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Prospectivity of Pliocene-Miocene deposits of the Khasilat field of the Absheron oil and gas bearing region according to surface and well seismic data

Y.T. Alibekova, 2024

Azerbaijan State Oil and Industry University, Baku, Azerbaijan
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The article begins with a history of commercial hydrocarbon production in the Absheron Peninsula, which is one of the oldest oil and gasbearing regions in the world. Despite the long exploitation of hydrocarbons here, this region has a strong industrial potential, especially in the lower Pliocene and underlying sediments. A lithological-stratigraphic boundary separating the Qala Suite of the Productive Series into two parts has been delineated by a Well Logging complex. The lower part is most likely represented by sandstones deposited during the transgressive phase of development of this part of the peninsula, while the upper part is characterized by complete and incomplete regressive cycles. The boundary of stratigraphic unconformity was marked, and also the boundary of thermobaric system change can be synchronously connected with it. As for the older sediments, their prospectivity is indicated by commercial production of hydrocarbons in the adjacent areas.

An indirect indication of oil and gas prospects of the underlying Productive Series fields is the identification of a zone of Abnormal Formation Pressure in the Khasilat field according to the Vertical Seismic Profiling results of two wells.

The results of reinterpretation of 3D seismic data are widely reported in the article. Temporal thickness maps suggest a large river delta in the area during the formation of the Qala Suite deposits. Obviously, the appearance of numerous deltaic channels and straits was associated with gentle slopes and shallow depths of the coastal part of the basin where the delta was formed. Based on the constructed map of temporal thicknesses between the seismic horizon confined to the QaS-2 and SH-IV strata, which in the conventional time scale represents the paleorelief at the start of the formation of the Qala Suite deposits, the most favorable areas for the accumulation of sandy sediments were determined.

Key words: Absheron Peninsula, Pliocene-Miocene deposits, Qala Suite, seismic survey, vertical seismic profiling, time section, «bright spot» anomaly.

Introduction. The Absheron Peninsula is one of the main oil and gas bearing regions of Azerbaijan. The history of industrial production of hydrocarbons (HC) here dates back about two centuries, if we consider that the first well was drilled here by the percussion method to a depth of 21 meters under the guidance of V.N. Semenov in 1846 near Baku, in the village of Bibi Eibat (now it is very close to Baku). The main objects of exploitation in the Absheron Peninsula and the Azerbaijani sector of the Caspian Sea are still separate formations of the Productive Series (PS) which belongs to the Lower Pliocene [Mammadov, 2018]. Along with these deposits, the attention of geologists and geophysi-

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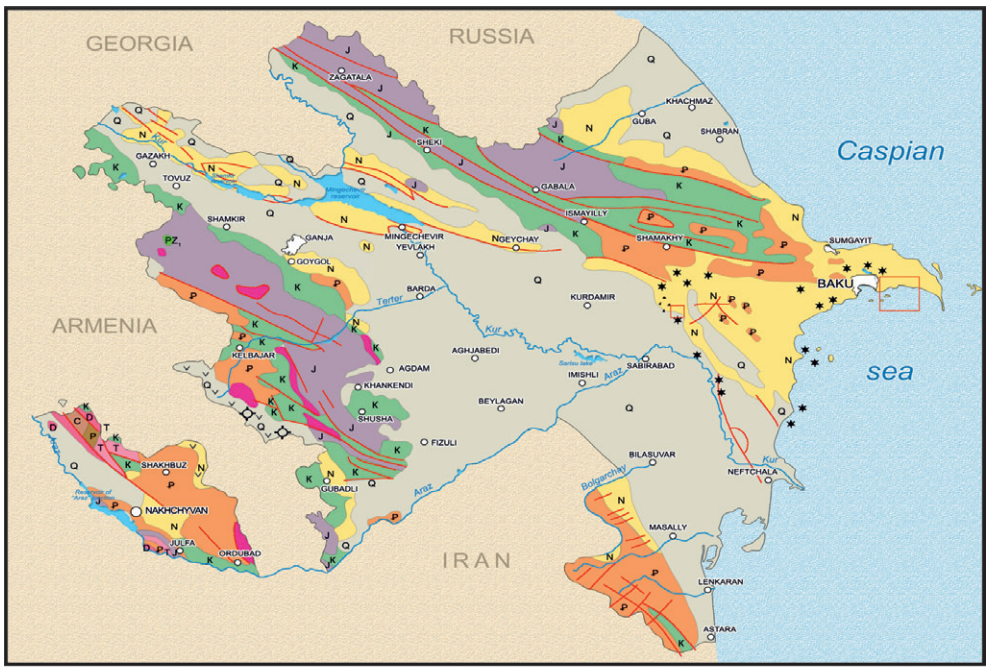
cists has recently been attracted to Miocene deposits underlying them, in which HC deposits are also expected.

The Zira, Karachukhur-Zykh and east of the latter Khasilat oil and gas fields are located in the south-eastern plain part of the Absheron Peninsula (Fig. 1).

The Zyrinskoye, Karachukhur-Zykhskoye,



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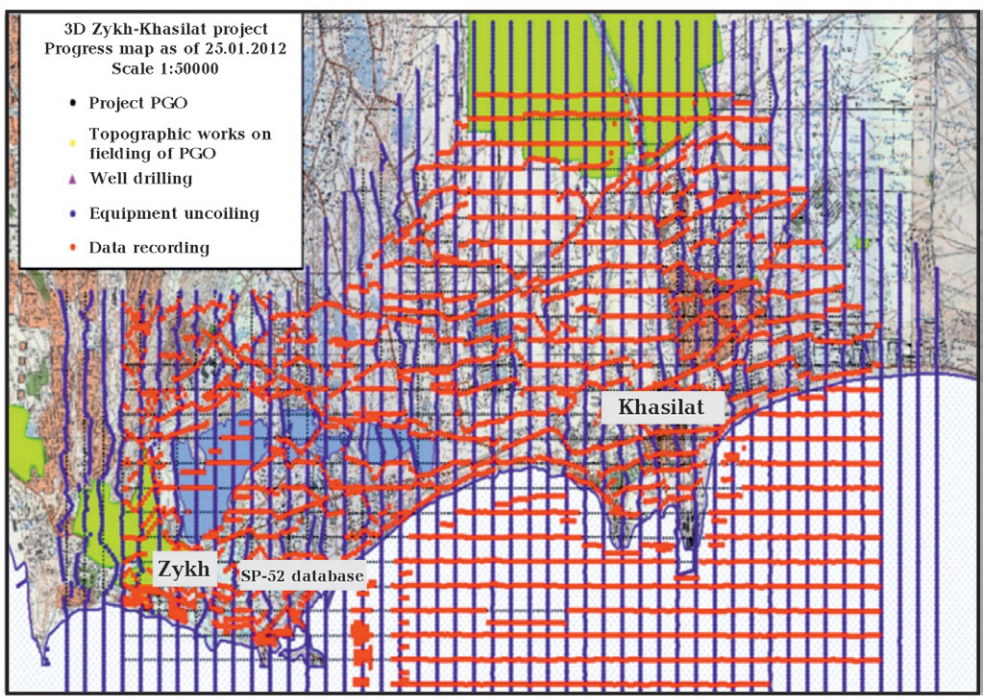

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Fig. 1. Geological map the area (excerpted from the Agency on State Support to NGOs of the Republic of Azerbaijan (https://boundtoazerbaijan.com/maps/) (*a*). The black rectangle shows the outline of work using the Common Depth Point (CDP-3D) method. The Khasilat area with 3D excitation and registration lines (*b*): black — project PGO-points of geophysical observations, yellow — topographic works on field of PGO, purple — well drilling, blue — equipment uncoiling, red lines — data recording.

and east of the latter Khasilat oil and gas fields are located in the south-eastern lowland part of the Absheron Peninsula.

The Karachukhur field has been operated since the 1920s, and the others since the late 1940s, after WWII [Alieva et al., 2008]. All fields were put into operation with high flow rate wells, for example, the wells of Zira field were put into operation with aninitial daily flow rate of 300.000—600.000 m^3 and acondensate of 50—130 tons (from all objects of the Lower Kirmaky (LK) and Qala Suites (QaS)). The Karachukhur-Zykh field is characterized by the largest oil-bearing area in the LK,Kirmaky (KS), and QaS. According to new geological and geophysical data, the Khasilat field can be confined to a distant dip of the eastern wing of the Karachukhur-Zykh fold, where QaS is wedged upward along the upthrust, lying on an eroded Pontic surface with a sharply pronounced angular unconformity. Here in the QaS section there are four production objects with a total thickness of 250—350 m, in which their lowered, comparatively thicker parts are the most productive, and the outcropping head parts are less productive.

As can be seen, the main production facilities are located in the Lower Pliocene Productive Series (PS) deposits. Prospects of oil and gas bearing capacity of this part of Absheron Peninsula are connected with PS deposits and underlying deposits, in the study of which seismic survey plays the main role. The present research is aimed at a detailed 3D seismic survey of QaS of the PS and the underlying deposits in order to identify oil and gaspromising intervals and areas in the Khasilat area.

Methods. Fig. 2 shows a schematic diagram of the structure of the QaS strata, including the upper part of the suite, well-researched by drilling, and its lower, prospective part. The figure clearly shows that the lithologic-stratigraphic boundary separating the two parts is distinguished by the Well Logging (WL) complex. The lower part is most likely represented by sandstones deposited during the transgressive phase of development of this part of the Absheron Peninsula, while the upper part is characterized by complete and incomplete regressive cycles. The wavy line in the figure shows the boundary of stratigraphic unconformityalso, the boundary of the thermobaric system change can be synchronously associated with it [Buryakovskiy, 1991]. This is indicated by low values of SER (specific electrical resistance), «clay line» at the SP (Spontaneous Potential) curve. It should be noted that under the conditions of Abnormal Formation Pressure (AFP), the readings of resistance, SP, AL (Acoustic Logging), NGL (Neutron Gamma Logging) methods are distorted and most often shifted to low values.

A detailed cyclostratigraphic model of the QaS strata based on data from several wells shows a large number of unconformity surfaces of different rank and scale. All this indicates unstable paleogeography and paleogeomorphology of this sedimentation area.

Taking into consideration that there is no uncovered part of the section of Paleogene-Miocene deposits available for study, we use analogous fields and regional paleogeographic maps for the region. In this case, we will cite the Muradkhanli field, where an oil field was discovered in 1978 in the Upper and Middle Eocene deposits (Fig. 3), as well as the Jafarli field in Middle Eocene deposits

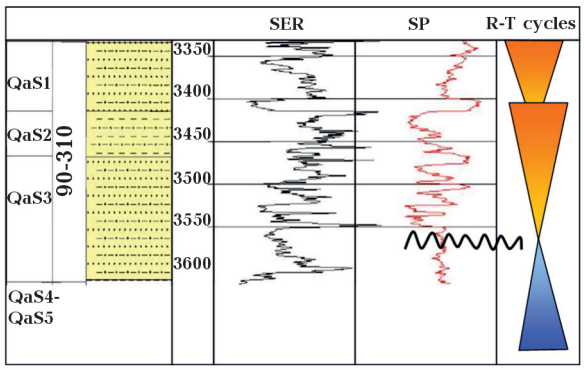


Fig. 2. General scheme of the Qala Suite structure: SER — specific electrical resistance, SP — Spontaneous Potential, R-T cycles — regressive-transgressive cycles. The wavy line shows the boundary between cyclites (procyclites with lithology from coarse-grained to fine-grained from QaS3—QaS5 suites, recyclites with lithology from fine-grained to coarse-grained from QaS1 to QaS3 suites).

[Kerimova, Samadzadeh, 2023]. The reservoirs are represented by deposits, probably of weathering crust and terrigenous rocks, which were deposited near the source of removal. According to the paleogeographic map, terrigenous-carbonate sediments were accumulated during the Eocene-Late Cretaceous [Khalifa-Zadeh et al.,2006].

The most favorable conditions for accumulation of HC deposits in Paleogene-Miocene reservoirs are noted in the AbsheronOil-and-Gas Bearing Region (OGBR) [Abdullayev et al., 2012]. In Miocene, deposits of the peninsula's undiscovered oil resources are mainly confined to reservoirs of the Diatom Suite and Chokrak horizon. Expected types of the fields: lithological-stratigraphic and tectonically shielded.

Interpreting the seismic data, the range of HC traps in the lower part of the sedimentary section (Paleogene-Miocene interval) can be wide: stratigraphic, tectonic, lithological, combined. Thus, seismic surveys established that the Paleogene-Miocene deposits and the Productive Series (PS) have a non-conformity, which makes the formation of lithological-stratigraphic traps the most probable.

Borehole VSP (vertical seismic profiling)

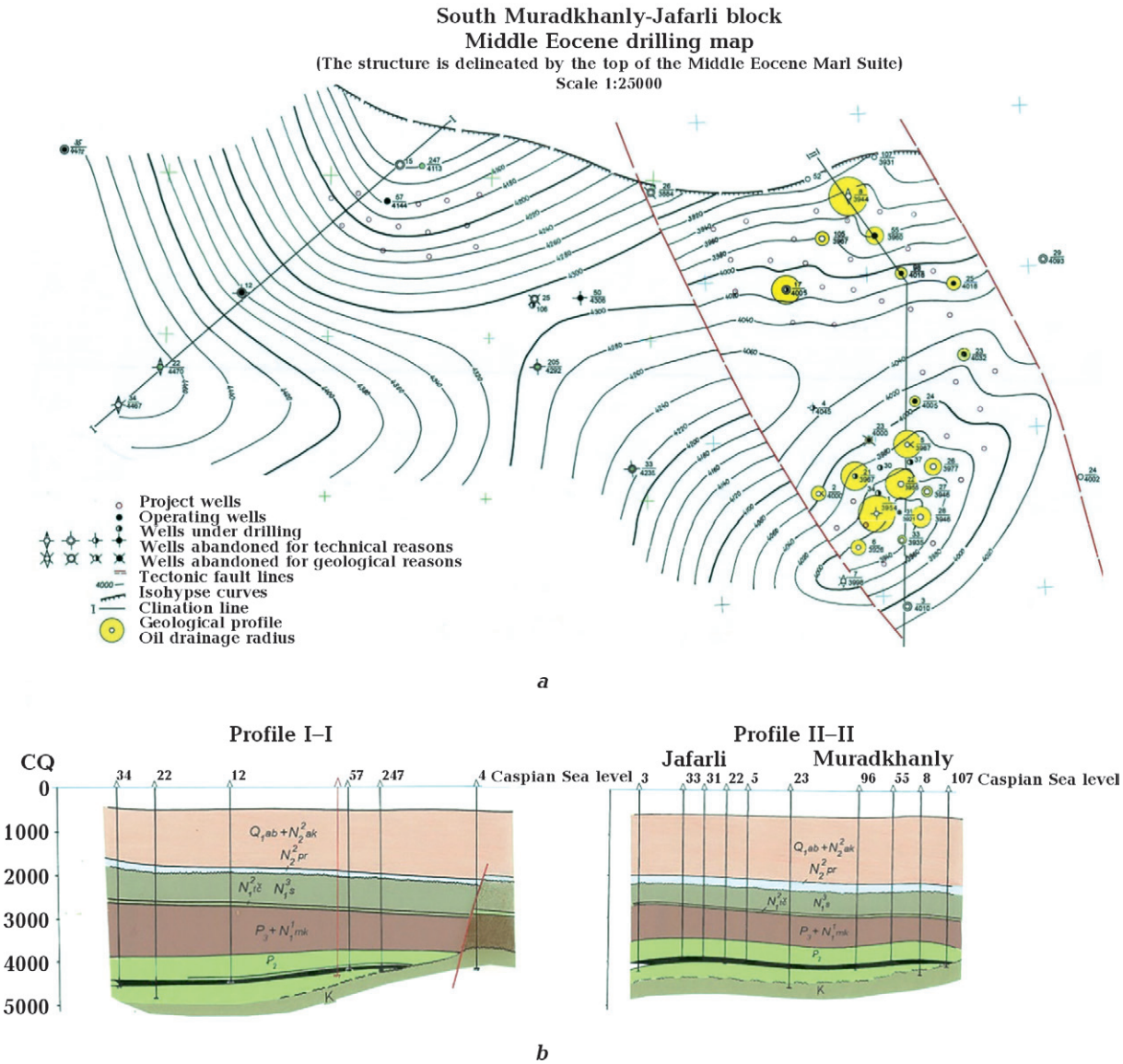


Fig. 3. Structural map (*a*) and geological sections of the Muradkhanly field (*b*).

surveys were conducted at one of the wells of the neighboring Khasilat field in 2010. Processing and interpretation of VSP data showed anomalously low interval velocities of seismic waves at the depths of 3900—4250 m (Fig. 4).The velocities are characteristic of absolutely shallow depths, which,according to some researchers, indicates that here de-

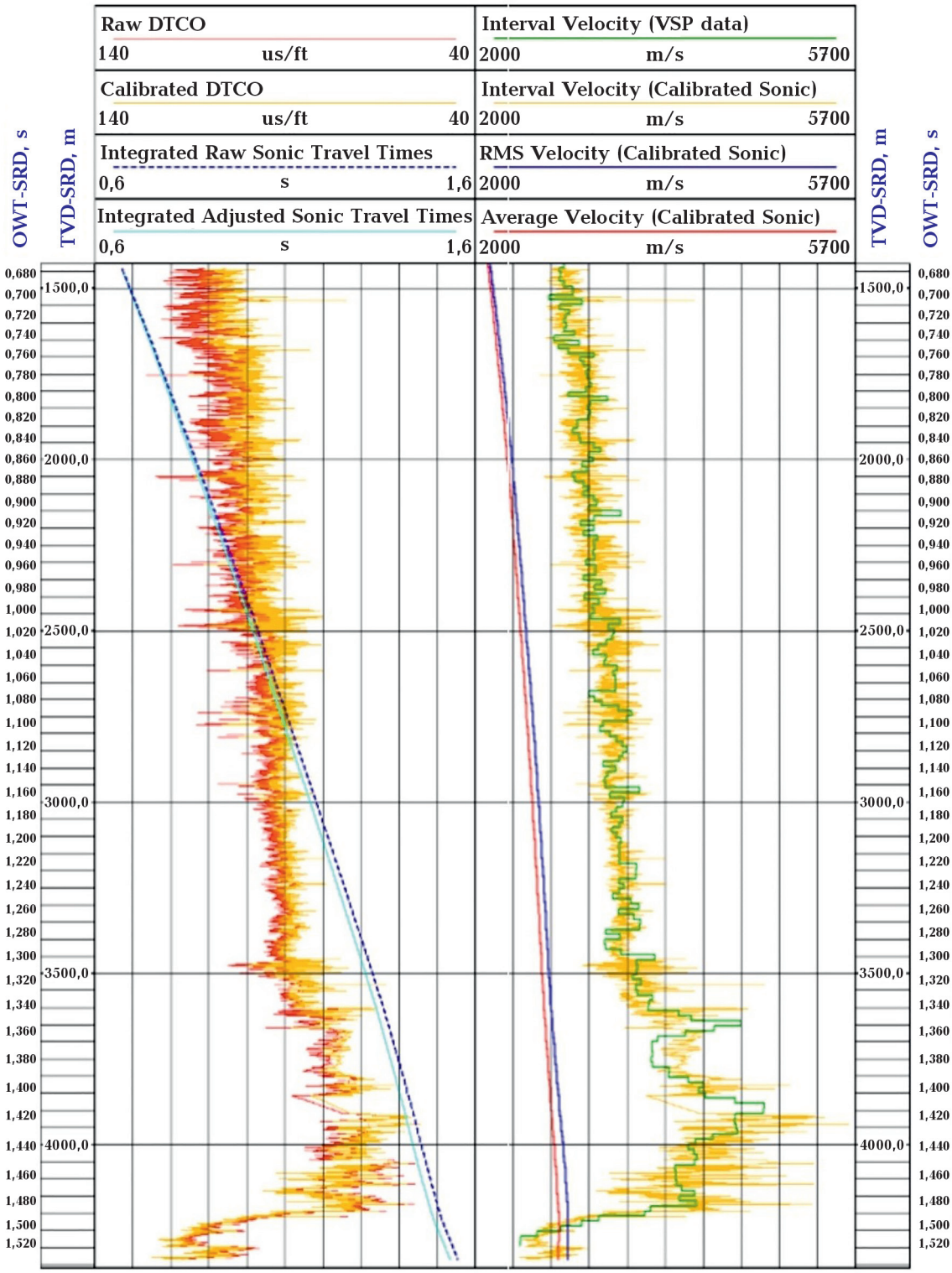


Fig. 4. Anomalously low values of seismic wave velocities indicating the development of the AFP zone.

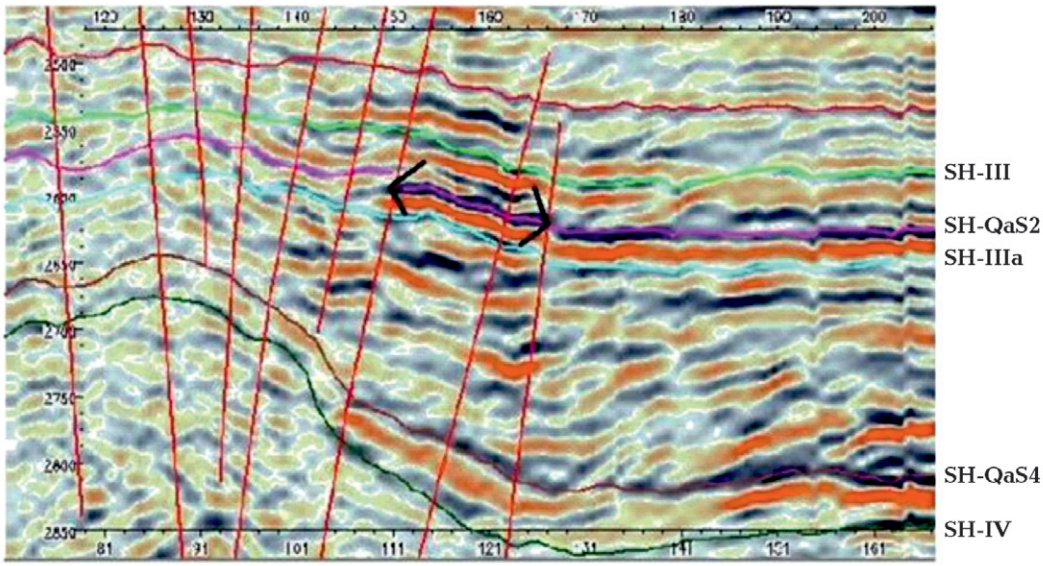
velops a zone of AFP (Abnormal Formation Pressure). This assumption was confirmed by further drilling of wells that uncovered Miocene deposits at these depths [Akhmedov et al., 2012; Ahmadov et al., 2012].

The main prospects of the surveyed areas are associated with the QaS deposits, in the section of which a number of independent exploitation objects are distinguished. Analysis of the geological evolution and paleostructural reconstructions has shown that the fold and fracture structures, associated with the

Fig. 5. Schematic map of the South Caspian Basin and adjacent areas in the Lower Pliocene [Kroonenberg et al., 2005].

fields, are characterized by different time of emplacement and changes in the intensity of their development in certain periods of geological time.

Studying the genesis and paleogeography of the sedimentation basin established that the PS on the Absheron Peninsula was deposited in the coastal zone of the sea basin and is represented by the Absheron type of sediments containing quartz as the main rock-forming mineral. This type of rocks is characterized by relatively good fossilization



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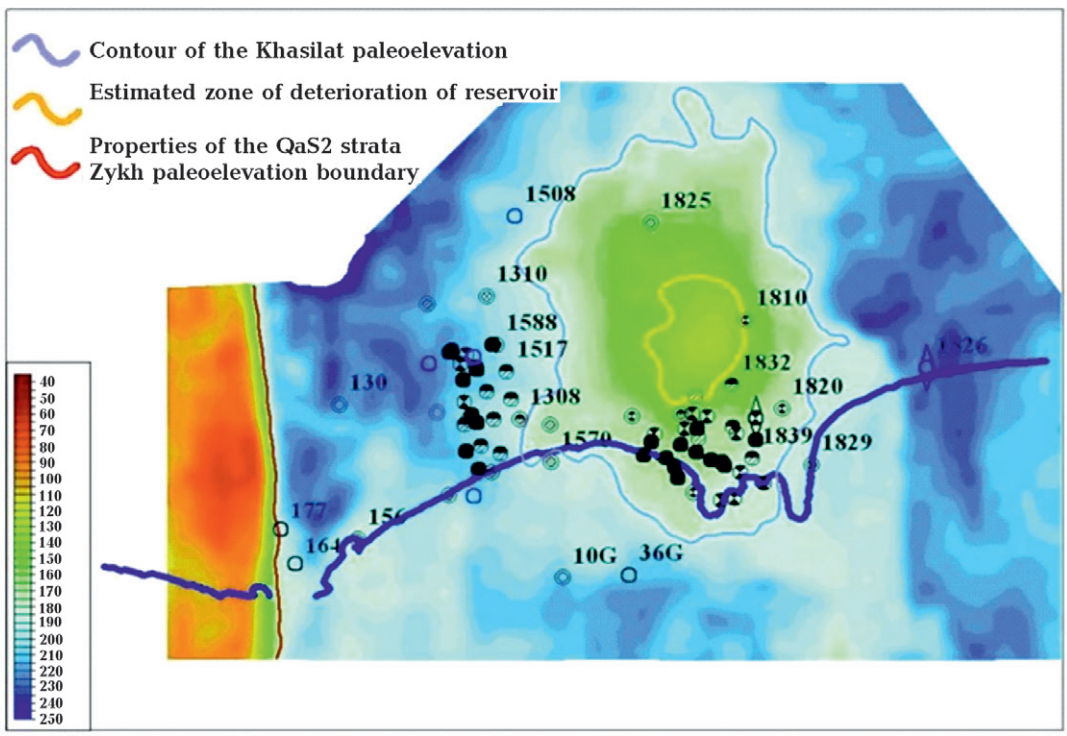

b

Fig. 6. Fragment of the time section (*a*) and map of temporal thicknesses between seismic horizons confined to the QaS2 and SH-IV deposits assigned to the top of the Pontic deposits (*b*).

of grains composing sandy rocks and predominance of the sandy fraction over siltstone and clayey fraction [Khalifa-Zadeh et al., 2006].

According to Khalifa-Zadeh et al. [2006], sedimentation took place in shelf conditions outlined by separate upliftzones, sometimes protruding above the sea level. In the basins of the Qala and Lower Kirmaky times, there were ancient islands that originated in the pre-Pontic and Pontic times, some of which continued to exist until the Upper Kirmaky time. Sedimentation proceeded at the expense of bearing provinces, in the composition of which the rocks rich in quartz took part [Levyant et al., 2006]. It should be emphasized that the basin owes its development not only to tectonic processes, but also to the inflow of large rivers controlled by both climatic conditions and the paleo-relief of the territory formed for the period. All ofthese factors had a significant impact on changes in the flow velocity and water quantity in the paleo-rivers. At the same time, the mountain structures bordering the basin from the westwere experiencing uplift and supplying huge volume of clastic material to the sedimentation zones (Fig. 5) [Markovskiy, 1973].

The lithofacial analysis of Pliocene deposits shows that these sediments contain diverse facies and have both deltaic and coastal-marine origin. The rhythmicity of the sediments in the area is closely related to the change in their accumulation conditions. Based on the paleostructural reconstructions and taking into account the published results, it can be assumed that the QaS deposits formed predominantly in marine conditions due to the large amount of sedimentary material brought by waters of the deltaic system and its distribution within the paleostructure in the central part of the study area (Δt maps).

The temporal thickness maps suggesta large river delta in the surveyed area during the formation of the QaS deposits. Consequently, the appearance of numerous deltaic channels and straits was associated with gentle slopes and shallow depths of the coastal part of the basin in which the delta was formed. Based on the map of temporal thicknesses between the seismic horizon (SH) confined to the QaS-2 and SH-IV strata, which in the conventional time scale represents the paleorelief at the time of the beginning of the formation of the QaS deposits, it is possible to determine the most favorable areas for the accumulation of sandy deposits (Fig. 6). The elevated values on the map of temporal thicknesses correspond to submerged areas of the paleorelief. Thus, traps were formed within the southeastern and western slopingparts of the paleostructure, where the oil fields of the Khasilat field were subsequently discovered. Along the eastern slope of the high-amplitude structure located in the western part of the area, a lens of predominantly sandy material was formed, which served as the basis for the formation of the Zykh field oil deposit. A total of 321 wells were drilled within the Zykh-Khasilatarea, of which 105 wells (for which we have complete data) penetrated the Qala deposits. Structural mapping based on seismic data, supplemented by seismogeologic, seismostratigraphic, paleogeomorphologic and seismic-facial analysis, was the main research method used to delineate the Qala part of the section.

Results. It should be noted that interpretation of 3D seismic data, conducted here in 2012, was not performed properly by specialists from «GeoRes» (Tyumen) [Levyant et al., 2006]. Comparative analysis of the results of the work performed by «GeoRes» LLC showed that their structural-tectonic model is not quite correct.

Fig. 7 shows the main tectonic faults identified by the specialists in the area of the survey, showing our point of view on the tectonic model of the East Khasilat field. Along the axis of the paleo-elevation along the ancient sediments we can clearly see the spreading faults penetrating sediments up to and including the QaS strata. One of the main tectonic factors of the oil and gas potential realization and HC migration conditions is the presence of tectonic faults. Eastern Khasilat is not an exception, which allows us to conclude that it is necessary to more carefully identify and justify the tectonic model of the field. In this case, tectonic disturbances are not so much a zone of reservoir fluids' deposition, but also a

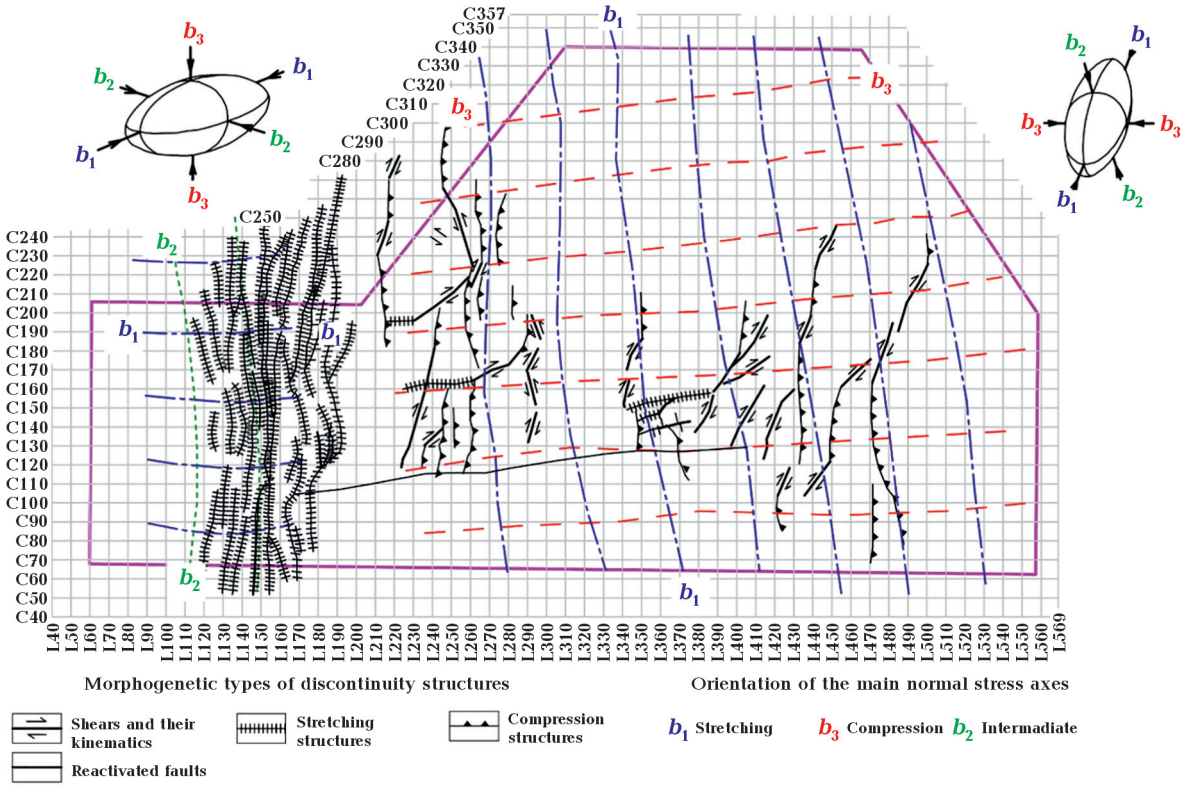

Fig. 7. Structural expressions of tectonic stress fields for the area shown in Fig. 6, *b*. C40-357 — seismic data views in the crossline direction, L40-569 — seismic data views in the inline direction.

direction of HC migration through the lower deep horizons of Miocene deposits of the prospective part of the section (Fig. 6, *a*). By using kinematic and dynamic signs of tectonic dislocation and tracing the seismic records, we were able to trace a different view of the development of the DD (disjunctive dislocations) system, where the main zone of tectonic dislocation is identified.

Conclusions. 1. Regional studies established that the area was in favorable paleogeographic conditions and stratigraphically complete (or sufficiently complete) intervals of the section were accumulated.

2. The oil system has agreat potential due to the large volume of oil-bearing rocks, not only due to Miocene deposits, but also to Eocene deposits (Koun Suite). Potential reservoirs are expected in the Maikop and Chokrak deposits. In addition to the terrigenous reservoirs, fractured dolomites and limestones are expected as potential HC prospecting objects in Diatom Suite formations, in the Meotis and Sarmatian section (Upper Miocene).

3. The main risks of trap prospecting in the deposits below the QaS are the presence of reservoirs, as well as complex mining and geological conditions (great depths, high pressures and temperatures), and the identified zone of Abnormal Formation Pressure (AFP).

Thus, we consider that further increase of oil and gas prospects within the south-east of Absheron Peninsula is associated with the prospecting and preparation of HC traps in the Paleogene-Neogene section associated with terrigenous carbonate reservoirs in the Eocene, sandy-siltstone reservoirs in the Maikop Suite and Chokrak horizon, terrigenous reservoir in the Diatom Suite, which are covered by thick impermeable clayey strata. In our opinion, in the proximity of oil and gas source beds very favorable conditions are createdfor the formation of hydrocarbon deposits.

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Перспективність пліоцен-міоценових відкладів родовища Хасілат Абшеронського нафтогазоносного району за даними наземних і свердловинних сейсмічних досліджень

Я.Т. Алібекова, 2024

Азербайджанський державний університет нафти і промисловості, Баку, Азербайджан

Наведено історію промислового видобутку вуглеводнів Абшеронському півострові, що є одним із найдавніших нафтогазоносних регіонів світу. Зазначено, що

незважаючи на тривалу експлуатацію вуглеводнів, цей регіон має потужний промисловий потенціал, особливо в низах нижнього пліоцену та підстильних відкладах. За комплексом геофізичних досліджень свердловин виділено літолого-стратиграфічну межу, що поділяє на дві частини калінську світу продуктивної товщі. Нижня частина, найімовірніше, складена пісковиками, які відкладалися в трансгресивну фазу розвитку цієї частини Абшеронського півострова, для верхньої частини світи характерні повні і неповні регресивні цикли. Проведено межу стратиграфічного неузгодження, з ним може бути синхронно пов'язана межа зміни термобаричної системи. На перспективність давніших відкладів вказує промисловий видобуток вуглеводнів у сусідніх регіонах.

Наголошено, що непрямою ознакою перспектив нафтогазоносності відкладів, які підстилають продуктивну товщу, є виявлення на родовищі Хасілат зони аномально високого пластового тиску за даними вертикального сейсмічного профілювання двох свердловин.

Широко висвітлено результати переінтерпретації даних сейсморозвідки 3D. Аналіз карт тимчасових потужностей дав змогу припустити, що у період формування відкладів калінської світи у досліджуваному районі існувала дельта великої річки. Вочевидь поява численних дельтових каналів і проток була пов'язана з пологими нахилами і малими глибинами прибережної частини басейну, в якому формувалася дельта. На підставі аналізу побудованої карти часових потужностей між сейсмічним горизонтом, приуроченим до пласта КаС-2, та СГ-IV, який в умовному часовому масштабі є палеорельєфом поверхні на початок формування відкладів калінської світи, визначено найсприятливіші ділянки для нагромадження піщаних відкладів.

Ключові слова: Абшеронський півострів, пліоцен-міоценові відклади, калінська світа, сейсмічна розвідка, вертикальне сейсмічне профілювання, часовий розріз, аномалія типу «яскрава пляма».