

Prospects for Determination of Hydrocarbon Deposits in a Platform Autochthone under Thrust of the Pokuttya-Bukovyna Carpathians

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Abstract

Substantiation of prospects for oil and gas presence in the platform autochthone under the thrust of the Pokuttya-Bukovynian Carpathians. Complex analysis of drilling materials, seismic prospecting, information on the properties of reservoir rocks, oil and gas presence in nearby deposits, hydrocarbon outcrops, geochemical criteria for oil and gas presence. 125 oil and gas deposits have been opened in Western Ukraine, of which 117 million tonnes of condensed oil and 309 billion m³ of gas have already been extracted. However, scientists estimate they compose only 36% of the initial total hydrocarbon resources. One of the most perspective sites in Western Ukraine is the autochthonous complex of the Neogene, Paleogene, Cretaceous and Jurassic of the Pokuttya-Bukovyna Carpathians, overlapped by the overthrusts of the Boryslav-Pokuttya zone and Folder Carpathians. The Lopushnya oil deposit has already been discovered here. According to seismic data, fifteen promising objects have been discovered in the platform autochthone at a depth of more than 6 km. These are brachyanthyclines dislocated by faults, the area of which varies from 15 to 45 km². They are grouped into several structural lines of the subcarpathian extension. By analogy with the Lopushnya field, deposits of Neogene, Paleogene, Cretaceous and Jurassic can be presence. Reasonable perspectives for oil and gas prospectiv of the identified objects, were grounded and their resource base was estimated by volumetric method. According to the results of structural-tectonic analysis of autochthone formations, study of the parameters of rock-reservoirs and oil and gas presence of the Lopushnya structure, with consideration of the surface oil-gas manifestations and aureoles of sulfide mineralization, as well as information on the oil and gas presence of the border areas of Romania and Poland, refined geological structure of the platform autochthone of the Pokuttya-Bukovyna Carpathians, reasonable hydrocarbon potential of the autochthonous complex in the amount of 268.1 million tons of oil. The complex of geophysical works and drilling of the first parametric well on the Yablunytyska or Dychtynetska structures is proposed to clarify the geological structure and to estimate the industrial oil and gas content of the platform autochthone.

Keywords: Oil; Gas; Deposit; Resources; Autochthone.

1. Introduction

According to the State balance of minerals resources of Ukraine 129 oil and gas deposits have been discovered in Western Ukraine. They are mostly related to the Boryslav-Pokuttya (43 deposits) and Bilche-Volytsya (67 deposits) zones of the Precarpathian depression. The level of development of initial balance reserves of hydrocarbons is quite high and is 73% - 117 million tons of oil with condensate and 309 billion m³ of gas have already been extracted from the bowels of Western Ukraine. However, scientists estimate that this represents only 36% of the initial total hydrocarbon resources of western Ukraine [1]. The developed oil and

gas infrastructure of the Western Region and the country's urgent need for energy and chemical raw materials are challenging geologists to justify new sites for offshore oil and gas drilling. One of the most perspective in the territory of Western Ukraine is a platform autochthone complex of Neogene, Paleogene, Cretaceous and Jurassic of the Pokuttya-Bukovyna Carpathians (south-eastern part of the Ukrainian Carpathians), which lies at depths of 6.0-6.7 km (Fig. 1). They are drawn by the Boryslav-Pokuttya area and the Folding Carpathians, composed of the Neogene, Paleogene and Cretaceous formations (Fig. 2). The initial total resources of the oil and gas region of the Carpathian platform autochthone are estimated at 96.5 million tonnes in oil equivalent [2].

The aim of the research is to substantiate the prospects of oil and gas presence in the platform autochthone under the thrust of the Pokuttya-Bukovyna Carpathians and assessing its resource potential.

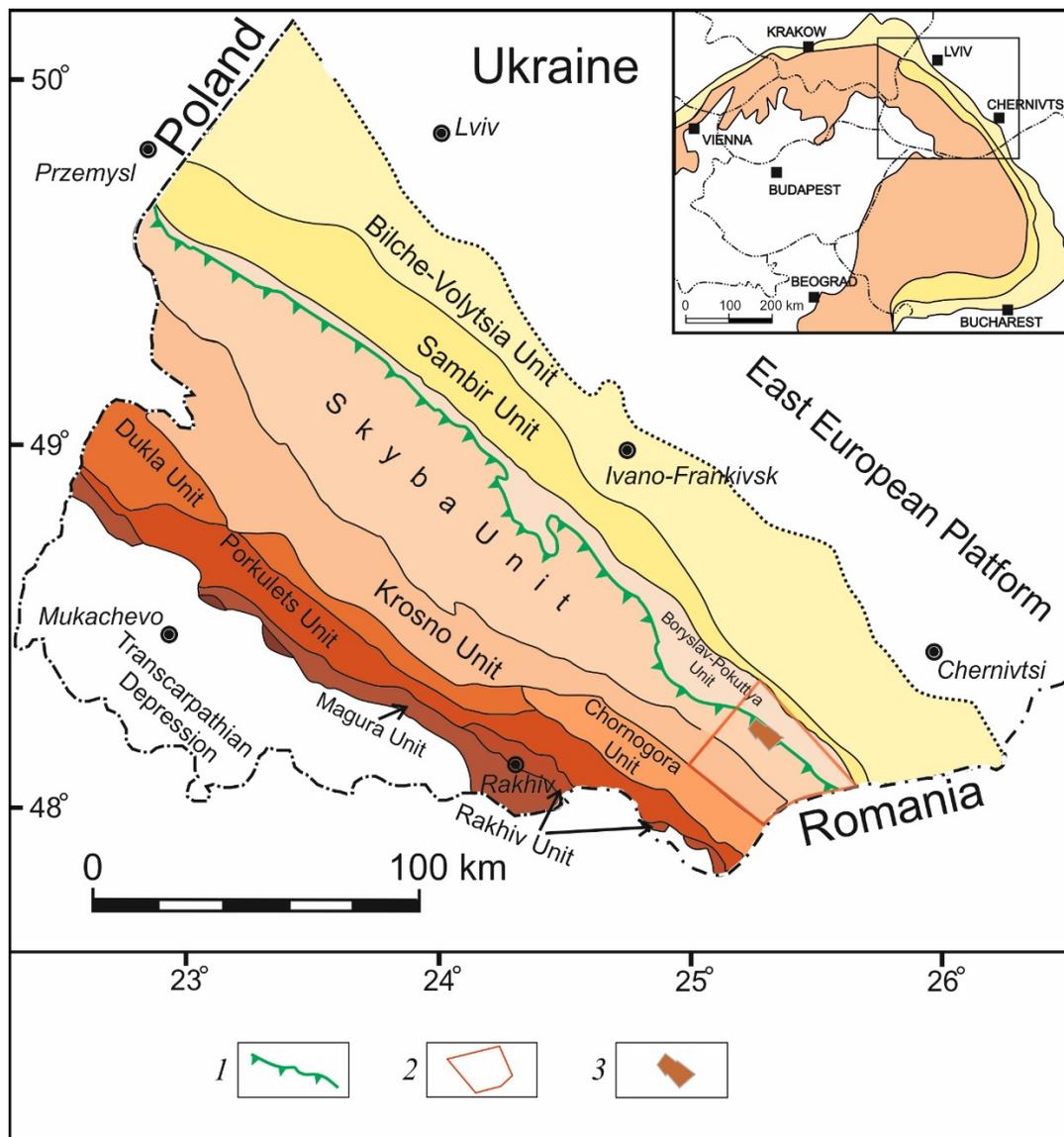


Fig. 1. Sketch geological map showing the location of the main tectonic units of the Ukrainian Carpathians and location of the study area. (geology after Nakapelyukh *et al.* [3] and Slaczka *et al.* [4])

1 – thrust of the Skyba Nappe over the Boryslav-Pokuttya Nappe, 2 – study area, 3 – Lopushnya oil field

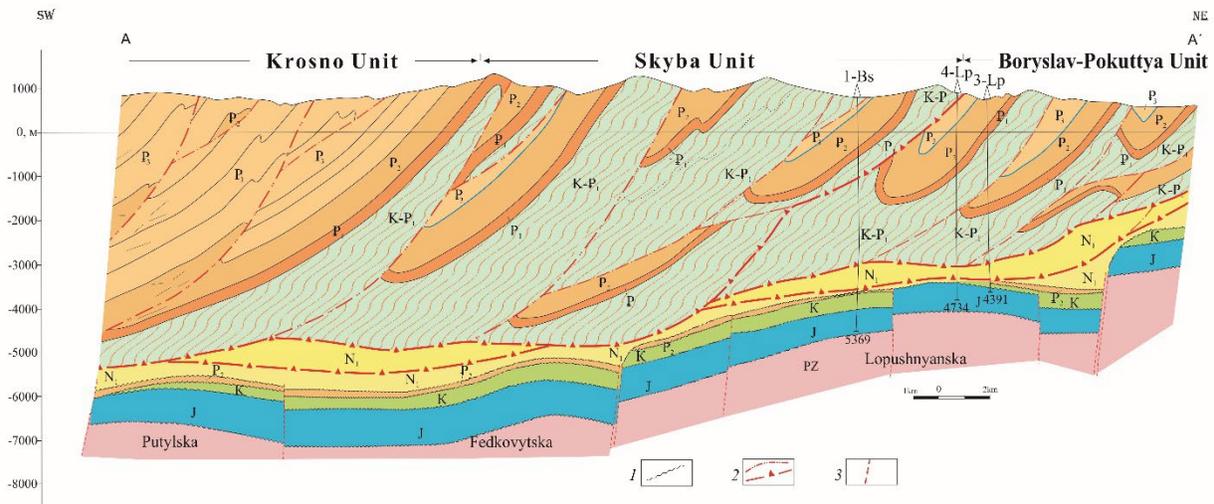


Fig. 2. Regional cross-section along line A-A' of the Pokuttya-Bukovyna Carpathians (cf. Fig. 5). (according to Sheremeta *et al.* [51])

2. Methodology

Systematization and complex analysis of drilling materials, seismic prospecting, information on the properties of reservoir rocks, oil and gas prospective of adjacent fields, hydrocarbon outputs on the daily surface, geochemical criteria for oil and gas perspectives.

3. Results and discussion

In the territory of the Pokuttya-Bukovyna Carpathians, gravimetric survey was compiled at a scale of 1: 50000 over a network of 0.5 × 0.5 km. Gravimetric modelling was compiled on several regional seismic survey profiles. The territory is covered by a 1: 200000 scale magnetic survey. However, the magnetic and gravitational fields maps have not been constructed yet, that is, brought into line with modern scientific and technical requirements. The question of linking these maps with similar maps of neighboring Romania also remains open. But basic information on the structure of the autochthone platform under the Carpathian thrusts can only be given by seismic survey. Western Ukrainian geological exploration expedition performed two regional 2D seismic profiles of the methods of common depth point and depth seismic testing. 2D seismic surveys with a total length of seismic profiles of about 1000 km were also performed. The density of the profiles is approximately 1 km per 1 square kilometer of the study area. However, the network of seismic profiles is uneven. The mountainous terrain with absolute elevations from 600 m to 1200 m is difficult to reach, as well as the compact buildings of mountain valleys did not allow qualitative field seismic research in some areas. In the north-eastern part of the Pokuttya-Bukovyna Carpathians, about two dozen wells were drilled, which revealed deposits of a platform autochthone. The vast majority of them are located on the Lopushnya structure, which is associated with the oil field of the same name.

General features of the geological structure of the autochthonous of the Pokuttya-Bukovyna Carpathians are described by Krupsky [61], Mykhailov *et al.* [71]. According to the results of the analysis of the gravitational field and density modelling, Mayevsky offered his own vision with co-authors for perspective structures of the north-eastern part of the study area near the Lopushnya structure [81]. According to the interpretation of the materials of geophysical exploration of wells of the mentioned structure, petrophysical dependences for terrigenous and carbonate reservoir rocks were established by Grytsyshyn [91]. Prospects of oil and gas presence appreciates Rudko with co-author [101].

The current ideas about the geological structure of the Carpathian platform autochthone are rather approximate. However, today a certain amount of geological and geophysical materials has been accumulated, analysis of which allows to refine the geological model and

prospects of the oil and gas presence in the autochthone under the Carpathians. Materials from the hydrocarbon outputs on the bottom surface, as well as some geochemical indicators, are also included in the analysis to substantiate the prospects for the oil and gas prospects of the Pokuttya-Bukovyna Carpathians.

In addition, the current assessment of hydrocarbon resources of platform autochthone is made by the method of comparative geological analogies with internal (within the region) or external (Poland, Romania) standards with using methods of determining specific resource densities per unit area [2]. In our opinion the materials obtained are sufficient for the objective estimation of the hydrocarbon potential by the volumetric method, which is much more accurate than the method of comparative geological analogies.

Therefore, the main task of the article is to clarify the geological structure and prospects of the oil and gas presence in the Pokuttya-Bukovyna Carpathians, based on their estimation of hydrocarbon resources by volumetric method and substantiation of priority prospects for geological prospecting works.

The prospect of the subsoil complex is undoubted, since the Lopushnya oil field was discovered at the platform autochthone below the boundary of Skyba and Boryslav-Pokuttya covers (Figs. 3, 4).

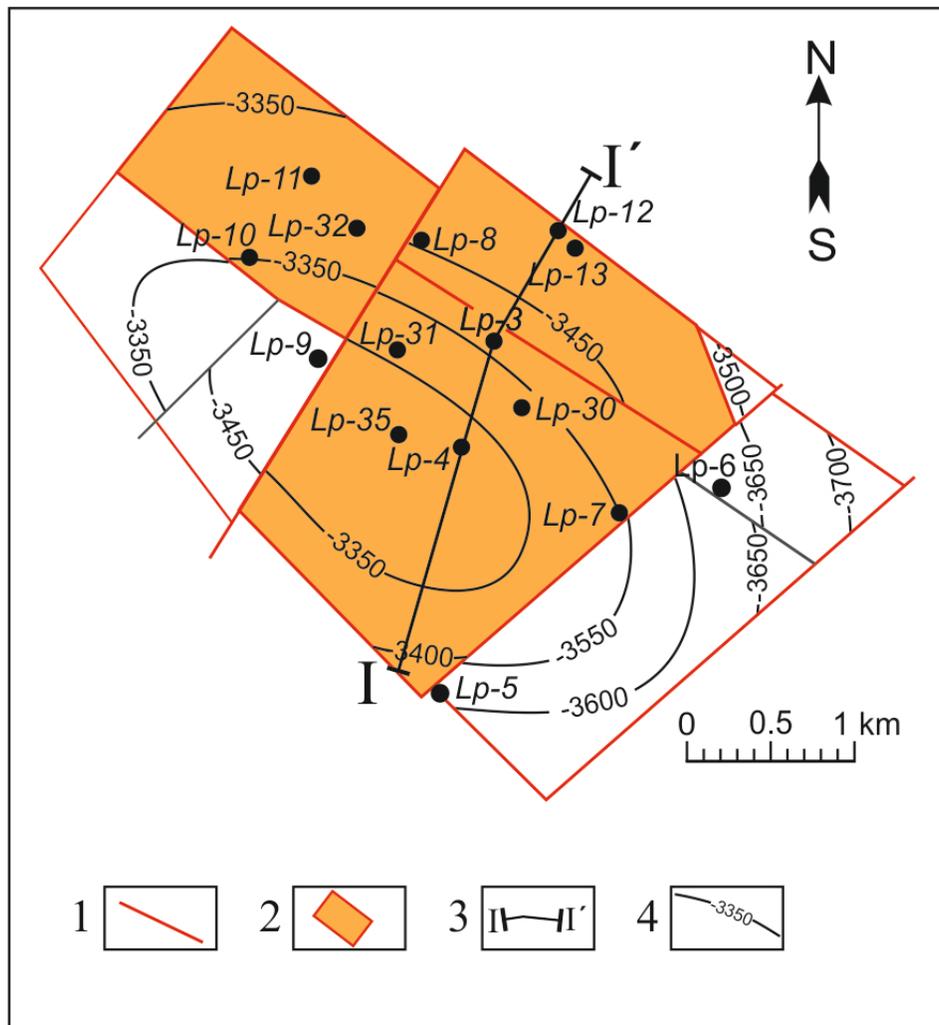


Fig. 3. Structural map of the Lopushnya oil field on the top of Cenomanian, modified. (according to Musyka [11])

1 – tectonic disturbances, 2 – oil deposits, 3 – geological cross-section (cf. Fig. 4), 4 – isohypses of the cover of Cenomanian sediments, m

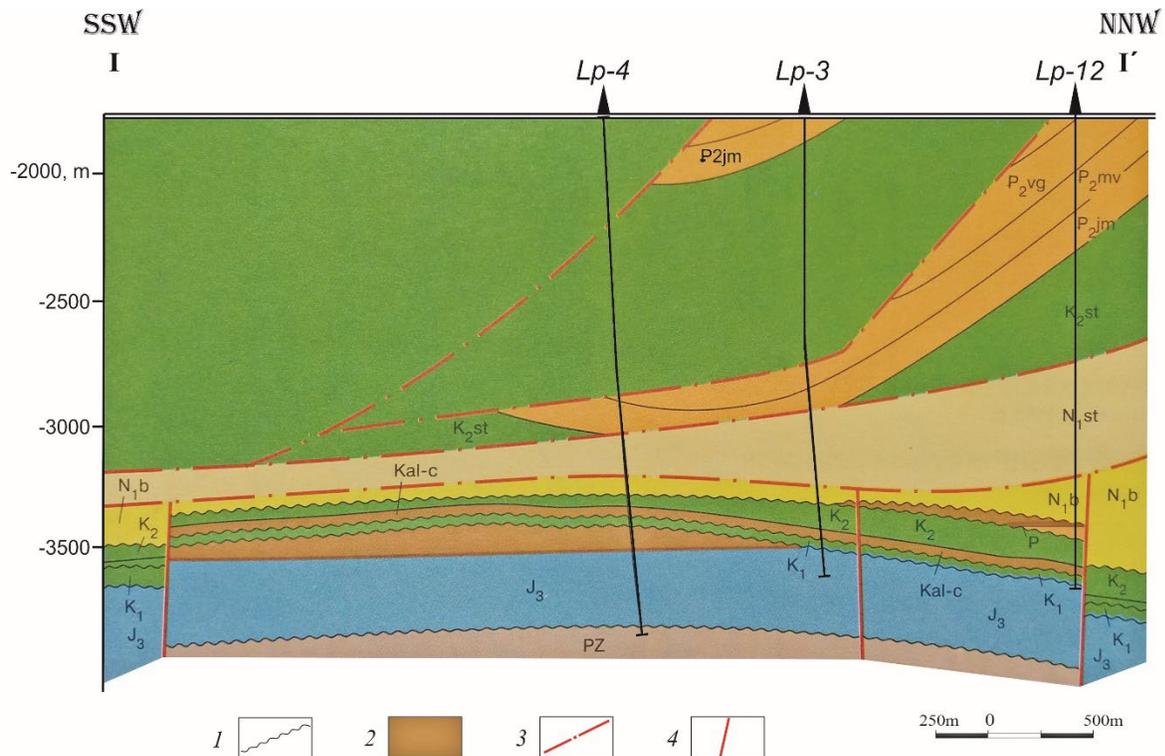


Fig. 4. Geological cross-section along the line I-I' of Lopushnya oil field (cf. Fig. 3), (modified. according to Trushkevych [11])

1- unconformity, 2 - oil deposits, 3 - lines of thrusts, 4 - tectonic disturbances

On the covering of the Cenomanian deposits of Upper Cretaceous, the Lopushnya structure is a brachyanthycline of the north-western extension, measuring approximately 4.5×2.5 km in size and with an amplitude of up to 150 m.

In 1984, during the test of Albian and Cenomanian sediment well 3 from a depth of 4180-4199 m, an oil inflow of 283.4 tons per day was obtained through a 10-mm diaphragm. The reservoirs are tectonically shielded, confined to three blocks. Subsequently, two more deposits were established at the deposit. Paleogene deposits from well 8 produced an oil inflow of 103.6 tons per day through a 8 mm diaphragm. Further exploratory drilling has revealed that the deposit is lithologically screened, located on the north-east wing of the fold. Another deposit was discovered in the formations of the Upper Jurassic at a depth of 4300-4316 m by well 4, during which the test produced an inflow of oil with a flow rate of 104.3 tons per day through a 7-mm diaphragm. The deposit is massive and sheetlike. Lopushnya deposits are located at depths of 4080-4383 m, forming a total oil prospecting floor of more than 300 m.

Sandstones with a porosity of 7.4-12.5% and a permeability of 0.001-0.003 mD serve as reservoirs for the Paleogene deposit. The effective reservoir thickness ranges from zero to 7.4 m. The Albian and Cenomanian sandstones have high filtration-capacity characteristics: porosity 12.9-18.6%, permeability 0.010-0.025 mD, which provides significant oil flows. The effective thickness of the reservoir rocks is 23.3-37.0 m. The Jurassic deposit is associated with fractured-pore organogenic-fragile limestones, in the section of which there are several interlayers with sufficiently high filtration-capacity properties – porosity 11.2-14.3% and a permeability of 0.002-0.004 mD. The effective Jurassic deposit thicknesses are the largest and fluctuate within 19.2-42.8 m.

The covering of the deposits serves as well-preserved layers of mudstone and marl.

The geological reserves of the oil deposits are estimated at almost 15 million tons, of which about 1 million tons have already been extracted. The main object of production is the massive reservoir of Jurassic deposits. The mode of operation of deposits - elastic and dissolved gas.

The gas content varies widely: from 25.1 m³/ton for Jurassic deposit to 507.9 m³/ton for Paleogene deposit.

It should be noted that in such a geostructural situation under the forced Carpathian elements in platform deposits in the territory of Romania, the Cuejdiu, Frasin, Malini, Secuieni, Valea Secu, Bacau, Margineni, Zemes, Tasbuga, Slanic, Pipirig gas-condensate deposits were discovered [12-14], and in the territory of Poland the gas-condensate deposits of Liachowice, Lonkta, Stryzava, Zalessie, Ushkovce, Cytynya and oil Nosuvka [15-16].

The Lopushnya deposit discovered in the territory of Ukraine and the results of the seismic surveys, prospecting, research and geological materials of Romania and Poland allow to get approximate ideas about the geological model of the platform autochthone under the Carpathian slope and to highly evaluate the prospects of its oil and gas. The structural plan of platform autochthone deposits of the Pokuttya-Bukovyna Carpathians most clearly reflects the reflection horizon J, confined to the Jurassic cover. According to his behavior, the platform autochthone is immersed in the south-west direction in the system of stepped faults of the Carpathian stretch. In addition, it is broken by transverse disturbances, which together with longitudinal faults cause the block structure of the Mesozoic base.

To the south-west of the Lopushnya deposit, seismic exploration revealed a large number of perspective objects, united in several structural lines of the north-western direction: Rozhenska – Biskivska – Petrovetska – Staykivska, Usteritska – Fedkovytska – Zagulivska – Shurdynska, Chotkevyska – Dychtynetska – Lustunska, Putylska – Ploskivska, Yablunytska – Selyatynska, Probiynivska – Goloshynska (Fig. 4). According to the P. M. Sheremeta with co-authors [5] further south-west there may be several more structural lines. All of these objects are brachianticline oriented in the Carpathian north-west. The length of the lift ranges from 6-10 km, width - 3-5 km, amplitude - 150-300 m. Most structures, like Lopushnyansk, are broken up by the orthogonal system of disturbances into separate blocks. The areas of structures vary from 15 to 45 km². The Lopushnya structure (about 4300 m) lies closest to the surface, the depths of the rise are raised up to 6500-7000 m towards the south-west. Biskivska structure is also confirmed by scientists of Ivano-Frankivsk State Technical University of Oil and Gas based on the results of data analysis of a complex of gravimetric and seismic surveys [17]. In the far southwest of the study area, the platform autochthone is expected to be raised by seismic survey materials, so the Yablunytska structure may lie at depths up to 6100 m.

Only the Lopushnyanska anticline, located in the first, least deep structural line, was studied by drilling. One well was drilled at the Rozhenska, Tatalivska, and Petrovetska uplifts, but they were not in optimal structural conditions. However, in the well 13 of the Tatalivska fold there were oil and gas during drilling. The main reason for failures of exploratory drilling is the low quality of seismic structures, which often do not correspond to the actual geological structure of exploration objects.

According to the results of seismic survey and drilling at Lopushnya, Tatalivska, Rozhenska, Petrovetska structures, it was founded that a significant role in the formation of hydrocarbon traps, in addition to tectonic processes of plicative and disjunctive nature belongs to active erosion processes. They were most intensive from the end of the Late Cretaceous to the beginning of the Paleogene. Paleovalleys and paleocuts are mapped to the north-east of the Lopushnya field and within its boundaries probably continue in the platform autochthone and under the thrust of the Pokuttya-Bukovyna Carpathians. Pre-Neogene paleorelief was an important factor in the formation of hydrocarbon traps. Oil-bearing sandstones of the Neogene were deposited on the sides of the Paleovalleys, which led to stratigraphic traps. Vaulted tectonic shielded deposits formed in Mesozoic erosional ledges (Fig. 4).

Radkovets *et al.* [18] has proposed a scheme of hydrocarbon migration to the formation of a platform autochthone. According to the results of their research, hydrocarbons move along the planes of the Carpathian thrusts, forming deposits in the autochthon. One of the co-authors of this article came to a similar conclusion [19]. According to him, hydrocarbons migrate along the planes of curved thrusts first horizontally and then vertically, reaching the earth's surface. Shlapinsky believes that the evidence of hydrocarbon deposits at depth is a

significant number of oil and gas manifestations on the earth's surface. Hydrocarbons migrate from the autochthone through the rocks of the flysch complex, but do not form significant accumulations in it due to the lack of trap conditions. The mentioned researcher recorded oil source from the indigenous and Quaternary rocks, spots of oil on water, bituminosity of rocks, the smell of oil in the rocks and the outflows of combustible gas. These data are shown in (Fig. 5).

Investigating the alluvium of Carpathian rivers, Shlapinsky established a correlation between sulfide mineralization of rocks and hydrocarbon deposits [20].

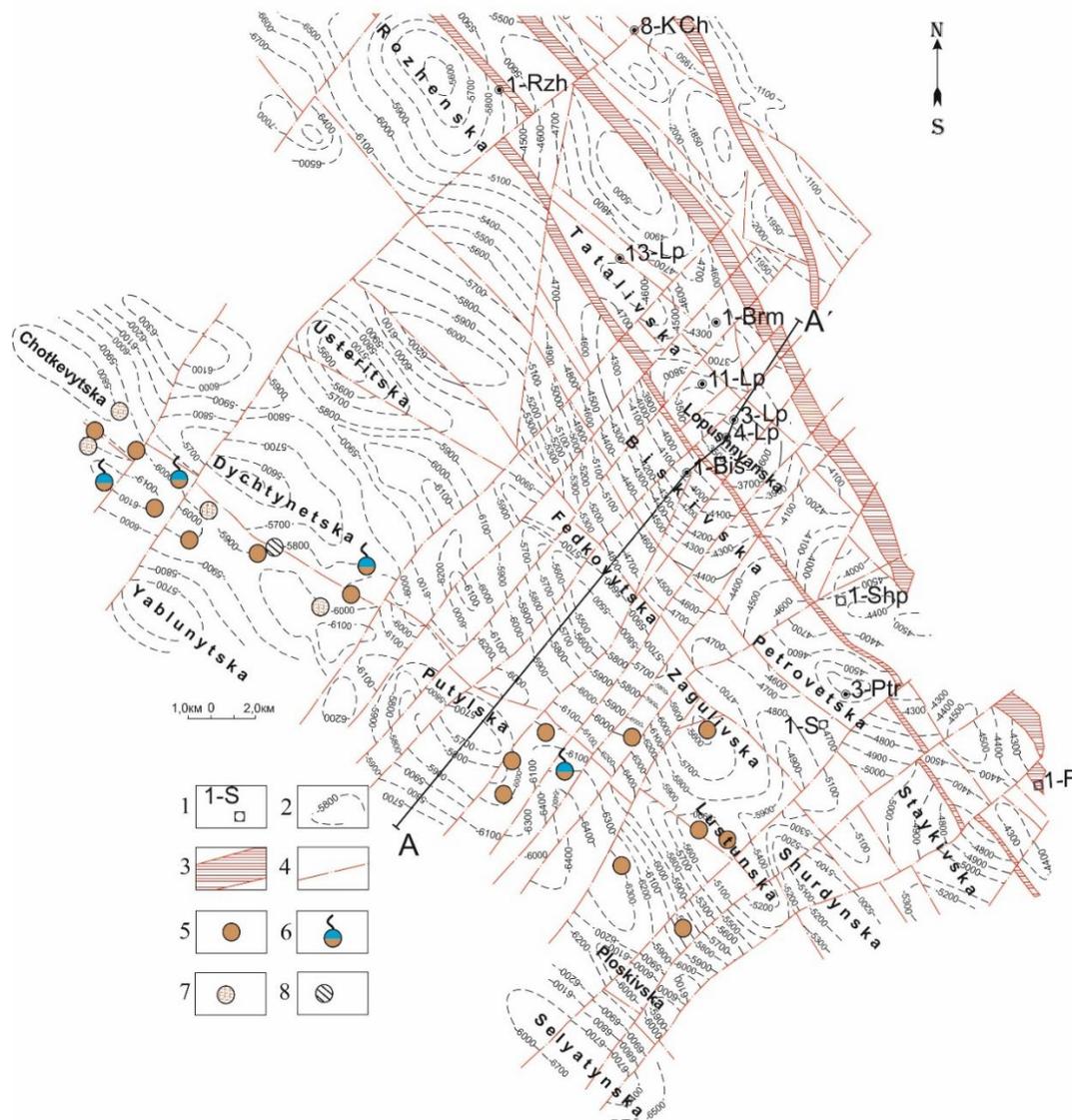


Fig. 5. Forecast structural map of the Pokuttya-Bukovyna Carpathians along the horizon of reflection J in the cover of the Rava-Ruska suit of Jurassic. Based on the materials of the Western Ukrainian geological exploration expedition [21] with generalizations and additions by the authors.

1 – wells; 2 – isohypses along the reflection horizon J, m; 3 – regional faults; 4 – tectonic disturbances; 5 – manifestations of oil on the surface; 6 – oil and gas manifestations on the surface; 7 – manifestations of on the surface; 8 – rocks with a smell of hydrocarbons on the surface.

The sources of sphalerite, galena, chalcopyrite are Cretaceous-Paleogene flysch rocks. According to V. Shlapinsky, sulfides are formed due to the interaction of groundwater saturated with metal ions with hydrogen sulfide coming from places of accumulation of hydrocarbons. He admits that larger accumulations of hydrocarbons correspond to higher sulfide contents in the surrounding rocks. Significant content of sulfides of zinc, lead and native

lead sulfides in the heavy fraction of alluvium was recorded in many oil fields, including Lopushnya. Background values or absence of sulfides are typical for areas where there are no industrial hydrocarbon deposits. Lengthening and contrasting areas with sulfide content up to 15% of the weight of the heavy fraction of alluvium were established by us in the Pokuttya-Bukovyna Carpathians along the structural line Khotkevyska - Dykhtynetska - Yablunyska - Putylska - Lustunska - Ploskivska, which may be a search sign of hydrocarbon deposits.

Table 1. Oil resources of the platform autochthone of the Pokuttya-Bukovynian Carpathians

Structure	Oil-bearing area. km ²	Effective oil-saturated thickness. m	Coefficient			Oil density. g/cm ³	Oil resources. million t
			porosity	oil saturation	Recalculated oil shrinkage)		
1	2	3	4	5	6	7	8
Staykivska	15.6	5	0.12	0.60	0.6	0.82	2.8
	15.6	7	0.13	0.62	0.6	0.82	4.3
	15.6	30	0.14	0.66	0.6	0.84	21.8
							28.9
Putylska	7.5	15	0.12	0.62	0.6	0.82	4.1
	6	10	0.13	0.64	0.6	0.86	2.6
	6	20	0.14	0.66	0.6	0.86	5.7
							12.4
Tatalivska	7.9	4	0.12	0.63	0.618	0.82	1.2
	7.9	15	0.14	0.64	0.7	0.85	6.3
	7.9	30	0.14	0.67	0.626	0.83	11.5
							19
Rozhenska	24	5	0.12	0.62	0.6	0.82	4.3
	24	10	0.13	0.64	0.6	0.86	10.3
	24	20	0.14	0.66	0.6	0.86	22.9
							37.5
Fedkovytska	15	6	0.15	0.6	0.63	0.83	4.2
	15	7	0.15	0.6	0.62	0.83	4.9
	15	20	0.12	0.6	0.67	0.83	12
							21.1
Zagulivska	6	6	0.15	0.6	0.63	0.83	1.7
	6	7	0.15	0.6	0.62	0.83	2.0
	6	20	0.12	0.6	0.67	0.83	4.8
							8.5
Usteritska	15	6	0.15	0.6	0.63	0.83	4.2
	15	7	0.15	0.6	0.62	0.83	4.9
	15	20	0.12	0.6	0.67	0.83	12
							21.1
Dykhtynetska	30	7	0.15	0.6	0.63	0.83	10
	30	8	0.15	0.6	0.62	0.83	11.1
	30	15	0.12	0.6	0.67	0.83	18
							39.1
Shurdynska	10	6	0.15	0.6	0.63	0.83	2.8
	10	7	0.15	0.6	0.62	0.83	3.3
	10	20	0.12	0.6	0.67	0.83	8
							14.1
Lustunska	10	6	0.15	0.6	0.63	0.83	2.8
	10	7	0.15	0.6	0.62	0.83	3.3
	10	20	0.12	0.6	0.67	0.83	8
							14.1
Ploskivska	5	15	0.15	0.6	0.63	0.83	3.5
	5	10	0.15	0.6	0.62	0.83	2.3
	5	15	0.12	0.6	0.67	0.83	3
							8.8
Selyatynska	12	20	0.15	0.6	0.63	0.83	11.3
	12	10	0.15	0.6	0.62	0.83	5.6
	12	10	0.12	0.6	0.67	0.83	4.8
							21.7

Structure	Oil-bearing area. km ²	Effective oil-saturated thickness. m	Coefficient			Oil density. g/cm ³	Oil resources. million t
			porosity	oil saturation	Recalculated oil shrinkage)		
Yablunytska	12	20	0.15	0.6	0.63	0.83	11.3
	12	10	0.15	0.6	0.62	0.83	5.6
	12	10	0.12	0.6	0.67	0.83	4.8
In all							21.7
							268.1

Taking into account the parameters of the Lopushnya deposit, and also taking into account the conclusion of the Sheremeta *et al.* [21] on increasing the thickness of Paleogene rocks in the western direction to 300-400 m, we calculated the probable hydrocarbon potential of the platform autochthone. The total geological resources of oil of Jurassic, Cretaceous and Paleogene-Neogene complexes, which lie under the thrusts of the Pokuttya-Bukovyna Carpathians, are estimated at 268.1 million tons (see Table 1). This is several times more than the number of resources 73.1 million tons determined by the method of comparative geological analogies [22]. This method involves the use of internal (within Western Ukraine) and external (Lithuania, Poland, Romania) data to determine the specific densities of resources per unit area (one square kilometer). However, the estimation of hydrocarbon potential by the method of comparative geological analogies is very inexact.

It is possible that simultaneously with the search for deposits under the thrust of the south-eastern Carpathians, hydrocarbon deposits will be discovered in allochthonous rocks, in which Nazariivska, Maksymivska, Shepitska, Sergiivska, Magurska and other structures have been discovered (according to the research of the Western Ukrainian geological exploration expedition during 1998-2006).

The development of such significant hydrocarbon resources for Ukraine is hampered, first of all, by insufficient geological exploration of the study area. It is necessary to make high-precision gravity and magnetic exploration, as well as 3D seismic exploration in order to clarify the structure of the platform autochthone of the Pokuttya-Bukovyna Carpathians. The main task of parametric drilling is to study the composition, thickness and prospects of industrial oil and gas deposits of autochthone deposits to the south-west of the Lopushnya area, where, according to preliminary materials, an increase in the thickness of Paleogene and Upper Cretaceous shelf formations are possible. To resolve this issue, it is advisable to drill a parametric well at the Yablunytska or Dychtynetska structures with a projecting depth of 6300-6400 m. Of all the identified structures they have significant oil resources, lie closely to the surface, least disturbed by faults, near them are fixed oil and gas prospects increase in the concentration of sulfides in the bedrock. Resources of the Yablunytska structure are defined by us in 21.7 million tons of oil, Dychtynetska – 39.1 million tons of oil. It is possible to estimate the industrial oil and gas content of the Paleogene and the Upper Cretaceous and to determine the feasibility of preparation for exploratory drilling of other structures of the Pokuttya-Bukovyna part of the Carpathians. Considering the mountainous terrain of the study area, particular attention should be paid to the environmental risks of well drilling [23] and the risks of emergencies [24].

According to the results of structural-tectonic analysis of the autochthone formations, the study of the parameters of the reservoir rocks and the oil and gas prospects of the Lopushnya structure, taking into account the surface oil-gas manifestations and aureole of sulphide mineralization, as well as information about the oil and gas prospective of the border areas of Romania and Poland the geologic structure of platform autochthone of the Pokuttya-Bukovyna Carpathians was verified and prospects for exploring medium and large hydrocarbon deposits were grounded.

The hydrocarbon potential of the Pokuttya-Bukovyna Carpathian autochthone complex in the amount of 268.1 million tons of oil is grounded. The complex of geophysical researches and drilling of a parametric well on the Yablunytsia structure is offered with the purpose of

estimation of industrial oil and gas prospectives of autochthone deposits of Paleogene and Upper Cretaceous and determination of expediency of preparation for exploratory drilling of other perspective objects.

4. Conclusions

Western oil and gas region of Ukraine still has significant prospects for discovering new fields. One of the most promising is the Paleogene, autochthone platform of the Paleogene, Cretaceous and Jurassic of the Pokuttya-Bukovyna Carpathians, which is covered by the flysch of the Carpathian Mountains. In the platform autochthone under the Carpathian Lopushnya oil deposit was discovered, more than one and a half dozen prospective structures were discovered by seismic exploration, the resource base of which was estimated by us at 268.1 million tons of oil.

Development of the prospective complex is restrained by insufficient geological exploration of the territory of the Pokuttya-Bukovyna Carpathians by seismic exploration and drilling, significant depths of the prospective complex, the inaccessibility of mountain areas and the absence of investors willing to invest in the project. Depth indicators are oil and gas on the earth's surface and aureole of increasing sulfide concentrations in the bedrock.

We suggest drilling a parametric well at the Yablunytska or Dychtynetska structures to estimate the industrial oil and gas content of the Paleogene and Upper Cretaceous platform complex after 3D seismic exploration,.

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