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Lithological models of reservoir rocks for upper cretaceous deposits in East Caucasian Region

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Abstract. The article describes the results of lithological and petrophysical investigations that would be a base for characterization of reservoir rocks in Upper Cretaceous deposits. These investigations include thin sections description, SEM and NMR analysis. As found that three main factors have constrained final quality of reservoir rocks: 1) depositional settings favorable for coccoliths and chalk sedimentation; 2) late diagenesis changes – compaction and recrystallization degree; 3) fracture intensity.

Keywords: Upper Cretaceous deposits, East Caucasian region, chalk limestones, pore and fractured reservoir rocks

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Introduction

The East Caucasian Region presently is one of the most explored petroleum provinces (Gorkushin, Naidenova, 1978; Likov et al., 1980; Paporotnaya, 2011, Postnikov et al., 2016). Investigation results obtained over the past century have been published by many respectful scientists: V.E. Hain, I.O. Brod, N.A. Krylov, B.A. Sokolov, N.A. Eremenko, A.I. Letavin, M.F. Mirchink, A.N. Shardanov et al.

Upper Cretaceous carbonate formation is high productive reservoir which provides significant part of petroleum reserves. However, nowadays the majority of developed fields are at the minimum of production. Reserve replenishment requires a new discovery as well as enhancement of recently productive areas.

For the proceptivity reevaluation, augmentation and refinement of existing geological models considered to be highly demanded. Comprehensive litho-petrophysical model of the Upper Cretaceous reservoir rocks is the first priority of these processes.

Lithological investigation of outcrop samples and drill cores showed that Upper Cretaceous carbonates are predominantly limestones, which consist of clay sized particles – less than 5 µm. They are chalks and calcareous mudstones with sparse biota fragments (foraminifers and others).

Recently, such rock types are considered as reservoirs of the lowest quality, which do not have effective porosity. The only way for reservoir formation is a fracture development (Borisenko et al., 2007).

Nevertheless, unstable rate of production and variation of recovery factor requires new more detailed models of the reservoir properties, which are based on structure-texture and mineralogy determination. It is possible to model using modern analytical tools and methods.

Such a set of analyses was applied to the drilling results of one well (Sovetsko-Kurskaya area) and outcrop samples from the Belgorod, Stavropol, Dagestan and Karachay-Cherkessia regions.

Materials and Methods

Lithological, mineralogical and reservoir properties analysis were performed for 46 core samples from the well of the Sovetsko-Kurskaya area and 11 outcrop samples (Fig. 1).

Mineralogy, structures and textures were defined on the rock slices, petrography and special analytical thin sections.

Rock slices (up to 0.5 cm) and analytical thin sections (without cover glass) were investigated under JSM

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6610 LV scanning electron microscopy (JEOL, Japan), which have IE350 energy dispersive X-ray analyzer (OXFORD INSTRUMENTS, UK). SEM analysis was performed in two modes: secondary electron image (SEI) and back scattered electron (BSE). Secondary electron image is a main mode because it gives a clear view of sample topography and maximum resolution. The main characteristics of the analysis as follows: accelerating voltage 20–30 kV; spot size 40–45; working distance 10–12 mm.

Petrographic thin sections were made using stained epoxy resin and examined with a research grade optical polarizing microscope Axio Imager A2m (Carl Zeiss MicroImaging GmbH).

In addition to lithological studies, to assess the void space of rocks, the results of petrophysical studies by NMR (nuclear magnetic resonance) were used, from which the parameters of open, effective porosity, average pore diameter and residual water saturation of the samples were calculated.

Results

Texture parameters

The results of rock studies under optical and scanning microscopes showed that the main constituent parts of the rocks of the Upper Cretaceous complex are:

- micrite, probably cyanobacterial in some areas;
- shells and fragments of coccolithophorid shells;
- shells and fragments of foraminifera.

The amount and combination of these components allows distinguishing three main types of rocks according to the following predominance:

- shells of foraminifera and coccolithophorids – micritic limestones with foraminifera (wackestones and packstones);
- shells of coccolithophorids and micrite – chalk;
- micrite – bioturbated micritic limestones (mudstones and wackestones).

The rocks with micritic calcite prevalence contain a small (up to 5 %) amount of clay.

The change in the components amount and bioturbation caused the heterogeneity of the microstructure.

The orientation of the shells in rocks with a predominance of coccolithophorids is chaotic, the individual skeletons have point contacts. The porosity of these rocks is very high, up to 30 %. However, the size of these pores is from 1 to 10 microns (Figs. 2–4).

Only the rocks taken from natural outcrops have such a highly porous structure. These rocks, apparently, did not undergo significant late diagenetic transformations inherent in deep horizons.

Core samples from the well of the Sovetsko-Kurskaya area, from depths of about 3–4 km, as well as samples from natural outcrops that have been buried in the geological past, are characterized by the other textural parameters. The preservation of biomorphic elements is various: in some cases, they are almost completely replaced by crystallomorphic calcite, apparently as a result of recrystallization of shells and areas, which probably have partly cyanobacterial nature (Fig. 4). The volume of porosity decreases in these rocks, and they become unevenly permeable. The latter is proved by the saturation of the rock samples with colored epoxy resin, which penetrates either uniformly throughout the sample, or along cracks, or vague spots, sometimes inside the trace fossils (Figs. 5–8).

Pore space parameters and diagenetic alterations

Variation in the porosity and residual water saturation, determined by the method of nuclear magnetic resonance

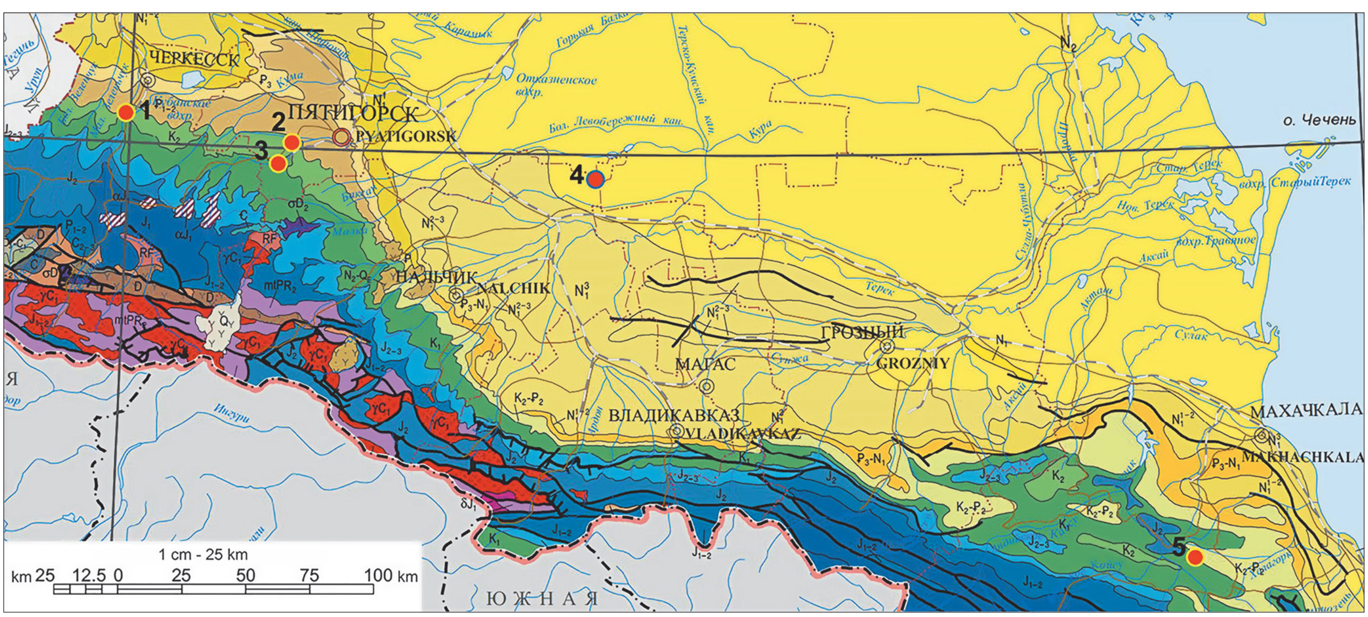

Fig. 1. Location of sample places on the North Caucasus geological map (VSEGEI, 2018): 1,2,3 – outcrop in the Stavropol and Karachay-Cherkessia areas, 4 – the well location in the Sovetsko-Kurskaya area, 5 – Okhly-Aymaky outcrop, South Dagestan.

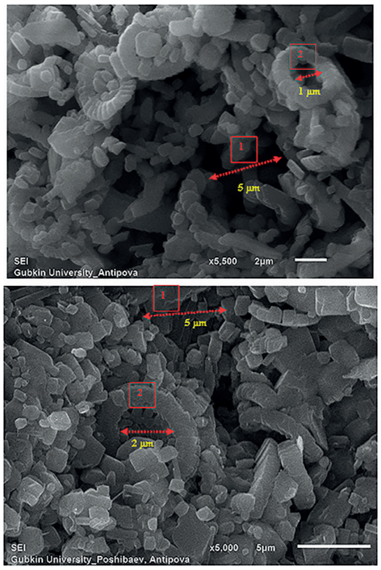

Fig. 2. Inter- (1) and intraparticle (2) pores ranging in size from 1 to 5 microns. Upper Cretaceous deposits. SEM photo (BSE): at the top – outcrop sample. Belgorod region; at the bottom –core sample from the well of the Sovetsko-Kurskaya area(depthof 3419.55 m).

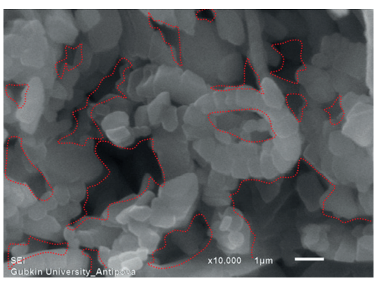

Fig. 3. Inter- and intraparticle pores ranging in size from 1 to 5 microns. Chalk. Outcrop sample. Belgorod region. SEM photo (BSE).

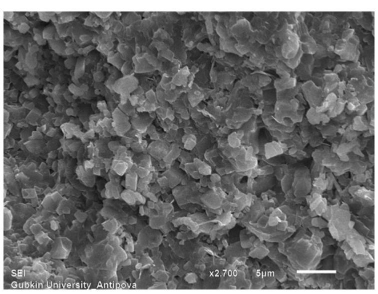

Fig. 4. Crystallomorphic calcite (probably cyanobacterial nature). Core sample from wells of the Sovetsko-Kurskaya area (depthof 3476.40 m). SEM photo (BSE).

(NMR), reflects changes in the rock properties in accordance with the burial depth and the degree of late diagenetic alterations.

Chalk and micritic bioturbated limestones have different volumes of porosity and residual water saturation, due to different degrees of compaction and recrystallization. It was revealed when comparing the data of 1 outcrop sample and 5 core samples.

The highest intensity of such alterations is determined for samples from depths of 3476.40; 3721.16; 3729.77

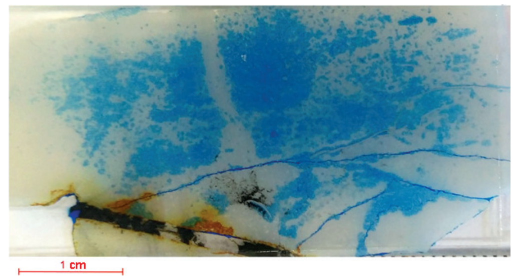

Fig. 5.Uneven saturation by colored epoxy resin (blue color is porous part). Fracture with bituminous filling. A sample from the well of the Sovetsko-Kurskaya area (depthof 3463.33 m). Thin section photo.

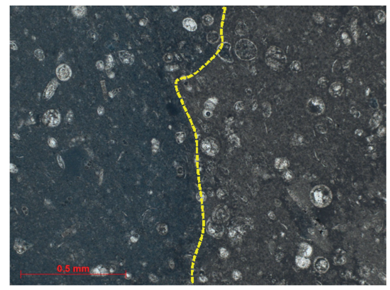

Fig. 6. Uneven saturation by colored epoxy resin: on the right – porous saturated part, on the left – tight part of rock. A sample from the well of the Sovetsko-Kurskaya area (depth of 3463.33 m). Thinsectionphoto in plane polarized light.

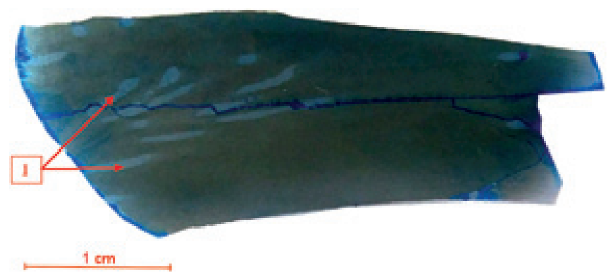

Fig. 7. Porous trace fossils are saturated by colored resin. Outcrop sample. No. 280, Okhly-Aymaky, South Dagestan. Thin section photo.

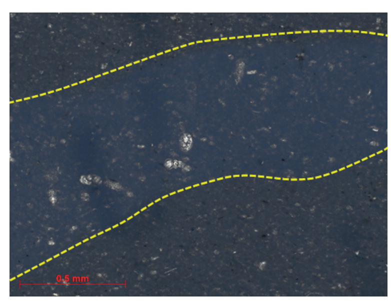

Fig. 8. Porous trace fossil is saturated by colored resin (central part). Outcrop sample. № 280, Okhly-Aymaky, South Dagestan. Thin section photo in plane polarized light.

meters (Fig. 9). These samples also possess lower porosity values along with an increase in the residual water saturation, except the sample from depth of 3476.40 m. Nevertheless, this is most likely because the NMR measurements were made on the fractured sample. Therefore, the calculated data of the average radius of

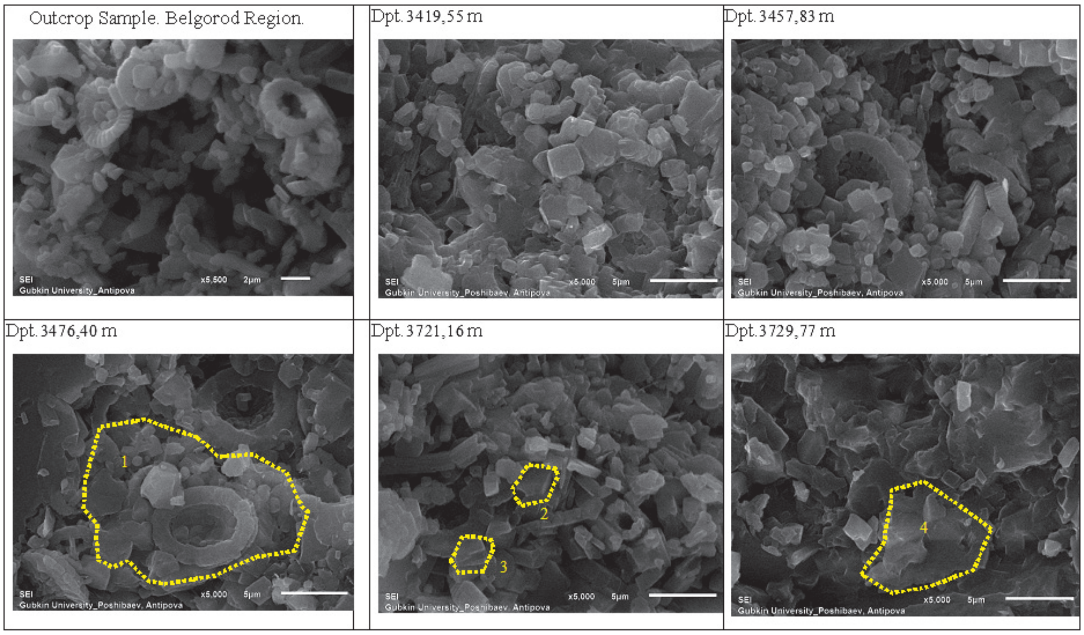

Fig. 9. Late diagenetic alterations of the rocks of the Upper Cretaceous deposits: from left to right – an increase in the degree of compaction. 1 – area of compaction and secondary calcite formation; 2, 3, 4 – crystals of the newly formedcalcite.

pores (fractures) increased, and this led to an increase in the value of porosity and a decrease in the calculated data of water saturation (Table 1).

In conclusion, the primary textural parameters, such as the ratio of the amount of shell remains and micritic calcite, determine the direction of the diagenetic alteration.

The most porous texture is defined along with an increase in the amount of weakly transformed coccolithophorids. A general decrease in the porosity due to compaction and recrystallization is observed in the samples with an increase in the number of remains of foraminifera shells and the intensity of bioturbation. In this case, the residual pores have an isometric shape. Therefore, there were no subsequent processes of dissolution and leaching.

The results of optical and additional studies in SEM make it possible to distinguish three main porosity types:

- residual intraparticle pores (inside foraminifera shells) with an average size of 0.20 mm;
- intraparticle pores (inside coccolithophorids shells) with an average size of 3 microns;
- interparticle pores with an average size of 5 microns.

The amount of the second and third pore types depends on the ratio of coccolithophorids and micritic calcite in the rock: the smaller number of coccolithophorids, the less amount of intra- and interparticle pores.

Despite the fact that the residual pores in foraminifera shells are larger, their number is small and does not make a significant contribution to the rock's porosity.

In addition, in samples with a large amount of micrite, the processes of recrystallization and compaction are more intense, which in general cause a decrease in the number of pores. Intensive bioturbation in micritic limestones did not lead to an increase in the total and effective porosity of rocks, since in some cases porous trace fossils are located in a dense micrite matrix.

The model of the reservoir texture with such small pore sizes implies the consideration of these rocks as the rocks with water-saturated matrix. (Figs. 10–12).

Depth, m	Age	Rock Type	Open Porosity, %	Effective Porosity, %	Residual Water Saturation, %	Average Pore/Fracture Radius, µm
3419.55	K_2m	chalk	20.4	11.0	46.1	0.83
3457.83	K_2m	chalk	19.9	13.8	30.7	1.70
3476.40	K_2m	chalk	15.0	10.7	28.4	2.03
3721.16	K_2km+st	micritic bioturbated limestone	11.0	4.3	61.1	0.54
3729.77	K_2km+st	micritic bioturbated limestone	1.8	0.0	100.0	0.20

Table 1. Results of NMR studies of the five Upper Cretaceous rock samples from the well of the Sovetsko-Kurskaya area

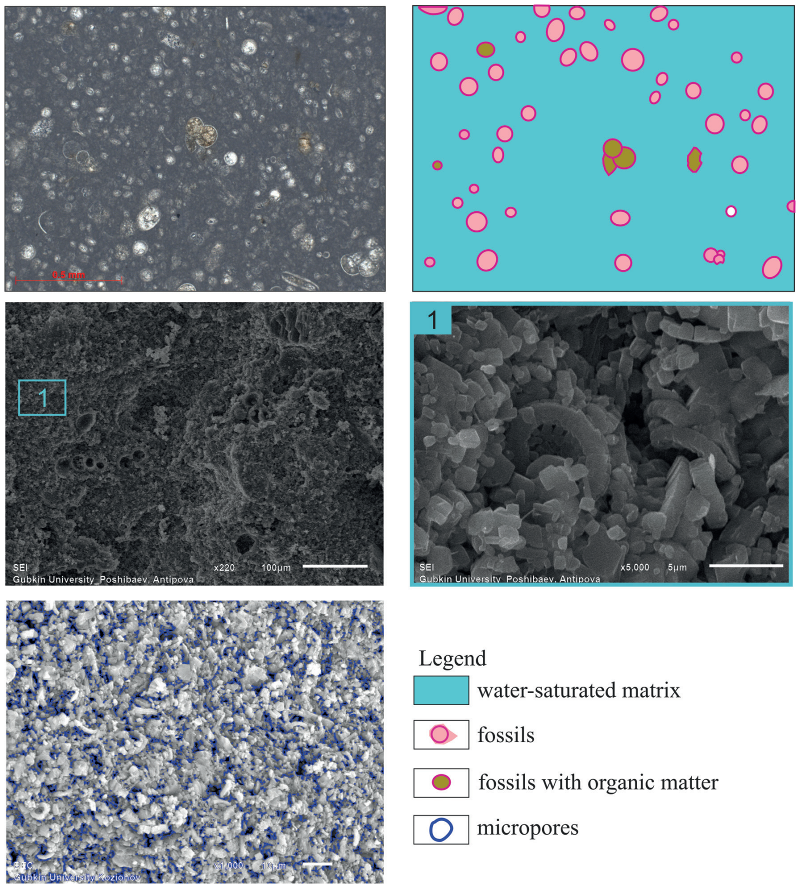

Fig. 10. Model of the reservoir of the Maastrichtian chalk. Thin section photo in plane polarized light. Scheme of the rock texture.Three SEM photo with the highlighted micropores in the rock matrix.

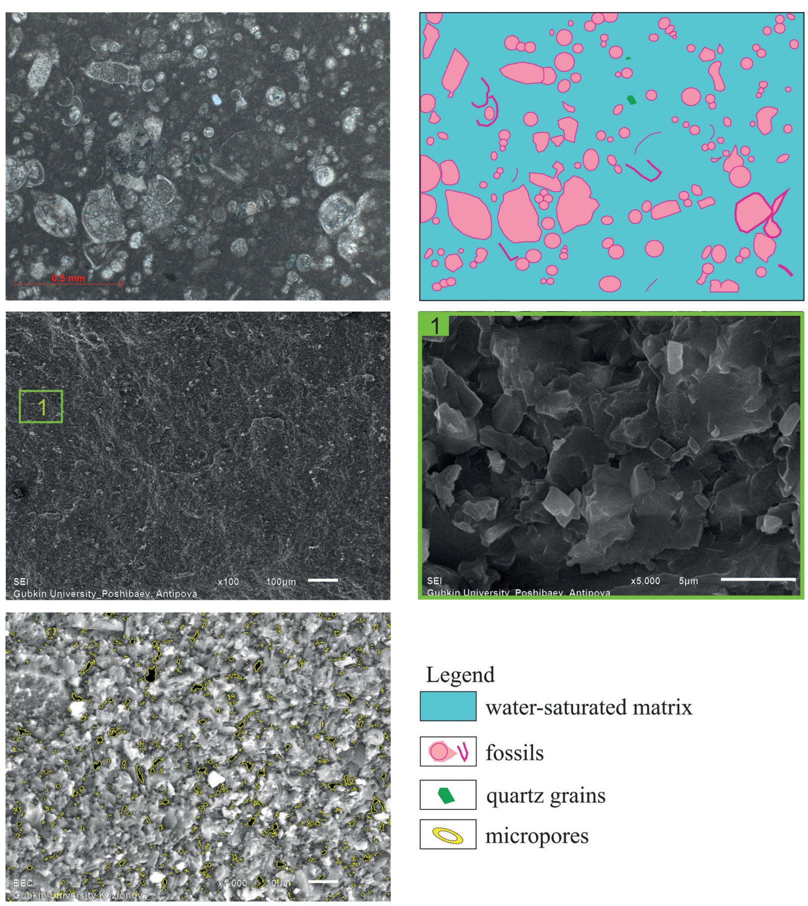

Fig. 11. Model of the reservoir of the Maastrichtian micritic limestones. Thin section photo in plane polarized light. Scheme of the rock texture. Three SEM photo with the highlighted micropores in the rock matrix.

Their effective reservoir capacity is confined to the fracture zones. However, in the studied samples, zones of hydrocarbon penetration were found. They are confined to the fractures.

Apparently, along with fractures, these near-fracture zones with an average width of 0.30 mm will also contribute to the effective capacity (Fig. 12).

Conclusion

The investigation results allow to suggest three main conditions which constrain reservoir quality of the Upper Cretaceous carbonate rocks:

1) sedimentological – coccolithophorid dominance;

2) degree of late diagenesis alteration – compaction and recrystallisation;

3) fracturing intensity.

Though these deposits have low facies diversity, nevertheless the content of sediments at early stage constrains the following diagenesis alteration of these rocks.

As it is shown with an empirical relation (Bramwell, 1999), a coccolithophorid limestone remains highly porous even after interdependent multidimensional alterations. Therefore, a forecast of the better-quality reservoir may significantly benefit with deducing from core data the facial conditions which are favorable for coccolithophorid flourishing and chalk formation.

The data from a studies of core samples from the North Sea, the Gulf of Mexico and European outcrops (Scholle, 1977) showed that chalk porosity changes are depth dependent.

In the most cases this dependence is linear – the more is a depth, the less is a porosity. At the 2000–3000 meters porosity is reduced to 10–20 %. It is connected with mechanical compaction which causes pressure dissolution at calcite grain contacts. The dissolved material then precipitates as a newly formed cementation.

However, even in this case pure chalk has more pore volume than other limestones. The reasons for this are the chaotic grain distribution and significant amount of free sedimentary water. These conditions cause a decreasing of the compaction effect because an interpore pressure remains high enough (Glennie, 1998).

In the wackestones and packstones with shell fragment abundance and intensive bioturbation, grain packing is more aligned. It causes a compaction effect intensification and vertical permeability reducing (Glennie, 1998; Fabricius, 2003).

Additionally, clay content increase contributes to the porosity reducing: dissolution is more active at the contact of clay and carbonate minerals, and dissolved material precipitates here (Scholle, 1977).

The results of this work confirm the described above suggestions. Less packed chalk has bigger porosity values (20.4 % at a depth of 3419.55 m, core sample of the Sovetsko-Kurskaya area).

While a content of shell fragments and clay minerals increases, the recrystallization becomes more intensive and porosity has lower values (1.8–11.0 %). The isometric shape of pores in such rocks suggests the absence of secondary dissolution.

The amount of interparticle pores (foraminifera and other shells) is not considerable and does not contribute to porosity significantly. Although the increase of fossil amount correlates with micritic calcite increase and porosity loss.

The bioturbation intensity also correlates with porosity reducing. Probably it is because trace fossils are detected predominantly in the tight micritic matrix even if they are porous themselves.

Therefore, a highly fractured zone of chalk may be considered as prospective fractured porous reservoir.

It is necessary to estimate statistically significant amount of fracture porosity together with the additional volume of penetration zones along the fractures. These data will allow researchers to correctly calculate the volume of effective porosity.

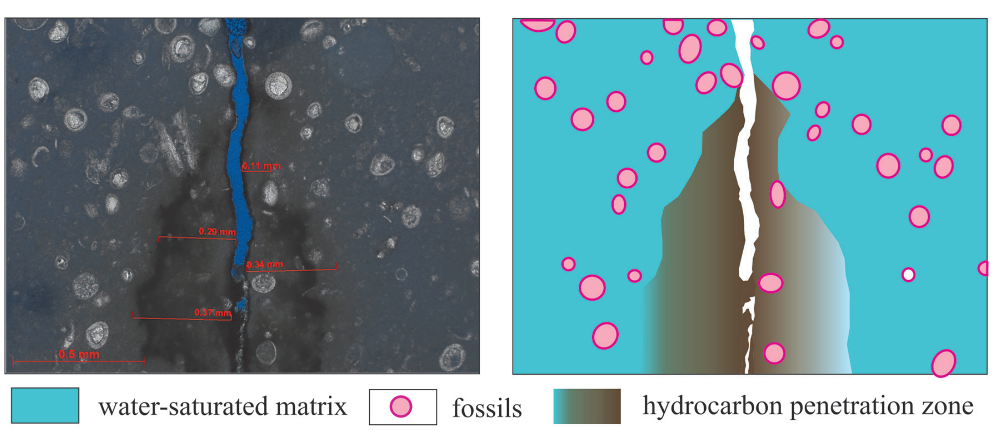

Fig. 12. Model of the hydrocarbon penetration zone along the fracture. Thin section photo in plane polarized light. Scheme of the rock texture.

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