of the cyclites anhydrite (upper) parts. Therefore, the isopachyte schemes of their lower (terrigenous-carbonate) parts reflect the main features of the sedimentation basin bed relief. It was the focus that allowed us to outline the lithofacial zones in general terms and outline the contours of certain sedimentation conditions.

Cyclic structure

The Eifeelian deposits of the Dobrudja foredeep (Biloliskyy block) are composed of interbedded anhydrites, dolomites, limestone, mudstones, and sand-siltstone rocks that form cyclic sequences [Hnidets, et al., 2003; Hnidets, et al., 2016].

Five sedimentary cyclites of regressive nature (I–V from bottom to top) were identified in the section. They have a two-term structure and are regionally traced by a complex of lithological and geophysical data within the entire study territory (Fig. 2). Their lower part is represented by carbonate or a terrigenous-carbonate rock, the upper part is marl-sulphate and sulphate (anhydrites). In the upper parts of cyclites, the anhydrite content is 35–73.8 %, marls – 8.8–54 %; in the lower ones, 0–41.5 % and 0–36.2 %, respectively.

The quantity of carbonate rocks (limestone, dolomites) varies from 0 to 41.6 % (upper part) and from 12.3 to 85.8 % (lower).

These cyclites are characterized by certain spatial and temporal variations of both thickness and rock composition. Thus, the cyclite thickness varies from 17 m (II cyclite of borehole Balabanivska-1) to 200 m (I cyclite of borehole Saryyarska-1). In general, values of about 50–70 m predominate. The highest thickness is in the I, and the smallest is in the V cyclite.

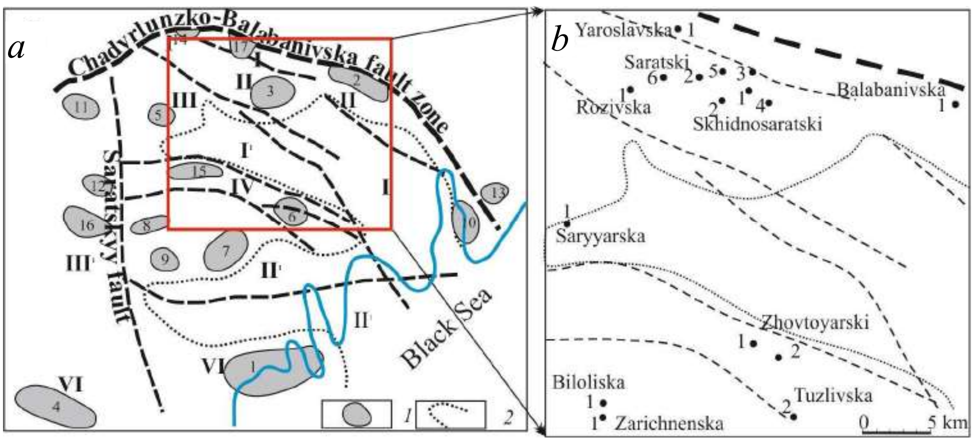

Fig. 1. Structural elements of the eastern part of the Dobrudja foredeep by [Skachedub, 1998]:

(a) (in the red rectangle – the study area) and the layout of the studied boreholes (b). *Anticlinical zones*: I – Rybalsko- Yaroslavska; II – Saratsko- Balabanivska; III – Grigorivska; IV – Saryyarsko- Zhovtoyarska; V – Kagylnytsko-Zarichnenska; VI – Hlybokynsko-Lymanska; *1 – local uplifts*: 1 – Lymanske; 2 – Balabanivske; 3 – Skhidnosaratske; 4 – Hlybokynske; 5 – Grigorivske: 6 – Zhovtoyarske; 7 – Zarichnenske; 8 – Kagylnitske; 9 – Kantemyrivskoe; 10 – Kurortne; 11 – Novoselivske; 12 – Pavlivske; 13 – Primorske; 14 – Rybalske; 15 – Saryyarske; 16 – Tatarbunarske; 17 – Yaroslavske; *2 – depressions*: I1 – Tuzlivska; II_1 – Alybeyska; III_1 – Tatarbunarska

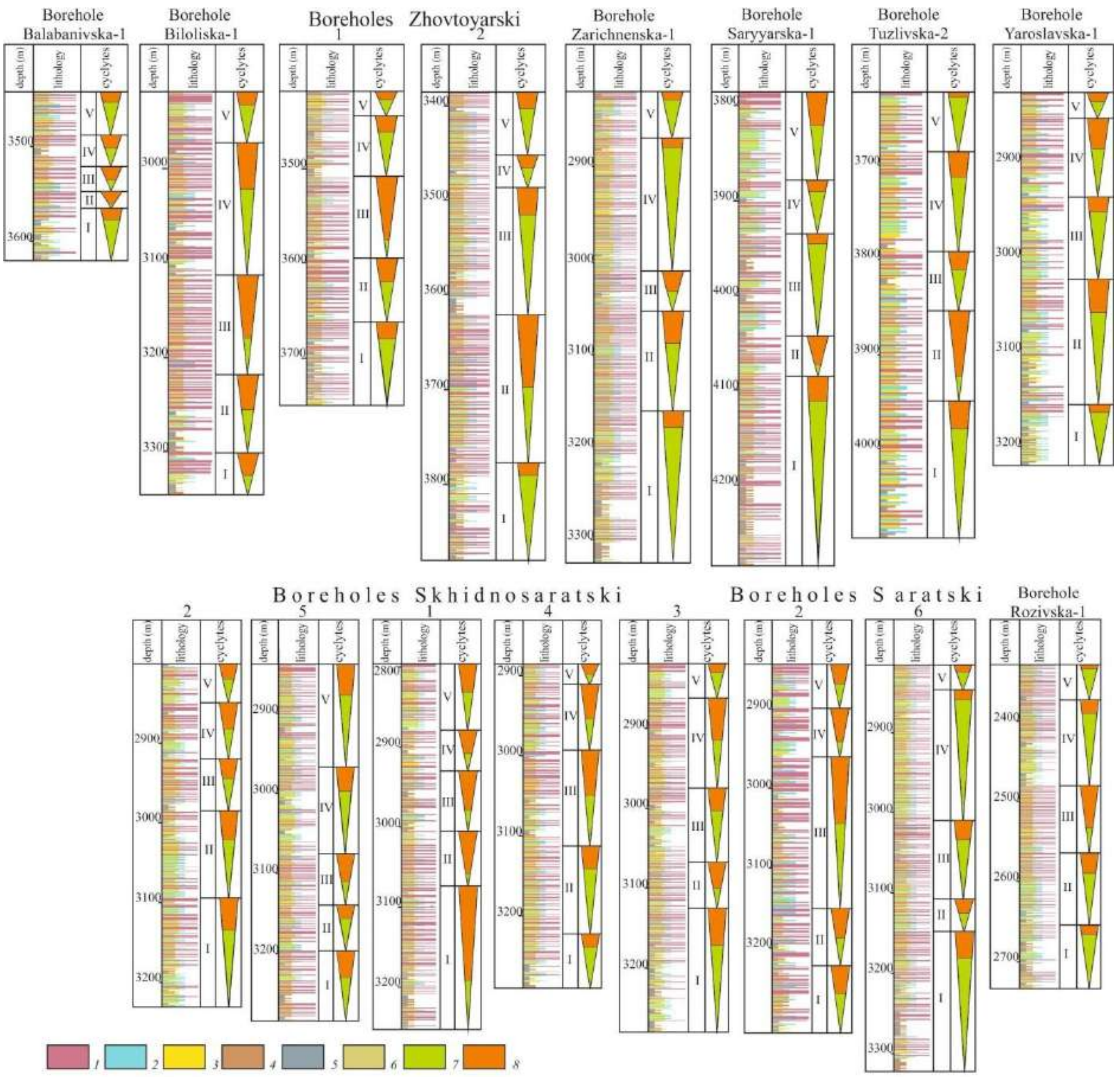

Fig. 2. Cyclites of the Eifelian deposits
Lithology: 1 – anhydrites; 2 – dolomites; 3 – limestones; 4 – marl; 5 – mudstones; 6 – sandstones, siltstones; cyclites: 7 – transgressive; 8 – regressive parts

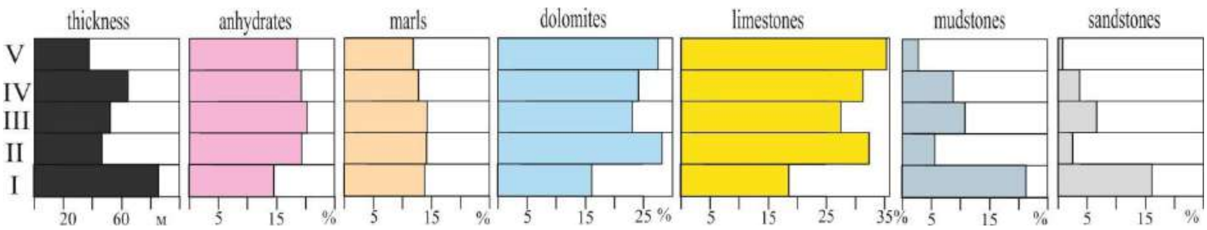

Fig. 3. Average rock contents in cyclites

The average values (for individual cyclites) (Fig. 3) of the thickness and rocks content, despite their lateral heterogeneity for each cyclite, reveal certain (cyclic) features of changes in the Eifelian deposits section. So, the average thickness decreases from I to II cyclite, then it increases to IV, and then decreases. Anhydrites and marls in the section are generally developed uniformly with some decrease from the bottom up. Carbonate (dolomites, limestones) and terrigenous (mudstones, siltstones, sandstones) rocks differ in the more complex nature of changes from I to V cyclites: the content of the first increases, the second decreases). There are some cyclic fluctuations which are also characterized by inverse correlation (the maximums of carbonate rocks content correspond to the minimums – terrigenous). All of the above is certainly related with regional changes of the sedimentation conditions over the Eifelian age.

Below, we consider the main lithological features of each cyclite.

The thickness of the I cyclite varies from 45 m (borehole Biloliska-1), 55 m (borehole Balabanivska-1) to 175 (borehole Saratska-6) and 200 m (borehole Saryyarska-1). The thickness of its upper part varies mainly from 8 to 47 m and only at borehole Skhidnosaratska-1 reaches 118 m. The lower part of the cycle has the thickness 21–174 m. In the regional context, the proportion of sulphate-marl part is rarely more than 20 % of the total thickness of the cyclite. And only at boreholes Biloliska-1 and Skhidnosaratska-1, this value is 53 and 71 %, respectively.

A characteristic feature of cyclite is a significant role in its lower part of terrigenous rocks (mudstones, siltstones, sandstones). The total content of the latter varies from 19.3 to 60.9 %. Moreover, the highest values of the parameter are observed at boreholes Saryyarska-1, Biloliska-1, Zarichnenska-1, and Balabanivska-1, the smallest values are at boreholes Skhidnosaratska-2, -5 and Tuzlivska-2.

It is typical that in boreholes with a maximum content of these lithotypes, they form mainly individual packs up to 10–14 m thickness (mudstones up to 4 m, sandstones and siltstones up to 1.5–2.5 m), alternating with horizons of carbonate rocks (up to 15–20 m), forming smaller cycles. At boreholes Yaroslavska-1 and Skhidnosaratska-2, a rather thin interlayer of terrigenous rocks and limestone is observed.

The sulphate element of cyclite is composed mainly of anhydrites and marls. In some cases, (boreholes Skhidnosaratski-2 and -4) individual packs of carbonate rocks (limestone, dolomites) up to 7–10 m thickness were recorded.

The second II cyclite differs from the first I by slightly smaller thickness which varies from 17 (borehole Balabanivska-1), 40 m (borehole Saratska-6) to 133 (borehole Yaroslavska-1), 155 m (borehole Zhovtoyarska-2). In addition, there is the increase in the role of sulphate-marl part as a whole, as well as its dominance (up to 52–81 %) in individual areas (boreholes Skhidnosaratska-1, -3; Saratska-2; Saryyarska-1; Tuzlivska-2, Balabanivska-1).

The development of terrigenous rocks in the composition of the cyclite is insignificant, which is recorded both by their local distribution (boreholes Biloliska-1, Saratska-2, Yaroslavska-1, Zhovtoyarska-1, -2), and a lower content in the section. Only at the first two boreholes their content exceeds 30 %, and only clay lithotypes are recorded in the Zhovtoyarska area. The thickness of terrigenous packs does not exceed 3–5 m. But layers of mudstones are also observed in the sulphate-marl part of cyclite at boreholes Saryyarska-1 and Zhovtoyarska-2.

The limestone-dolomite rocks in the upper part of cyclite are usually interbedded with anhydrites and marls, and in the lower part they form packs up to 20–23 m thick.

The thickness of the III cyclite varies from 27 m (borehole Balabanivska-1), 42 m (borehole Zarichnenska-1) to 135 (borehole Zhovtoyarska-2), 191 m (borehole Saratska-2). The thickness of its upper (anhydrite-marl) part varies from 15 to 83 m, the lower – from 12 to 108 m, which is generally correlated with the total capacity. There is a marked lateral irregularity (even within the same structure) of the role of the upper part of the cyclite (12–81 % of the total thickness). The maximum values are set at boreholes Skhidnosaratska-1, -4, -5; Biloliska-1, Zhovtoyarska -1; the minimum – in boreholes Zhovtoyarska -2, Yaroslavska-1, Skhidnosaratska -3, Saryyarska-1, Saratska-6, Tuzlivska-2. Similarly, to I, the lower part of III cyclite contains a rather significant number of mudstones, sandstones and siltstones (packs up to 12–16 m thickness). Most of them (over 25–30 %) were identified in the section of boreholes Skhidnosaratski-1, -3, -4; Saryyarska-1, Zhovtoyarski-1, -2. In some cases, these lithotypes (up to 5–15 %) were also recorded in the sulphate-marl part of cyclites (boreholes Saratski-2, -6; Saryyarska-1, Zhovtoyarska-1, Skhidnosaratski-1, -3) where they form packs not more than 2–5 m thickness.

Carbonate rocks (limestone, dolomites) are distributed in the upper part of cyclite in the form of layers (up to 2–5 m), and in the lower part, there are packs up to 12–15 m thick.

The thickness of IV cyclite varies over a wide range: from 34 m (borehole Balabanivska-1), 55 m (borehole Saryyarska-1) to 140, and 163 m (boreholes Biloliska-1 and Saratska-6, respectively). The role of the sulphate-marl part is less in comparison with II and III cyclites. Its thickness usually does not exceed 20–30 m, and its content (of the total thickness) is 30 %. Only locally, this index is more than 50 % (boreholes Saratska-2, Skhidnosaratski-1 and -4). The thickness of the lower part of the cyclite varies from 19 to 151 m, which, in contrast to the upper, is consistent with the total thickness of the cyclites.

Mudstones, siltstones,and sandstones were identified in both upper and lower parts of the cyclite in almost all studied boreholes. Furthermore, both clay and clastogenic lithotypes are in the lower part of the cyclite, the maximum number of which is observed at boreholes Balabanivska-1 and Zhovtoyarska -1 (sandstones with siltstones – 10; 19.4 %, mudstones – 17.0; 26.1 %, respectively) where they form packs up to 7–10 m thick (in other boreholes – up to 2– m). Mainly mudstones which do not form packs (separate layers) are distributed in the anhydrite-marl part of the cyclite. On the other hand, sand-siltstones formations (packs up to 3–5 m thickness) are also recorded at boreholes Skhidnosaratski-1 and -3 .

Carbonate rocks (limestone and dolomites) in the lower part of cyclite are maximally developed at boreholes Saratska-2, Skhidnosaratska-4, -5, Tuzlivska-2, Zarichnenska-1, Saryyarska-1 (total content

55.8–85.8 %) where packs up to 12–20 m thick are formed. Carbonate lithotypes are interbedded with anhydrites and marls at the top.

V cyclite is generally characterized by the lowest thickness and low content of clay and terrigenous rocks. So, its thickness usually does not exceed 40–60 m and only at boreholes Skhidnosaratski-1 and -5 it reaches values of 84; 128 m respectively. The content of the anhydrite-marl part is predominantly 10–20 % of the total thickness; only at boreholes Skhidnosaratski-1 and -4 this index exceeds 40–50 %. The number of terrigenous-clay rocks is mainly 5–10 % and they are not everywhere. The content of these lithotypes is increased only at boreholes Zarichnenska-1 and Skhidnosaratska-2 (more than 20 % in the latter). A predominance of clay rocks (average content of mudstone – 6.9 %; sandstone and siltstone – 2.2 %) is characteristic. Moreover, their significant role is fixed in the upper part of the cyclite where the number of mudstones reaches 17.9 % (borehole Skhidnosaratska-2).

Carbonate rocks (limestone, dolomites) form packs in the lower part of cyclite, usually up to 5–9 m thick, only at boreholes Tuzlivska-2 and Saryyarska-1, this index is 12 and 22 m, respectively.

Lithofacies

According to [Botvinkina, 1991], it is appropriate for cyclically constructed strata to create sedimentation maps for individual cyclites or their parts, which should be preceded by lithofacial studies.

The rock composition of individual parts of the cyclites of the Eifelian deposits is characterized by a certain variability. In order to reveal the lithological features of individual cyclites (and their parts), the appropriate schemes of the distribution of individual lithotypes within the Biloliskyy block have been constructed. This is the basis for further reconstruction of the sedimentation conditions. Such schemes are made for lower (transgressive) parts cyclites, since the trial model of the upper part of the I cyclite for the dominance of anhydrites and marls in the section (total content up to 90 %) showed a rather uniform picture. The latter reflects a maximum regression with equalization of sedimentation conditions (sebkha environment [Wilson, 1980; Hnidets, et al., 2003].

The thickness of deposits of the lower part of the *I cyclite* varies from 21 to 174 m (Fig. 4). At the same time two depocenters stand out. They are quite clearly compared with the Tuzlivska and Alibeyska depressions, whose localization was argued by [Skachedub, 1998].

The lower part of the *I cyclite* is characterized by considerable development in its composition along with limestone, dolomites and anhydrites of sandy-siltstone and clay rocks. The content of clastic formations in the section varies from 9.3 to 28.8 %, and clay formations – from 10.7 to 39.5 % (see Fig. 2, 3). Enrichment with terrigenous-clay material is observed in the western part of the Biloliskyy block, which suggests that there are certain denudation areas beyond the Saratskyy fault. The minimum contents of terrigenous-clay formations tend to the arch parts of the Shkidnosaratska and Zhovtoyarska structures.

The anhydrite content is 0–26.7 %, values of the order of 10–15 % prevail. The maximum number of sulphate rocks was recorded in the arches of the Skhidnosaratska and Zhovtoyarska structures. Increased numbers of carbonate (limestone, dolomite) rocks are confined to the slopes of the latter (the total content reaches 55–58.6 %).

The increase in the content of marls in the section is observed in the depocenter of the Tuzlivska depression (25–30 %). In addition, the maximum values of the parameter (up to 36.2 %) are indicated in the arches of the Skhidnosaratska structure.

The characteristic features of the sulphate-marl pack of the I cyclite include its anomalously high thickness on the Skhidnosaratska structure (118 m at borehole 1) and the presence of limestone-dolomite bodies on its slopes. The latter inherits to some extent the features of the distribution of such formations in the cyclite lower part.

The distribution of isopachytes of the lower part of the *II cyclites* is slightly different from the previous one. It is reflected in a change of configuration, narrowing, and displacement in the north direction of the Tuzlivskyy depocenter (sediment thickness is more than 80 m). In turn, Alibeyskyy depocenter shifted to the south. Obviously, this may be due to the expansion of the Saryyarsko-Zhovtoyarskyy uplift, where the minimum thickness is observed (see Fig. 4).

The increased content of sulphate rocks (26.4–31.8 %, with background values of 15–20 %) tend to the Skhidnosaratska, Zhovtoyarska, and Zarichnenska structures. These areas are bordered by areas of significant development in the section of limestone and dolomites (total content exceeds 80 %). The marls tend to the Saryyarsko-Zhovtoyarska and Skhidnosaratska areas. Clastogenic and clayey rocks are locally developed in the northern and south-western parts of the territory, forming elongated maximum (boreholes Saratska-2 and Biloliska-1).

The thickness of the deposits of the lower part of the III cyclite varies from 12 to 108 m. The maximum value field is located in the axial part of the Tuzlivska depression. The minimum thickness is noted at boreholes Balabanivska-1 and Zarichnenska-1. This picture is in some way similar to the nature of the isopachyte distribution of the *I cyclite.*

The highest content of anhydrites was noted in two areas. The first is in the region of minimal capacities (borehole Biloliska-1), the second area tends to a local depression (borehole Saratska-2). A similar distribution pattern is also characteristic of marls with local maximum in the regions of boreholes Skhidnosaratska-5, Rozivska-1, Biloliska-1. In the axial part of the depression, there is a minimal (less than 20 %) content of limestone and dolomite, which increases in the northern and southern directions (up to 60–85 %). Terrigenous rocks of maximum development are acquired in the areas of boreholes Skhidnosaratska-1 and Zhovtoyarski-1, -2.

The pattern of isopachyte distribution of the lower part of the *IV cyclitis* is in some way similar to the *II*: the depocenter in the axial zone of the Tuzlivska depression and fragments of the Alibeyska slope in the south. Although, the former has a saddle with the formation of a local northern depression (the region of borehole Saratska-6)where the thickness reaches 151 m.

Increased numbers (more than 25 %) in the section of sulphate rocks generally tend to areas with a minimum thickness of deposits.

The maximums of the development of carbonate rocks (limestones, dolomites) are generally observed on the northern slopes of both the Tuzlivska and Alibeyska depressions (the total content over 35–40 %). The marls are characterized by a uniform development within the territory (10–20 %) with several local lows (6–9.5 %) compared to other cyclites. The area of increased content in the terrigenous rocks section (sandstones and siltstones 10–19.4 %; mudstones 26.1–27.7 %) is observed in the form of an elongated strip that extends from borehole Balabanivska-1 to borehole Zhovtoyarska-1. Actually, a minimal role in the limestone and dolomites section is noted in this area.

The thickness of deposits of the lower part of the *V cyclite* vary from 13 to 90 m. In general, the configuration of the region of increased values covers the Tuzlivska and Alibeyska depressions. A local maximum of thickness is observed in the region of boreholes Skhidnosaratski-1 and 5.

The content of sulphate rocks is mainly 20–30 %, it locally (borehole Rozivska-1) makes 31.3 %. The number of anhydrites in the section is slightly reduced (10–20 %) and is observed in the area strip: Yaros-lavska-Saratska-Saryyarska and borehole Skhidno-saratska-3. Limestone form several maximums (40–43.2 %). The first borders on the arch part of the Skhidnosaratska structure from the west, south and east; the other two are located on the northern and southern slopes of the Zhovtoyarska structure. The increased role of dolomites (over 35 %), like limestone, is observed along the periphery of the Skhidnosaratska structure and at borehole Saryyarska-1. Their minimum value (up to 20 %) was recorded at boreholes Rozivska-1 and Zhovtoyarska-1. Interestingly, in the latter case, the "dolomite" minimum spatially corresponds to the "limestone" maximum. Marls are characterized by the regional background (10–20 %) content with a local area (Rozivsko-Yaroslavska) of elevated (20–30 %) values, and several with the content (0–8.9 %): regions of boreholes Saratska-2, -6; Skhidnosaratski-1, -4; Zarichnenska-1, and Tuzlivska-1. The role of terrigenous rocks in V cyclites is insignificant (sandstones up to 4.1 %; mudstones mainly 0–10 %).

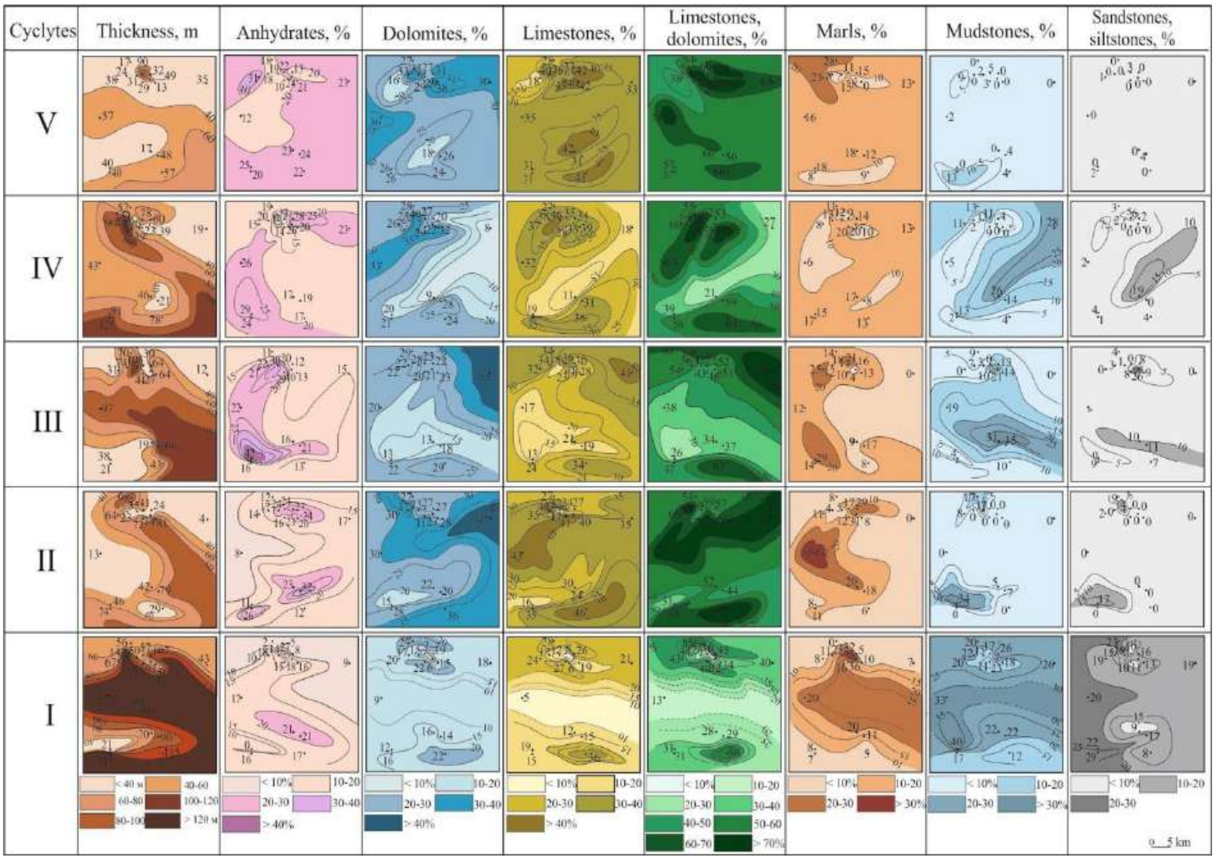

Fig. 4. Lithofacial schemes of cyclites of the Eifelian deposits

Sedimentary environments

Determining the conditions for the formation of sulphate-carbonate deposits is important for predicting the prospects for their oil and gas potential, since it makes possible to determine the spatial and time features of the development of carbonate formations and sulphate horizons. The former appear to be natural reservoirs in the known oil and gas basins [Hnidets, et al., 2003, Konyukhov, 2013]. And the latter play the role of fluid cap rocks. A characteristic feature of sulphate-carbonate strata is the cyclical section structure which reflects a certain frequency of sea level changes. In this case, sulphate formations reflect the regressive, and carbonate formations reflect the transgressive stages of the development of the sedimentation basin. Fig. 5 shows the characteristic features of the cyclicity of the Eifelian deposits of the Biloliskyy block of the Dobrudja foredeep. That indicates the variability of sedimentation conditions during the Eifelian age. There are six types of the latter. However, as is obvious, each of them is not connected with a certain area. Even within the same structure in different boreholes, a variety of sediment cycles is observed. This indicates the complex nature of the interaction of the sea level changes and structural deformations and, accordingly, the consediment character of the latter.

The first type of cyclicity is generally characterized by an increase in regression from the beginning to the end of the Eifelian age. In this case, if a certain correlation between the role of sulphate and carbonate formations is recorded at borehole Skhidnosaratska-2 (the increase of the content of the former corresponds to the decrease of the content of the latter), then there is no such connection at borehole -4.

The second-fifth types differ in the more complicated character of the cycle section. In the second type, the regression maxima is associated with II and IV, in the third – with II and V, in the fourth – with III, in the fifth – with III and V cyclites. In most cases, the inverse ratios of the contents of sulphate and carbonate formations are observed.

The sixth type of cyclicity is characterized by the growth of transgressive tendencies from the beginning to the end of the Eifelian age. There is also the increase in the role of carbonate rocks with a decrease in sulphate rocks.

With the general features of the second to sixth types, it should be noted the absence of limestone dolomite packs in a number of cyclites. This is most manifested at borehole Biloliska-1, Zhovtoyarska-1, Balabanivska-1. In addition, there is no correlation between the number of carbonate horizons and the sedimentation cyclicity.

Sedimentation conditions were modelled for the lower parts of each cyclite (Fig. 6) They were based on lithofacial constructions, features of the lithological structure of sections, taking into account the well-known models of shelf sulphate-carbonate accumulation [Reding, et al., 1990; Taninskaja, 2010].

There are three main facies zones: 1) supralittoral, littoral; 2) upper sublittoral; 3) lower sublittoral [Becker, Bechstädt, 2006; Ocakoğlu, 2001]. The first zone is represented by the formations of the sabkha, lagoons, coastal and inflow plains. The deposits of these environments are composed of clay-carbonate, sulphate-carbonate, sulphate, carbonate, and sometimes terrigenous-clay formations. In the sublittoral zone, the role of sulphate rocks decreases, and the role of carbonate, especially limestone increases. In particular, the development of biogenic structures (bioherms, biostromes) is characteristic of the upper sublittoral.

Within the studied territory, due to its uneven boring, the contours of the sedimentation zones are significantly predictable (primarily, the lower sublittoral). Despite the emphasis [Taninskaja, 2010] on the insignificant role of sulphate formations in the sublittoral deposits, in our opinion, they may contain the latter. This is due to the fact that in plate-water slightly inclined environments by storm and wave-breaking processes, the small-grained material of carbonate-sulphate composition was mobilized at the highest hypsometric level of the basin (littoral, supralittoral) and discharged into a deeper subbasin zone (semi-isolated gulf).

In the following description, we will focus on the features of the development in the lower parts of cyclites of carbonate accumulating bodies, which are of interest as potential reservoir rocks. According to the features of their development in section, according to [Makhnach, et al., 1984], these formations can be attributed to the type of "multi-story biostroms".

The latter are localized quite confidently. That was confirmed by their opening at boreholes, as well as by prediction based on the development of high-sulphate sediments in adjacent littoral areas, the formation of which was caused by isolation from a more open sub-basin. These deposits are composed of carbonate packs (limestone, dolomites). In the rocks, there are biogenic residues in the amount of the first percentages up to 50–70 %, which are represented by fragments of shells of foraminifera, ostracods, pelecipods, brachiopods and char algae. The latter, due to the secondary processes of micritization and recrystallization, acquire the features of an organogenic-detrital, clot-lumpy texture. The interformed space is filled with pelitomorphic calcite which in some places is recrystallized with the formation of a micro-fine-grained structure. Recrystallization processes sometimes capture biogenic residues: secondary calcite fills foraminifera shells. The rocks in many cases are dolomitized and anhydritized in scattered and spotted forms. The content of new formations is 15–25 %, in some cases, up to 40–60 % or more with the formation of transitional varieties of calcareous anhydrite dolomites. Anhydrites are often registered in these packs, according to the well logging features However, their parasteresis and value, subordinate to carbonate rocks, make it possible to consider them as strongly anhydratizated limestones and dolomites and, therefore , include them in the volume of the organogenic body.

During the formation of the *I cyclite* (see Fig. 6), the supralittoral and littoral zones covered the Bilolisko-Zhovtoyarska and the Saratsko-Balabanivska areas. The formation of the lower sublittoral zone tended to the Tuzlivska and Alibeyska depressions. These facies environments were delimited by the upper sublittoral zone, within which a number of carbonate biogenic structures were localized. The largest of themborders on the Bilolisko-Zhovtoyarska uplift area in the south, east, and north. Bioherm (biostrome) formations are disclosed by boreholes Zarichnenska-1 and Tuzlivska-2. They are composed of three carbonate packs with a total thickness of 75–79 m which are delimited by terrigenous-clay horizons. The continuation of the organogenic body to the east and north is predicted, taking into account the increased content of anhydrites in the Zhovtoyarska area where a shallow saline lagoon supposedly existed.

Two biogenic bodies tend to the area of Saratska and Skhidnosaratska structures. The first is revealed in borehole Rozivska-1 and is composed of two carbonate packs with a total thickness of 20 m. The second one borders on Skhidnosaratska structure in the south and east and is fixed at boreholes -2, -3 and -4. At borehole -2 it is a pack of mainly limestone-dolomitic rocks with a thickness of about 36 m; at boreholes -3 and -4 the biostrom body is represented by three packs with a total thickness of 18 and 35 m, respectively. This organogenic body apparently caused the formation of an isolated lagoon in the arch part of the Skhidnosaratska structure where sulphate formations were deposited. Considering the features of the distribution of clay and sand-siltstone rock (see Fig. 3), the main sources of supply were located in the west and north. The clastic material discharged by the Saratskyy, Saryyarskyy, and Zarichnenskyy, flows to the Tuzlivska and Alibeyska depression zones.

The configuration of the sedimentation basin during the formation of *II cyclite* changed slightly. This was manifested in the increase in the area of the supralittoral-littoral zones which extended to the region of the Saryyarska structure. This caused a narrowing of the sublittoral sedimentation area in the Tuzlivska depression. But the biostromic formations tended to the same areas as before. At the same time, the southern structure as a whole retained its spatial position. Though, its maximum has shifted towards borehole Zarichnenska-1 (three packs with a total thickness of 75 m, while at borehole Tuzlivska-2 – one pack – 18 m.). The northern structure expanded in the northwest direction (see Fig. 6). At the same time, its thickness increased significantly (up to 57–69 m at borehole Skhidnosaratski-2 and -4). Sulphate formations of isolated lagoons were deposited at borehole Saratski-2, -6, Skhidnosaratska-5 regions and Bilolisko-Zhovtoyarska area. Two directions of terrigenous flows (Saratskyy and Zarichnenskyy) have been preserved.

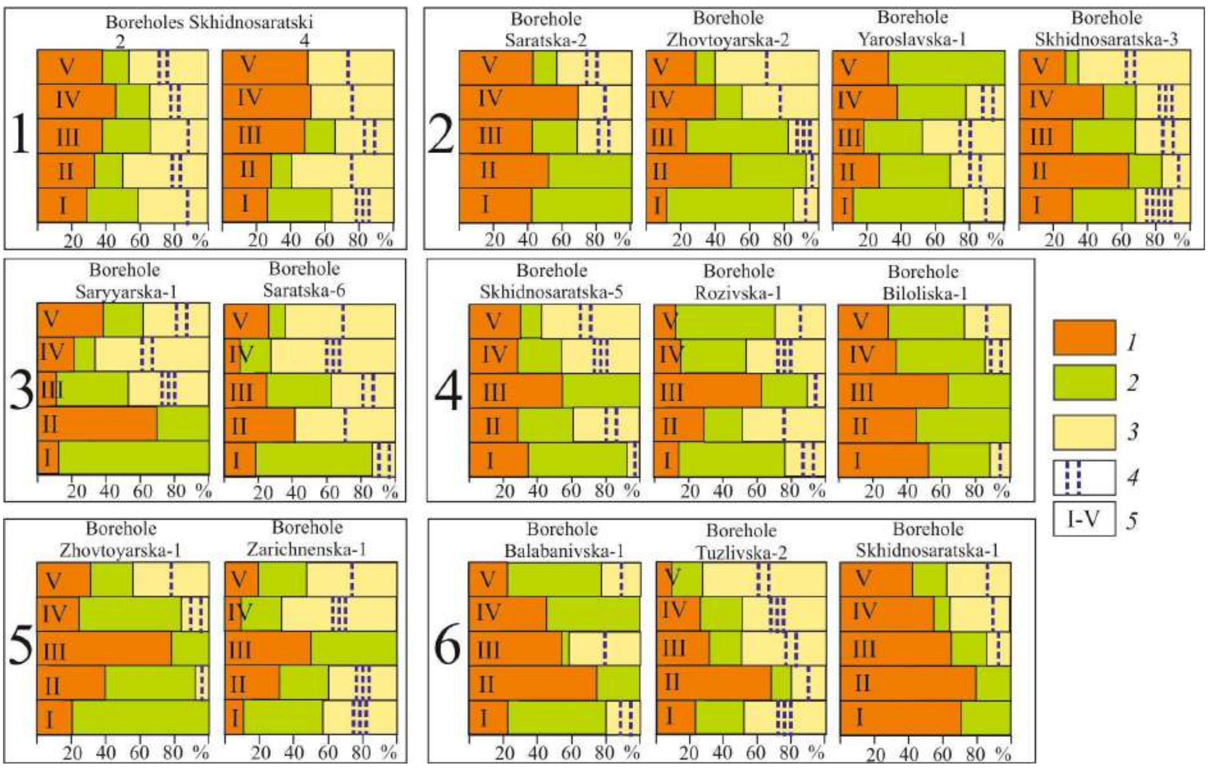

Fig. 5. Types of cyclicity of the Eifelian deposits:

Elements of cyclites: 1 – marl-sulphate; terrigenous-carbonate: 2 – terrigenous rocks, marls, anhydrites; 3 – carbonate (dolomite-limestone) rocks; 4 – number of limestone-dolomite packs; 5 – cyclites

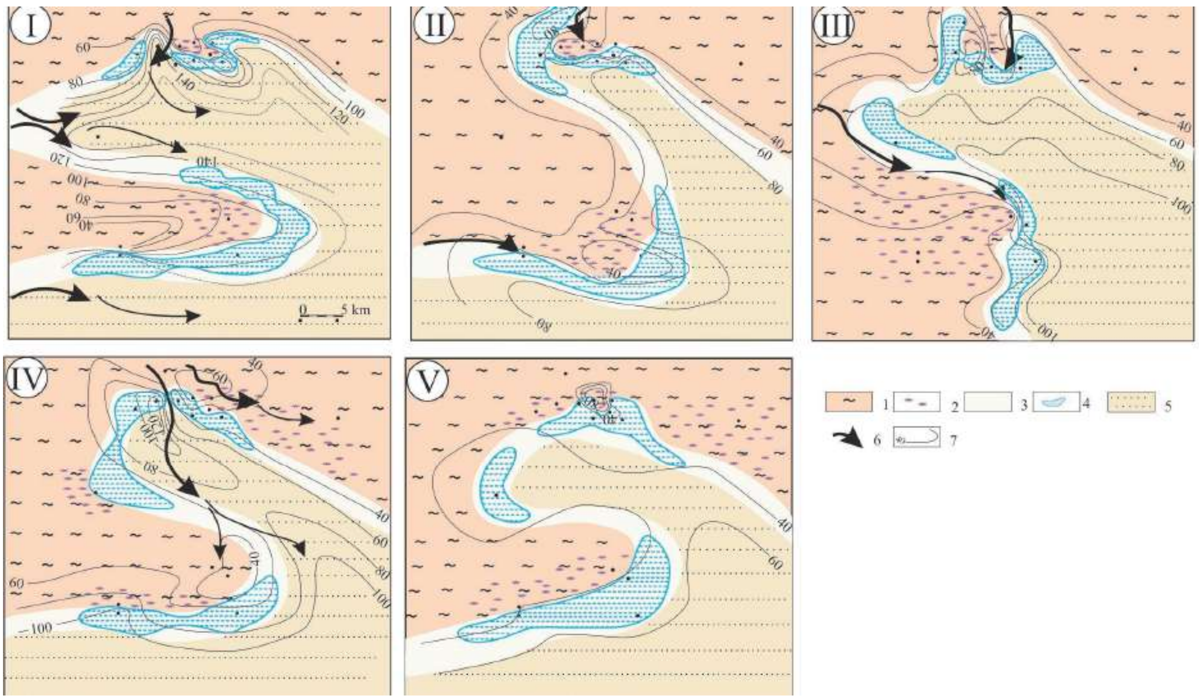

Fig. 6. Sedimentary environments of the Eifelian deposits cyclites the Biloliskyy block of the Dobrudja foredeep:

1 – supralittoral, littoral; 2 – isolated lagoon; 3 – upper sublittoral; 4 – biogenic bodies (biostromes); 5 – lower sublittoral; 6 – terrigenous flows; 7 – isopachitis

The character of the development of the III cyclite sedimentation conditions has changed significantly, compared with the previous ones. This was primarily due to the extension of the supralittoral-littoral facies zones in a southerly direction (Biloliska, Zarichnenska areas). At the same time, the area of sublittoral sedimentation in the Tuzlivska depression increased and acquired contours similar to the *I cyclites*. In this regard, the features of the spatial development of biogenic structures (especially in the southern part of the territory) have changed. The southern construction acquired the submeridional extension and covered the Tuzlivska and eastern periclines of the Zhovtoyarska structures (borehole 2) where the total thickness of carbonate packs is 24 and 32 m, respectively. The biostromic body is fixed at borehole Saryyarska-1 (three packs: 12, 13, and 26 m). These biogenic formations contributed to the formation of an isolated lagoon in the area of boreholes Zhovtoyarska-1, Biloliska-1, Zarichnenska-1 where the anhydrite content in the section reaches 41.5 %, with background values less than 20 %. The Saratska and Skhidnosaratska areas are characterized by the inherited character of the development of the organogenic body which bordered on the arch part of the structure in the west, south and east, where the isolated lagoon existed. It is composed mainly of two carbonate packs, the maximum total thickness of which is determined at boreholes Yaroslavska-1 Saratska-2, Skhidnosaratska-4 (42, 59 and 43 m, respectively). Significant development in the section of boreholes Zhovtoyarska-2 and Skhidnosaratska-1 terrigenic-clay formations (40.5 and 46.3 %) indicates the existence of the Saratskyy and Saryyarskyy directions of terrigenous flows.

The configuration of facial zones during the accumulation of *IV and V cyclites* generally coincided. The lower sublittoral zone covered the Tuzivska and Alibeyska depressions. The biostromic formations of the upper sublittoral area were localized in the Zarichnensko-Tuzlivska, Saryyarska, and Saratsko-Skhidnosaratska areas. At the same time, the thickest biostrom body is observed in the first section where it is composed of three limestone-dolomite packs with a total thickness of 52–95 m. The terrigenous discharge in the *IV cyclite* was provided by the Saratskyy flows, and in the *V cyclite* clastic material practically did not enter the basin.

Cyclicity of the Eifelian deposits and the structure of the reservoirs of the Skhidnosaratske deposit

As noted above, the territory of the Biloliskyy block is drilled extremely unevenly. In this regard, the Sarasko-Skhidnosaratska area is studied the most.

This made it possible to consider in detail the peculiarities of the Eifelian deposits composition of the Skhidnosaratska structure in the aspect of their cyclic nature and its importance in the formation of the morphostructure of the reservoirs of the same named oil deposit.

The total content of anhydrites and marls in the upper parts of 5 selected cyclites is 66–83 %, in the lower – 27–39 %; limestone and dolomites – 16–38 % and 44–61 %, respectively. The thickness of cyclites varies from 25 m (the V cyclite of borehole Skhidno-saratska-4) to 179 m (the I cyclite of borehole Skhidno-saratska-1). In general, the value of about 50–60 m prevails.

The same is applied to the thickness of the upper and lower parts of cyclites. So, the thickness of the sulphate part varies from 15–17 m to 54–118 m. The latter is inherent to borehole Skhidnosaratska-1 in which the total content of anhydrite-marl parts reaches 62 % of the total thickness of the section (against the background of 30–35 % in the remaining boreholes of the Skhidnosaratska structure). The thickness of the lower part is 12–107 m. The maximum values are at boreholes Skhidnosaratska-3 and 2 (up to 70 % of the total thickness of the section).

Rock composition of some parts of cyclites is changeable in some way. Thus, I cyclite is characterized by a significant development in its lower part, along with limestones and dolomites, of sand-siltstone and clay rocks, the content of which varies from 27 % (borehole 5) to 44 % (borehole 3). Layers of terrigenous rocks are also observed in the III cyclite, whose content is 17–46 % (boreholes -2 and -1, respectively). The amount of limestone and dolomites varies both laterally and in the section. Separate horizons of carbonate rocks have been developed in the sulphate parts of cyclites, the content of which can reach 20–35 %. Anhydrites, in turn, are observed in the lower parts of cyclites (content from 10 to 52 %). This character of rock distribution causes the formation of smaller cyclicity deposits. For example, such cyclites were selected in the I cyclite, from 5 (borehole 4) to 10 (boreholes 1, -2).

From an oil-geological point of view, anhydrite-marl parts of cyclites are considered as cap rocks and carbonate or terrigenous-carbonate are considered as reservoirs.

In this regard, the distribution of reservoirs and their internal structure are determined by sedimentation cyclicity. The sequence of stratification of rocks of different composition – limestones, dolomites, marls, and anhydrites – determines the confinement of reservoirs and cap rocks to certain parts of the cyclite. The variability of the thickness and composition of individual parts of cyclites complicates the structure of the reservoirs. So far, two productive packs $D_{2\text{-}1}$ and $D_{2\text{-}2}$ have been identified in the Eifelian deposits of the Biloliskyy block, the thickness of which in different boreholes is 103–183 m [Ivanyuta, et al., 1998]. Obviously, it exceeds the thickness of the identified cyclites, which in our opinion, actually represent productive horizons, composed of screening and collector parts. A comparison of these units showed that these productive packs either include several horizons or irregularly cross cap rocks (anhydrite-marl layers).

In our opinion, the hypsometry of the bed of the latter determines the morphostructural features of traps and reservoirs of hydrocarbons of the Skhidno-saratske deposit. These features (for each of the whole of five cyclites) differ from the structural plans for the beds and tops of the Eifelian deposits. According to the latter, the arch tends to borehole Skhidnosaratska-1 which formed the basis for prospecting and exploration, and oilfield research. Instead, our constructions (sections of boreholes 5–1–4 and 2–1–3) showed that the reservoirs of each cyclite are characterized by specific features (Fig. 7).

Thus, two arch type reservoirs were discovered in the I cyclite. The first reservoir tends to borehole 2, the second one tends to borehole 3 which are delimited by a saddle (borehole 1). According to the structural plan of the bed of marl-sulphate fluid cap rocks, the height of the first reservoir is about 30 m, and the second one is about 20 m. The thickness of the collector horizon (limestones, dolomites) does not exceed 9–11 m. Below the section there are several more collector packs (two at borehole 2-11 and 35 m, four at borehole 3 – 10–15 m) which are delimited by terrigenous-carbonate-sulphate layers (5–30 m) that can play the role of cap rocks. Moreover, if at borehole 2 these possible reservoirs (traps) are anticlined, then at borehole 3, they are lithological (due to wedging of limestone-marl horizons in the direction to borehole 1).

In the II cyclite, the main reservoir of the anticlined type tends to borehole 2 (with some elongation the direction to borehole 1). It is composed of a thick (up to 40 m) horizon of limestones and dolomites which are screened by a sulphate-marl, pack (35 m). The possible height of the trap is about 35 m. In the lower part of the cyclite there is a horizon of carbonate rocks which is wedged out in the direction to borehole 1. The similar picture is characteristic in the area of the boreholes 3, 4, 5, which suggests the possibility of the existence of lithological traps here.

In the III cycle, the apical part of the anticlined trap is also located in the area of the borehole 2. The trap is sloped and locked near the borehole 1. The height of the reservoir is about 35 m. It is composed of two horizons of carbonate reservoirs with a thickness of 8–12 m. Lithological traps are predicted to develop between Boreholes 3 and -1, due to wedging of the limestone-dolomite packs.

To a certain extent, the morphostructure of the IV cyclite reservoir is similar to the previous one. The height of the main reservoir (area of borehole 2) is about 25 m. However, here the horizon of reservoir rocks (10 m) is developed only in its lower part. Lithological wedging traps are predicted between boreholes 3 and 1, and -1 and -2.

The reservoir of V cyclite covers a relatively large area, extending from borehole 2 to borehole 3. Its height is about 25 m. The horizon of carbonate reservoir rocks (9–11 m) lies directly below the anhydrite-marl cap rock. At borehole 1, the lens-shaped limestone-dolomite reservoir is developed, but more likely that it is below the probable water-oil contact.

Thus, determining the cyclic structure of the Eifelian deposits made it possible to elucidate the features of the lithophysical structure (development in the section of reservoir and cap rocks) of the Skhidnosaratske deposit (Fig. 8). In contrast to the previously identified two productive packs with a thickness of 103–183 m, 5 productive horizons are localized. Hypsometry of the beds of anhydrite-dolomite packs of cyclites determined the main features of the morphology and structure of the reservoirs of the Skhidnosaratske deposit. The main reservoirs (anticlinal and lithological traps) of all the five identified productive horizons tend to the borehole 2. The borehole 1, which is located in the arch of the structure along the top and bed of the Eifelian deposits, in most cases, discovered only the periphery of these reservoirs.

The southern part of the inherited development of biostromes (Tuzlivska, Zhovtoyarska areas) has considerable interest. Previous studies [Hnidets et al., 2018] established a wedging out in the lower part of the Eifelian deposits (in fact, the I cyclite) of limestone-dolomite (collector) horizons in the direction of boreholes Tuzlivska-2-Zhovtoyarska-2-Zhovtoyarska-1, which allowed predicting the formation of lithological traps on the southern slope of the Zhovtoyarska structure. The completed constructions (see Fig. 6) showed that similar traps could be formed on the eastern and northern slopes.

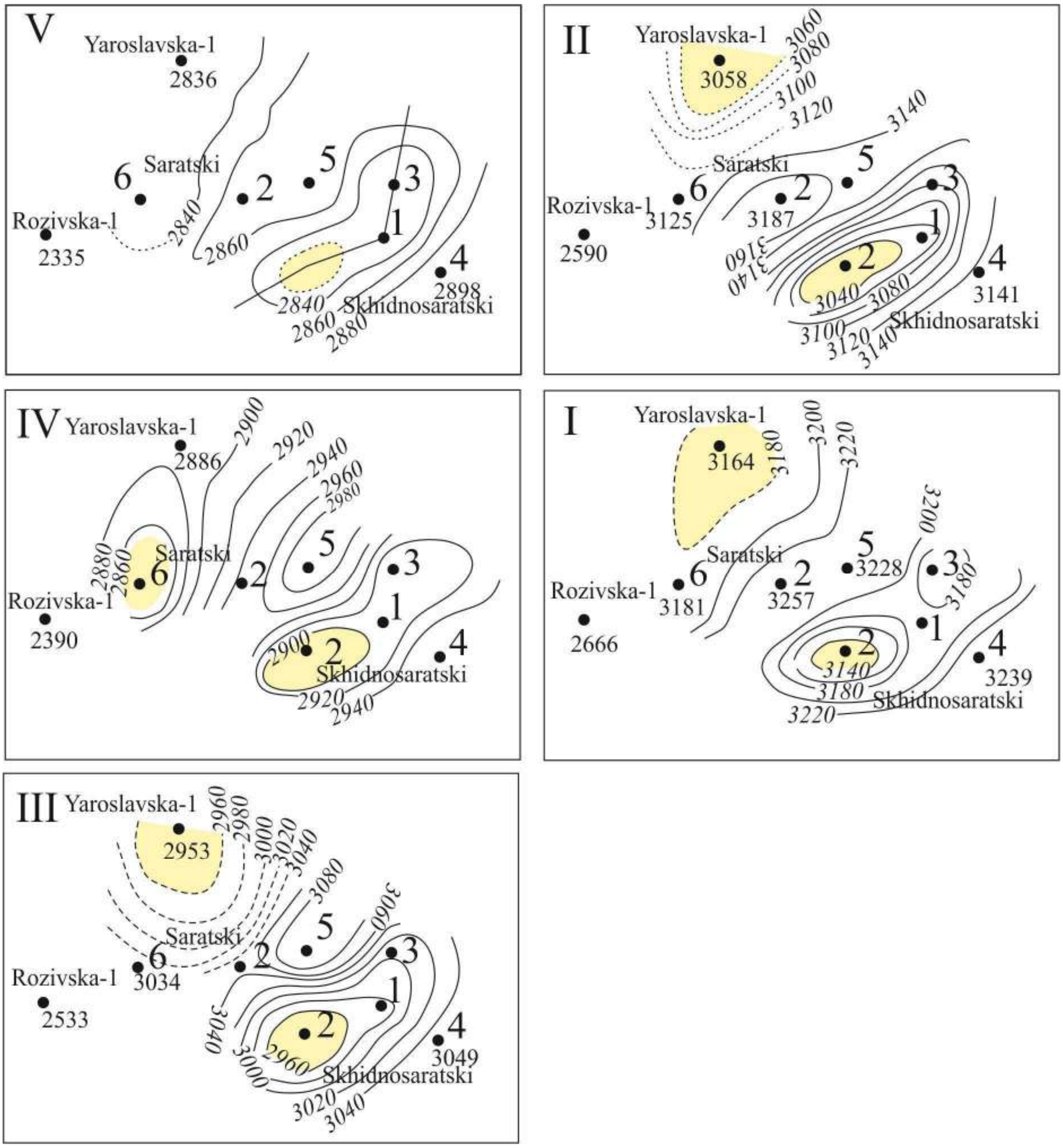

Fig. 7. Hypsometry of the anhydrite-marl horizons bed of the cyclites (I–V) of the Eifelian deposits of the Skhidnosaratske deposit

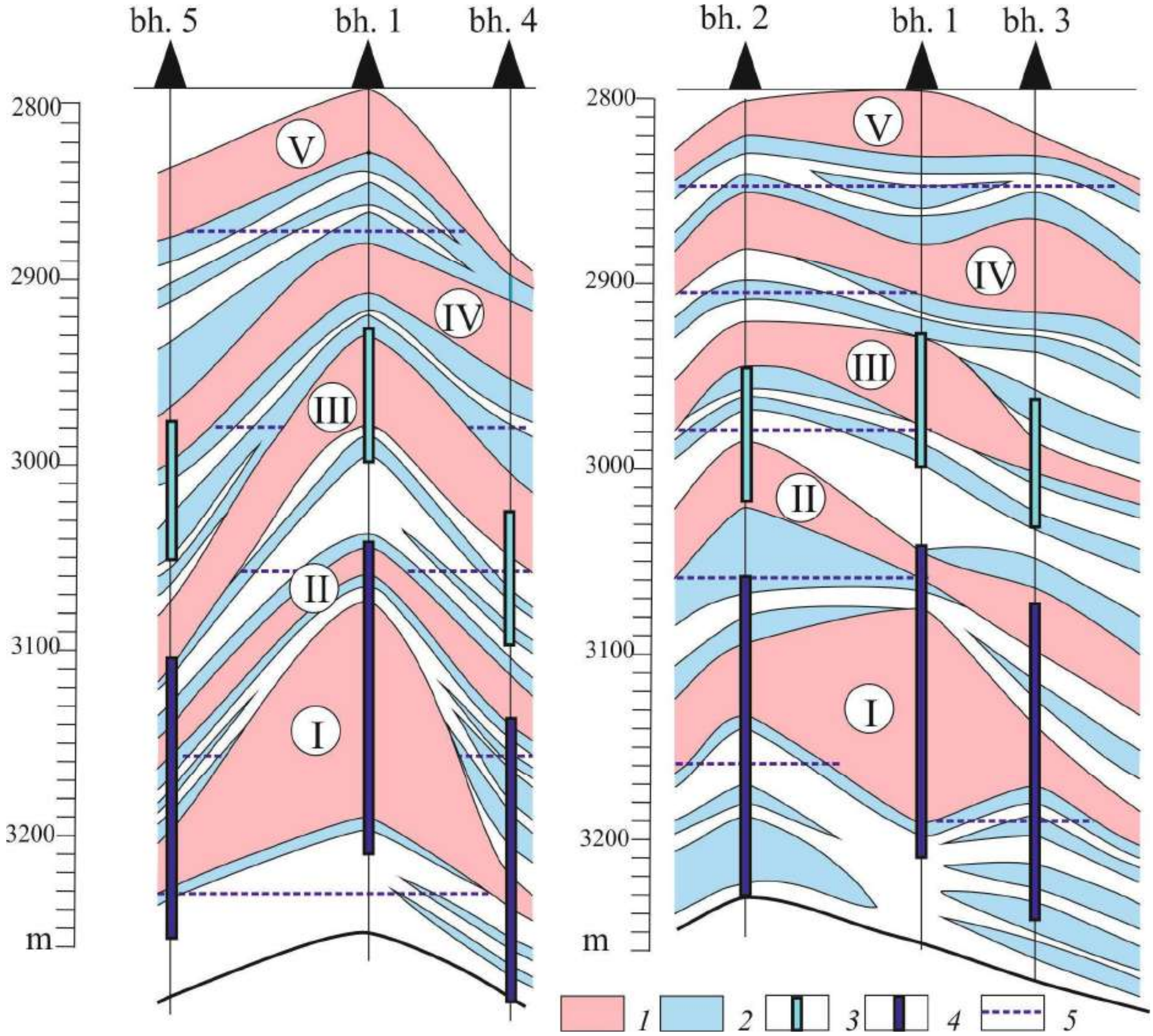

Fig. 8. Lithophysical structure of the Eifelian deposits of the Skhidnosaratske deposit:

1 – cap rocks; 2 – reservoirs. Productive packs by [Atlas..., 1998]; 3 – D_{2-1}; 4 – D_{2-2}; 5 – probable level of execution of hydrocarbon traps

Conclusions

1. Five sedimentary cyclites of regressive nature (I–V from bottom to top), which are traced throughout the study area, were identified in the section of the Eifelian deposits of the Biloliskyy block of the Dobrudja foredeep. Cyclites have a two-term structure: the lower part is represented by carbonate or terrigenous-carbonate rocks, the upper part consists of marl-sulphate and sulphate (anhydrites).

2. Characteristic changes in the content of main lithological differences from I to V cyclites have been determined. Anhydrites and marls are generally developed uniformly in the section. Dolomites and limestones, with some cyclicality, show the increase in content from the beginning to the end of the Eifelian age. The content of mudstones and terrigenous rocks is characterized by the inverse tendency.

3. There are six types of the cyclicity of the Eifelian deposits. At the same time, a variety of sediment cycles is observed even within the same area. This indicates the complex nature of the interaction of the sea level changes and structural deformations and, accordingly, the consedimentation character of the latter, and reflects the rhythmic variability of sedimentation conditions during the Eifelian age.

4. The lithofacial features (the character of the distribution of main rocks) of the terrigenous-carbonate parts of the *I–V* cyclites of the Euphelian deposits have been determined.

5. Sedimentation reconstructions showed some inheritance of localization of biostrome bodies during the Eifelian age. The main areas of development of these formations tend to the slopes of the Skhidnosaratska and Zhovtoyarska structures. However, if in the first case, their thickness from I to V cyclite decreases, it increases in the second one . The terrigenous flows are also characterized by the preservation of the main directions: western and northern.

6. Based on the study of the cyclic structure of the Eifelian deposits, the features of the lithophysical structure of the Skhidnosaratske deposit have been clarified. It was determined that the main reservoirs (anticlinal and lithological types) of all the five identified productive horizons of the deposit tend not to the modern arch of the structure, but to its southwestern pericline. In this context, the Tuzlivsko-Zhovtoyarska area is of interest. Based on the lithological and facial features of the deposits, there are grounds to predict lithological traps within the southern, eastern, and northern slopes of the Zhovtoyarska structure.

Scientific novelty

The constructed lithological, paleo-oceanographic, lithophysical models, allowed determining the peculiarities of the spatial-temporal heterogeneity of the lithological structure of the Eifelian deposits of the Biloliskyy block of the Dobrudja foredeep and to correct the current estimation of their oil and gas prospects.

Practical significance

The study of the features of the lithological structure of the strata, the creation of lithological, lithophysical, and paleo-oceanographic models will help to clarify the nature of the spatial-temporal development of sedimentary solids of various composition and genesis. All this will serve as a lithological basis for a more reasonable forecast of the distribution of oil and gas prospective objects.

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ЦИКЛІЧНІСТЬ, ЛІТОЛОГО-ФАЦІАЛЬНІ ОСОБЛИВОСТІ ТА ОБСТАНОВКИ СЕДИМЕНТАЦІЇ ЕЙФЕЛЬСЬКИХ ВІДКЛАДІВ ПЕРЕДДОБРУДЗЬКОГО ПРОГИНУ

Мета. Встановлення літофаціальної будови та реконструкція умов осадонагромадження відкладів ейфельського віку Білоліського блока Переддобрудзького прогину в аспекті формування продуктивних горизонтів та локалізації перспективних об’єктів. **Методика**. Комплекс літологічних, палеоокеанографічних, літофізичних та геофізичних (ГДС) досліджень. **Результати**. У розрізі відкладів ейфельського віку Білоліського блока Переддобрудзького прогину виділено п’ять седиментаційних циклітів регресивної природи, які простежено в межах усієї досліджуваної території. Цикліти мають двочленну будову: нижня частина представлена карбонатними або теригенно-карбонатними породами, верхня – мергельно-сульфатними та сульфатними (ангідрити). Встановлено характерні зміни вмісту основних літологічних відмін циклів у просторі й часі та ритмічну природу умов їх осадонагромадження. Реконструйовано седиментаційні особливості розвитку біостромових тіл протягом ейфельського часу та локалізовано ділянки їх максимального розвитку, що тяжіють до схилів Східносаратського та Жовтоярського піднять. З’ясовано особливості літофізичної структури Східносаратського родовища. Встановлено, що основні резервуари (антиклінального та літологічного типів) усіх п’яти виділених продуктивних горизонтів родовища тяжіють не до сучасного склепіння структури, а до її південно-західної периклінали. Ґрунтуючись на літологічних та фаціальних особливостях ейфельських відкладів регіону, високо оцінюють перспективи в нафтогазопошуковому плані пасток літологічного типу в межах південного, східного та північного схилів Жовтоярської структури. **Наукова новизна**. Побудовано літологічні, палеоокеанографічні, літофізичні моделі, які дали змогу встановити особливості просторово-часової неоднорідності літологічної структури ейфельських відкладів Білоліського блока Переддобрудзького прогину та скорегувати нинішню оцінку їхньої нафтогазоперспективності. **Практична значущість**. Вивчення особливостей літологічної будови товщі, створення літологічних, літофізичних та палеоокеанографічних моделей сприятиме уточненню характеру просторово-вікового розвитку осадових тіл різного складу та генезису. Усе це слугуватиме літологічним підґрунтям для обґрунтованішого прогнозу поширення нафтогазоперспективних об’єктів.

Ключові слова: літологічна структура; циклічність; ейфельські відклади; Білоліський блок; Переддобруджа; нафтогазоносність.

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