

LITHOLOGY, FACIES AND DYNAMICS OF FORMATION OF THE ALBIAN-CENOMANIAN RESERVOIR ROCKS OF THE POKUTTYA-BUKOVYNA PART OF THE CARPATHIAN AUTOCHTHON

The purpose of this work is to study the Upper Albian-Lower Cenomanian psammitic complex of the platform basement of the Pokuttya-Bukovyna part of the Carpathian Foredeep, which is one of the main reservoir strata of the Lopushna oil field. Methodology. The complex of investigations includes correlation of the well-log data, lithological studies of core material, mineralogical and petrographic analysis of rocks, and paleogeographic studies of the sedimentary basin. Results. On the basis of the analysis of all existing wells, it was established that the deposits of the Late Albian-Early Cenomanian age within the entire territory of the autochthon of the Pokuttya-Bukovyna Carpathians are mostly represented by sandstones. They are composed of quartz (50–80 %), feldspar (1–5 %), muscovite (0.1–3 %), pyrite (0.1–3 %) and accessory minerals – zircon and epidote. A significant part of sandstone is composed of the authigenic minerals – glauconite (10–15 %, sometimes up to 45 %) and phosphate (1–3 up to 10 %). The matrix in the rocks is mainly porous and contact-porous (10–15 % of the rock volume), which provides these psammites with good reservoir properties. On the basis of paleogeographic reconstructions, it was established that in the Late Albian-Early Cenomanian, terrigenous sedimentation prevailed within the entire shelf basin of the Carpathian branch of the Meso-Tethys, which caused the accumulation of the thick sandstones' strata. The burial history and post-sedimentary evolution of rocks took place under the influence of the thrusting of the Carpathian Fold Belt. This resulted in the formation of reservoir rocks and traps in the Upper Albian-Lower Cenomanian sequence. The peculiarities of hydrocarbon migration in the studied region indicate a high probability of discovering new deposits in the autochthon of the Pokuttya-Bukovyna Carpathians. Originality. The applied complex of lithological, geological-geophysical and paleogeographical studies made it possible to investigate the features of distribution of the Albian-Cenomanian psammitic complex of rocks, both laterally and in section, their mineralogical and petrographic characteristics, sedimentary environments. The post-sedimentary evolution of the study strata and features of hydrocarbon migration were caused by the dynamics of the Carpathian Flysch Belt thrusting over the margin of the East-European platform. Practical significance. The obtained results show that the Upper Albian-Lower Cenomanian sandstones, which are oil and gas-bearing in the Lopushna field, represent the potential reservoirs in terms of both thickness and mineral composition within the entire autochthon of the Pokuttya-Bukovyna Carpathians. Since the Pokuttya fault could serve as a migration path for the hydrocarbons from the Carpathian flysch sequence into the platform basement strata, there is a high probability of the discovery of new accumulations in the structures similar to the Lopushna, revealed by seismic studies in the autochthon of the Pokuttya-Bukovyna Carpathians.

Key words: autochthon of the Ukrainian Carpathians; Albian-Cenomanian; psammitic reservoir rocks; mineral composition of rocks; shelf sedimentary basin; hydrocarbons migration

Introduction

Significant potential in many oil and gas-bearing provinces of the world is represented by oil and gas deposits in platform sediments, which occur under the thrust of folded belts [Picha, 1996]. The discovery of the Lopushna oil field in the Mesozoic and Paleogene strata of the subthrust part of the autochthon of the Pokuttya-Bukovyna Carpathians showed the prospect of finding hydrocarbons in this geological setting. A significant part of the oil reserves of the Lopushna

field occurs in the Upper Albian-Lower Cenomanian sandstone reservoirs [Fedyshyn, 1998].

The general features of the geological structure of the Pokuttya-Bukovyna part of the Carpathian Foredeep and the Carpathians were established at the beginning of the 20th century. A detailed study of the geological structure of the Pokuttya Carpathians was carried out by K. Tolwinski in 1938–1950 [Tolwinski, 1950]. For the first time, he considered the issue of the Pokuttya autochthon folds, noting that they represent a

special part of the Carpathian Foothills, and occur here within the boundaries of a large transverse uplift – the “Podillya culmination”. The lithological-stratigraphic investigations of the Cretaceous strata of the autochthon of the Pokuttya-Bukovyna part of the Carpathian Foredeep, which occur at significant depths (300–4.500 m), began only in the 1960s [Dulub, 1965; Linetska and Utrobin, 1965]), when core material was obtained as a result of exploration drilling. Paleontological studies of rocks, carried out during the 60s and 80s of the 20th century [Pasternak and Ulizlo, 1980; Gavrylyshyn, 1998], made it possible to stratify the sequence of Mesozoic strata in the autochthon of the Pokuttya-Bukovyna Carpathians, in particular, the oil and gas-bearing sandstones of the Late Albian-Early Cenomanian age.

Given the current state of knowledge about the geological structure and oil and gas potential of the platform basement of the Pokuttya-Bukovyna part of the Carpathian Foredeep, the study of mineralogical-petrographic, facial, and paleo-oceanographic features of the Albian-Cenomanian psammites is of significant importance for evaluating the further directions of prospecting in the region.

Geological structure

The study area covers the autochthonous part of the Pokuttya-Bukovyna Carpathians, which corresponds to the southeastern part of the platform basement of the Carpathian Foredeep and of Skyba Unit (Figs. 1, 2). The sequence of the autochthon consists of Riphean, Paleozoic (Cambrian, Silurian, Devonian), Mesozoic (Jurassic, Cretaceous), and locally Paleogene (Eocene) rocks, which are unconformably overlain by a thick succession of Miocene molasse (Carpatian, Badenian, Sarmatian). The zone is characterized by the existence of significant faults in the basement, which caused its block structure, as well as the presence of sloping anticlinal structures that extend from the northeast to the southwest [Krupskyi, 2001]. In the northeast, the study area borders on the East European platform, and its southeastern part is covered by the thrust of the Carpathian Flysch belt (Fig. 2).

The Mesozoic complex consists of Cretaceous (Neocomian, Albian, Cenomanian, Turonian, Senonian) and Jurassic sediments [Gavrylyshyn, 1998]. It rests unconformably on Paleozoic strata. The thickness of the Cretaceous deposits within the platform basement of the Pokuttya-Bukovyna uplift reaches 200 m.

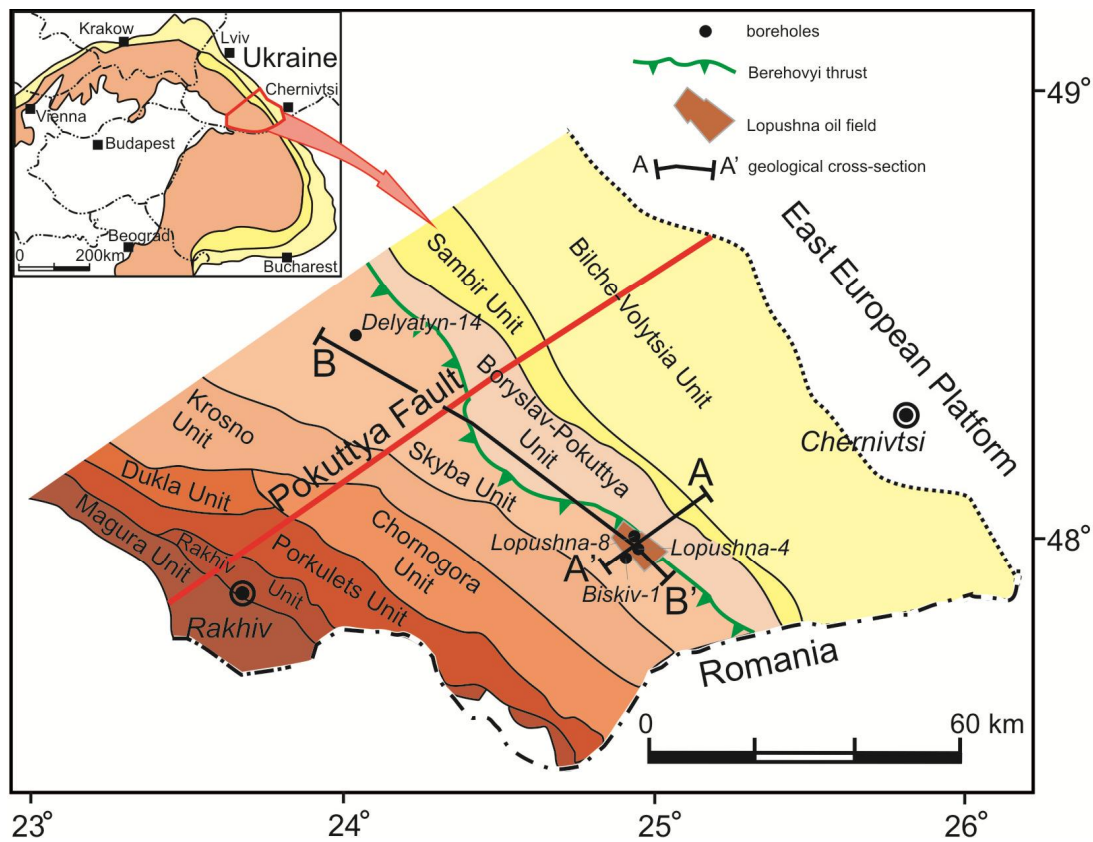


Fig. 1. Geological map of the Pokuttya-Bukovyna Carpathians. Geological structure after [Shakin et al., 1977, Kruglov et al., 1985].

According to the stratigraphic scheme [Gavrylyshyn, 1998], the studied strata belong to the Lower Cretaceous, partly Upper Cretaceous series and are represented by an undivided sequence of the Upper Albian-Lower Cenomanian (Fig. 3). They unconformably cover the Lower Cretaceous (Valanginian-Hotherivian-Barremian) [Radkovets, 2017] clay-terrigenous strata and are overlain with a stratigraphic unconformity by the

Upper Cenomanian inoceram limestones. A layer of basal gravelstones occurs in the base of the Upper Albian-Lower Cenomanian sediments. It is covered by the glauconite-quartz sandstones, in which the chalcedony concretions are locally established. The sandstones are overlain by thin layers of sandy and bioclastic limestones and chalcedony and limy spongoliths.

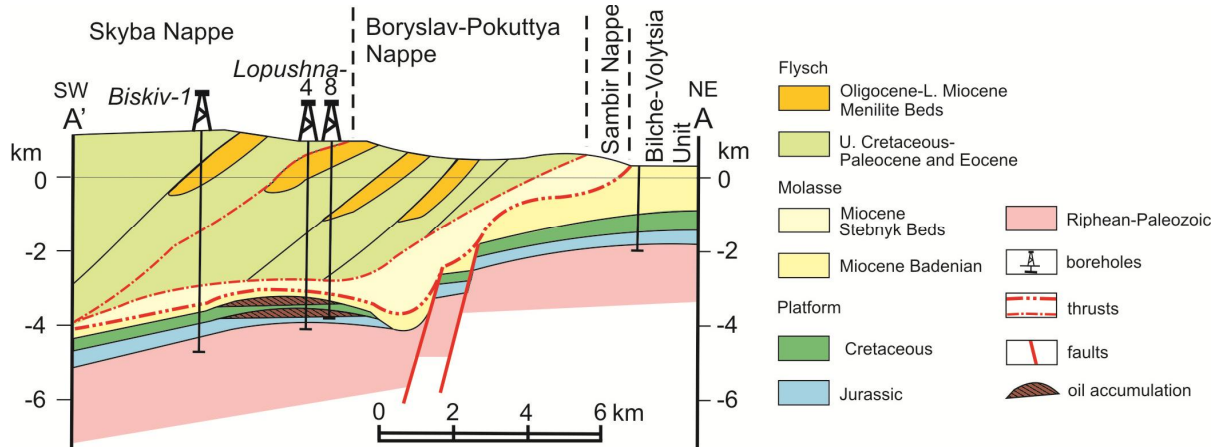


Fig. 2. Geological cross-section through the platform basement of the Pokuttya-Bukovyna Carpathians, the Carpathian Foredeep and the north-eastern part of the Skyba Nappe. Modified after [Oszczypko et al., 2006].

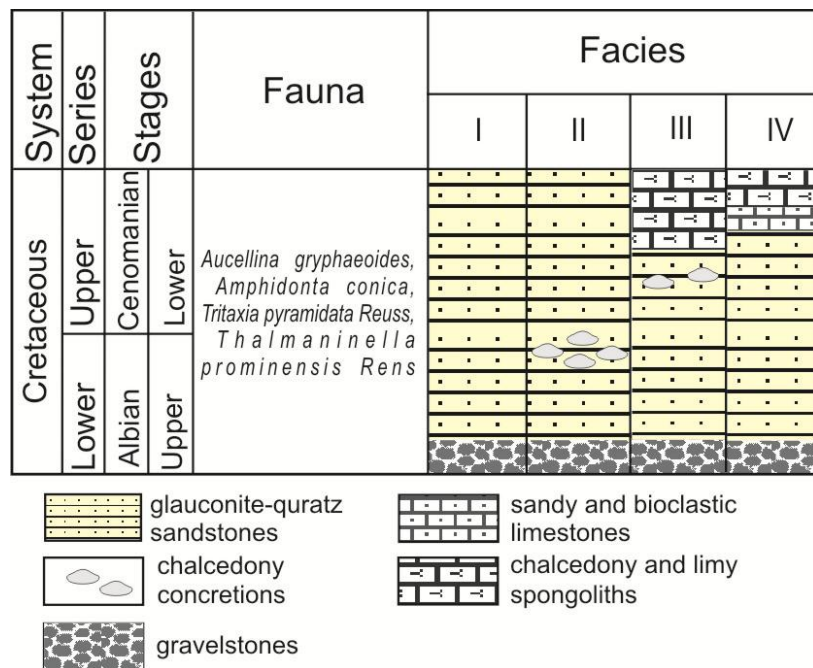


Fig. 3. Lithological-stratigraphic scheme of Cretaceous deposits of the Pokuttya-Bukovyna Carpathians. Stratigraphy after [Gavrylyshyn, 1998].

Purpose

The purpose of this work is to study the Upper Albian-Lower Cenomanian psammitic complex of the

platform basement of the Pokuttya-Bukovyna part of the Carpathian Foredeep, which is one of the main reservoir strata of the Lopushna oil field.

Methodology

The complex of investigations includes correlation of the well-log data, lithological studies of core material, mineralogical and petrographic analysis of rocks, as well as paleogeographic studies of the sedimentary basin.

Results

Spatial distribution and facies of the Upper Albian-Lower Cenomanian sediments

Based on the analysis of all available wells, it was established that deposits of the Late Albian-Early Cenomanian age within the entire territory of the autochthon of the Pokuttya-Bukovyna Carpathians are represented mostly by sandstones, which are the reservoir rocks at the Lopushna oil field. (Fig. 4). The layer (0.2–1.2 m) of gravel of pre-Cretaceous rocks lies at the base of the section of the studied age interval. Lithological sections (Fig. 5) of the Late Albian-Early Cenomanian strata exhibit facial variability, both horizontally and vertically. This conclusion was reached through mineralogical and petrographic analysis of rocks and interpretation of well-log data from the eleven most representative wells in the study area. In the northeastern part of the study region (e.g. borehole Storozhynets-55) the section consists mainly of coarse-grained, moderately sorted psammites, the thickness of which increases from 5 to 10 m in the direction of dip of the autochthon. In the northwestern part of the study area, the Albian-Cenomanian sequence is also mainly represented by green-gray coarse-grained sandstones, 15–20 m thick, which in the upper part of the section are replaced by chalcedony and limy

spongoliths with the thickness ranging from 0.5 to 4 m (e.g. borehole Korshiv-Ispas-59). In the central and eastern parts of the territory (e.g. borehole Svyatoslavska-3), the section is dominated by glauconite-quartz sandstones, the thickness of which is 8–11 m. They are covered by a layer of sandy limestones (up to 0.5 m), which is overlain by biotrital limestones (up to 0.5 m), which are replaced by limy spongoliths (0.5–3 m). In the southern part of the study region, the section is represented by sandstones, the thickness of which is 15–25 m, up to 30 m. Chalcedony concretions are found in the sandstone strata [Senkovskiy, 1977].

Petrographic composition of sandstones

Glauconite-quartz sandstones are light gray, gray, light green, and dark green in color (Fig. 6). Rocks, in general, are weakly cemented, mostly massive, homogeneous, rarely with an obliquely layered, and unclear layered texture. They are medium-fine-grained and fine-grained, although there are coarse-grained varieties that tend to the lower part of the sandstone layer. The clastic material of the rocks is semi-rounded, sometimes rounded, medium, often well-sorted, and evenly distributed in the rock. It is represented by quartz grains (50–80 %), feldspar (1–5 %) (microcline and orthoclase predominate, acidic plagioclase are less common), muscovite flakes (1–3 %) (Table 1). Accessory minerals occur sporadically – zircon and epidote. Of the ore minerals, pyrite (0.1–3 %) and single grains of ilmenite are observed.

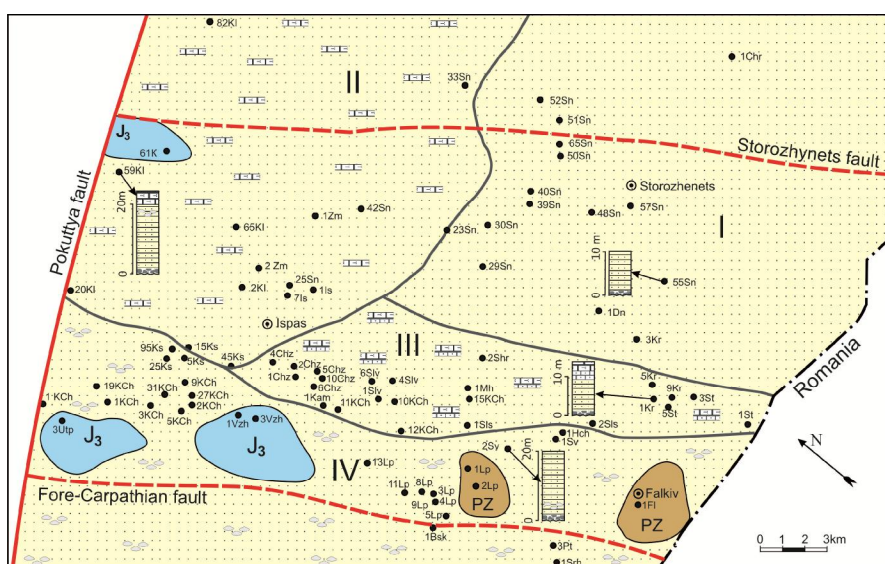


Fig. 4. Lithofacial map of the Upper Albian-Lower Cenomanian autochthonous deposits of the Pokuttya-Bukovyna Carpathians.

Boreholes: Bsk – Biskiv, Chr – Chernivtsi, Chz – Chornohuzu, Dn – Davydeny, Fl – Falkiv, Hch – Hilche, Is – Ispas, Kam – Kamenska, KCh – Kovalivka-Chereshenka, KI – Korshiv-Ispas, Kr – Krasnoilsk, Ks – Kosiv, Lp – Lopushna, Mh – Myhiv, Pt – Petrovets, Shr – Sheremety, Sls – Solonets, Slv – Slavets, Sn – Storozhynets, Srh – Serhiyi, St – Svyatoslavska, Sv – Sehiv, Utp – Utoropy, Vzh – Vyzhnytsia, Zm – Zamostya.

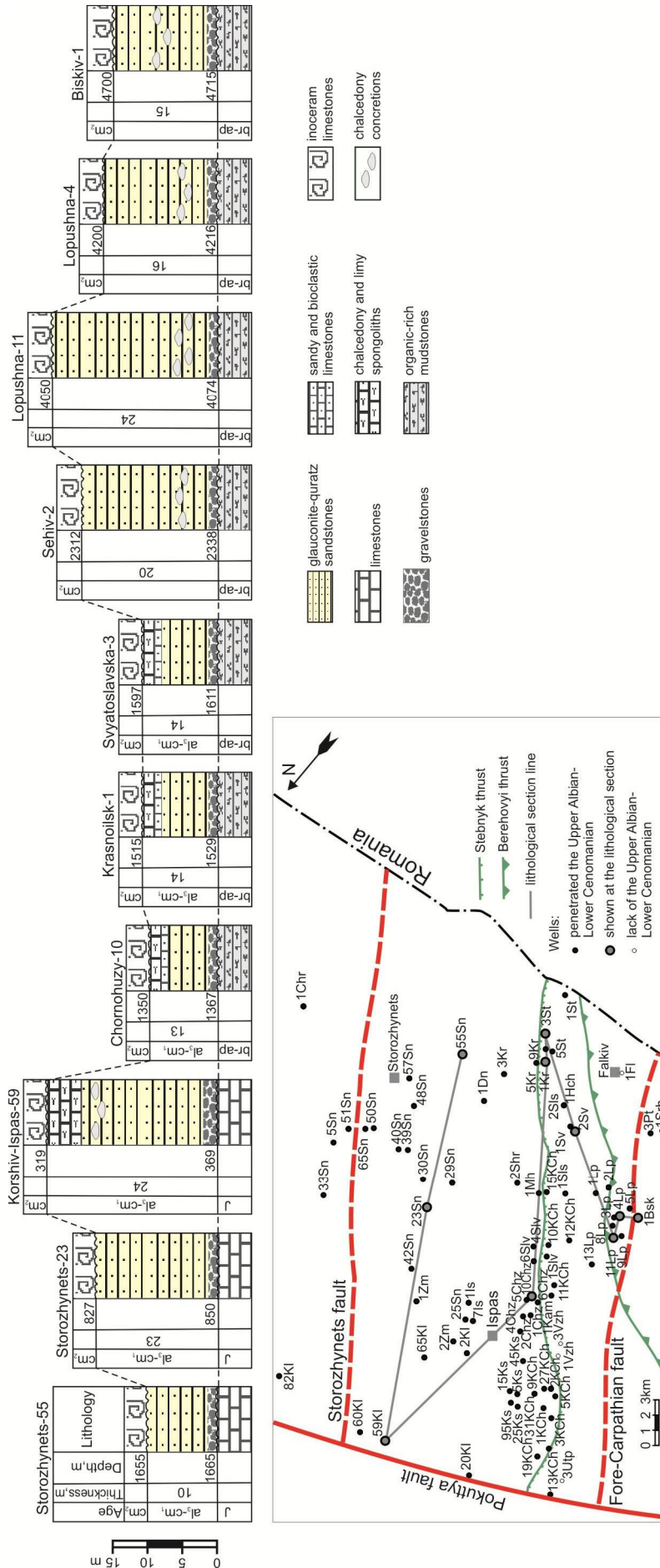


Fig. 5. Lithological section of the Upper Albian-Lower Cenomanian deposits of the Pokuttya-Bukovyna Carpathians.

Boreholes: Bsk – Biskiv, Chr – Chernivitsi, Chz – Chornohuzy, Dn – Davydeny, Fl – Falkiv, Hch – Hiiiche,

Is – Ispas, Kam – Kamenska, KCh – Kovalivka-Chereshenka, KI – Korshiv-Ispas, Kr – Krasnolisk, Ks – Kosiv, Lp – Lopushna, Mh – Myhiv, Pt – Petrovets, Shr – Sheremety, Slv – Solonets, Siv – Slavets, Sn – Storozhynets, Srh – Serhiyi, St – Svyatoslavsk, Sv – Sehiv, Utp – Utoropy, Vzh – Vyzhnytsia, Zm – Zamostya.

A significant part of the petrographic composition of sandstones belongs to authigenic minerals – glauconite and phosphates. The glauconite content is 10–15 %, sometimes reaching 45 %. The glauconite grains are of oval or irregular shape, 0.1–0.5 mm in size. Glauconite often acts as cement, its agglomerations are observed, which fill the intergranular space in the rock

[Radkovets and Yaremchuk, 2007]. Phosphates, the maximum content of which reaches 10 %, are observed in the lower part of the sandstone layers and are represented by nodules of irregular shape with a size of 0.3–0.5 mm, sometimes up to 5.0 cm. The cement in the rock is represented by clay-carbonate material. Its content is mostly 10–15 %, sometimes reaching 45 %.

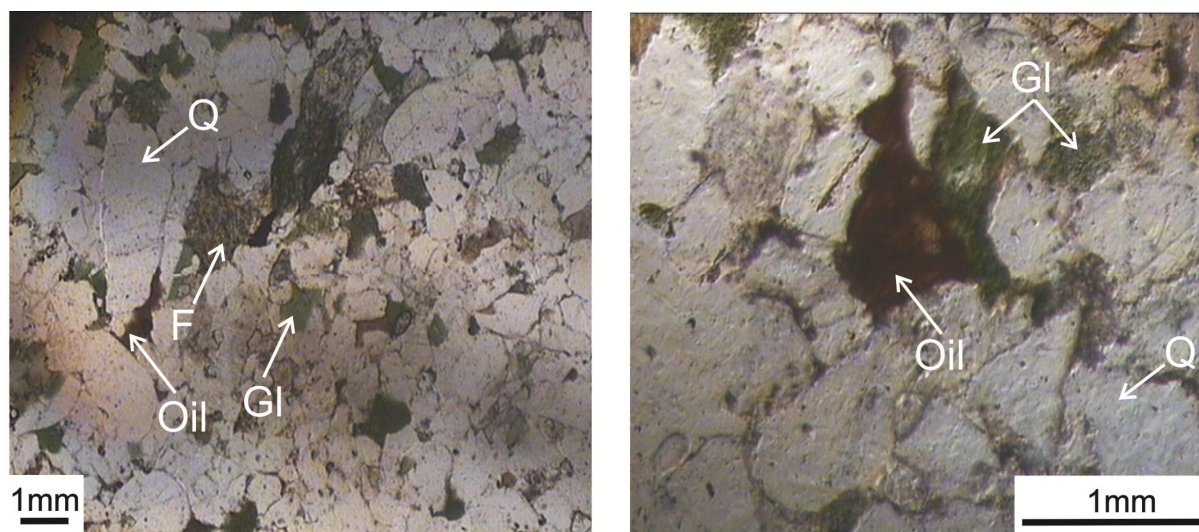


Fig. 6. Photomicrographs of reservoir rocks of the Upper Albian-Lower Cenomanian age of the Lopushna oil field. Oil-saturated sandstone from the Lopushna-4 borehole, depth 4210 m. Q – quartz; Gl – glauconite; F – feldspar; Oil – oil in the intergranular space.

Table 1

Mineral composition of the Upper Albian-Lower Cenomanian sandstones of the Pokuttya-Bukovyna Carpathians’ autochthon

Quartz-glauconite sandstones							
Minerals							
terrigenous			authigenic		carbonate		clay
quartz	feldspar	muscovite	glauconite	phosphates	calcite	dolomite	illite, kaolinite, chlorite
Size, mm							
0.1–0.5	0.1–0.5	0.1–0.3	0.1–0.5	0.3–0.5	0.01–0.2	0.01–0.2	< 0.01
Content in rock, %							
50–80	1–5	1–3	10–15, to 45	1–3, to 10	10–40	1–5	5–10

Clay minerals (according to X-ray analysis) are represented by illite (around 95 %), with a minor admixture of chlorite and kaolinite. Its content reaches 10 % in rock. Carbonate material, in general, is represented by calcium carbonate (10–30, up to 40 %), both crystalline (0.1–0.2 mm) and pelitomorphic.

Dolomite often develops on calcite and makes up to 1–5 % of the rock. The type of cement is porous and contact-porous, sometimes basal. The Upper Albian-Lower Cenomanian sandstones of the Lopushna oil field are characterized by good reservoir properties. Their porosity ranges from 9.2 to 16 %, and their

permeability is 0.7 mD [Fedyshyn, 1998]. Petrographic studies of these sandstones showed that oil in them is in the form of irregular shape accumulations, 0.50–1.5 mm in size, filling the space between the quartz grains (Fig. 6).

Geodynamic factors of the oil and gas-bearing deposits formation in the autochthon of the Pokuttya-Bukovyna Carpathians

After the continental period, which occurred during the Aptian-Middle Albian [Senkovskiy et al., 2004], as the result of the Late Albian-Early Cenomanian global transgression, a marine basin with mainly terrigenous sedimentation was formed in the study region. This caused the accumulation of up to 25 m thick sandstone layers over the entire shelf basin of the Carpathian branch of the Meso-Tethys. The psammitic facies were widely developed throughout the study area, and siliceous sediments were accumulated locally (Figs. 4, 5). While sea-level changes had a decisive influence on the distribution of facies in the sedimentary basin, the post-sedimentary evolution of the deposits under study was controlled by tectonic factors. The burial history of the southwestern part of the autochthon occurred as a result of geodynamic processes of thrusting of the Carpathian Fold Belt, which determined the depth of occurrence of the studied deposits and the degree of their post-sedimentary transformation. The autochthonous Cretaceous strata beyond the overthrust occur within the depth range of around 300 to 1.600 m (Figs. 2, 5). In the borehole Svyatoslavskaya-5 the value of Rock-Eval parameter T_{max} for the Cretaceous rocks at a depth of 1.613 m is 423 °C [Koltun et al., 1998], showing that their maturation level did not reach the top of the oil window. Simultaneously the autochthonous sequence under the overthrust is rapidly dipping to the southwest. The top of the Cenomanian occurs at depths of over 4.000 m in the Lopushna area and is further dipping under the Carpathians Thrust Belt. Thus, the Cretaceous rocks beyond the Carpathian Overthrust reached their present maturation level exclusively as a result of the sedimentary subsidence and remained immature. The way in which the Cretaceous strata beneath the Carpathian Overthrust were buried and developed was primarily determined by tectonic activity resulting from the Early Miocene overthrusting of the Carpathian flysch sequence. As a result, the tectonic factors played a crucial role in shaping the structural characteristics and reservoir properties of the psammites as well as traps formation. As shown by geochemical studies of oils from the Lopushna field [Radkovets et al., 2016], they are quite different from the oils from the accumulations of the platform basement in the northwestern part of the Carpathian

Foredeep [Kokhanivka and Orkhovychi oil fields] in terms of a number of geochemical parameters. At the same time, their geochemical parameters coincide with such of the oils from Carpathian flysch deposits. These data allow us to consider them as one and the same oil family. This indicates that the deposits of the Menilite formation of the Carpathian flysch were the source rocks for the oils of the Lopushna field. Considering the features of the geological structure of the study region, the basement of the Pokuttya-Bukovyna Carpathians, due to the Pokuttya fault, is raised relative to the adjacent block. Thus, as shown in Fig. 7, the layers of the Carpathian flysch occur deeper than the Mesozoic rocks of the platform basement, and this fault could serve as a route for the migration of hydrocarbons from mature oil source rocks of the Menilite formation [Koltun et al., 1998; Kotarba et al., 2019, 2020] to the deposits of the Lopushna field.

Seismic surveys revealed numerous structures within the Pokuttya-Bukovyna Carpathians [Pylypchuk and Karpenchuk, 1988; Havenzon et al., 2011], which are similar to the Lopushna oil field by their geological structure. The possibility of filling the traps of the Mesozoic platform basement with hydrocarbons, which were generated within the Carpathian flysch strata, indicates a high probability of the discovery of new oil and gas accumulations of this type in the autochthon of the Pokuttya-Bukovyna Carpathians.

Originality

The applied complex of lithological, geological-geophysical, and paleogeographical studies made it possible to investigate the features of the distribution of the Albian-Cenomanian psammite complex of rocks, both laterally and in section, their mineralogical and petrographic characteristics, sedimentary environments. The post-sedimentary evolution of the study strata and features of hydrocarbon migration were caused by the dynamics of the Carpathian Flysch Belt thrusting over the margin of the East-European platform.

Practical significance

The obtained results show that the Upper Albian-Lower Cenomanian sandstones, which are oil and gas-bearing in the Lopushna field, represent the potential reservoirs in terms of both thickness and mineral composition within the entire autochthon of the Pokuttya-Bukovyna Carpathians. Since the Pokuttya fault could serve as a migration path for the hydrocarbons from the Carpathian flysch sequence into the platform basement strata, there is a high

probability of the discovery of new accumulations in structures similar to the Lopushna, revealed by seismic

studies in the autochthon of the Pokuttya-Bukovyna Carpathians.

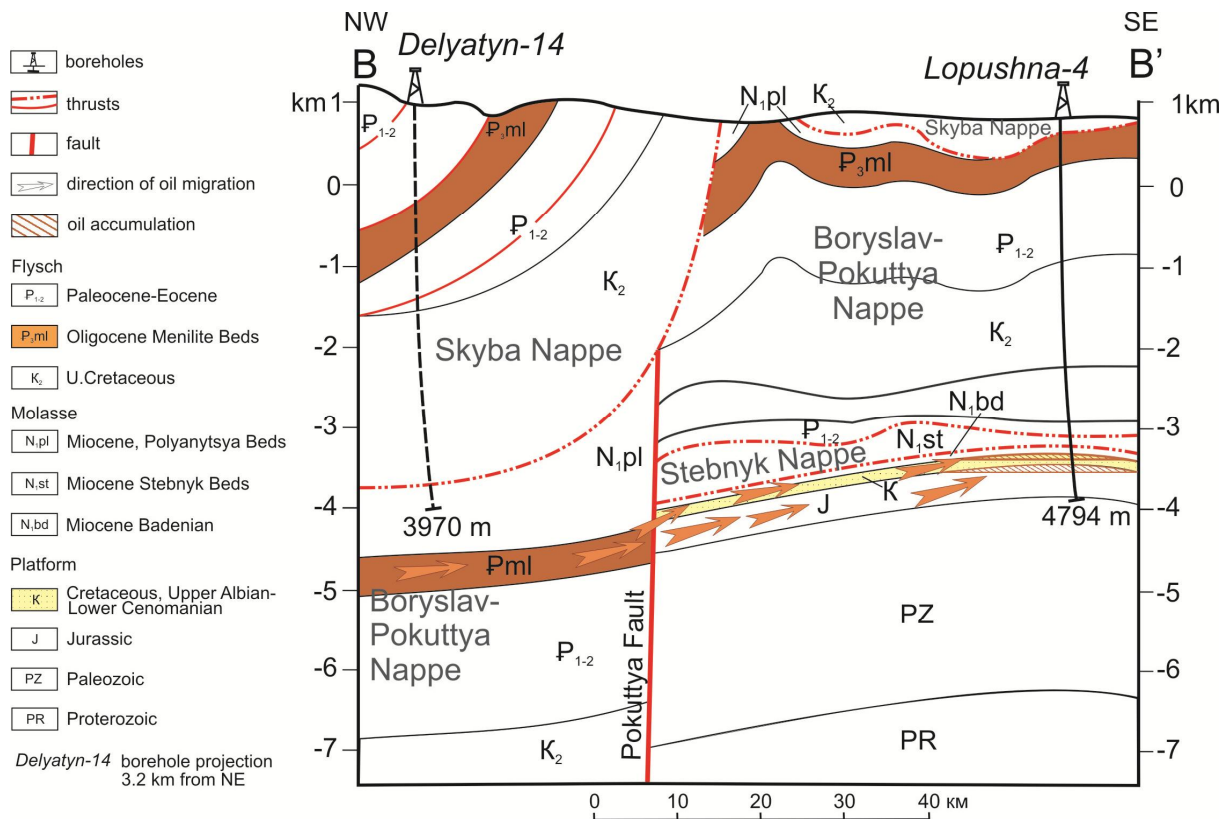


Fig. 7. Schematic longitudinal geological cross-section through the Pokuttya-Bukovyna Carpathians (see Fig. 1). Modified after [Radkovets et al., 2016].

Conclusions

The Late Albian-Early Cenomanian sequence within the entire territory of the autochthon of the Pokuttya-Bukovyna Carpathians is represented mostly by sandstones, which are oil reservoir rocks at the Lopushna field. The thickness of the psammities is 5–30 m. In the subthrust part of the autochthon, they are 15–30 m thick. Within the entire study region, the sandstones are similar in composition to the oil-bearing sandstones of the Lopushna oil field, and in terms of both thickness and composition, they represent the potential reservoir rocks within the entire subthrust area of the Pokuttya-Bukovyna part of the Carpathian foredeep. Petrographically the sandstones are glauconite-quartz with mainly pore and contact-pore cement. Its content mostly does not exceed 10–15 % of the rock volume, providing these psammities with good reservoir properties. According to petrographic studies, oil in sandstones is in the form of accumulations of irregular

shape, 0.5–1.5 mm in size, filling the space between quartz grains.

Changes in sea level had a decisive influence on the formation and distribution of sandy facies in the shelf basin of the Carpathian branch of the Meso-Tethys. The post-sedimentary evolution of these deposits occurred as a result of the geodynamic processes. The burial and maturation history of the Cretaceous strata under the Carpathian Overthrust was controlled mainly by the tectonic processes, caused by the Early Miocene overthrusting.

The tectonic factors had a significant influence on shaping of both structural features and reservoir properties of psammities, as well as on traps formation.

The possibility of filling the traps of the Mesozoic platform basement with hydrocarbons, which were generated within the Carpathian flysch sequence, as confirmed by geochemical studies of rocks and oils, indicates a high probability of the discovery of new accumulations similar to the Lopushna one in the autochthon of the Pokuttya-Bukovyna Carpathians.

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ЛІТОЛОГІЯ, ФАЦІЇ ТА ДИНАМІКА ФОРМУВАННЯ АЛЬБ-СЕНОМАНСЬКИХ ПОРІД-КОЛЕКТОРІВ ПОКУТСЬКО-БУКОВИНСЬКОЇ ЧАСТИНИ АВТОХТОНУ КАРПАТ

Метою цього дослідження є вивчення псамітового комплексу верхнього альбу–нижнього сеноману платформового фундаменту Покутсько-Буковинської частини Передкарпатського прогину, який є однією із основних колекторських товщ Лопушнянського нафтового родовища. Методологія. Комплекс досліджень охоплює кореляцію геофізичних досліджень свердловин, літологічні дослідження керна матеріалу та мінералого-петрографічний аналіз порід та палеогеографічне вивчення седиментаційного басейну. Результати. На основі аналізу всіх наявних свердловин встановлено, що відклади пізньоальбського-ранньосеноманського віку у межах всієї території автохтону Покутсько-Буковинських Карпат представлені здебільшого пісковиками, які складаються із кварцу (50–80 %), польового шпату (1–5 %), мусковіту (0,1–3 %), піриту (0,1–3 %), акцесорних мінералів – циркону й епідоту. Значну частку в складі пісковиків становлять аутигенні мінерали і мінеральні утворення – глауконіт (10–15, іноді до 45 %) та фосфатна речовина (1–3, до 10 %). Цемент у породах переважно поровий і контактово-поровий (10–15 % від об'єму породи), що забезпечує цим псамітам хороші колекторські властивості. На основі палеогеографічних реконструкцій встановлено, що у пізньоальбському-ранньосеноманському віці на теренах усього шельфового басейну Карпатської гілки Мезо-Тетису переважала теригенна седиментація, що спричинило нагромадження потужної товщі пісковиків. Занурення і постседиментаційна еволюція відкладів відбувались під впливом насування Карпатського складчастого поясу, результатом якого стало формування порід-колекторів і пасток у нашаруваннях верхнього альбу – нижнього сеноману. Особливості міграції вуглеводнів у дослідженому регіоні вказують на високу ймовірність відкриття нових родовищ в автохтоні Покутсько-Буковинських Карпат. Наукова новизна. Застосований комплекс літологічних, геолого-геофізичних та палеогеографічних досліджень дав змогу дослідити особливості поширення альб-сеноманського псамітового комплексу порід як по площі, так і у розрізі, їх мінералого-петрографічних характеристик, умов седиментації. Постседиментаційна еволюція досліджених відкладів та особливості міграції вуглеводнів зумовлені динамікою насування Карпатського флішового поясу на край Східноєвропейської платформи. Практична значущість. Одержані результати показують, що верхньоальбські-нижньосеноманські пісковики, які є нафтогазоносними на Лопушнянському родовищі, з огляду як на товщини, так і на речовинний склад, є потенційними колекторами у межах усього автохтону Покутсько-Буковинських Карпат. Оскільки Покутський розлом міг слугувати шляхом міграції вуглеводнів із флішової товщі Карпат у відклади платформового фундаменту, висока ймовірність відкриття нових родовищ в аналогічних до Лопушнянської структурах, виявлених сейсмічними дослідженнями в автохтоні Покутсько-Буковинських Карпат.

Ключові слова: піднасув Українських Карпат; альб-сеноман; псамітові породи-колектори; речовинний склад порід; шельфовий седиментаційний басейн; міграція вуглеводнів.

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