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Two models of hydrocarbon deposits formation in the South Caspian and Middle Kura Depressions

N.P. Yusubov*[1], *I.S. Guliev*[2], *2024

[1]Institute of Oil and Gas of the Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan
[2]National Academy of Sciences of the Republic of Azerbaijan, Baku, Azerbaijan
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The model for the formation of hydrocarbon deposits in the South Caspian and Middle Kura Depressions, despite a detailed study of the problem using geophysical and geochemical methods, remains a subject of debate. The model, shared by most researchers, assumes that the deposits in these depressions were formed according to the classical scheme of sediment compaction and horizontal-vertical migration of hydrocarbons along a system of bedding and fractures. According to seismic data, such a model of field formation, under some assumptions, corresponds to the conditions of the Middle Kura Depression, where no vertical channels for the migration of hydrocarbon fluids formed in sediments of the Middle Eocene and partially Maikop (Oligocene-Miocene). Here, hydrocarbon deposits were formed due to the intrastratal migration of fluids.

Geological and geophysical data show that this model does not fit well into the paleotectonic cycles of the South Caspian basin formation, where the source rocks are Oligocene-Miocene (Mayopian) rocks, and hydrocarbon deposits were discovered in Pliocene reservoirs. The model developed by the authors and supported by several researchers suggests that the determining factor in the formation of oil and gas fields is the paragenetic development of mud volcanoes and traps, and the main routes for fluid migration are the eruption channels of mud volcanoes. The following facts are cited in favor of this hypothesis: in the South Caspian Depression, all large and giant deposits are associated with eruption channels of mud volcanoes; here, the development of structures and the formation of mud volcanism are synchronized and conjugate in space and time. The chemical and isotopic composition of fluids found in breccias of mud volcanoes and samples taken from deposits is almost identical. The above opinions of the authors are formulated based on the geological interpretation of seismic data and the results of geochemical studies.

Key words: migration of hydrocarbons, faults, mud volcanism, oil and gas traps, type of reservoirs.

Introduction. The places of formation of hydrocarbons and their industrial accumulations usually do not coincide, which implies the migration of oil and gas from the places of their formation to the places of their accumulation, i.e., to fields. The results of a synthesis of published data show that there is no unity in the opinions among the scientists on the mechanism of hydrocarbon migration, and, consequently, on the formation of oil and gas fields. Some scientists support the idea of deposit formation only as a result of vertical migration (along faults). In contrast, others support only the lateral migration of hydrocarbons and their accumulation in traps.

The formation of hydrocarbon deposits during vertical migration along a fault could be provided that the fault closes somewhere

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higher. In such a «trap», gas will be at the top and liquid hydrocarbons at the bottom. Vertical migration is assumed to be characteristic of basins whose structures are disturbed by large and extended faults [Bush, 1977; Leader, 1986].

If the hydrocarbon field is multi-layered (like in the South Caspian Basin), then, taking into account the similarity of the oil's composition and properties and the presence of faults with which the source rocks are in contact, it can be assumed that it was formed as a result of the vertical migration of hydrocarbons.

It has been established [Bush, 1977; Tissot, Veltier, 1981; Leader, 1986] that the best conditions for the deposit formation exist in a dome (anticlinal) trap since the deposit formation here occurs as a result of the hydrocarbons migration along the entire perimeter of the uplift, and the trap quickly fills. In the worst conditions, there are dead-end traps where hydrocarbon accumulation occurs only on one side.

The discrepancies between calculations of the hydrocarbon potential of «source oil» strata and the volume of hydrocarbons produced during the operation of long-term fields also confirm the idea that deposits are formed as a result of fluid dynamic processes. Many researchers have established deposit replenishment facts based on oil-producing companies' data, including geophysical research data [Bochkarev, Evik, 2013; Yusubov, Guliev, 2022].

Questions about the migration range of hydrocarbons also do not find a clear solution among the scientists. A significant group of scientists believe that the range of lateral migration does not exceed 100—150 km [Bush, 1977; Tissot, Veltier, 1981; Leader, 1986].

The time and duration of the formation of oil and gas deposits are also debatable. The duration of oil and gas field formation ranges from 1 Ma to 10—12 Ma, while the formation rate ranges from 12 tons to 700 tons per year [Bush, 1977; Tissot, Veltier, 1981; Leader, 1986].

According to Yusubov [2023b], on the territory of Azerbaijan, regardless of the opinions of researchers on this issue [Aliev, Aliev, 2011; Aliev et al., 1985; Averbukh, 1995; Kerimov et al., 2002, 2003], instead of more than ten, only two oil and gas bearing regions can be distinguished: the Middle Kura Basin and the South Caspian Basin. To the north-west of the Absheron Peninsula, there is a small region with the oil and gas potential of Mesozoic deposits and insignificant established reserves (Fig. 1).

In the Middle Kura Basin, discovered hydrocarbon deposits are confined to layers formed by oil source rocks. In the South Caspian Basin, the source rocks are Oligocene-Miocene (Maikop) sediments, and hydrocarbon deposits have been discovered in Pliocene traps.

The article discusses two models based on the sedimentation-migration theory of hydrocarbon deposits formation in the indicated oil and gas regions.

The work used GIS and 2D/3D seismic data. By determining the stratigraphy of seismic horizons and lithofacies intervals, data from vertical seismic profiling (VSP), apparent resistivity (RL), spontaneous polarization (SP), gamma ray, and neutron-gamma ray logging were used.

Tectonic overview of the study from seismic stratigraphic. The territory of Azerbaijan, which belongs to the Alpine fold belt, includes the southeastern part of the Greater Caucasus, the northeastern part of the Lesser Caucasus, the Kura intermountain depression, as well as the Middle Caspian and South Caspian Depressions. The South Caspian Depressions include the Lower Kura Lowland and the Gobustan-Absheron marginal depression as the western side and northwestern part, respectively. The geological structure of the territory contains complexes of sediments from all geological periods, formed from sedimentary, volcanogenic-sedimentary, volcanogenic, and continental rocks, starting from the Precambrian and including sediments of the modern period.

Along the basement of the study area, there is a stepwise descent from west to east (Fig. 2) and from north to south. In the Upper Cretaceous, sea waters covered the entire territory of the Kura and South Caspian Depressions, the Greater and Lesser Caucasus regions. At that time, there were small islands along the periphery of the Kura Basin, on the site of the modern Caucasus Mountains. By the beginning of the Paleogene, the basin's central zones had low-height mountain structures separating the Middle Kura Depression from the Lower Kura and, consequently, the South Caspian Depression. This mountain range included [Yusubov, 2023a,c; Feyzullaev et al., 2020] the Mingachevir-Saatly-Talysh zone of Mesozoic uplifts. During this time, the greatest subsidence occurred between these central and peripheral elevations. These troughs accumulate the bulk of clastic material from the embryonic uplifts of the Greater and Lesser Caucasus [Khain, Shardanov, 1952]).

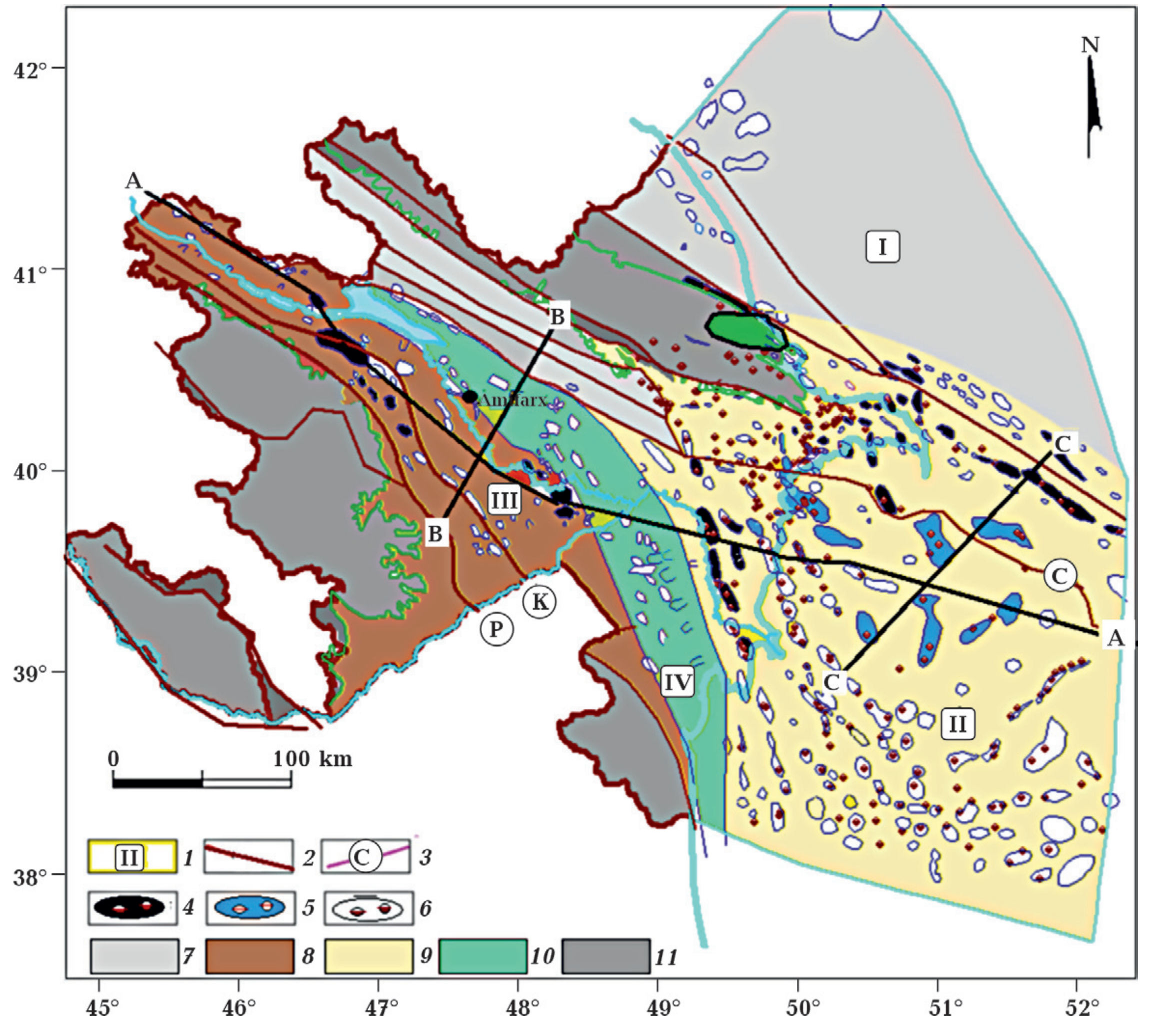

Fig. 1. Schematic map of the study region showing the junction of troughs: I — Middle Caspian trough, including the Caspian-Guba region as part of the Terek-Caspian trough and the North-Absheron syncline; II — South Caspian trough with Absheron, Gobustan and Lower Kura zones (oil and gas bearing zone); III — Yevlakh-Agjabedinskaya (Middle Kura Basin) one with the area between the Kura and Gabyrry rivers (oil and gas bearing zone); IV — zone of Mesozoic uplifts Mingachevir-Saatly-Talysh (unpromising in oil and gas terms); *1* — major depressions; *2* — tectonic faults according to geological and seismic data (P — pre-Caucasian Fault, K — Kurinsky, C — fault according to geology, seismic exploration and seismology data); *3* — tectonic fault according to seismological data [Yusubov, 2023b]; *4* and *5* — oil, gas and gas condensate fields; *6* — anticlinal uplifts and mud volcanos; *7* — unpromising zones; *8* — promising zone fed by Eocene-Maikop hydrocarbon-forming complex; *9* — promising zones fed by the Maikop hydrocarbon-forming formation; *10* — zone associated with the Mesozoic oil and gas generating complex; *11* — mountainous areas. A—A, B—B, and C—C — seismic observation lines, time sections shown in Fig. 2, 5, and 6.

The Cenozoic evolution of the study region can be divided into several regular stages, separated from each other by periods of more or less sharp changes in the regime of oscillatory movements.

The first stage corresponds to the Paleogene geotectonic setting inherited from the Upper Cretaceous. Since then, the greatest deepening of the basement has been observed in the central part of the Kura Depression, the Pritalysh, Shemakhino-Kobustan, and Apsheron Depressions (north of the Absheron-Pribalkhan threshold). In the Paleogene, a general subsidence of 500—800 m was observed in the Middle Kura Basin.

The next stage of development of the Middle and Lower Kura Depressions against the background of the continuous uplift of the Lesser and Greater Caucasus created favorable conditions for the formation of the Maikop sedimentary basin, which also covered the entire territory of the South Caspian Depression. The general subsidence in the Oligocene and early Miocene led to an anaerobic basin in these depressions (see Fig. 2), where widespread Maikop source rocks accumulated (Fig. 3).

By the beginning of the Oligocene, both in the Greater Caucasus and in the Lesser Caucasus regions, quite large landmasses arose, uniting a number of earlier uplifts and absorbing the depressions that separated these uplifts. They not only had significant sizes but were also relatively elevated, especially in the Lesser Caucasus, where the relief amplitude could reach 1000 m [Khain, Shardanov, 1952; Klenova et al., 1962]. All this led to significant areas of erosion around the Middle Kura and South Caspian Depressions and the entry of a large amount of terrigenous material into their territory. The clay fraction of this material was accumulated in the South Caspian Depression and the Lower Kura, Shamakhi-Gobustan, and Absheron troughs.

At the same time, very intense subsidence occurred in the Kura Depression itself, the depth of which in some places reached 3000 m (Well 1M in the Shirvanlinskaya area). The zone of maximum subsidence is slightly shifted to the south relative to the geometric axis of depression, i.e., near the Lesser Caucasus, which in this area experiences a much more intense uplift than the Greater Caucasus. The eastern part of the basin continued to be bordered by the Shemakhino-Kobustan and Talysh troughs, which also underwent significant subsidence — up to 1500 m for the first and up to 3000—3500 m for the second; in the central part of the depression of the corresponding section, the thickness is probably much less [Yusubov, Guliev, 2022].

In other parts of the territory, the thickness of these deposits is much less and ranges from 150 m on the periphery to 1900 m in the central zones of the basin. According to deep drilling data, the thickness of the Maikop deposits is 30 m in the junction zone of the Middle Caspian and Caspian-Guba Depressions. In the

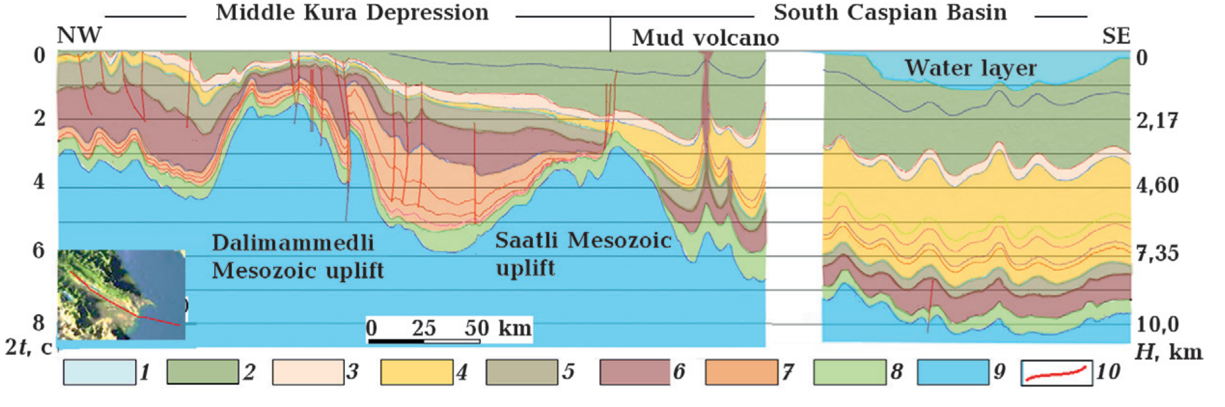

Fig. 2. Seismic geological profile NW-SE direction (Fig. 1, Line A—A): *1* — water layer, *2* — Holocene+Pleistocene, *3* — agchagyl, *4* — Pliocene, *5* — Miocene, *6* — Maikop, *7* — Paleogene, *8* — chalk, *9* — Jurassic, *10* — tectonic faults.

south-southeast direction from this area, the thickness of the Maikop deposits gradually increases and amounts to about 2300 m in the area of the North Absheron syncline. Here, according to seismic data, the total thickness of the Paleogene-Miocene deposits reaches 3300 m. In this geological section interval, the deposits'thickness is distributed in the following sequence: Miocene — 300 m, Maikop— 2300 m, and Paleogene — 700 m [Yusubov, Guliev, 2022].

In the South Caspian Basin, Maikop deposits with a thickness of 450 m were found in the areas of the North Absheron zone of Mesozoic uplifts. In the rest of the territory, the thickness of the Maikop deposits was determined based on two-dimensional seismic data. According to our assessment, based on the interpretation of seismic [Yusubov, Guliev, 2022] 2D data, the thickness of the Maikop deposits in the central part of the South Caspian Basin can reach ~2600 m (see Fig. 2).

The third stage of development of the study region corresponds to the Miocene time. This period inherited mainly the structure of the MaikopBasin, which in some places differed in some features. At this time, the zone of the Mesozoic uplift Mingachevir-Saatly-Talysh and the Pre-Talysh marginal trough, which had become isolated in the Maikop time, continued to stand out. The Lesser Caucasus and Talysh, starting from the end of the Maikop Era, formed a single large landmass. The maximum thickness of Miocene sediments is observed, according to deep drilling and seismic surveys, in the interfluve of the Kura and Iori about 2000 m, decreases in the area of the Dalimamedli ledge to zero and increases

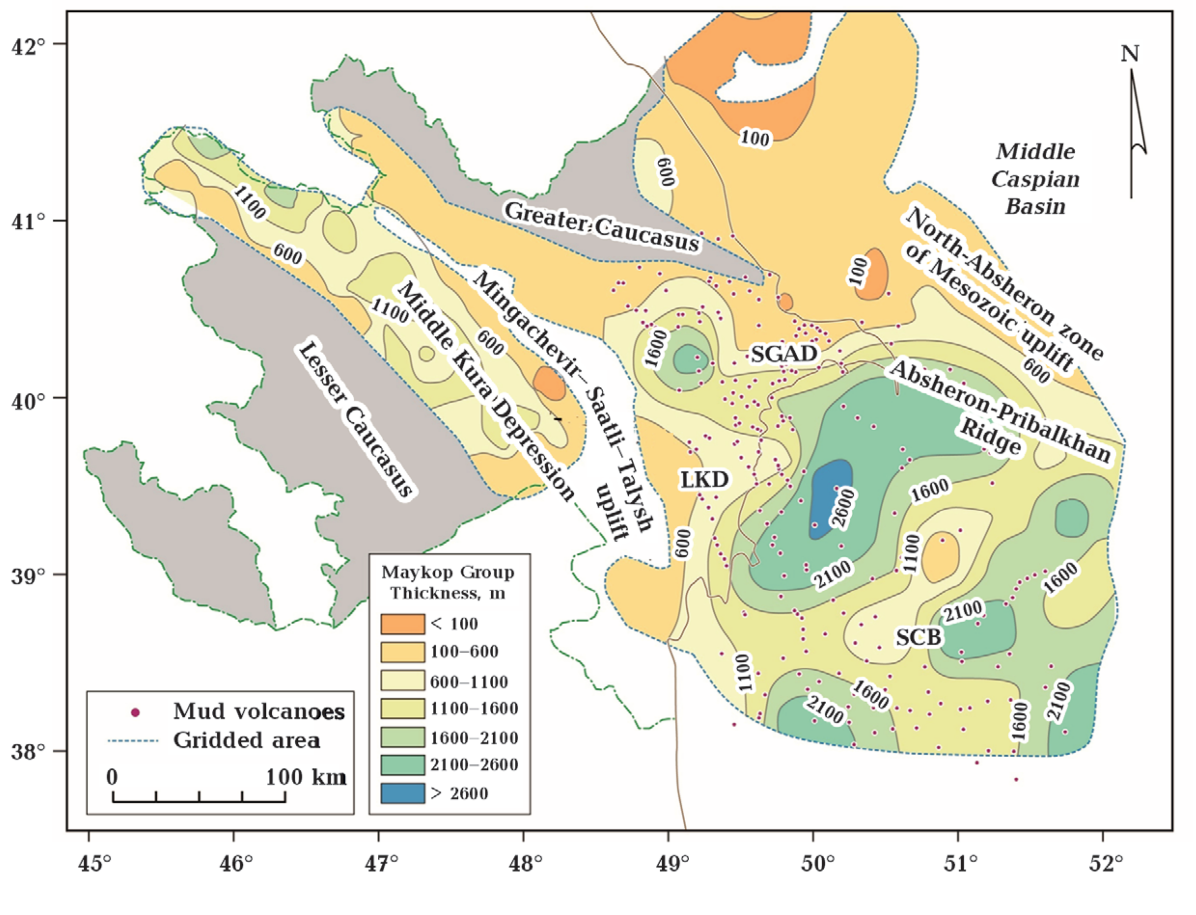

Fig. 3. Isopach map of the Maikop Group in the Azerbaijan sector of the South Caspian Basin (combining onshore and offshore data). Isopaches are measured as the actual vertical stratigraphic thickness of this unit (according to [Yusubov, Guliev, 2022]). This map is derived using seismic observations and borehole information. Abbreviations: LKD — Lower Kura Depression; SCB — South Caspian Basin; SGAD — Shamakhi-Gobustan and Absheron troughs.

again in the Muradkhanly section to 1100 m. In the Shemakhino-Kobustan trough, the thickness of the Miocene reaches 500—800 m; in the South Caspian Basin 400—600 m, in the Middle Caspian Basin 600 m.

In the Sarmatian, the uplift rate of the Greater and Lesser Caucasus sharply increased. At the same time, the scale of subsidence of the Kura Depression itself increased significantly. This is consistent with the increasing advance of the Greater Caucasus over the Lesser Caucasus in terms of the rate of uplift and the ever-increasing relative role of the Greater Caucasus in feeding the Kura Basin with terrigenous material. The subsidence of the Shemakhino-Kobustan and North Talysh troughs is becoming less and less comparable in comparison with the subsidence of the main part of the Kura Depression. In Kobustan and Northern Talysh, the thickness of the Sarmatian only in places exceeds 1000 m.

However, after the formation of the Miocene basin succession, a tectonic event occurred in the region, which led to a drop in the base level of erosion in the South Caspian Basin. Traces of this event are recorded in the geological section in the area of the Saatli uplift [Yusubov, 2023a,c]. In the Pliocene, there was an intensive accumulation of Lower Pliocene sediments of the Lower Kura Depression (the western flank of the South Caspian Sea) and the South Caspian Depression. Only by the end of the Pliocene of the Sabunchin Formation did the sea flood the Middle Kura Basin. As a result, sediments of the Surakhan Formation and later geological periods accumulated in both basins (see Fig. 2). At the same time, from the beginning of the Lower Pliocene to the end of the Sabunchin Formation of the Pliocene, arid territories predominated in the Middle Kura Trough.

The above description of the geological section permits to make an important conclusion. During the Oligocene-Quaternary period of the basin formation, as a result of the activity of river systems above Maikop, a system of layers was formed consisting of terrigenous deposits of low and high compaction with a total thickness of more than eight kilometers.

Interestingly, these events' timing roughly coincides with the «Messinian salinity crisis» (Late Miocene). As it is known [Reynolds et al., 1998], the fall in the base level, which approximately coincided with the Messinian salinity crisis, led to the isolation of the Caspian Sea from the World Ocean, and correspondingly of its western part, i.e., the Lower Kura trough. Such a large-scale geological event integrated drainage systems into this sharply reduced base level, thereby ensuring the delivery of large volumes of sediment and water from the Caucasus Mountains to the South Kura Basin, involving the Paleo-Kura and its many tributaries (mountain rivers).

Our seismostratigraphic studies and reconstruction of the profile of the Kura Basin at the end of the Miocene (see Fig. 2) showed that the base level here was between 1360 and 1800 m, which is consistent with the abovementioned statement. Although the time of origin of this event corresponds to the Late Messinian eustatic drop in sea level in the Mediterranean region [Haq et al., 1988], we believe that the base level here could have fallen as a result of the subsidence of the bottom of the Lower Kura Basin, and therefore the South Caspian Basin as a whole [Yusubov, 2023a,c].

The analysis of logging and seismic data shows that the sedimentary basin in theLower Kura Depression was formed in coastal zones and shallow sea depths (up to 40 m) with gentle relief. As a rule, terrigenous reservoir rocks are common in such conditions, forming bars, shafts, and ridges up to several meters high, parallel to the shore and beach formations. All this occurs due to transgression and regression, which ultimately led to the movement of the coastline. At the base of the transgressive sequence,basal horizons are often composed of clastic grains sorted by size. As it is known [Bush, 1977; Leader, 1986], coastal facies are extremely favorable for the discovery of thick, relatively consistent terrigenous reservoirs with high capacity and filtration properties. If impermeable rocks cover them, they become lithological natural oil and gas reservoirs.

The productive strata of the South Caspian Basin are a wedge of fluvial deltaic and lacustrine sediments, typically 5—7 km thick, that thin and gradually overlie the Upper Miocene unconformity throughout the central Caspian region.

The basal horizons of Kalinskaya and Podkirmakinskaya are composed of sandstones. The Kirmakinsky horizon, represented by a river-delta system, indicates the retreat of the sedimentation basin to the north. The Nad-Kyrmakas and stones in the north consist of braided fluvial deposits that grade into deltaic fluvial deposits in the center of the basin in the south. The middle part of the productive strata is composed of shales of the Nadirmakinsky horizon and sandstones of the Fasilinsky and Balakhani formations. The Sabunchin Formation contains layered channel sands interbedded with relatively thick shale layers. The overlying Surakhan formation on the shelf of the Southern Caspian Sea consists of clayey-sandy rocks and has a thickness of about 2—2.5 km [Abdullayev et al., 2012]. Clay rocks deposited during the Akchagyl period of sedimentation at high sea levels formed a regional seal throughout the Lower Kura Depression.

Absheron terrigenous deposits are developed throughout the study region. The divergent nature of the reflections of the complex indicates its formation under the conditions of gradual inclination of the sedimentation surface. The high-amplitude nature of the seismic record indicates interlayering of sandy and clay deposits. As seen from the regional profile, this section interval was formed in shallow marine conditions. Changes in the nature of reflection amplitudes indicate variability in the rate of subsidence of the paleobasin. The sharp differentiation of electrical logging curves (RL, SP) and reflections on the time section indicates a frequent change in transgressive and regressive conditions for the supply of sedimentary material, which indicates a shallow-marine sedimentation regime. The Caucasus Mountains, rising, were subject to erosion, supplying the foothills with coarse material, where, emerging from gorges and mountain valleys, rivers deposited powerful layers of pebbles in huge fan-shaped alluvial cones. A boulder-pebble path of the foothills was formed, which, far from the mountains, was replaced by smaller clastic material: sands, small pebbles, and clays in standing basins.

Oil source rocks and time of hydrocarbon formation. As follows from [Ali-zade et al., 1975], when assessing the hydrocarbon-forming properties of sediments and their productivity, it is necessary to take into account not only the digital values of geochemical indicators but also the volume of the oil source formation as a whole. The results of geochemical studies show that on the territory of Azerbaijan, there are some centers of hydrocarbon formation, which take into account both factors of influence in Eocene and Maikop deposits [Ali-zade et al., 1975; Guliev et al., 2004; Tagiev, Zeinalov, 2010; Guseinov et al., 2015; Alizade et al., 2018].

The literature [Tissot, Veltier, 1981; Leader, 1986] describes in detail the thermobaric conditions for the hydrocarbons formation. It is noted that the formation of liquid hydrocarbons starts at 65 °C and ends at the temperature range 135—150 °C. In our case, this so-called «liquid window» corresponds to a depth range 2.0—8.0 km (Fig. 4), while the natural gas is formed at higher temperatures— in the range of 120—200 °C and depths of 6.5—10 km. In this case, the «liquid window», as seen in Fig. 4, corresponds to 2.1—6.0 s of the double reflection time, and to 6.5—10 s for the «gas window». Limiting ourselves to this, consider the possibility of realizing these intervals of the geological section for the conditions of oil source rocks in Middle Kura and South Caspian Depressions. For this purpose, we used seismic time sections presented in Figs. 5 and 6 (for their location, see Fig. 1).

Fig. 5 shows a time section of the geological structure of the Middle Kura Depression along the line B—B (for the location, see Fig. 1). When comparing Figs. 4 and 5, it becomes obvious that Eocene deposits are located in the zone of transformation of organic matter (OM) into hydrocarbons. These deposits occupy a time interval of 2 to 5 s, which corresponds (see Fig. 4) to a temperature of 60—90 °C («liquid window»). Here, Maikop deposits are observed in the time interval of 0.5—4.0 s, which corresponds to 40—80 °C. This interval is partially included in the oil formation zone. The line B—B passes south-east of the Amirarch area, where oil was extracted from the Middle Eocene at a depth of 5087 m (with a reservoir thickness of 11 m). A comprehensive geological and geophysical data interpretation allows us to identify a similar zone along the seismic section B—B. This area is marked in Fig. 5 by a rectangle with a red outline. Such a situation is typical for some areas located along the north-eastern side of the Middle Kura Depression. Several deposits of Maikop and Eocene age were found on the left side of the Middle Kura Depression (Gazanbulag, Terter, etc.).

When comparing Figs. 4 and 5, it becomes obvious that in the Middle Kura Depression, the transformation of OM into hydrocarbons began for Eocene rocks from the end of the Maikop time and for the Maikop sediments — from the end of the Miocene. Naturally, this conclusion is approximate, but it suggests that the region has the potential to form oil and gas in the future geological time. It should be noted that the conclusion was made without considering paleodepths of oil-forming rocks. According to the time section presented in Fig. 5, it is clear that at the end of Maikop, the depth of the left side of the basin was much greater. With the growth of the Lesser Caucasus, the region rose by about 1.5—2.0 km and the upper part of the Maikop deposits in some areas was eroded. This happened along the Pre-Lesser Caucasus and Kura faults (see Figs. 1 and 5).

Fig. 6 shows a time section characterizing the structure of the geological section of the South Caspian Depression along the

2*t*, c	*H*	*T*	Zones		
0,5	0,4	30			
1,0	0,8	40			
1,5	1,3	50			
2,0	1,7	58			
2,5	2,3	66	Oil		
3,0	3,0	74	Oil		
3,5	3,6	82	Oil		
4,0	4,4	90	Oil		
4,5	5,2	97	Oil		
5,0	6,2	103	Oil	Gas condensate	
5,5	7,0	109	Oil	Gas condensate	
6,0	7,9	117	Oil	Gas condensate	
6,5	8,8	124		Gas condensate	Gas
7,0	9,7	131		Gas condensate	Gas
7,5	10,6	138		Gas condensate	Gas
8,0	11,5	145		Gas condensate	Gas
8,5	12,4	152			Gas
9,0	13,3	159			Gas
9,5	14,2	166			Gas
10,0	15,1	173			Gas

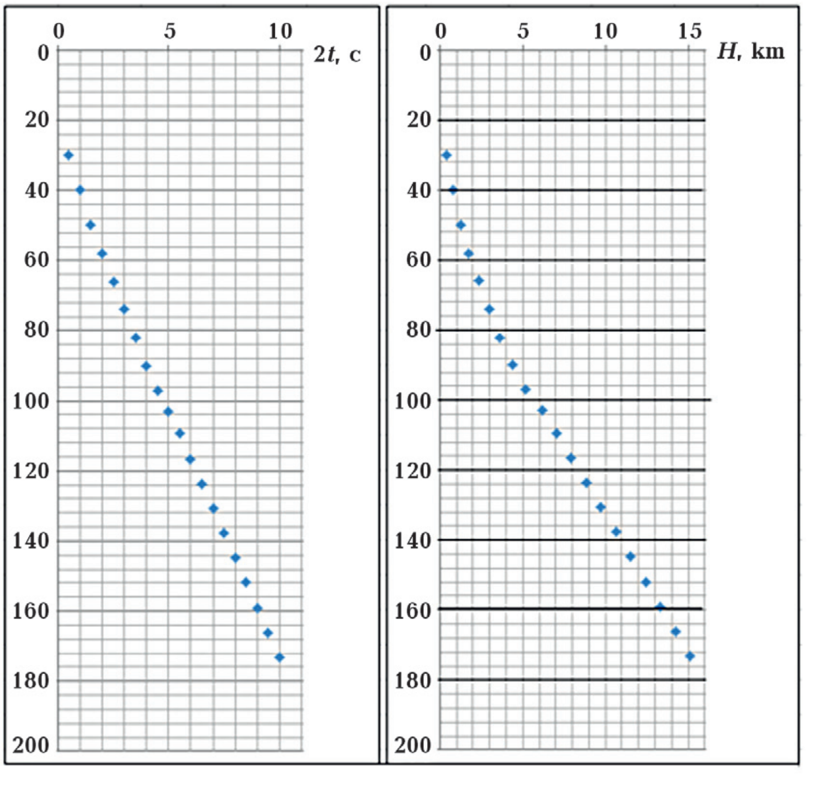

Fig. 4. Temperature dependence on depth and twice the time of the reflected wave. The graph was built according to data [Tissot, Veltier, 1981; Guliev et al., 2004; Aliev, Aliev, 2011] after averaging the data and double recalculation of depths, which serves for the preliminary assessment of the hydrocarbon-forming potential in the oil and gas regions of Azerbaijan. If VSP (vertical seismic profiling) data and temperature measurements are known, the graph can easily be converted to a more accurate one using the EXCEL; 2*t* — time in seconds, defined as the time of travelling ofthe waves reflected from the surface of the productive formation (fluid-forming rock) on the time section; *T* — temperature in degrees; *H* — depth of fluid-forming rock in km.

line C—C marked in Fig. 1. Comparison of Fig. 6. Fig. 4 shows that Maikop deposits located in the zone of transformation of OM into hydrocarbons. These deposits occupy a time interval 5—7.5 s, which corresponds to temperature 85—140 °C («liquid window») in Fig. 4. In some places, the depth of Maikop sediments reaches 8 s or more.

Here, the process of hydrocarbon formation («liquid window») began at the end of the Pliocene Sabunchin Formation (productive strata). During the Surakhani Formation period, the basin's depth increased by approximately 3 km, which led to an increase in temperature in the centers of hydrocarbon formation. In other words, gas condensate pockets appeared on the geological section. In the Pleistocene, centers of gas formation appeared.

Hydrocarbon migration channels. «It can be considered almost certain that the hydrocarbons that make up the majority of the world's oil reserves were formed and migrated from source rocks at temperatures of at least 50—70 °C at depths of at least 1000—1500 m...» [Tissot, Veltier, 1981]. This conclusion fully reflects the situation with the processes of hydrocarbon migration in the conditions of the geological structure of the territory of Azerbaijan.

There are many types of hydrocarbon migration. Consider lateral migration (intralayer and interlayer) and vertical migration (through faults and cracks). Other types of migration cannot be determined from seismic data and, therefore,are not considered here.

Since deposits in the Middle Kura Depression were found inside layers composed of oil source rocks, the conclusion suggests itself that the deposits here were formed as a result of intralayer migration of hydrocarbons. Indeed, as can be seen from Fig. 1, the deposits here are located far from tectonic faults. According to seismic data, there are no tectonic faults and cracks here (see Fig. 5), which could serve as channels for fluid migration [Yusubov, 2012, 2017a,b, 2020; Guliev et al., 2020].

From Figs. 1 and 6, we can conclude that the deposits in the South Caspian Depression, without exception, are associated with mud volcanoes [Yusubov, 2012, 2017a,b, 2020; Yusubov, Guliev, 2022; Guliev et al., 2020]. Here, mud volcanoes'eruptive channels play a role as migration channels. The interpretation of geological and geophysical data confirmsthis conclusion.

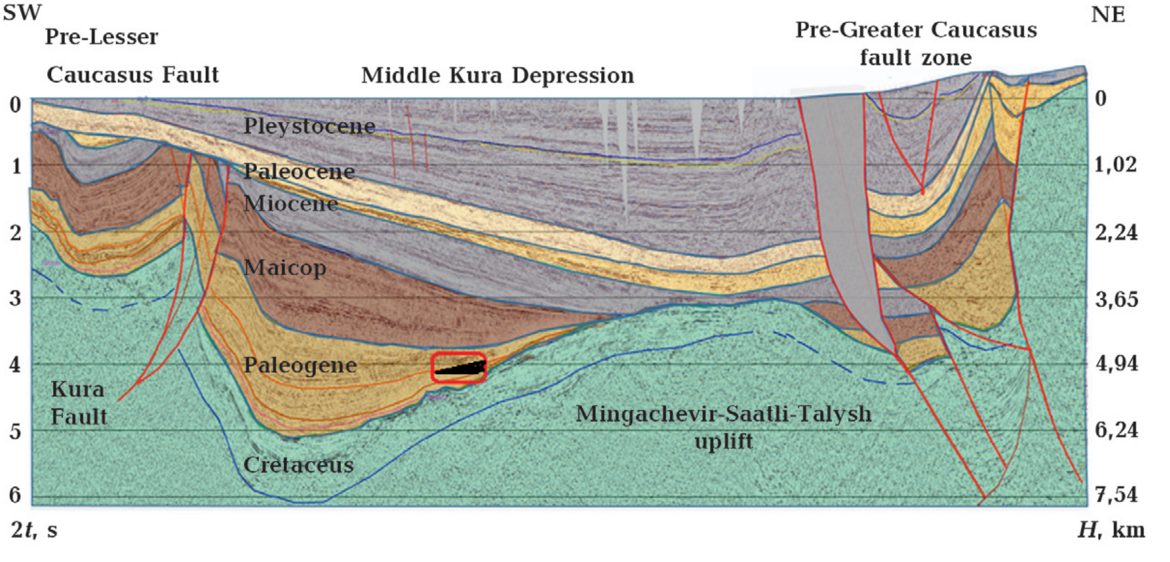

Fig. 5. Time section along line B—B (for the location, see Fig. 1). In the left and right parts of the profile, the Kura, Pre-Lesser Caucasus, and Pre-Great Caucasus tectonic faults are shown. Calculations show that the Pre-Lesser Caucasus fault with an amplitude of more than 1.5 km was formed after the migration of hydrocarbons into the sand reservoirs located in the basal Maikop horizons, formed in Maikopian rocks. The rectangle with a red outline shows the promising oil production area.

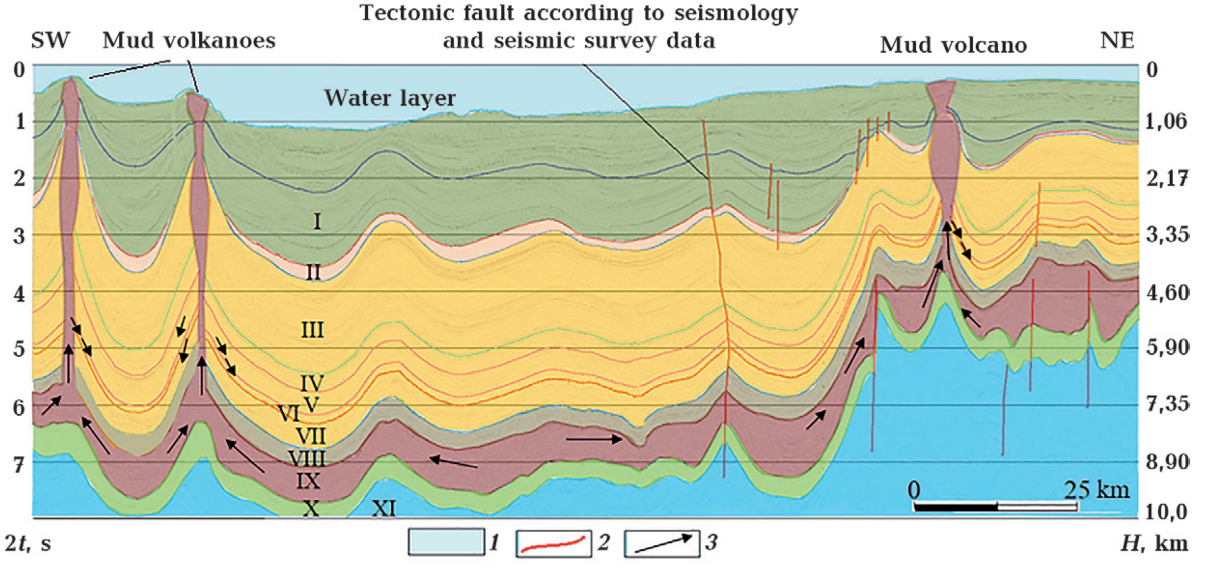

Fig. 6. Time section in the South Caspian Depression along the C—C line (see Fig. 1). The figure shows the intersection of the profile line with a fault identified from seismological and seismic data. In this area, the fault is marked by low-amplitude displacement, which is not visible due to its scale: *1* — aqueous layer, *2* — tectonic faults, *3* — migration of Maikopian source rocks (mud volcanism), I — Pleistocene + Quaternary deposits, II — agchagyl, III — Surakhani formation of the Pliocene, IV — Sabunchinsky formation of the Pliocene, V — horizons of the Balakhana formation and the «break formation», VI — Perupa Formation, VI — Kirmakinskaya+Kalinskaya Formation, VIII — Miocene, IX — Maikop oil source rocks, X — Cretaceous , XI — Jurassic deposits.

Fig. 7 shows the result of seismic data interpretation in the area of active mud volcano. Shows that the mud volcano has an eruptive channel with dimensions of horizontal cross-section of approximately 9×6=54 km^2 at a time of 2.5 s (2.9 km). On the horizontal section of the cube corresponding to time 6.0 s (8.9 km), the eruptive channel of the mud volcano is absent (Fig. 7, *b*, *d*). The roots of this volcano are located at the level of Maikop sediments. From the vertical sections of this seismic cube in two directions,one cansee that the hydrocarbon deposits discovered on the Lower Pliocene horizons are connected with the oil source deposits (Maikop) only by the eruptive channel of the mud volcano. Tectonic faults, essentially cracks formed under the pressure of horizontal forces with small amplitudes of movement, do not participate in redistributing hydrocarbons formed in Maikop deposits.

Discussion of results and conclusions. According to geological and geophysical data, the deposits discovered in the Middle Kura Depression have no connection with neighboring stratigraphic intervals of the geological section. They were discovered inside the Middle Eocene and Maikopian layers, i.e., where the OM (organic matter) was transformed into hydrocarbons. In other words, within the Middle Kura Depression, sediments are confined to layers with oil source rocks. True, there is one (only) exception to this scheme — in the example of the Muradkhanlinsky massive field, located in effusive rocks of Mesozoic age, subjected to denudation processes and fed by Eocene and Maikop oil. Here, the process of hydrocarbon formation and their migration began at the end of the Miocene and continues today (see Figs. 4 and 5).

Hydrocarbon deposits discovered in the South Caspian Basin are confined to geological bodies with good reservoir properties in marine, continental, and transitional sedimentation zones. The main property of such a geological section is the absence of vertical communication channels between objects with reservoir properties — tectonic faults.

As a result of studying the isotopic composition of oil, gas, hydrogen, and oxygen in the waters of mud volcanoes, it was establishedthat fluid generation in the South Caspian Basin occurs in the stratigraphic interval of sediments from the bottom of the Paleogene to the bottom of the Pliocene [Guliev et al., 2004].

Here, the process of hydrocarbon formation («liquid window») began at the end of the Pliocene Sabunchin Formation (productive strata). During the Surakhani Formation period, the basin's depth increased by approximately 3 km, which led to an increase in temperature in the centers of hydrocarbon formation. In other words, gas condensate pockets appeared on the geological section. In the Pleistocene, centers of gas formation appeared. These processes continue today.

As can be seen from Figs. 1, 2, and 6, in the

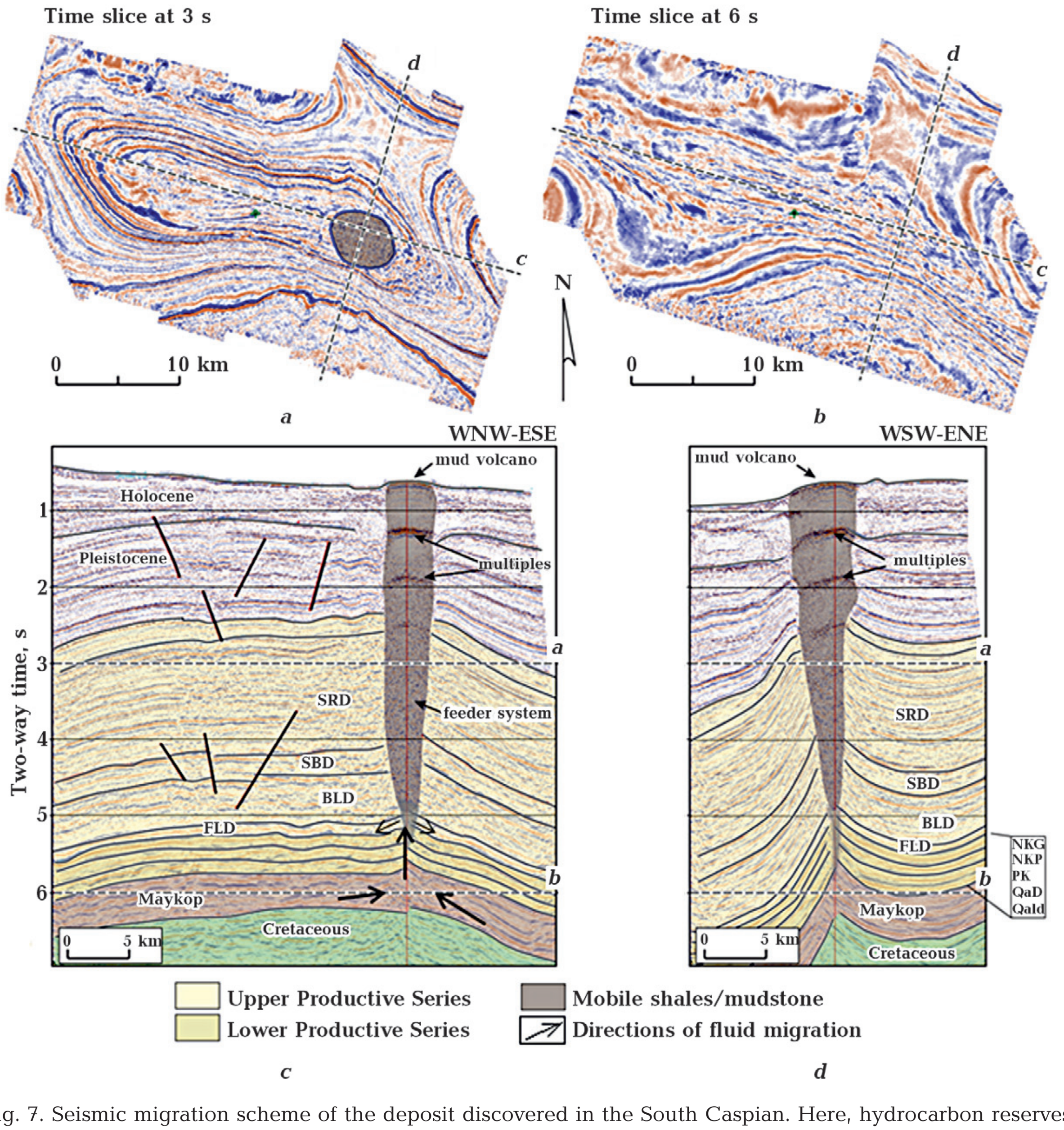

Fig. 7. Seismic migration scheme of the deposit discovered in the South Caspian. Here, hydrocarbon reserves are confined to the FLD horizon, possibly also to the NKP. Stratigraphic units and ages are detailed in Figure: Pleistocene and Holocene series correspond to the Agchagil-Absheron and Bakunian sequences, respectively. Abbreviations: BLD — Balakhany Formation, FLD — Fasila (or Pereryva) Suite, KS — Kirmaky Suite, NKG — Qirmakiustu shale, NKP — Qirmakiustu sand, QAD — Qirmakialti Suite, QaLD — Kala Suite, SBD — Sabunchy Formation, SRD — Surakhany Formation.

geological section of the South Caspian Basin there are no tectonic faults connecting hydrocarbon deposits with oil source (Maikop) rocks. At the same time, in the South Caspian Basin, all hydrocarbon deposits, without exception, are associated with mud volcanic structures (see Fig. 1), i.e.,regardless of their shape, they are contact deposits located in reservoirs of Pliocene age. Consequently, under the conditions of the South Caspian Basin, the process of horizontal, within the parent horizon (Maikop deposits), and vertical migration of hydrocarbons along the eruption channels of mud volcanoes occurs in combination with processes associated with mud volcanism.

References

Abdullayev, N.R., Riley, G.W., & Bowman, A.P. (2012). Regional controls on lacustrine sandstone reservoirs: The Pliocene of the South Caspian Basin. In O.W. Baganz, Y. Bartov, K. Bohacs, D. Nummedal (Eds.), *Lacustrine sandstone reservoirs and hydrocarbon systems* (pp. 71—98). AAPG Memoir 95. https://doi.org/10.1306/13291385M953446.

Aliev, A.I., & Aliev, E.A. (2011). *Oil and gas potential of great depths. Problems of forecasting, search and reconnaissance*. Baku: Oscar, 420 p. (in Russian).

Aliev, A.I., Bagir-Zade, F.M., Buniat-Zade, Z.A., Guseinov, A.N. et al. (1985). *Oil and gas fields and promising structures of the Azerbaijan SSR*. Baku: Elm, 298 p. (in Russian).

Ali-zade, A.A., Akhmedov, G.A., Aliev, G.-M.A. et al. (1975). *Assessment of oil-producing properties of Meso-Cenozoic deposits of Azerbaijan*. Baku: Elm, 139 p. (in Russian).

Alizade, Ak.A., Guliev, I.S., Mamedov, P.Z., Alieva, E.G., Feyzullaev, A.A., & Guseinov, D.A. (Eds.). (2018). *Productive strata of Azerbaijan. Vol. II. Bosom*. Moscow, 236 p.(in Russian).

Averbukh, B.M. (1995). Oil and gas geological zoning of complex regions using a retrospective analysis of the evolution of sedimentary rock basins. *Geology of Oil and Gas*, (1), 5—11 (in Russian).

Bush, D.A. (1977). *Stratigraphic traps in sandstones*. Moscow: Mir, 216 p. (in Russian).

Bochkarev, A.V., & Evik, V.N. (2013). The nature of anomalous phenomena in bituminous clays of the lower Maikop of the Central Ciscaucasia. *Oil Field Business*, (7), 8—18 (in Russian).

Feyzullaev, A.A., Kocharli, Sh.S., & Abbasova, S.V. (2020). Superimposed troughs of Azerbaijan in connection with their oil and gas potential. *Mining Sciences and Technologies*,(2), 72—81 (in Russian).

Guliev, I.S., Guseinov, D.A., & Feizullaev, A.A. (2004). Geochemical features and sources of fluids from mud volcanoes of the South Caspian sedimentary basin in the light of new data on the isotopes of hydrocarbons, hydrogen and oxygen. *Geochemistry*,(7), 792—800 (in Russian).

Guliev, I.S., Yusubov, N.P., & Guseinova, Sh.M. (2020). On the mechanism of formation of mud volcanoes in the South Caspian basin according to 2D/3D seismic data. *Physics of the Earth*,(5), 131—138 (in Russian).

Guseinov, B.B., Ibadov, F.I., Salmanov, A.M., Alieva, E., Magerramov, B.I., & Tagiev, M.F. (2015). Paleotectonic substantiation of the potential of non-traditional hydrocarbons in the sediments of theMaikop complex of the Yevlakh-Agdzhabedinsky trough. *SOCAR Proceedings*, (3), 9—18. https://doi.org/10.5510/OGP20150300247 (in Russian).

Haq, B.U., Hardenbol, J., & Vail, P.R. (1988). Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In C.K. Wilgus, B.S. Hastings, C.G.St.C. Kendall, H.W. Posamentier, C.A. Ross, J.C. Van Wagoner (Eds.), *Sea-level change: an integrated approach* (pp. 40—45). SEPM Spec. Publ. 42. http://dx.doi.org/10.2110/pec.88.01.0071.

Kerimov, K.M., Guseinov, A.N., Gadzhiev, F.M., Gasanov, I.S., Guseinov, G.A., Kocharli, Sh.S., & Zeynalov, M.M. (2002). *Map of tectonic zoning of oil and gas bearing regions of Azerbaijan*. Baku: Cartography Factory, 18 p. (in Russian).

Kerimov, K.M., Guseinov, A.N., Gadzhiev, F.M., Gasanov, I.S., Guseinov, G.A., Kocharli, Sh.S., & Zeynalov, M.M. (2003). *Map of oil and gas geological zoning and oil and gas potential prospects of Azerbaijan*. Baku (in Russian).

Khain, V.E., & Shardanov, A.N. (1952).*Geological history and structure of the Kura depression*. Baku: Publ. House of the Academy of Sciences of Azerbaijan SSR, 300 p. (in Russian).

Klenova, M.V., Solovie, I.F., Aleksina, A., Vikhrenko, N.M., Kulakova, L.S., Maev, E.G., Richter, G., & Skornyakova, N.C. (1962). *Geological structure of the underwater slope of the Caspian Sea*. Moscow: Ed. Academy of Sciences of the USSR, 638 p. (in Russian).

Leader, M.R. (1986). *Sedimentology*. Moscow: Mir, 439 p. (in Russian).

Reynolds, A.D., Simmons, M.D., Bowman, M.B., Henton, J., Brayshaw, A.C., Ali-Zade, A.A., Guliev, I.S., Suleymanova, S.F., Ateava, E.Z., Mamedova, D.N., & Koshkarly, O. (1998). Implications of outcrop geology for reservoirs in the Neogene Productive Series: Apsheron Peninsula, Azerbaijan. *AAPG Bulletin, 82*, 25—49. https://doi.org/10.1306/1D9BC38B-172D-11D7-8645000102C1865D.

Tagiev, M.F., & Zeynalov, G.A. (2010). On the study of the generation potential of rocks and the efficiency of the primary migration of hydrocarbons from oil source deposits based on pyrolysis data. *SOCAR Proceedings*,(2), 16—19.

Tissot, B., & Veltier, D. (1981). *Formation and distribution of oil*. Moscow: Mir, 501 p. (in Russian).

Yusubov, N.P. (2012). Features of seismicity in the oil and gas regions of Azerbaijan. *Geophysics*,(2), 48—53 (in Russian).

Yusubov, N.P. (2017a). On the connections between the foci of intermediate and shallow-focus earthquakes and tectonic faults according to seismic data using the common depth point method.*Bulletin of PNIPU. Geology. Oil and Gas and Mining Business, 16*(4), 304—312 (in Russian).

Yusubov, N.P. (2020). On the issue of fault tectonics of depression zones of Azerbaijan according to seismic data. *SOCAR Proceedings*,(3), 11—17 (in Russian).

Yusubov, N.P. (2017b). On the issue of the existence of the West Caspian fault (in order of discussion). *Azerbaijan Oil Economy*, (4), 12—17 (in Russian).

Yusubov, N.P. (2023a). On the nature of the Talysh-Vandam Mesozoic uplift and the West Caspian tectonic fault (new data and versions). *Azerbaijan Oil Industry*, (11), 4—12 (in Russian).

Yusubov, N.P. (2023b). On the need to revise maps of tectonic and oil and gas geological zoning of depression zones of Azerbaijan. *Azerbaijan Oil Industry*, (4), 63—72(in Russian).

Yusubov, N.P. (2023c). Traces of paleogeodynamic processes in the zone junctions of the Middle and Lower Kura depressions. *Geofizicheskiy Zhurnal*, *45*(5), 119—125. https://doi.org/10.24028/gj.v45i5.289115.

Yusubov, N.P., & Guliev, I.S. (2022). *Mud volcanism and hydrocarbon systems of the South Caspian basin (according to the latest data from geophysical and geochemical studies)*. Baku: Elm, 168 p. (in Russian).

Дві моделі формування покладів вуглеводнів у Південнокаспійській і Середньокуринській западинах

Н.П. Юсубов[1], І.С. Гулієв[2], 2024

[1]Міністерство науки і освіти Азербайджану, Інститут нафти і газу, Баку, Азербайджан
[2]Національна академія наук Азербайджану, Баку, Азербайджан

Модель формування покладів вуглеводнів у Південнокаспійській і Середньокуринській западинах, незважаючи на детальне вивчення проблеми геофізичними та геохімічними методами, залишається предметом дискусій.

Модель, яку поділяють більшість дослідників, припускає, що поклади в цих западинах утворилися за класичною схемою ущільнення осадів і горизонтально-вертикальної міграції вуглеводнів по системі пластів і тріщин.

За сейсмічними даними така модель формування родовища, за деякими припущеннями, відповідає умовам будови Середньокуринської западини, де відсутні вертикальні канали міграції вуглеводневих флюїдів, утворених у відкладах середнього еоцену і частково майкопського ярусу (олігоцену—міоцену). Тут у результаті внутрішньопластової міграції флюїдів утворилися поклади вуглеводнів, що тяжіють до цих стратиграфічних інтервалів геологічного розрізу.

Згідно з даними геолого-геофізичних досліджень ця модель погано вписується в палеотектонічні цикли розвитку Південнокаспійської западини, де вихідними породами є олігоцен-міоценові (майкопські) породи, а в пліоценових колекторах виявлено поклади вуглеводнів. Ця западина характеризується моделлю, розробленою авторами статті та підтриманою низкою дослідників, яка передбачає, що визначальним фактором формування нафтогазових родовищ є парагенетичний розвиток грязьових вулканів і пасток, а основними шляхами міграції рідини є канали виверження грязьових вулканів.

На користь цієї гіпотези наведено такі факти: у Південнокаспійській западині всі великі і гігантські родовища пов'язані з виверженнями грязьових вулканів, розвиток структур і формування грязьового вулканізму синхронізовані і спряжені в просторі і часі. Хімічний та ізотопний склад флюїдів, виявлених у брекчіях грязьових вулканів, і проб, взятих з родовищ, практично ідентичні.

Наведені вище думки авторів сформульовані на підставі геологічної інтерпретації сейсмічних даних і результатів геохімічних досліджень.

Ключові слова: міграція вуглеводнів, розломи, грязьовий вулканізм, нафтогазові пастки, тип колекторів.