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DISTRIBUTION OF FORMATION PRESSURES AND COLLECTOR PROPERTIES OF MOUNTAIN ROCKS AT GREAT DEPTHS IN OIL AND GAS BASINS OF UKRAINE

The study of geodynamic processes, the distribution of reservoir pressures and the properties of deep rocks in Ukraine's oil and gas basins, is crucial for enhancing geological exploration, predicting hydrocarbon accumulation, and assessing production methods. This is an important and timely issue in the field today. Analysis of geological and geophysical studies, deep drilling, laboratory studies of core and sludge, as well as experiments to examine the physical properties of reservoir rocks, form the optimal approach to address this issue. The research compared results in different regions of Ukraine, particularly the Dnipro-Donetsk Depression and the Precarpathian Foredeep. The main prospects for discovering oil and gas deposits at great depths in Ukraine are associated with the Precarpathian Foredeep and the Dnipro-Donetsk Depression. The prospects for oil and gas resources in deep-seated horizons are closely linked to studying the region's geodynamic features, rock reservoir properties, and the distribution of reservoir pressures and temperatures within sedimentary basins. Many works, ranging from articles and dissertations to comprehensive monographs, have been devoted to the problem of the distribution of reservoir pressures and temperatures, as well as the reservoir properties of these rocks. The study found that with depth, the porosity and permeability of rocks gradually decrease. Still, in some horizons, anomalously high values of these characteristics are observed, which opens up new opportunities for the industrial development of deep hydrocarbon deposits. In particular, sandstones with an open porosity of up to 5.58 % were discovered at a record depth of over 6.5 km for the Dnipro-Donets Depression, indicating the possibility of effective reservoirs even at such significant depths. It was determined that at depths of up to 10–12 km under anomalously high reservoir pressures, the reservoir properties of rocks are preserved, which is critically important for predicting new deposits. It was confirmed that a sharp increase in reservoir pressure is observed in closed deposits, which gradually reach geostatic values, creating favorable conditions for forming oil and gas clusters. These studies also demonstrate the influence of secondary changes in rocks on their filtration and capacity properties and substantiate the role of thermobaric factors in forming anomalous reservoir pressures. Based on the results obtained, models and formulas were proposed to calculate the depths of preservation of reservoir rocks in various geological conditions. This significantly expands the idea of the prospects of deep-seated horizons for hydrocarbon production. The following can be highlighted as a scientific novelty. For the first time, the study conducted a detailed analysis of the relationship between reservoir pressure, geostatic conditions, and secondary changes in reservoir rocks at great depths; formulas were proposed for estimating reservoir rocks' maximum depths of existence. The study's results help predict hydrocarbon accumulations and choose optimal extraction methods at great depths, increasing the efficiency of geological exploration and reducing risks in exploiting oil and gas deposits.

Key words: core studies, porosity and permeability, reservoir rocks, deep-seated horizons, hydrocarbon deposits, oil and gas fields, thermobaric conditions, Dnipro-Donetsk Depression, Precarpathian Foredeep.

Introduction

Today, the prospects for discovering new hydrocarbon deposits in Ukraine are largely associated with deep-seated, complex-structured, and low-porosity horizons in the Western Ukrainian and Eastern Ukrainian oil and gas-bearing regions (Fig. 1).

The depletion of resources at shallow and medium depths in many regions of the country poses the task of scientists to study deep horizons, which are characterized by variable geodynamics, complex geological conditions, high reservoir pressures, and temperature regimes.

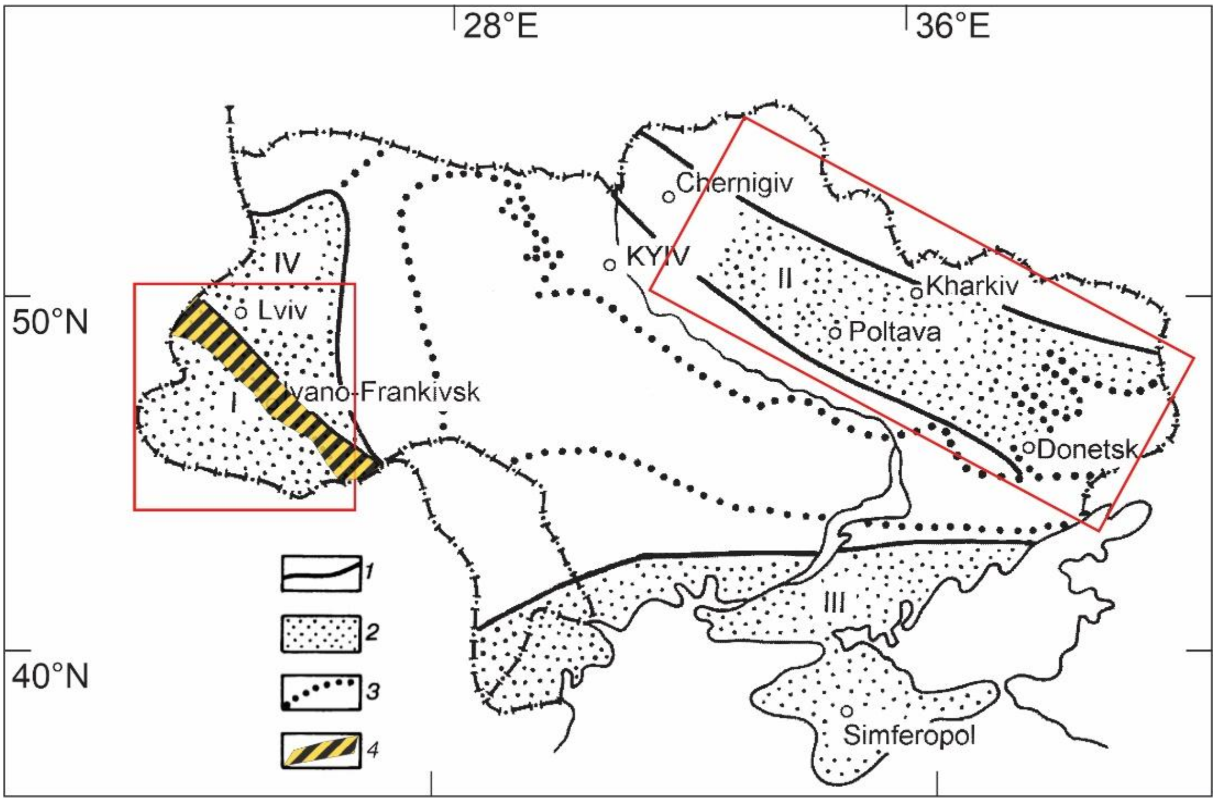

Fig. 1. Scheme of oil and gas geological zoning of Ukraine:

1 – boundaries of oil and gas provinces; 2 – oil and gas provinces and regions; 3 – boundaries of geostructural elements; 4 – Precarpathian Foredeep; I – Carpathian oil and gas province (Western Ukrainian oil and gas region); II – Dnipro-Donetsk oil and gas province (Eastern Ukrainian oil and gas region); III – Black Sea-Crimean oil and gas province (Southern Ukrainian oil and gas region); IV – Volyn-Podilsk oil and gas region (Western Ukrainian oil and gas region).

These factors significantly complicate the processes of drilling, geophysical research, and hydrocarbon production. In such conditions, it becomes especially important to systematize the geodynamic features of the region. This includes analyzing the results of geological and geophysical research, conducting laboratory tests on core samples and sludge, and conducting experimental studies of the physical properties of reservoir rocks. Additionally, it is crucial to know how these properties change under the influence of reservoir pressures and temperatures.

Understanding geodynamics, compaction processes, cementation, and transformation of rocks at great depths is the basis for predicting the prospects of oil and gas-bearing capacity. This allows for a more reasonable assessment of rocks' filtration and capacity properties to improve geophysical research quality and determine the optimal methods for revealing productive horizons. The study of deep-seated deposits is a scientific and practical necessity, given the growing demand for hydrocarbons and the rapid development of production technologies.

The geodynamic development of both the Carpathian folded structure and the Dnipro-Donetsk Depression (DDZ) contributed to the processes of oil and gas formation and, accordingly, the formation of their deposits and the peculiarities of their location [Tretyak, Maksymchuk & Kutas, 2015; Pymonenko, Skopychenko & Vergelska, 2020; Sheremeta, Nazarevych A. & Nazarevych L., 2023; etc.]. The main hydrocarbon supply structures were deep faults, especially the zones of their intersection with other disjunctive disturbances. Accordingly, significant oil and gas potential prospects are associated with deep-lying horizons, where reservoir temperatures and pressures are high.

Of course, a significant number of works, from articles and dissertations to comprehensive monographs, have been devoted to the problem of the distribution of reservoir pressures and temperatures along the section of sedimentary basins and the reservoir properties of rocks in Ukraine [Glushko et al., 1977; Glushko & Kruglov, 1977; Zolotov et al., 1984; Orlov, 1980; Krayushkin, 1988; Pluzhnikova & Tarakanova, 1988; Lodzhevskaya, 1990; Maevsky et al., 2012; Maevsky et al., 2013; Khomyn et al., 2019; Dubei, 2019; Lazaruk, 2023; Fedoryshyn et al., 2024;

etc.]. Therefore, we believe there is no need to conduct even a brief review of them; instead, we will focus only on the following main conclusions and results. The study found that with depth, the porosity and permeability of rocks gradually decrease. Still, in some horizons, anomalously high values of these characteristics are observed, which opens up new opportunities for the industrial development of deep hydrocarbon deposits.

Authors [Dobrynin, 1968; Distrianov, 1974; Gabinet, 1982; Trushkevych & Shvai, 1998; Yemets & Bezrodna, 2023; etc.] indicate that at great depths, based on the patterns of geodynamic compaction of rocks, one should not expect reservoir rocks with high filtration-capacitive properties. Reservoir rocks at great depths are characterized by a very high degree of compaction, which leads to a decrease in granular porosity to minimum limits and, thus, extremely low reservoir indicators. The density values of such rocks are 2.580–2.650 kg/m^3; open porosity does not exceed 5 %. Thus, on the one hand, sandy-silty rocks from depths of more than 5.000 m are mostly low-porous. On the other hand, the world experience in the development of oil and gas fields indicates that at great depths, rocks can have high reservoir properties [Bonter & Trice, 2019; Krézsek et al., 2023; Wang et al., 2024; Nakajigo et al., 2024; Wu et al., 2024; etc.], but the nature of this phenomenon remains insufficiently studied today.

This article is devoted to analyzing the distribution of reservoir pressures and reservoir properties of deep rocks in Ukraine's oil and gas basins. It summarizes the results of previous studies and offers new approaches to understanding geodynamic and deep geological processes, which opens up prospects for further development of complex horizons.

Objective

The study is aimed at examining the distribution of reservoir pressures and properties of deep rocks in Ukraine's oil and gas basins. The main goal is to optimize geological exploration processes, improve the quality of forecasting hydrocarbon accumulations in deep-seated horizons, and provide a scientifically sound assessment of rocks' filtration and capacity properties. This will allow the development of effecttive methods of drilling, reservoir development, and production under high pressures and temperatures.

Geological Background

Industrial gas, gas condensate, and oil have been found in phase-heterogeneous deposits at more than 4.000 m depths across more than 70 oil and gas basins worldwide. Additionally, industrial oil and gas potential at depths of more than 6.000 m has been proven in 28 NGBs, where almost 100 hydrocarbon deposits have been discovered [Mayevsky et al., 2013]. In Ukraine, the main prospects for discovering oil and gas deposits at great depths today are associated with the Precarpathian trough and the Dnipro-Donetsk depression.

Oil and gas productive horizons in the Precarpathian trough (Fig. 2) are mainly concentrated in the deposits of the Paleogene and, in some cases, of the Upper Cretaceous and Miocene. Most deposits here are multi-layered and confined to narrow folds pushed on each other, forming multi-tiered structures characteristic of the area. On the territory of the Western Ukrainian oil and gas region, the search for deep-immersed hydrocarbon deposits began with the drilling of wells 1-Luga (depth 6.266 m) and 1-Shevchenkovo (7.522 m). During the drilling of the latter in the interval of fractured sandstones (7.014–7.022 m, reservoir pressure about 120 MPa, temperature – 170 °C) of the Lower Cretaceous, intense oil and gas manifestations occurred. In the grinds of rocks from this interval, pore and fissure-cavernous-pore collectors are observed in the cracks and caverns of which there was oil or bitumen.

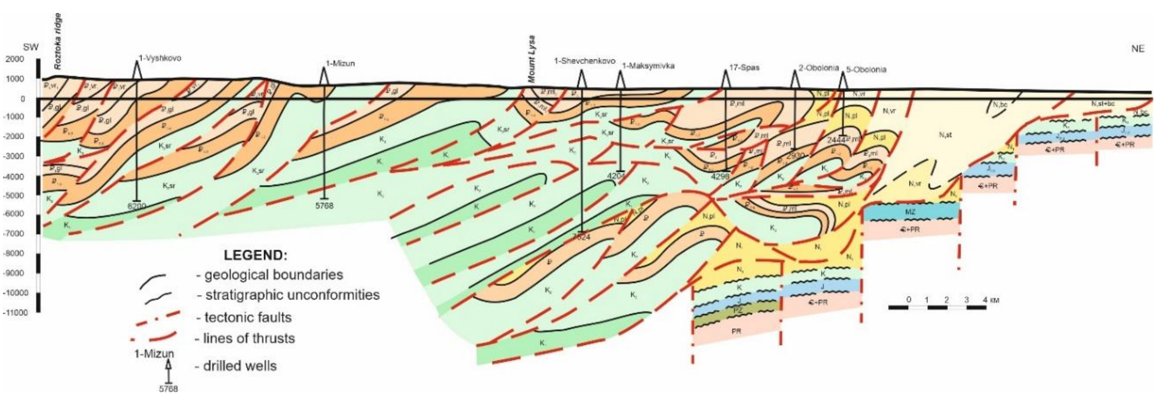

Fig. 2. Regional geological profile along the Vyshkovo-Shevchenkovo-Obolonia line in the Western Ukrainian oil and gas region (compiled by Monchak L. S. & Khomyn V. R., 2012).

Particular attention should be paid to the horizons of fractured sandstones in the intervals 7.420–7.380, 7.360–7.320, 7.070–6.945, 5.960–5.900, and 5.630–5.550 m, the open porosity of which varied from 5–7 % to 11–13 %, oil saturation – about 60 % [Mayevsky et al., 2013]. Oil inflows at depths of more than 5.000 m were obtained in wells 2-Novovostochnytsia (5.476–5.984 m, reservoir pressure 68.1 MPa, temperature – 134 °C), 1-Severnaya Zavoda (5.704–5.797 m, 88.5 MPa, 130 °C), 17-Semiginov (5.200–5.245 m, 67.5 MPa, 128 °C) and others. A significant inflow of oil (up to 500 tons / day) was obtained in the interval of 6.200–6.500 m from the Zhivet limestones of the pre-Alpine basement of the Romanian Precarpathian region on the territory of the old field of Gergias. However, most discovered commercial oil deposits in the Precarpathian region are located at depths less than 5.000 m, where reservoir temperatures are below 120 °C and pressures below 80 MPa [Mayevsky et al., 2013].

Also, the Dnipro-Donetsk depression is one of the objects of study of the prospects for the oil and gas potential of deep-immersed horizons in Ukraine (Fig. 3). Here, almost all explored resources and reserves of hydrocarbons and prospects for oil and gas potential are associated with Paleozoic formations. Most discovered deposits are contained in brachyanticlines of various sizes, complicated to one degree or another by halokinesis. Single- and multi-layered deposits are disturbed by discharges with one- and two-kilometer floors of continuous productivity. In the northwest, oil accumulations are mainly known, while in the southeast, gas is predominant. Between them, there are hydrocarbon deposits from different phase states. The regularities of their placement in multilayered deposits have not yet been established. In general, the prospects for oil and gas potential of the Dnipro-Donetsk depression are associated, as a rule, with unconventional traps and depths of 5.000–7.000 m or more. The proven depth of industrial gas content in the Perevozivska area reaches 6.300 m, and the oil content in the Sukhivska area is 5.050 m [Ivanyuta et al., 1998].

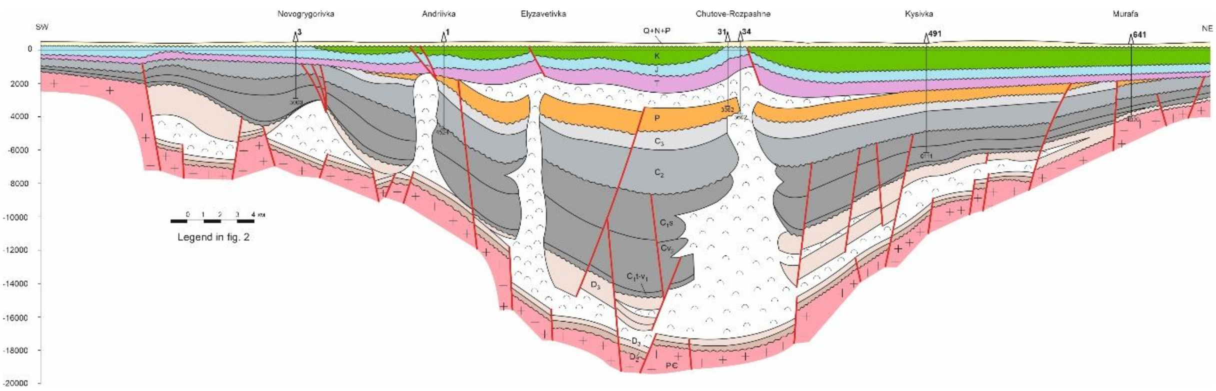

Fig. 3. Regional geological profile along the Gupalivka-Guty line in the Dnipro-Donetsk depression [Ivanyuta et al., 1998].

Methodology

The study was based on a comprehensive approach, which included the analysis of the results of geological and geophysical studies, deep drilling data, laboratory experiments, and modeling of the physical properties of rocks. To determine the relationships between reservoir pressures, temperature, and properties of reservoir rocks, methods of comparison and systematization of data obtained in various oil and gas-bearing regions of Ukraine were used, in particular in the Dnipro-Donets Depression and the Precarpathian Foredeep.

Geological and geophysical studies emphasized the distribution of reservoir pressures, temperature regimes, and the structure of reservoir rocks in sections. For this purpose, standard methods of industrial geophysics were used, such as reservoir pressure measurements, geothermal gradient analysis, as well as petrophysical study of core and sludge samples.

Laboratory studies included determining rock filtration and capacity properties on core samples. Their porosity, permeability, density, and chemical composition were analyzed using modern equipment for measuring parameters in artificially created thermos-baric conditions. Special attention was paid to modeling compaction processes, secondary cementation, and chemical changes in reservoir rocks. The lithological-facies studies of Ukraine's main oil-and-gas-prospective complexes of sedimentary basins were analyzed using about 1.300 lithophysical data from laboratory core studies and 160 rock grinding.

Mathematical modeling was carried out to calculate the depths of preservation of porous reservoirs, using the proposed formulas. These formulas considered such parameters as the density of the solid and liquid phases, the initial porosity of terrigenous rocks, the porosity limits of industrial reservoirs, and the coefficient of anomaly of reservoir pressures.

The results obtained were compared with data from other researchers published in the scientific literature. This allowed us to clarify the regional features of the distribution of reservoir pressures and temperatures in the bowels of Ukraine, as well as to establish new relationships between the depth of occurrence, pressure, and reservoir properties of rocks.

Results

For conducting oil and gas exploration and exploitation works, it is important to know and predict the behavior of reservoir pressures at depths exceeding 4.000–5.000 m since pressure and temperature dictate the degree of compaction, cementation, rock transformation, the state and mobility of fluids, and their transformation.

It is known that the temperature and pressure in the Earth's interior increase with depth. The temperature increase is due to the heat flow from warmer deep zones to the surface. The magnitude of this flow, expressed through the geothermal gradient, is 2.4–4.6 °C/100 m for various oil and gas basins. Such a temperature gradient is characteristic of depths of 6.500–8.700 m [Monchak & Omelchenko, 2015]. Each basin or its parts is characterized by its temperature gradient, which depends on the territory’s geotectonic position and the rock’s thermal conductivity. It is known from the results of direct measurements in wells.

The situation with the behavior of reservoir pressures is somewhat more complicated. Reservoir pressure largely depends on the geological structure, especially on blocking. Up to depths of 3.000–4.000 m, it is quite easy to predict the magnitude of reservoir pressure in aquifers in most cases since it is a direct function of the depth of the rocks. It is mainly called normal hydrostatic pressure. Up to the specified depths, there is mainly a direct or indirect connection with the Earth’s surface, which ensures a normal pressure increase per the law of hydrostatics. A temperature increase and the amount of dissolved gas compensate the water density increase due to its mineralization. Therefore, the density of water in reservoir conditions rarely exceeds 1.025 kg/m^3, and is about 1.000 kg/m^3.

Reservoir pressures have been studied for a long time. The most famous works on these issues were published by B. A. Tkhostov (1966), K. A. Anikiev (1971), R. M. Novosiletskyi (1969), O. O. Orlov (1980), I. I. Chebanenko et al. (1986), etc., as well as reflected in textbooks for higher education institutions [Monchak & Omelchenko, 2015].

The deviation from normal hydrostatic reservoir pressure observed in deposits with a significant height is associated with the lower density of oil, especially gas, compared to water. This difference creates excess pressure in oil and gas deposits while still adhering to the principles of hydrostatics, as demonstrated in [Monchak & Omelchenko, 2015; Khomyn et al., 2019]. Predicting reservoir pressures becomes challenging at depths exceeding 3.000–5.000 m (Tables 1 and 2), where ultra-high (anomalous) reservoir pressures begin to prevail. Consequently, it becomes practically impossible to calculate the absolute position of the water-oil and gas-water contacts without knowing the pressure in the aquifer part of the reservoir.

Table 1

Selected data on the distribution of reservoir pressures of deep-seated productive horizons of deposits in the Eastern Ukrainian oil and gas region

Deposit, horizon	Reservoir pressure, MPa	Measurement depth, m	Anomaly coefficient
Bairatske, S-9	77.09	4.675	1.65
Vasylivske, T-1	62.60	4.800	1.30
Ryaskivske, T-4	86.97	5.120	1.70
Sakhalinske, B-22	96.60	5.220	1.85
Gogolivske, B-18b	82.74	5.255	1.57
Krasnokutske, B-14	99.80	5.416	1.84
Magurske, T-4	107.30	5.555	1.93
Rudkivsko-Chervogozavodske, T-3	82.30	5.683	1.46
Zahednokoshavyske, B-22	85.31	5.800	1.47
Semyrenkivske, B-19	58.71	5.505	1.07
Semyrenkivske, well No. 17	107.9	6.571	1.64

Table 2

Selected data on the distribution of reservoir pressures of deep-seated productive horizons of deposits in the Western Ukrainian oil and gas region

Well	Reservoir pressure, MPa	Measurement depth, m	Anomaly coefficient
1-Pasichna	52.4	3.855	1.36
17-Semygyniv	67.0	4.100	1.63
5-Rozhnyativ	98.5	4.627	2.12
1-Nyzhnya Zavoda	63.9	4.773	1.34
103-Yankivska	74.6	5.183	1.44
103-Yankivska	98.0	5.200	1.88
419-Novoselytsia	89.5	5.610	1.60
1-Pivnichna Zavoda	91.9	5.750	1.60
4-Novoshkhidnytsia	97.8	6.050	1.55
1-Luhy	98.5	6.230	1.55
1-Shevchenkovo	129.0	7.225	1.73
1-Pidberezka	88.5	5.660	1.56
1-Sokolovetska	91.8	5.740	1.60
2-Smolyanska	72.5	5.126	1.41
5-Novoshkhidnytsia	77.3	5.200	1.49

With increasing depth, the porosity and permeability of rocks decrease, their density increases, and the closure of deposits increases. In closed (isolated) deposits, the pressure becomes greater than hydrostatic and gradually approaches geostatic.

E. B. Chekalyuk (1967) indicates that the transition from hydrostatic to geostatic pressure occurs within approximately 3.000 to 15.000 m, depending on the deposit's degree of closure (isolation).

It is important to understand that deposits' closure (isolation) occurs due to various factors. The first and most obvious is the increase in geostatic pressure, which is directly reflected in the reduced porosity of the rocks, and the displaced pore water from the rocks with increasing temperature leads to an increase in the processes of secondary cementation, the precipitation of cement in the pores and catagenetic changes in the mineralogical composition of the rocks themselves, and the healing of cracks by mineral formations.

It is known [Monchak & Omelchenko, 2015] that the processes of secondary cementation occur more intensively in the water-bearing parts of the deposits, i. e., outside the deposits. As a result, the rock along the oil-bearing contour loses its permeability, and the deposit becomes completely isolated from all sides. Accordingly, liquids and gases take on most of the geostatic pressure until the formation and geostatic pressures are equalized.

It is also known that under the influence of pressure, the rocks are compacted. Compaction is a pressure-controlled phenomenon in which the centers of the grains that make up the rock approach each other, mainly in the vertical direction relative to the layering of the deposits. Compaction is largely irreversible, and removing pressure leads only to elastic recovery (with some exceptions). An increase in the depth of occurrence leads to compaction and deformation of the rocks, secondary cementation, and decreased porosity. However, the results of deep drilling showed that against the general background of deterioration of the capacitive properties of reservoirs with depth, intervals are observed in which rocks are characterized by increased porosity and permeability values.

Clays are most compacted with depth due to gravitational compaction, which causes particle reorientation and denser packing [Engelhardt, 1964]. Clays of different compositions are compacted with depth differently, but starting from a depth of approximately 5,000 m, the difference in the compaction rate practically disappears, and the open porosity of clays approaches zero.

Based on the gravitational compaction model, in which there is a free outflow of fluids (compression with drainage) [Vasylechko et al., 1998], we proposed a formula for calculating the reservoir conservation depth:

$$H = \frac{200\cdot(m_0 - m_1)}{r_m - r_B}, \tag{1}$$

where r_m i r_B are averaged over the section densities of the solid and liquid phases, respectively, kg/m^3; m_0 is the maximum initial porosity of terrigenous rocks, %; m_1 is the lower limit of the porosity of the industrial reservoir for the lithological-stratigraphic complex under consideration, %. The numerical coefficient 200 is taken from the data of studies by E. I. Stetyukha (1964) for the conditions of the Ciscaucasia's sandy rocks; in clays, this coefficient will be 80–120.

From a geostatistical perspective, preserving porosity at depths exceeding the limit value can be explained by the appearance of the sedimentary layer of the compression phenomenon without drainage. This situation occurs when the displacement or outflow of water slows down or becomes impossible, leading to a porosity reduction. Porosity is preserved in the massif itself.

The main factor that controls the occurrence of such a state in the massif of sedimentary rocks is the presence of a water-resistant complex in the section.

Under the water-resistant layer, sedimentary rocks are less compacted due to the perception of part of the pressure from the mass of the overlying rocks by the fluid. That is, anomalous reservoir pressure arises here (which is reflected by the anomaly coefficient Ka). The pressure on the rock skeleton under the water-resistant layer decreases, and accordingly, the rocks can retain a higher porosity.

Then the formula (1) for determining the maximum depth of existence of granular reservoir rocks will be as follows:

$$H = \frac{200 \cdot (m_0 - m_1)}{\rho_T - \rho_B \cdot K_a}. \qquad (2)$$

Thus, formula (2) becomes suitable for undrained and drained conditions (*Ka*=1) and is universal for the compaction processes of sandy and clayey rocks, only with different statistical coefficients. Where reservoir rocks disappear, the reservoir pressure increases sharply. It gradually reaches the geostatic value (Fig. 4), and sharp changes (step jumps) of the reservoir pressure occur in fluid-bearing horizons under high-quality covers.

It should also be noted that the formation of reservoirs with anomalously high values of their porosity and permeability primarily occurs due to the post-sedimentation transformation of the components of silty-sandy reservoir rocks (micas, clay components of mudstones, siltstones, sandstones, carbonate rock residues, etc.) under the influence of carbon dioxide [Sakhibgareev, 1989; Lebedev, 1992]. Carbon dioxide or deep carbon hydrothermal vents entering the reservoir through faults contributed to a sharp increase in the acidity of pore solutions and, as a result, are the cause of a significant decrease in pH.

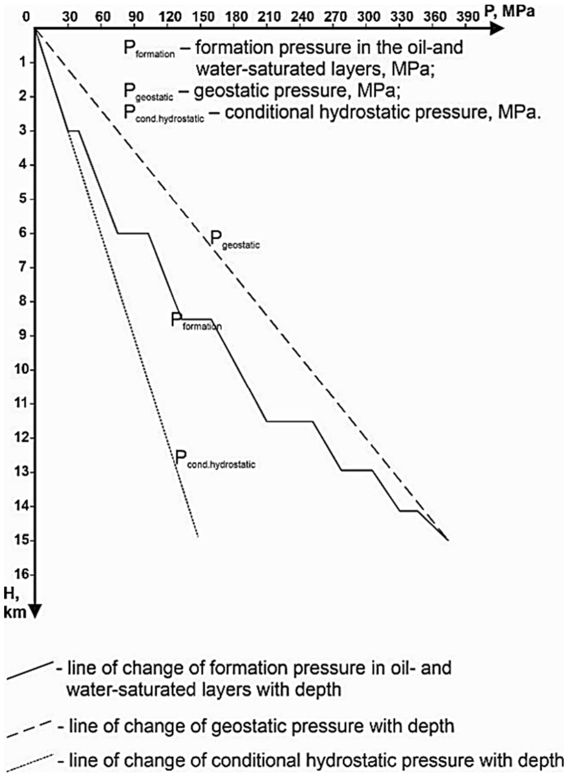

Fig. 4. Formation pressure increase with depth.

When the acidity of pore solutions changes, quartz, and siliceous fragments are formed, and porous kaolinite is synthesized. In addition, acidic, aggressive solutions intensively dissolve unstable minerals, including carbonates and aluminosilycates, when pH decreases. This process also removes Ca, Mg, Fe, Na, Al [Sakhibgareev, 1989]. At the same time, in local areas, due to the influx of alkaline and alkaline-earth elements, the alkalinity of pore waters sharply increases [Mayevsky et al., 2012]. As a result, some minerals are replaced by others, resulting in the formation of sericites and kaolinites, as well as an increase in the porosity of rocks. With the supersaturation of solutions with cations, the precipitation of elements in the form of new mineral phases begins. In an acidic environment (pH<4), silicon, which is contained in pore solutions, becomes immobile and precipitates in quartz. Mass regeneration of quartz fragments in sandstones is observed in fracture zones. As already noted, with a decrease in acidity and an increase in alkalinity of solutions (to pH = 4–8), the mobility of aluminum, which precipitates in the form of kaolinite, decreases significantly. It is precisely due to the widespread development of porous kaolinite and the uniform distribution of inter-package pores in it that pore space is provided in sandstones.

All of the above explains the rather extraordinary and interesting geological situation that developed during the drilling, testing, and operation of wells of the Semyrenkivske deposit in the Eastern oil and gas region of Ukraine.

At the Semyrenkivske gas condensate field, the roof of the B-17 horizon (B-17a in the balance) lies at 5.155–5.275 m depths. Sandstones, siltstones, and mudstones represent the horizon. The sandstones are compacted and cracked in places, and their porosity varies within 5–30 %. During testing in well No. 2, a gas inflow with a free flow rate of 35.4 thousand m^3/day was obtained. The roof of the B-18 horizon (B-17b in the balance) lies at depths of 5.230–5.350 m. According to the results of GDS and core studies, the horizon contains layers of fine-grained sandstones with a porosity of 3.0–9.7 %, permeability of 0.17–8.60 10^{-15} m^2, and gas saturation of 80 %. When testing well No. 2, a gas inflow of 101.6 thousand m^3/day was obtained at an 8 mm diaphragm.

The roof of the B-19 horizon (B-17v in the balance) lies in well No. 2 at a depth of 5.325 m. It comprises sandstones and siltstones with a porosity of 5.5–11.5 %, the permeability of 0.13–94.40·10^{-15} m^2, and a gas saturation of 73–91 %. It was tested with the B-20 horizon in well No. 2. A 166.1 thousand m^3/day gas inflow was obtained at a 7 mm diaphragm. The roof of the B-20 horizon (B-17v in the balance) in well No. 2 lies at a depth of 5.385 m. No inflow was obtained during the horizon testing in well No. 2 in the interval 5391–5413 m from the sandstone layer with a porosity of 8 %. The reservoir properties of all productive layers in the field are low. The open porosity is 8–10 %, the permeability varies in the B-18 horizon within 114–0.04·10^{-15} m^2, in B-19, 94.40–0.06·10^{-15} m^2, and in the B-21 horizon, it is 11.26·10^{-15} m^2. The average permeability in the horizons is 10–12·10^{-15} m^2. The low permeability of productive horizons is evidenced by the high depression on the formation obtained during the testing of well No. 2. A similar situation was observed when testing promising horizons in well No. 17. The porosity of the rocks is porous-fractured. An improvement in the reservoir properties of productive horizons is noted in the apical part of the structure, and their deterioration is significant within the periclinal areas and wings. This is associated with post-sedimentation changes in rocks under high temperatures and pressures and is an example of how hydrocarbons preserve pores and cracks in the rock catagenetic compaction process. It is on the core samples (Fig. 5), which were lifted from well 17-Semyrenkivska (interval 6.531.6–6.533.7 m), that we can observe caverns of considerable size, which were formed due to the mechanism mentioned above.

The core (see Fig. 5) is represented by gray mesomicte sandstone (graywacke-arkose-quartz), fine-grained with caverns and cracks of different ages, as well as with injections of dark-colored pelitomorphic polymineral substance (TPPR) with anomalies of mineral composition and geochemistry (traces of the inflow of high-pressure high-enthalpy deep anhydrous fluids based on super compressed hydrocarbon gas).

Fig. 5. Photo of the core with cavities and cracks from well 17-Semyrenkivska.

Similar facts are observed in other areas and deposits in the Eastern Ukrainian (Fig. 6, 7) and Western Ukrainian oil and gas regions (Fig. 8, 9).

Fig. 6. Photo of oil-saturated sandstone core from well 1-Kampanska (interval 4.640–4.657 m).

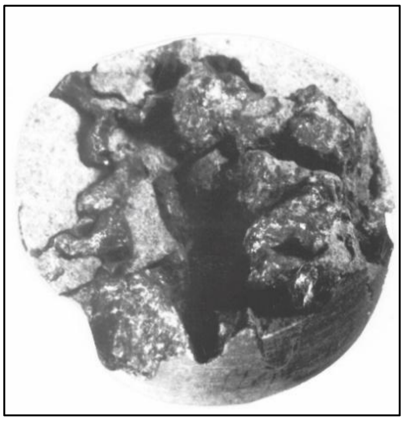

Fig. 7. Photo of a core of fractured-secondary porous sandstone from well 5-Skorobogatkivska (interval 5.130–5.140 m).

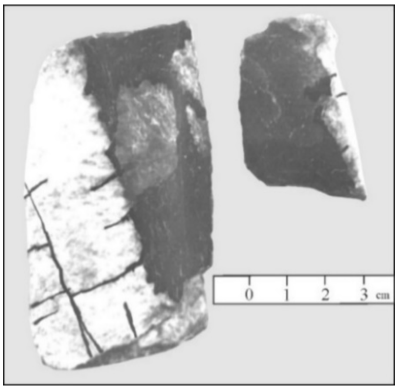

Fig. 8. Photo of a core of cavernous limestone (Jurassic, Nyzhniv Formation, Precarpathian Depression) from well 47-Korshiv (photo by O. O. Orlov, 1980).

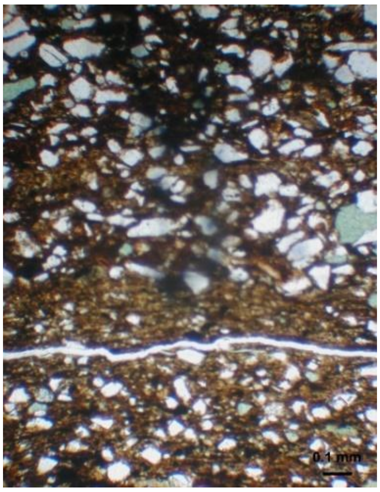

Fig. 9. Photo of a section with an open crack confined to a silty mudstone layer. The rock generally comprises layers of silty fine-grained sandstones and silty mudstones. Well 810-Pasichna, depth 4.638 m ×140, Nikoll parallel.

The core (see Fig. 6) is represented by a cavernous-secondary porous oil-saturated sandstone (*Kp* according to GDS – 0.11–0.13; *Kp* according to petrographic data – 0.12–0.18), which was taken on the Kampanskaya area from well No. 1 from the interval 4.640–4.657 m (horizon B-21).

The core (see Fig. 7) is represented by a fractured-secondary porous sand reservoir (*Kp* according to GDS – 0.105; *Kp* according to petrophysical data – 0.07–0.09), which was taken on the Skorobogatkivske deposit from well 5 from the interval 5.130–5.140 m. Fracture cracks with intensive clogging and stylolithization with supporting open cracks (water inflow was obtained from the reservoir during testing).

Practical significance

The study's results help predicts hydrocarbon accumulations and choose optimal extraction methods at great depths, increasing the efficiency of geological exploration and reducing risks in the exploitation of deposits.

Conclusions

Therefore, studying great depths requires a significant increase in local and zonal forecasting probability. Additionally, research into the potential for detecting large and medium-sized industrial hydrocarbon accumulations in the lower horizons of the sedimentary cover is particularly important. It is also necessary to conduct detailed economic assessments of the forecasted and prospective hydrocarbon resources at great depths based on specific costs associated with reserve preparation. In the oil-and-gas-saturated parts of the deposits, the permeability of the reservoir rocks is preserved, which allows for the extraction of oil or gas. However, we must understand that many pores are isolated and contain high-pressure liquids or gases. When the pressure in a reservoir decreases due to gas or oil extraction, it can cause cracking and damage to the reservoir rock. This damage can complicate the extraction process or even render it impossible. Additionally, these processes may affect the connections between different layers in the rock. If these connections are near aquifers, they could flood the productive layers.

Where the reservoir rocks disappear, the reservoir pressure increases sharply. It gradually reaches the geostatic value, and sharp (jump-like) changes in the reservoir pressure along the section occur in fluid-bearing horizons under high-quality caps and in them themselves.

The presence of sandstone with an open porosity of 5.58 % at a record depth of 6.531.6–6.533.7 m (core in Fig. 5) is a significant indicator of the potential for effectively porous reservoirs, not only in the DDZ but also in many oil and gas basins worldwide. This finding is particularly noteworthy given that more than 100 industrial gas condensate and gas deposits have been discovered in the DDZ at depths exceeding 5.000 meters, demonstrating that such reservoirs can exist even at great depths. The lack of a clear dependence on porosity and physical and mechanical properties of sandstones-metasomatized at depths ranging from 3.500 to 6.000 m can be attributed to two main factors. Firstly, it reflects the peculiarities of the thermobaric characteristics of the Paleozoic sediments found in the central part of the DDZ at these significant depths. Secondly, it indicates the uneven spatiotemporal nature of oil-metasomatic transformations, which are relatively young in geological age. Additionally, these transformations occurred alongside the existing catagenetic zoning and incompleteness.

Under ultra-high anomalous reservoir pressures (anomaly coefficient of more than 2.0) within oil and gas deposits (excluding aquifers), reservoir rocks can remain intact in individual reservoirs at depths of 10.000–12.000 m. Still, additional evidence is needed to support this finding. In oil and gas basins, including Ukraine, at depths of more than 10.000 m, reservoir pressures will approach geostatic values.

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РОЗПОДІЛ ПЛАСТОВИХ ТИСКІВ ТА КОЛЕКТОРСЬКІ ВЛАСТИВОСТІ ГІРСЬКИХ ПОРІД НА ВЕЛИКИХ ГЛИБИНАХ У НАФТОГАЗОНОСНИХ БАСЕЙНАХ УКРАЇНИ

Вивчення геодинамічних процесів, а також розподілу пластових тисків і колекторських властивостей порід на великих глибинах у нафтогазоносних басейнах України з метою удосконалення геолого-горозвідувальних робіт, прогнозування накопичення вуглеводнів та оцінювання методів видобування є надзвичайно важливою та актуальною проблемою сьогодення. Аналіз геолого-геофізичних досліджень, глибоке буріння, лабораторні дослідження керну та шламу, а також експериментальне вивчення фізичних властивостей порід-колекторів – оптимальний комплекс досліджень для вирішення цієї проблеми. Використано порівняння результатів у різних регіонах України, зокрема Дніпровсько-Донецької западини та Передкарпатського прогину. В Україні основні перспективи відкриття покладів нафти і газу на великих глибинах пов’язані із Передкарпатським прогином і Дніпровсько-Донецькою западиною. Відомо, що обґрунтування перспектив нафтогазоносності горизонтів, які глибоко залягають, завжди нерозривно пов’язано із вивченням геодинамічних особливостей регіону, колекторських властивостей порід, встановленням розподілу пластових тисків і температур по розрізу осадових басейнів. Проблему розподілу пластових тисків і температур по розрізу осадових басейнів і колекторських властивостей гірських порід розглянуто у численних роботах – від статей і дисертацій до узагальнювальних монографій. Дослідження показали, що з глибиною пористість і проникність порід поступово зменшуються, але в окремих горизонтах спостерігаються аномально високі значення цих характеристик, що відкриває нові можливості для промислового освоєння глибокозанурених покладів вуглеводнів. Зокрема, на рекордній для Дніпровсько-Донецької западини глибині понад 6,5 км виявлено пісковики із відкритою пористістю до 5,58 %, що свідчить про можливість існування ефективних колекторів навіть на таких значних глибинах. Встановлено, що на глибинах до 10–12 км в умовах аномально високих пластових тисків зберігаються колекторські властивості порід, що критично важливо для прогнозування нових родовищ. Підтверджено, що в закритих покладах спостерігається різке підвищення пластового тиску, який поступово досягає геостатичних значень, створюючи сприятливі умови для формування нафтогазових скупчень. Ці дослідження також демонструють вплив вторинних змін у породах на їхні фільтраційно-ємнісні властивості та обґрунтовують роль термобаричних факторів у формуванні аномальних пластових тисків. На основі отриманих результатів запропоновано моделі та формули для розрахунку глибин збереження порід-колекторів у різних геологічних умовах, що істотно розширює уявлення про перспективність глибокозанурених горизонтів для видобування вуглеводнів. Наукова новизна дослідження: вперше виконано детальний аналіз зв’язку пластового тиску з геостатичними умовами та вторинними змінами порід-колекторів на великих глибинах; запропоновано формули для оцінювання максимальних глибин залягання порід-колекторів. Результати дослідження допомагають прогнозувати накопичення вуглеводнів і вибирати оптимальні методи видобування на великих глибинах, підвищуючи ефективність геологорозвідувальних робіт та зменшуючи ризики під час експлуатації нафтових і газових родовищ.

Ключові слова: дослідження керну, пористість і проникність, породи-колектори, глибокозалягаючі горизонти, поклади вуглеводнів, родовища нафти і газу, термобаричні умови, Дніпровсько-Донецька западина, Передкарпатський прогин.

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