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INFUENCE OF GEODYNAMICAL REGIME ON FORMATION OF GEOLOGICAL STRUCTURE AND PETROPHYSICAL CHARACTERISTICS OF PLIOCENE SEDIMENTS IN KHAMAMDAG-DENIZ FIELD IN BAKU ARCHIPELAGO

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ВЛИЯНИЕ ГЕОДИНАМИЧЕСКОГО РЕЖИМА НА ФОРМИРОВАНИЕ ГЕОЛОГИЧЕСКОГО СТРОЕНИЯ И ПЕТРОФИЗИЧЕСКИЕ ХАРАКТЕРИСТИКИ ПЛИОЦЕНОВЫХ ОТЛОЖЕНИЙ МЕСТОРОЖДЕНИЯ ХАМАМДАГ-ДЕНИЗ БАКИНСКОГО АРХИПЕЛАГА

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This article presents complex results of petrophysical studies of rock samples from exploratory wells in area of Khamamdag-Deniz field, where sediments of pliocene time are widely spread. Selection of object of the study is related to the fact that in the given deposit within range of pliocene rocks depth degradation of porosity and permeability is different from traditionally forecasted, and at rather big depths primary reservoir productivity may be preserved, or acquired reservoir productivity may appear. Studies have shown that physical characteristics of rocks of the same age and same name may differ during lithogenesis process and due to influence of geological and geophysical factors. Reservoir properties of sedimentary rocks of pliocene age were studied. Data collected within the study are summarized in a table showing variation of physical properties of different reservoir rocks and regularity of their alteration by area and depth of location, with regard to geological peculiarities of the section. Except that, average values of granulometric composition of rocks by depth along the whole section of the abovementioned area were analyzed. It is found that at shallow depths (835–1088 m) rock fractional composition is favorable to high porosity (maximum 26,6 %) and is accompanied by high speed of ultrasound waves propagation (3000 m/sec) and density (2,28 g/cm^3). At medium depths (3669 m) with predominance of aleurolites (69,6 %) maximal rock porosity is,0 %, and permeability $32{,}6\cdot10^{-15}$m^2, which may be related to good grain grading degree and their weak compactness (as demonstrated by relatively low density and speed of ultrasound waves). Further, at large depths (4439 m) sandy-argillaceous aleurolites occurs, with contents of 53,3 % aleurolites, 21,9 % sand, 36,1 % clays and carbonate content 19,9 %. Here rock porosity is significantly less (maximum 21,3 %) and also rock permeability $129{,}0\cdot10^{-15}$m^2, showing relatively low degree of grading and related to it higher compactness of these sediments. This is also demonstrated by high speed of ultrasound waves propagation within the range of studied depths. Except that, the article reviews issues of permeability dependency on porosity, and porosity dependence on depth.

Ключевые слова:
геодинамический режим, петрофизические характеристики, плиоценовые отложения, гранулометрический состав пород, петрофизика, плотность, пористость, мезокайнозой, нефтегазонакопления, породы, литофации, графоаналитический, коллектор, карбонатность, скорость продольных волн, терригенно-карбонатные отложения.

Изложены комплексные результаты петрофизических исследований образцов пород, отобранные из поисково-разведочных скважин по площади месторождения Хамамдаг-Дениз, где широко распространены отложения плиоценовой толщи. Выбор объекта исследований связан с тем, что на указанном месторождении в интервале залегания плиоценовых толщ глубинное ухудшение пористости и проницаемости отклоняется от традиционно прогнозируемого, и на довольно больших глубинах может сохраняться первичная либо возникать приобретенная продуктивность коллекторов. Исследования показали, что физические характеристики одновозрастных и одноименных пород могут отличаться в процессе литогенеза и вследствие влияния геолого-геофизических факторов. Были изучены коллекторские свойства осадочных пород плиоценового возраста. Полученные данные сведены в таблицу, отражающую вариацию физических свойств различных типов пород-коллекторов и закономерность их изменения по площади и глубине залегания, с учетом геологических особенностей разреза. Кроме того, проанализированы средние значения гранулометрического состава пород по глубине вдоль всего разреза вышеуказанной площади. Выявлено, что на малых глубинах (835–1088 м) фракционный состав пород благоприятствует высокой пористости (максимум 26,6 %) и сопровождается высокой скоростью распространения ультразвуковых волн (3000 м/с) и плотностью (2,28 г/см^3). На средних глубинах (3669 м) при доминировании алевролитов (69,6 %) максимальная пористость пород составляет 20,0 %, а проницаемость $32{,}6\cdot10^{-15}$м^2, что может быть связано с хорошей отсортированностью зерен и слабой их уплотненностью (на это указывают относительно низкая плотность и скорость ультразвуковых волн). Далее, на больших глубинах (4439 м) залегают песчано-глинистые алевролиты с содержанием 53,3 % алевритов, 21,9 % песков, 36,1 % глин и карбонатностью 19,9 %. Здесь существенно ниже пористость (максимум 21,3 %) и проницаемость $129{,}0\cdot10^{-15}$м^2 пород, что свидетельствует об относительно низкой отсортированности и связанной с ней более высокой плотности этих отложений. На это также указывает высокая скорость распространения ультразвуковых волн в пределах рассматриваемых глубин. Кроме того, в статье пересмотрены вопросы зависимости проницаемости от пористости, а пористости от глубины.

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Introduction

Study of reservoir properties of rocks is one of the most important tasks in determining prospectivity of oil and gas containing formations and reserve calculation at explored fields. Except that, modern stage of development of oil and gas industry demands to increase effectiveness and improvement of technological processes of development of oil and gas deposits.

One of prospective structures in Baku archipelago – Khamamdag-Deniz (fig. 1) – was found in first half of previous century by map drilling, and then studied in more details by core and deep hole exploratory drilling.

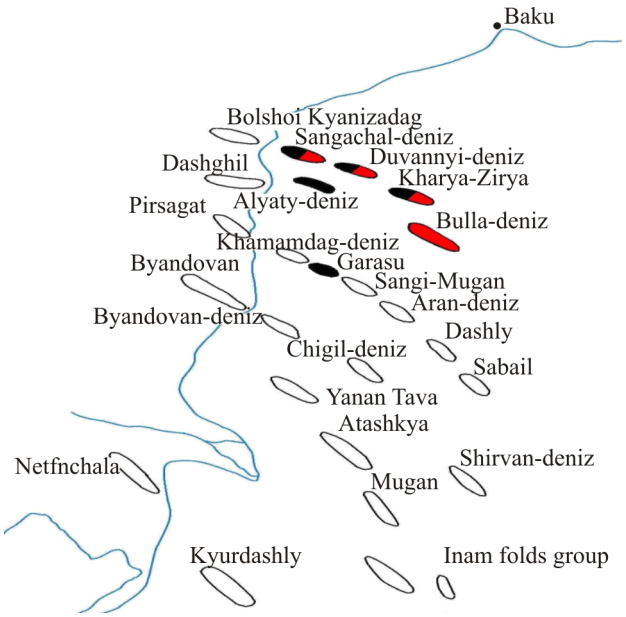

Fig. 1. Location of Khamamdag-Deniz in structural plan of Baku archipelago

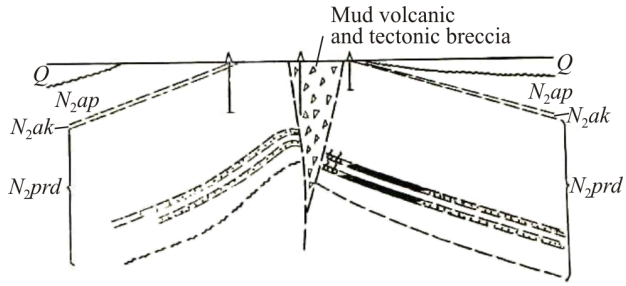

Fig. 2. Geological section of Khamamdag-Deniz structure

Taking into account that in the archipelago there are structures not fully studied, and also possibility to discover new oil and gas deposits, we have analyzed petrophysical characteristics of core samples taken from exploratory wells drilled in Khamamdag-Deniz field and adjacent areas. Analytic and graphical generalizations were performed for average values and variation ranges of data of granulometric analysis and reservoir properties of pliocene age sediments. It is established that in result of geological processes petrophysical properties of rocks of same type and same age underwent alterations within wide range of values.

Khamamdag-Deniz structure is geographically located to south-east of Pirsagat structure (see fig. 1). North-western periclinal part of the fold was mapped in 1936–1937. In 1950 map drilling was performed at sea from a launch. Its results confirmed presence of an independent uplift here. Seismic works were performed in 1951–1952. Later in 1954–1955 core drilling was performed in the area.

Oil and gas content and lithological and petrohysical characteristics of Pliocene age sediments in Khamamdag-Deniz field in Baku archipelago

In geological composition of Khamamdag-Deniz structure participate Akchagyl and Apsheron sediments, and also upper parts of productive strata. The latter sediments in crest area of the fold are eroded to depth of 900 m from the roof. The exposed part of the section is presented by gray, grayish-brown sandy clays with thin (from 0,05 to 1,5 m) layers of gray clay sands.

Akchagyl stage is presented by gray, dark gray laminated clays with thin layers of sands and volcanic ashes with thickness 70–80 m. Also formational breccia is found in the section.

Apsheron stage is developed in limb and periclinal parts of the structure and is presented by all three substages. Shelly limestones of Apsheron stage in south-western limb of the structure in some places are above water and form small islands.

In general Apsheron stage, about 900 m thick, is formed by alternation of gray, dark gray clays, shelly limestones, sandstones. Content of limestones increase in middle and upper substages.

In tectonic aspect Khamamdag-Deniz area is a symmetrical brachyanticlinal fold trending to south-west of the stretch (fig. 2) with slope angles 25–40º at both limbs. North-western periclinal part of the structure is located on shore, where mud volcano Khamamdag-Deniz is located.

As in the archipelago in whole, here prospective are sediments of VII horizon in lower part of productive strata.

While drilling first two or three exploratory wells with purpose to enter Miocenic sediments they were drilled deeper to 5000 m [1–6].

Granulometric composition (%), carbonateness (%), porosity ($K_м$, %), permeability (10^{-15} m^2), density (σ, g/cm^3) and ultrasound waves propagation velocity (V, m/sec) were studied in drilling.

As result of study of rocks granulometric composition in Pliocene age sediments over Khamamdag-Deniz area it was established that diameter of grains forming the sediments changes in range from over 0,25 to less than 0,1 mm, which shows that aleurolites are predominant in the section (table 1). As is follows from table 1, granulometric composition of Pliocene age sediments changes: in sands – from 4,9 to 50,0 %, in aleurolites – 24,1–69,9 %, in clays – from 22,6 to 90,0 %. On basis of the given data we determined regularity of distribution of physical properties of different age rocks from lithostratigraphic units participating in geological composition of the area, and also range of variations of strata reservoir properties was established, with average values calculation. From generalized analysis of fractional composition in section of Pliocene strata it is possible to conclude that it is presented mainly by aleurolites, except for depth range 3780–3835 m, where dominate psammites (61,7 %) and aleurites (24,0 %). That is, range 3780–3835 m is presented by argillaceous-silt sandstones.

More detailed analysis of rock reservoir properties dependency on granulometric composition with regard of depth influence shows (fig. 3, *a–c*), that at shallow depths (835–1088 m) rocks fractional composition is favorable to high porosity (maximum 26,6 %) and is accompanied by high velocity of ultrasound waves propagation (3000 m/sec) and density (2,28 g/cm^3) (see table 1).

At medium depths (3669 m) with dominance of aleurolites (69,6 %) maximal rock porosity is 20,0 %, and permeability – $32{,}6 \cdot 10^{-15}$ m^2, which may be relayed to good grading of grains and their weak compactness (which is demonstrated by relatively low density and velocity of ultrasound waves).

Further, and deeper depths (4439 m) lay sandy-argillaceous aleurolites with content of aleurolites 53,3 %, sands 21,9 %, clays 36,1 % and carbonateness 19,9 %. Here substantially lower are porosity (maximum 21,3 %) and permeability $129{,}0 \cdot 10^{-15} m^2$ of rocks, which says of relatively low grading and related to it higher density of the sediments. This is also demonstrated by high ultrasound waves propagation velocity within these depths [7–27].

Table 1

Results of petrophysical studies of Pliocene age sediments at Khamamdag-Deniz field

Depth range, m	Granulometric composition, %			Carbonateness, %	Porosity, %	Permeability, 10^{-15} m^2	Density σ, g/cm^3	Velocity of ultrasound propagation V, m/sec
	fraction over 0,25–0,1	fraction 0,1–0,01	fraction less 0,01					
502–834	0,3–49,95 9,62(39)	7,99–66,6 42,39(39)	26,32–90,89 47,74(39)	7,3–20,4 14,54(39)	2,0–24,4 15,25(20)	Impermeability	2,0–2,36 2,15(19)	2430–2920 2675(5)
835–1088	1,2–56,1 16,01(10)	4,6–68,8 38,77(10)	30,0–46,8 40,32(10)	11,0–22,1 15,19(44)	9,0–26,6 18,62(60)	9,0–987,0 101,8(20)	1,91–2,41 2,28(60)	1900–3500 3000(47)
1100–1200	9,3–14,0 11,65(2)	44,6–57,2 50,90(2)	28,7–46,0 37,35(2)	12,0–17,0 14,5(4)	12,7–24,5 17,14(4)	0,53–11,0 5,63(4)	2,17–2,31 2,25(4)	2800–3200 2950(4)
1450–1800	2,7–36,0 18,98(2)	24,6–57,4 43,22(3)	17,1–46,2 37,64(3)	7,5–22,0 13,39(4)	12,1–22,4 14,9(4)	5,0–26,0 12,28(4)	2,01–2,33 2,26(4)	2300–3500 2960(4)
2500–3669	2,5–60,2 29,38(4)	22,2–69,6 42,60(4)	14,0–42,0 26,70(4)	9,9–17,9 13,40(4)	7,8–20,0 11,63(4)	1,24–32,6 20,51(4)	2,24	2550
3780–3835	1,0–34,1 16,50(3)	9,6–37,9 24,13(3)	27,8–86,8 58,55(3)	3,3–17,3 9,38(3)	11,1–14,5 13,33(3)	0–154 74,0(3)	2,23	2750
4025–4114	33,0	43,7	22,6	32,3	8,1	0,11	2,26	2800
4114–4439	10,5–44,5 21,20(5)	24,1–53,3 41,25(5)	29,5–48,8 36,38(5)	8,9–15,9 12,65(5)	10,7–21,3 14,38(5)	0,23–129,0 33,75(5)	2,24	2700

Note: in the numerator – extreme values, in the denominator – average values of the parameters, in brackets – number of samples studied.

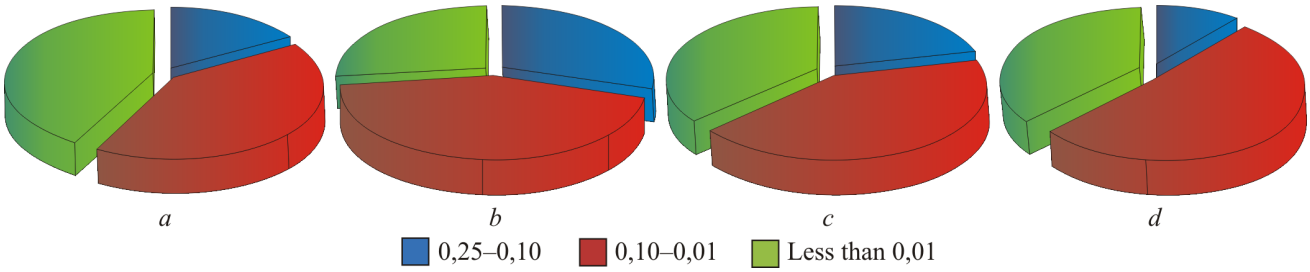

Fig. 3. Correlation of reservoir granulometric composition at shallow (*a*), medium (*b*) and deep (*c*) depths, and also in depth range 1100–1200 m (*d*)

Table 2

Alteration of petrophysical characteristics by depth in Pliocene age sediments at Khamamdag-Deniz deposits

Depth range, m	Granulometric composition, %			Carbonateness, %	Porosity, %	Permeability, 10^{-15}m^2	Density σ, g/cm^3	Ultrasound propagation velocity *V*, m/sec
	Fractions over 0,25–0,10	Fractions 0,10–0,01	Fractions less 0,01				dry	*V*
502–834	0 20 40	20 40 60	20 40 60	0 20 40	5 15 25	Impermeability	2 2.2 2.4	2400 2800 3200
835–1088						0 60 120		
1100–1200								
1450–1800								
2500–3669								
3780–3835								
4025–4114								
4114–4439								

At the same time relatively high permeability and porosity observed at depth 1100–1200 m (see fig. 3, *d*), where sandy-argillaceous aleurolites contain 46,5 % aleurite, 13,6 % sands, 37,6 % clays at carbonateness 17,0 % and are characterized by low grading, may be explained by secondary porosity. This assumption is confirmed by relatively high density and velocity of ultrasound waves propagation (see table 1). Consequently, appearance of secondary rock porosity in conditions of Baku archipelago is rather realistic.

Visualization of depth alteration of petrophysical characteristics and correlation of granulometric composition of reservoirs was implemented by building corresponding graphical relations for Pliocene age sediments at Khamamdag-Deniz (table 2).

As it is seen from graphical presentations and table data, clean correlation and direct stable dependency between the studied petrophysical parameters is not observed. Obviously this is related to multiplicity of factors determining values of the studied parameters.

It should be noted that at depth 4114–4439 m oil and gas bearing rocks are discovered. This gives a reason to forecast presence of oil and gas reservoirs in deep strata of the deposit, moreover as above deviation from general regularity of deterioration of rocks porosity and permeability with depth was already explained. Similar phenomenon was also observed in previous studies [8, 9], also proving possibility of preservation of primary productive properties of reservoir rocks, or newly obtained secondary productive properties, at relatively deep depths. This phenomenon is most typical for clays which in conditions of relatively high pressures and temperatures, by transforming into argillites, obtain

secondary porosity and permeability related to it. This fact deserves special attention, as productive strata, not only within Khamamdag-Deniz area, but also within the whole Baku archipelago, are characterized by high clayliness and lays at deep depths with geothermy of 100 °C and more. This greatly assists to processes of clay reformation to argillites. Geodynamical and tectonic influences are expressed here in development of transverse compressive stresses, leading to appearance of fractures in brittle argillites, resembling very much fractures in argillites of Bazhenov formation (Upper Jurassic complex) in Western Siberia.

In our deposit (Khamamdag-Deniz) density of argillaceous sediments changes within 2,10–2,36 g/cm^2, porosity – 5,4–26,5 %, e\ultrasound waves propagation velocity – 1900–3500 m/sec. On the other part, alteration of reservoir properties in deep and shallow wells in different tectonic blocks shows that in each of them porosity and permeability, and also other petrophysical properties differ significantly. It indicates that during lithogenesis and metamorphism processes under influence of temperature and pressure sediments, having passed primary compaction stages, later may acquire secondary porosity [28–37].

Influence of geodynamical regime on formation of geological structure

It is evident, that making assumptions on secondary structural alterations of production reservoirs, it is necessary to touch upon geodynamical nature of deep tectonic conditions existed in territory of Baku archipelago. As it is known, in depths of Baku archipelago since time of opening Krasnogorsky rift existed complex geodynamical development regime, controlled by advance of Arabian plate in northern direction. In process of this advance north-eastern projection of Arabic plate was subjected to flexure strain by narrow north-western part of Iran-Afghan plate in north-eastern direction [10]. As result to end of Pliocene Southern Caspian basin was separated from Black sea with simultaneous formation of western flank of Baku archipelago. Due to the described processes at present earth crust within Baku archipelago continue to stay under influence of compressing stresses of north-eastern orientation. At the same time, as known, bed of Southern Caspian sea is of complex graben structure, which aids to more intense lowering of sea bed, including Baku archipelago. On the other part, in the north, in zone of Apsheron-Pribalkhansky step, Southern Caspian bed moves below Middle Caspian bed, and on the southern flank - under narrow part of Iran-Afghan plate. All this together indicates presence in depths of Southern Caspian area, including territory of Baku archipelago, of compressing stresses of submeridional orientation. Nevertheless, more intense here stay stresses of north-eastern orientation, which is proved by north-western - south-eastern orientation of anticlinal zones of Baku archipelago. From the above it comes that geodynamical regime within Baku archipelago is favorable enough to appearance of secondary porosity in rocks of sedimentary complex [38–46].

Conclusions

1. Lithofacial composition of rocks, tectonic and thermobaric conditions in sedimentary section of Baku archipelago at deep depths are favorable for formation of secondary porosity within sedimentary complex.

2. Generalization of granulometric data showed that compaction of poorly graded terrigenous sediments with depth negatively influences their primary reservoir properties (up to formation of secondary porosity in them).

3. Rocks reservoir properties have no direct connection to their carbonateness, but it positively influences on their secondary porosity and permeability formation.

4. Ultrasound waves velocity in reservoir rocks is directly proportional to density and reversely proportional in cases of development of secondary porosity.

5. In forecasting of deep strata productivity, together with usage of modern geophysical methods, it is appropriate to attract also petrophysical studies of core material.

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