GEOLOGY

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STUDY OF GEODYNAMIC AND HYDROGEOLOGICAL CRITERIA FOR ASSESSING THE HYDROCARBON POTENTIAL OF THE ALAKOL DEPRESSION

Kazakhstan is experiencing a gradual decline in commercial oil reserves. First of all, this is due to the low probability of discovering new large deposits in the main oil and gas complexes, which are well studied by geological and geophysical methods.

Purpose. To identify key criteria that determine the possibilities for searching for hydrocarbons in a given geological area.

Methodology. The study includes an assessment of the underground horizons' structural features, reservoir properties analysis and study on hydrogeological parameters of the region.

For the analysis of hydrocarbon potential, the results obtained while conducting geological exploration work were used. The methods of mathematical statistics were used to process the experimental data.

Findings. The results of a complex analysis of geodynamic and hydrogeological factors affecting the hydrocarbon potential of the Alakol depression in Kazakhstan are presented. Geodynamic criteria play an important role in the assessment and exploration of oil and gas deposits. In this connection, the main geodynamic factors which are usually considered when studying the oil and gas potential are shown.

Originality. Based on the data from geodynamic and hydrogeological studies, it can be concluded that there are three eras of intense sedimentation in the region, with a special emphasis on the Carboniferous and Jurassic. Lower Jurassic deposits are important to study, especially in the context of hydrocarbon potential. Therefore, the results of the assessment of the oil and gas potential of the Alakol sedimentary basin are of scientific novelty.

Practical value. The results of the study are of practical significance and can be used in planning and carrying out work on the search and exploration of hydrocarbons in the Alakol depression.

Keywords: *hydrogeological factors, geodynamic criteria, Alakol basin, hydrocarbon potential, oil*

Introduction. The Alakol Basin, located in Kazakhstan, is a poorly studied basin and is currently assessed as a low-prospect area for the discovery of hydrocarbon resources. In the context of dynamic changes in the energy industry and the growing importance of ensuring the sustainability of the energy sector, conducting research in this region is becoming a priority in the scientific field. Currently, there is a low probability of discovering significant hydrocarbon reserves in the Alakol depression [1, 2].

The purpose of this scientific article is to conduct a comprehensive analysis of the factors affecting the hydrocarbon potential of the Alakol depression. To achieve this goal, it is planned to study the geodynamic features of the region, including the structural characteristics of underground horizons, as well as the analysis of hydrogeological parameters and reservoir properties [3, 4].

Literature review. Based on the conducted research, we are aimed at identifying key criteria that determine the prospects for effective search for hydrocarbons in a given geological area. Using modern methods and technologies, our goal is to provide new scientific data that can serve as the basis for the development of innovative strategies for the exploration of hydrocarbon resources in the Alakol Basin. This in turn helps promote sustainable development of the energy sector [5, 6].

The Alakol promising oil and gas basin is limited by folded structures, the Tarbagatai ridges in the north and the Dzungarian Alatau in the southwest, as well as the Berlik and Maili ridges in the southeast [7, 8]. In the Alakol basin, the thickness of the sedimentary cover reaches 4.0 km in its southwestern part and 2.0 km in the eastern part [9, 10].

Existing studies in the region highlight the complexity of the geological structure of the Alakol depression and its significance in the context of geodynamic processes. Works [11, 12] emphasize the need for an integrated hydrogeological parameters analysis, such as reservoir and aquifer properties, for a more accurate hydrocarbon potential assessment. In structural terms, along the surface of the basement, the Alakol basin is an extensive asymmetric depression with steep southwestern and gentle northeastern sides. In the most sagging zones, the depth of the foundation roof according to geological and seismic data is estimated at 2.0–3.0 km [13, 14].

The surface of the foundation is divided into separate blocks. In the northern part of the basin, there is identification of the Tarbagatai and Shyngys-Zhetysu deep faults northwestern strike. Identification of the Alakol-Zhetysu fault of sublatitudinal strike is in the southern part [15, 16].

On the surface of the Paleozoic, the South Sasykkol, South Alakol and East Alakol grabens are distinguished. The most developed in terms of area and thickness of sedimentary filling is the South Alakol graben (Fig. 1) [17, 18].

In the Alakol basin, the immersion depths of the Meso-Cenozoic complex allow us to conclude, taking into account the real value of the geothermal gradient (2.7 °C per 100 m), that some of them may be located in the main oil formation zone and, possibly, even in the main zone gas formation [19, 20].

Purpose. ***Geodynamic aspects of the Alakol basin.*** The Alakol basin is a region with a complex geological structure. Folded elements and a branched system of faults stand out here, formed as a result of tectonic processes that have affected this territory for a long time. These features are important for the distribution of rock structures and determining the potential of hydrocarbon deposits.

Past volcanic activity contributed to the formation of tuff and andesite deposits. These rocks play a key role in the analysis of possible hydrocarbon deposits. In addition, the presence of magmatic intrusions in the subsurface may influence the migration of hydrocarbons.

Studying the tectonic development of the region allows us to understand changes in sedimentation conditions and the formation of structural elements. Erosion and denudation processes reveal the nature of rocks brought to the surface. Hydrogeological conditions and thermal processes play a significant role in the analysis of hydrocarbon prospects.

A general study of the Alakol depression geodynamic aspects helps to fully understand the nature of the region and identify potential hydrocarbon resources.

The tectonic factor plays a significant role in the formation and retention of oil and gas accumulations. The subthrust structures development, tectonic disturbances and the uplift of Mesozoic rocks through volcanic vents affects the geological structure of the region, creating favorable conditions for the hydrocarbon reserve enrichment.

Hydrogeological features of the region. The hydrogeological features of the Alakol depression region are determined by the complex influence of geological and tectonic processes, which makes it a significant object for the water resources and hydrocarbon potential study and assessment. Let us consider key aspects of hydrogeology and reservoir properties of rocks.

1. Terrigenous strata of the Carboniferous and Permian. In the Carboniferous and Permian sections of the intermountain basins, they are predominantly represented by terrigenous strata, including sandstones and siltstones. These rocks, being reservoirs and seals, have the potential to accumulate and retain hydrocarbons.

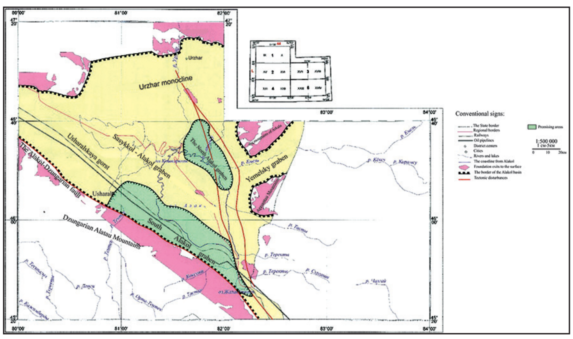

Fig. 1. Map of tectonic zoning of the Alakol basin

2. Triassic and Jurassic deposits. Mesozoic deposits in the Alakol depression and its surroundings date back to the Late Triassic, Lower and Middle Jurassic, and possibly Upper Cretaceous. They form graben and trough sediment complex. The rocks are lithologically represented by gray fine-grained sandstones, siltstones and mudstones with a total thickness in well A-1–155 meters. According to seismic data, in wells A-8 and A-3, the thickness of these deposits is 164 and 50 meters, respectively (Fig. 4). Triassic deposits, especially Jurassic ones, have significant thickness and contain terrigenous complexes with pronounced porosity and permeability. These strata can serve as potential oil and gas generating and oil and gas containing "sequences", influencing the capacitive potential of the region.

3. Lower Jurassic deposits. The Lower Jurassic deposits are characterized by alternating conglomerates, sandstones, siltstones and coals. An increase in the proportion of hydrocarbons in Lower Jurassic rocks may affect their potential as oil and gas bearing strata.

4. Coal deposits. Coal deposits, especially in the Carboniferous and Jurassic, are key formations with high organic matter content. These carbon strata, in combination with tectonic structures, can serve as reservoirs for oil and gas fluids.

5. Sapropelite and Eocene-Oligocene deposits. Sapropelite, formed due to the microscopic algae activity is an additional organic matter source. Lacustrine mudstones of the Eocene and Oligocene, acting as a regional seal, can also influence the conditions for hydrocarbon generation (Fig. 2).

In general, the hydrogeological features of the Alakol depression combine diverse geological and tectonic conditions, creating potential for the diversified use of groundwater resources and hydrocarbon potential assessment of the region.

Hydrodynamic conditions in aquifer complexes of sedimentary deposits in basins are one of the key factors influencing the formation of hydrocarbon deposits. These conditions are determined by the operating modes and filtration processes in the pools.

In our case, in accordance with the geological structure of the intermountain Alakol depression, surface and underground runoff from the Dzhungar Alatau and Western Tarbagatai ridges goes towards the zones of active water exchange in the central part of lakes Sasykkol and Alakol.

The known analysis data on the hydrogeological conditions of the sedimentary cover upper part make it possible to classify waters by type (surface and infiltration) based on their chemical composition and hydrogeological characteristics. Water of free water exchange with the earth's surface can negatively affect the hydrocarbon reserve safety; their classification is carried out according to hydrogeological characteristics. Since in the northern part of the Alakol basin the gradient of water pressure is less, it can be assumed that this is due to a decrease in geostatic load and a decrease in the degree of rock compaction, therefore the magnitude of the hydrodynamic factor in the formation of oil deposits in the northern part of the Alakol basin was insignificant.

A different situation within the southern hydrodynamic region of the Alakol basin indicates that the water flow lines in the Ilision water-pressure system are directed from zones of the greatest deflection to zones with lower pressures.

As a result, the underground force of hydrocarbon movement moving along the regional uprising of layers was summed up with the water pressure formation, where traps with a well-closed wing facing the flow could retain hydrocarbons. These may be the northern wings of local structures that are worth paying attention to when laying exploration wells to search for oil and gas [19]. Even based on the wing amplitude the structures of 35–40 m/km, capable of retaining hydrocarbons, the placement of oil deposits should be expected in the southern part sediments of the Alakol basin, where the sedimentary thickness cover is increasing.

Thus, the hydrogeological conditions and geological occurrence of Mesozoic and Paleozoic sedimentary strata, especially

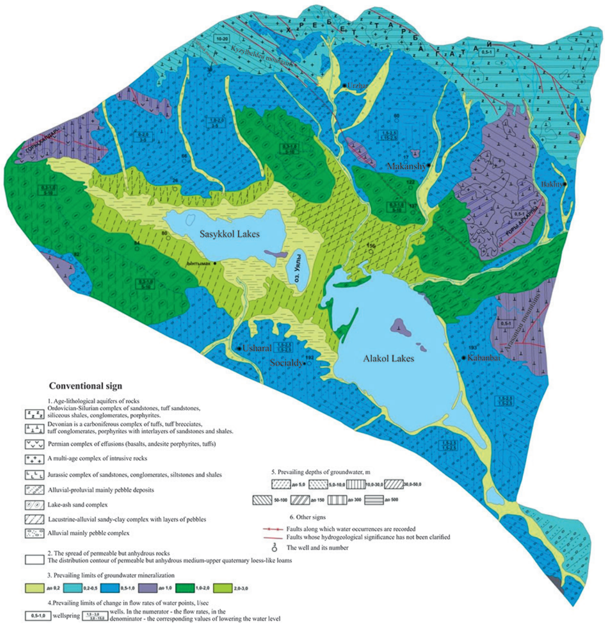

Fig. 2. Hydrogeological map of the Alakol depression, Scale 1 : 500,000

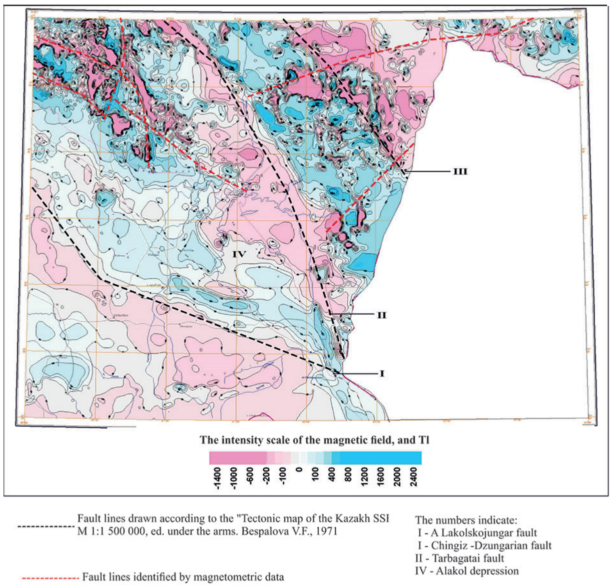

Fig. 3. Map of the anomalous magnetic field of the Alakol basin

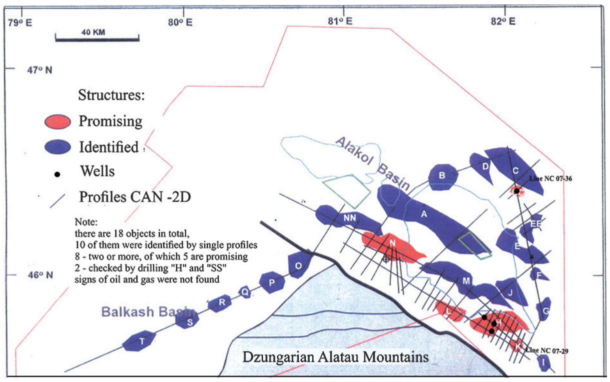

Fig. 4. Layout of structures of the Alakol depression (JSC Remas)

in the southern part of the Alakol basin, do not contradict the conclusion about the active participation of the hydrodynamic force formation in the hydrocarbon deposit formation.

Materials and research methods. A variety of research methods were used to gain a deep understanding of the Alakol Basin geology and hydrocarbon potential. Geophysical methods such as seismic tomography, electrical prospecting and gravimetry can reveal the earth structure and reveal important rock parameters.

Computer modeling is an integral part of the study, providing tools for creating numerical reservoir models, hydrodynamic and thermodynamic modeling. These methods make it possible to analyze the behavior of hydrocarbons underground, their movement and the conditions of deposit formation.

The choice of this methodology is justified by the desire to obtain a comprehensive picture of the regional geology. These methods complement each other, providing not only an overview, but also the specific data needed to predict and further recover hydrocarbons. This integrated approach is the key to successful exploration and development of the Alakol Depression.

The map of the anomalous magnetic field of the Alakol basin clearly shows the main deep faults, such as Chingiz–Dzungarian, Alakol–Dzungarian and Tarbagatai. These faults extend in a northwesterly direction and their orientation corresponds to the main geological structures of the region. Geological faults can influence the placement and formation of natural resources such as oil, gas and mineral ores. Studying faults and their influence on the geological structure allows us to understand better the geological history of the region and determine prospects for exploration and mining (Fig. 3).

The location of tectonic faults on the anomalous magnetic field map is characterized by high gradients of magnetic anomalies over large distances and a sharp change in the sign of the magnetic field.

Among the considered anomalous zones, the alternating field in the northwestern part of the tablet, consisting of local positive (up to +800 nT) and negative (–400 nT) anomalies, looks special. Based on the results of seismic exploration, 18 structures with different directions, intensity and plan sizes have been identified. Five of these structures were considered promising. In the period from 2009 to 2010, four exploratory wells were drilled at these promising sites: A-1, A-2, A-3 and A-8 (Fig. 4).

At the site with the symbol "N", wells A-1, A-2 and A-8 were drilled, which are located at a distance of about 5 km from each other. Well A-1 was stopped at a depth of 2,487.5 m and passed through effusive sedimentary deposits of undifferentiated Permian-Triassic, which were opened at a depth of 1,725 m.

Well A-2 penetrated the Permo-Triassic at a depth of 1,670 m and was stopped at a depth of 2,229 m. During the drilling of well A-2, a core measuring 5 m (from 1,917 to 1,922 m) was recovered, which came from the effusive sedimentary strata. In well A-8, a similar interval with a thickness of 164 m was discovered (Fig. 4).

All 4 wells in the depression at objects "N" and "SS" were mothballed without testing due to the lack of oil and gas shows during the drilling process, including well A-1 with a positive conclusion about it according to GIS data along the horizon in Jurassic deposits under the regional seal.

According to the well logging data, in well A-1, explored at the Karamaysky Institute for Research and Development of Fields, 3 potentially promising intervals were identified:

1. Paleogene: 805.1–855.3 m.
2. Jurassic–Cretaceous: 1,588.4–1,633.6 m.
3. Permo–Triassic: 2,057.1–2,074.3 m.

These intervals indicate potential horizons that may contain significant oil and gas reserves. In the final document for well A-1, only the interval 1,588.9–1,663.6 m was recommended for testing (Fig. 5). However, the well was suspended without testing this interval. Instead, in the interval 1,570–1,725 m, Jurassic-Cretaceous deposits with a total thickness of 155 m were identified (135 m belong to the Jurassic period and 20 m to the Cretaceous). This interval corresponds to the gap

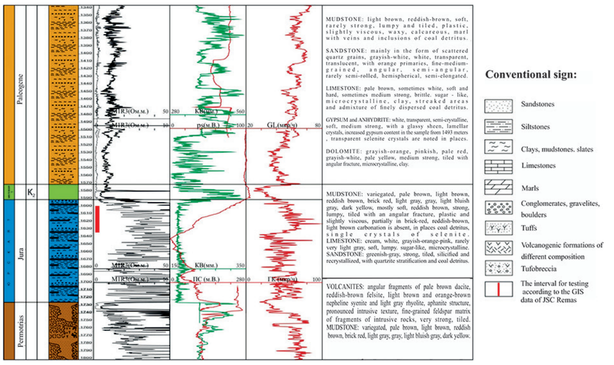

Fig. 5. Section of well A-1 of the Alakol depression

between the horizons RH-II and RH-III. Figs. 6 and 7 show the location of drilled wells at objects "N" and "SS".

Well A-3 is located in the northeast of the depression on a rise of the structural nose type at the intersection of profiles 19 and 36 with a Jurassic thickness of about 50 m (Fig. 7). Jurassic sediments in the volume of the Lower and Middle Jurassic at the Alakol coal deposit overlie Triassic sediments with a break. The lower parts of the Lower Jurassic are composed of conglomerates, sandstones, siltstones, mudstones, and coals, the upper parts are composed of various combinations of similar rocks. The deposit is located in the Kathu Mountains in a small graben in the zone of influence of a large regional fault, where the inclination angles of the layers range from 5 to 75°.

Object "L" is an anticline on the southern side of the trough. The anticline appears in Permo-Triassic to Neogene sediments, indicating the presence of various geological formations in this area. In the rest of the depression, the structural forms are less pronounced and more smoothed, which

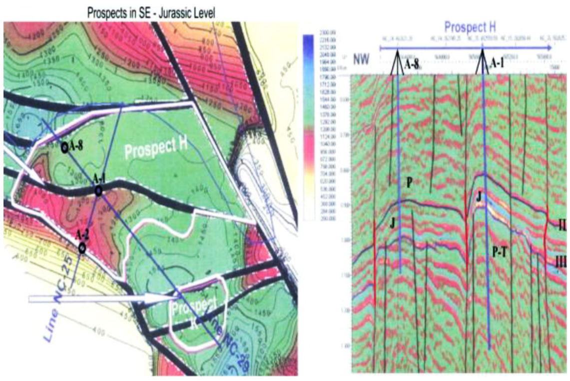

Fig. 6. location of drilled wells at objects:

a — Perspective section H; b — time section along line NC 07-29

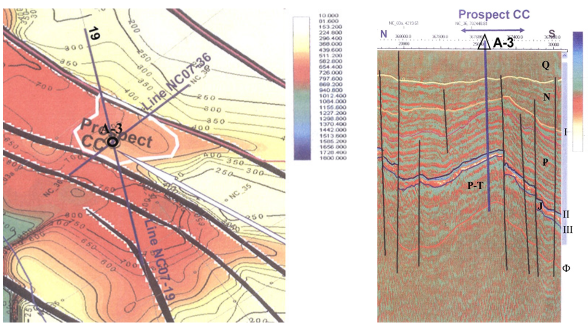

Fig. 7. location of drilled wells at objects:

a — Prospect section SS; b — time section along line NC 07-19 of Alakol basin

may indicate less complex geological structures. The maximum possible thickness of Meso-Cenozoic sediments (above the RH-III horizon) does not exceed 2.0 meters, which is important for understanding the thickness of the horizons in this region. The study of such structures and characteristics is important for geological analysis and determination of the oil and gas field prospects. In this case, knowledge of the possible thickness of sediments and structural features will help in planning further geological studies and carrying out exploration drilling (Fig. 8).

The information presented shows the distribution of the sedimentary complex structure from the map section, taking into account various horizons:

1. Horizon RH-I is displayed at the depths of the base of Neogene deposits.
2. Horizon RH-II can be traced at the lower boundary of Paleogene deposits.
3. Horizon RH-III is located on the upper surface of Permian (Permian-Triassic) deposits.
4. Horizon RH-IV is represented within the Paleozoic sedimentary rocks (QPC).
5. The exhaust horizon V is displayed on the upper boundary (surface) of the foundation.

Jurassic deposits are indicated within the limits between horizons RH-II and RH-III and are combined with Cretaceous sediments (Fig. 9). This information allows us to understand better the composition and location of sedimentary formations in the given area, which is important when studying geological processes and searching for natural resources.

From the description of profiles NC-01 and NC-04 it is clear that seismic geological sections were used to display changes in thickness in the sedimentary complex in both the transverse and depression longitudinal direction.

Additionally, smoother structural forms are observed in the rest of the basin. It is assumed that the maximum thickness of Meso-Cenozoic sediments (above the RH-III horizon) does not exceed 2.0 meters. This indicates a relatively thin thickness of younger sediments in this zone.

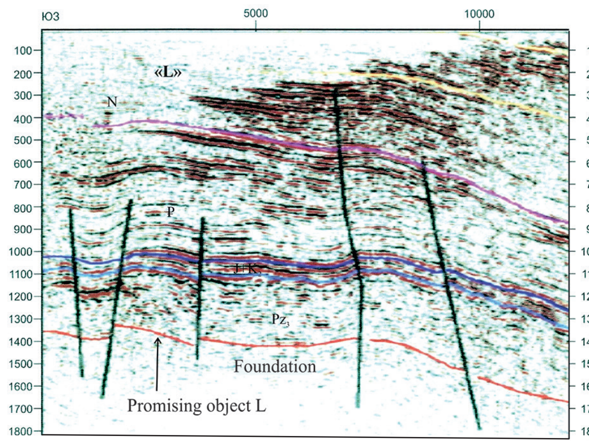

Fig. 8. Alakol basin. Time section along the NC-12 profile

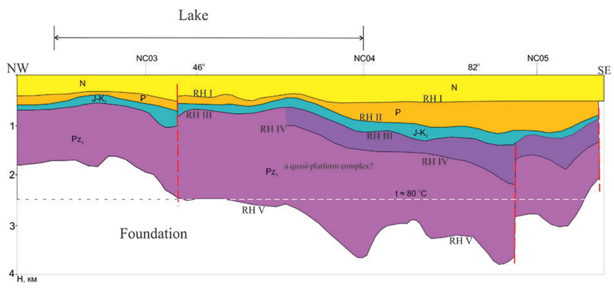

Fig. 9. Alakol basin. Seismic geological section along line NC-01

Key criteria for assessing hydrocarbon potential. In studying the hydrocarbon potential of the Alakol depression, we take into account several important things. First, we analyze how land structure and tectonics affect the ability to detect hydrocarbons. It is also important to understand how water horizons affect production processes and what rocks can serve as hydrocarbon carriers.

The interior parts of the depression, where Permian, Triassic and Jurassic coal-oil deposits are found, can be considered as potential oil and gas source zones. However, the depth of these deposits in most of the depression does not exceed 2.0 km, which does not allow them to reach the maturity of the main oil formation zone (MOZ), which is usually located at depths of 2.8–3.0 km for intermountain depressions. Such a shallow depth of sediments limits their potential for generating oil and gas. Moreover, since the bulk of organic sediments is represented by the higher plant remains, the nature of the organic matter in these sediments is mainly humic, which makes the active liquid hydrocarbon generation difficult. To begin the active formation of liquid hydrocarbons, immersion to depths is required, where temperatures remain in the range from 80–90 to 150–170 degrees Celsius at catagenesis various stages, such as DOM MK1-MK2. For example, in the nearest Zaisan depression a low-temperature regime is also established, and in the parametric well Sorbulak-1 a temperature of 100 °C is established at a depth of 4,400 m (a gradient of about 2.30 °C per 100 m).

When using data on the Zharkent trough the Alakol depression, the beginning of the oil formation primary zone within the Mesozoic-Cenozoic complex corresponds to depths of about 3 kilometers. Such great depths, extending to the foundation of the Alakol depression, are found only in a narrow strip near the Dzhungar fault (thrust) and in the southern part of the depression.

Data analysis on the East Alakol trough with a maximum depth to the basement of 2 kilometers suggests that when assessing the geothermal gradient, it is located only in the protocatagenesis zone PK 1–3. This means that the main promising object for the generation of hydrocarbons in the Mesozoic-Cenozoic complex in the Alakol depression is the South Alakol graben.

In Paleozoic deposits, Devonian, Carboniferous terrigenous-siliceous-carbon and Permian rocks can be considered as potential oil and gas source strata. They have significant thickness and are especially located in the subthrust and near-thrust zones. These rocks may be promising for the possible hydrocarbon generation and accumulation, and the study of their properties and distribution is important when analyzing the oil and gas potential in the region under consideration.

Results and discussion. From the information provided, we can conclude that deep drilling in the central parts of the Alakol depression and geochemical studies to predict oil and gas content have not yet been carried out. The Upper Devonian-Lower Carboniferous rocks are found at depths of 2.5 to 4 km and even lower, which may mean that they have reached the stage of active hydrocarbon generation maturity and may be potentially promising for oil and gas discovery.

Paleozoic aquifers contain predominantly fresh infiltration waters with low mineralization (1–2 mg/l). A similar level of mineralization is characteristic of Jurassic, Cretaceous and Paleogene deposits, but with increasing depth, mineralization increases to 20 g/l. These data indicate the importance of further research and a more in-depth study on geological structure and geochemical features of the region to assess its potential as a hydrocarbon deposit [5, 10, 19, 21, 22].

Studies of geodynamics and hydrogeology in the Alakol depression have led to valuable data that form the basis for a deeper understanding of the region. Let us consider the main results and their interpretation.

Geodynamic aspects. Analysis of the underground horizon structural features revealed a classical three-membered structure in the Carboniferous and Permian sections. Intermountain basins contain terrigenous strata, including sandstones and siltstones, which act as reservoir rocks and cap rocks.

Hydrogeological features. Hydrogeological parameter assessment confirmed the presence of aquifers with diverse reservoir properties. Triassic and Jurassic deposits are represented by promising strata for hydrocarbons, with coal deposits and oil shale.

Analysis and interpretation. Based on data from geodynamic and hydrogeological studies, it can be concluded that there are three eras of intense sedimentation in the region, with a special emphasis on the Carboniferous and Jurassic. Lower Jurassic deposits are important to study, especially in the context of hydrocarbon potential.

These geodynamics and hydrogeology study results significantly influence the general understanding of underground processes and resources of the Alakol depression. Further data analysis will allow us to determine more accurately mining strategies and the most efficient use of resources in this promising region.

Conclusion. From the data provided on the Alakol depression study, we can conclude that this is only the initial stage of the first working project to search for oil and gas in this region. At this stage, studies were carried out related to the drilled wells at objects "N" and "SS", where geological structures, sediment characteristics and other factors important for potential oil and gas content were studied.

In general, the Alakol depression study based on geodynamic and hydrogeological aspects allows us to draw several key conclusions. The region has numerous features, such as a three-membered structure in Carboniferous and Permian sections, a variety of Triassic and Jurassic terrigenous strata, as well as significant oil and gas accumulation zones. Deep geodynamic processes, including tectonic activity and volcanism, significantly influenced the formation of regional structure, creating favorable conditions for the hydrocarbon formation and retention. Stratigraphic data indicate the presence of potential petroleum-bearing strata, such as Triassic and Jurassic carbonaceous sediments.

Key criteria for assessing hydrocarbon potential include the terrigenous strata characteristics, the organic matter presence in sediments of various periods, the history of geodynamic processes and structural features. Determining these criteria allows us to make assumptions about the possibility of detecting hydrocarbons in the region. An important aspect is also the use of research methodology, which includes geophysical methods, computer modeling and experimental approaches. This allows for a deeper and more comprehensive look at the geological structure of the region and its potential for hydrocarbon development.

Despite the lack of actual experiments, preliminary conclusions are formulated based on analysis of existing data supported by geophysical studies and computer modeling. However, it must be emphasized that additional research and actual experiments can provide a more accurate picture of the hydrocarbon potential of the Alakol depression.

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Вивчення геодинамічних і гідрогеологічних критеріїв оцінки вуглеводневого потенціалу Алакольської западини

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Казахстан переживає поступове скорочення промислових запасів нафти. У першу чергу це пов›язано з низькою ймовірністю відкриття нових великих родовищ в основних нафтогазових комплексах, які добре вивчені геологічними й геофізичними методами

Мета. Виявлення ключових критеріїв, що визначають можливості пошуку вуглеводнів у даній геологічній області.

Методика. Дослідження включає в себе оцінку структурних особливостей підземних горизонтів, аналіз колекторських властивостей і вивчення гідрогеологічних параметрів регіону. Для аналізу вуглеводневого потенціалу використані результати, отримані у процесі ведення геологорозвідувальних робіт. Для обробки експериментальних даних застосовувалися методи математичної статистики.

Результати. Представлені результати комплексного аналізу геодинамічних і гідрогеологічних факторів, що впливають на вуглеводневий потенціал Алакольской западини в Казахстані. Геодинамічні критерії відіграють важливу роль в оцінці й розвідці нафтових і газових родовищ. У зв'язку з цим показані основні геодинамічні фактори, що зазвичай ураховуються при вивченні нафтогазоносності.

Наукова новизна. Ґрунтуючись на даних геодинамічних і гідрогеологічних досліджень, можна зробити висновок, що в регіоні існують три епохи інтенсивного осадконакопичення, з особливим акцентом на Кам'яновугільний і Юрський періоди. Нижньоюрські відкладення важливі для вивчення, особливо в контексті вуглеводневого потенціалу. У зв'язку з цим результати оцінки нафтогазоносності Алакольського осадового басейну мають наукову новизну.

Практична значимість. Результати дослідження мають практичне значення та можуть бути використані при плануванні й проведенні робіт із пошуку й розвідки вуглеводнів у Алакольській западині.

Ключові слова: *гідрогеологічні фактори, геодинамічні критерії, Алакольський басейн, вуглеводневий потенціал, нафта*

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