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STABILITY CONDITIONS OF OIL-SATURATED RESERVOIRS POROSITY WITH DEEP OVERLAYING

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Summary. This paper describes the studies covered the most typical for the region productive reservoirs containing pelitic, aleuritic, fine-grained sand and medium-grained sand fractions. The results of changes in the content of fractions depending on the depth are presented in the form of circular diagrams of changes in porosity, fractional composition and mechanical compaction of deposits. The regularities of compaction of the pore space of productive reservoirs in-depth and the relationship between the specific surface of the pore space and oil saturation were established. The results are based on statistical estimates of the impact of individual fractions (including dominant fractions) on porosity in various reservoir rock types. In particular, the obtained data showed that an increase in the content of the dominant fraction, as well as the 0.175 mm fraction in clay-sand siltstones, leads to an increase in porosity. İn the group of sandy-clayey siltstones, the porosity effect of both the dominant (0.055 mm) and larger (0.25 mm) fractions is negative. Finally, in sandy loam, the effect on the porosity of the dominant (fine 0.055 mm) and subordinate (more than 0.175 mm) fractions, as well as in the group of clayey-silty sands, is opposite. Thus, an increase in the content of the fine (0.055 mm) fraction in the sandy loams leads to a decrease in porosity, and an increase in the content of the larger fraction (0.175 mm) increases the value of porosity.

1. Introduction

Identification of productive horizons within oil and gas deposits is based on the assessment of reservoir properties, the values of which mainly depend on the nature of the pore space and the ability of fluid saturation. Typically, the variability of reservoir properties within the field is determined by laboratory studies of core samples under high pressure. In addition, 2D and 3D petrophysical models can also be used to predict reservoirs, based on a common analysis of well logging results and laboratory studies of core samples extracted from drilled wells. But, given that natural reservoirs are characterized by many parameters, such as the tortuosity and cross-sectional shape of pore capillaries, the thickness of the bound water layer, etc., the reservoir capacity cannot be accurately determined in laboratory conditions. Consequently, petrophysical models based only on core studies cannot be considered flawless. Another serious of petrophysical modeling is the effect of a decrease in reservoir properties during deposits processing due to the occurrence of in-situ stresses and deformation of the effective porosity of rocks. At the same time, the volumetric change in the initial porosity, in addition to the duration of the processing of the deposit, also depends on the mechanical properties (tensile strength and structural stability) of productive reservoirs. In this case, the determining conditions of the mechanical stability reservoirs are the change in the stress state of the environment during the development of the field. As a result, a pressure discontinuity occurs between the rock matrix and the fluids in productive horizons, which leads to the formation of low-pressure zone. Such a zone can, firstly, explain the possibility of a drop in hydrostatic pressure under conditions of a monotonous increase in rock mass with depth and, secondly, cause an effect similar to a natural suction pump. In both cases, intra- and inter-layer variations in porosity can become an additional incentive for the migration and inflow of hydrocarbon fluids within the body of the processed deposit. The prediction of possible variations of the pore space and the identification of the main conditions for such variation are defining tasks of modern oilfield practice.

Theory and research issues

One of the most famous deposits within Baku archipelago in the South Caspian Basin (SKB) is the Sangachaly-deniz–Duvanny-deniz–Khara-Zira (SDKhZ). SDKhZ was discovered in 1950-1951 as a result of drilling shallow (20-25 m) cartographic wells (Али-заде и др., 1966; Гасанов, 2021; Рахманов и др., 2013; Бабаев и др., 2014; Гурбанов и др., 2015; Гулиев и др., 2014; Кочарли, 2015; Yusifov, Aslanov, 2018; Юсифов, 2013). The form of the deposit looks as a brachyanticlinal structure and extends in the NW - SE direction (Fig. 1).

In general, three productive horizons (V, VII and VIII) have been identified in the section of the SDKhZ deposit. The saturation of the horizons belongs to the oil and gas condensate type, with distinct boundaries within the respective blocks. In particular, horizon V, due to its lithological composition, is composed of a series of reservoirs. The thickness of the horizon ranges from 2 m to 5-7 m; in some cases, the thickness reaches 10-12 m (Кочарли, 2015; Yusifov, Aslanov, 2018; Юсифов, 2013). The layers are combined into 3 sandy-siltstone units, separated by clay layers. Within the V horizon, the sand content of the layers increases in the NW - SE direction, and within the Sangachal-Deniz territory the high clay content of the V horizon nullifies its oil and gas capacity. In the direction to the SE, in the Duvanny-Deniz section, oil and gas saturated reservoirs of industrial importance appear. Thus, in terms of reservoir properties, horizon V has the best hydrocarbon's capacity in the region of Khara-Zira Island.

Due to existing of additional sandy-silt layers in the direction of Sangachaly-deniz – Duvanny-deniz, the thickness of the VII horizon increases, resulting in an increase in the effective thickness of the horizon. Subsequently, as the sandy-siltstone thicknesses decrease in the direction of the Khara-Zira Island, with a simultaneous increase in their thickness, the percentage of sand content of the horizon increases. As a result, in the section of Horizon VII, the lithological-facies characteristics and the grading of the rock-forming grains of the rocks are improved, with a relative increase in the coarse-grained sands, which leads to a strengthening of reservoir properties.

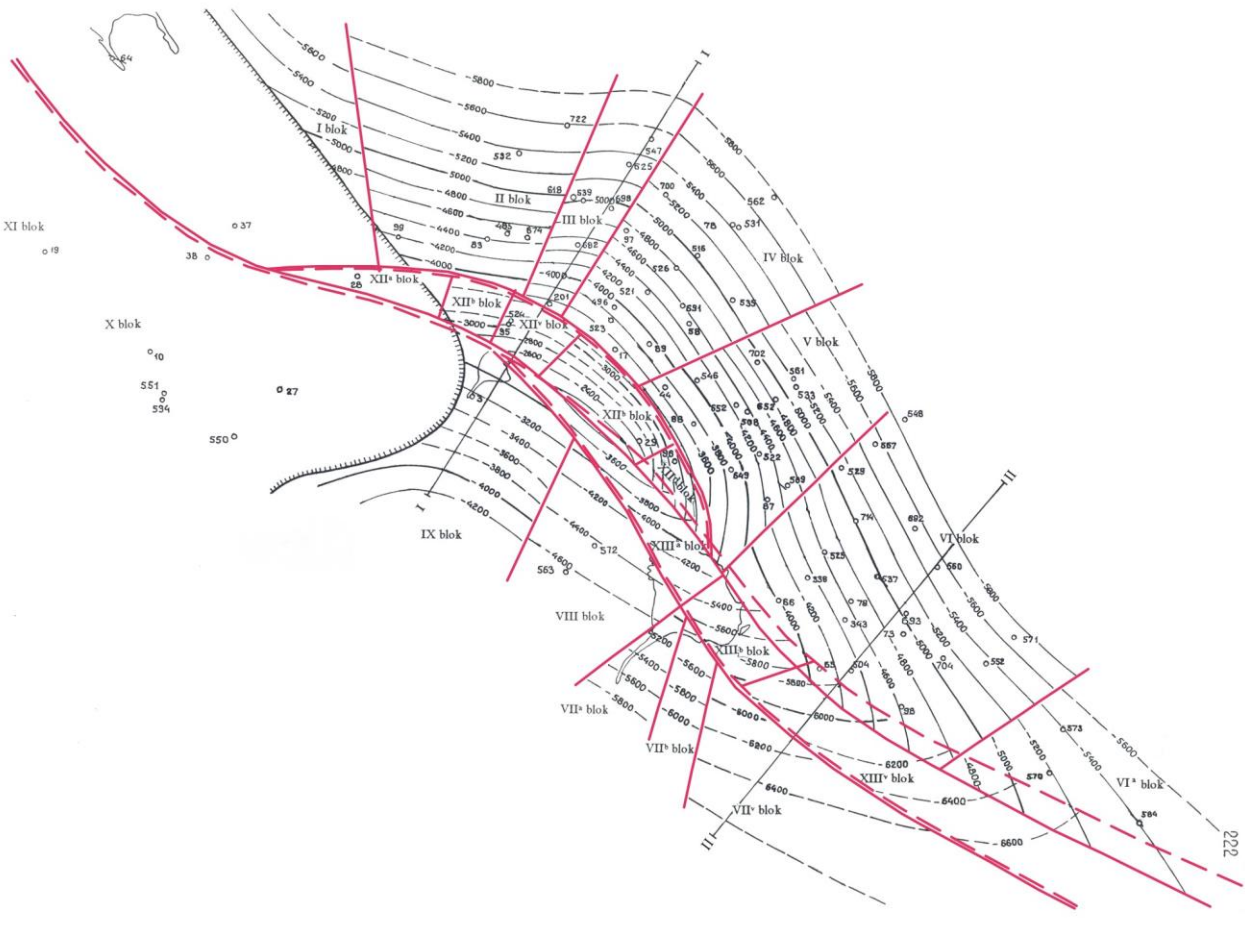

Fig. 1. Structure of the SDKhZ deposit (Кочарли, 2015; Yusifov, Aslanov, 2018)

Horizon VIII is distinguished by the accumulation of gas condensate on the north-west flanks of the structure (blocks II, III, IV, V, VI and VIa). In the direction of occurrence of horizon VIII within the blocks, the effective thickness, saturated with gas, increases. Gas-water contact inside blocks is defined only in block VI.

The lithological and reservoir characteristics of the SDKhZ field rocks for productive horizons were determined mainly based on the results of the analysis of core samples taken from prospecting and exploration wells (Кочарли, 2015; Yusifov, Aslanov, 2018; Юсифов, 2013). Here the rock samples cover the productive horizons, occurring in the interval of the section 1700-5750 m (Fig. 2).

This article presents a detailed analytical review of the results of granulometric analysis of cores from wells of one of the well-known oil deposits in Azerbaijan. The main oil reservoirs here are located in terrigenous-sedimentary rocks and consist of a structured matrix with texture-organized pore space. Typical structured matrix consists of malty sized mineral grains, which look like chaotic systems. The predominant composition of terrigenous-sedimentary reservoirs is represented by pelitic, silty, fine-grained and medium-grained sandy fractions.

Predictive assessments were carried out based on initial data, which include results of laboratory studies of plasticity and ultimate strength, as well as methods of modern graphic visualization of natural petrophysical fields.

Results and discussion

As follows from the results obtained, the values of clay content for horizons V, VII and VIII generally fluctuate in the range of 6.2-49.1%, with an average value of 23.1; 24.6 and 18.8% respectively.

Average distribution of clay content differs by one maximum along the V, VII and VIII horizons and, accordingly, fluctuates within 15-20% along the V horizon, 20-25% along the VII horizon and 15-20% along the VIII horizon.

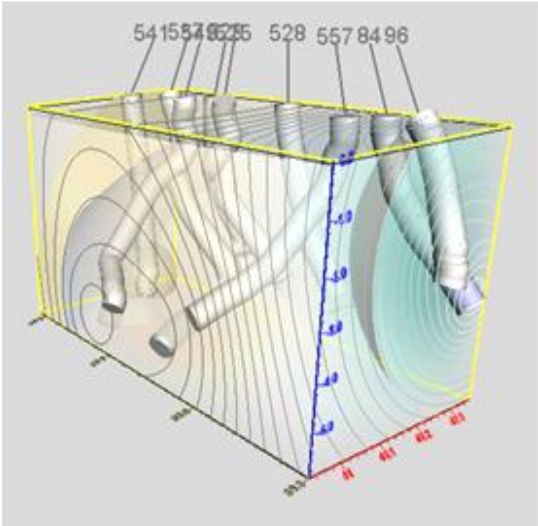

Fig. 2. SDKhZ deposit: location of some wells

The carbonate content of the analyzed sandy-silty rocks ranges from 2.5 to 36%, with the average values being, respectively, 12.5; 13.8 and 11.3%. But the curves of carbonate distribution along the horizons are characterized by a modal shape, and more than 35% of the results are concentrated in the range of 8-12%.

The porosity of the productive horizons ranges from 2.3 to 34.2%, and the arithmetic mean values are, respectively, 12.4; 13.2 and 15.9%.

Data on the mechanical properties of some rocks of the SDKhZ deposit were taken from (Иманов, 2011, 2012), where experimental estimates of the values of hardness and yield stress of core samples are described at various values of uniform pressure (Fig. 3).

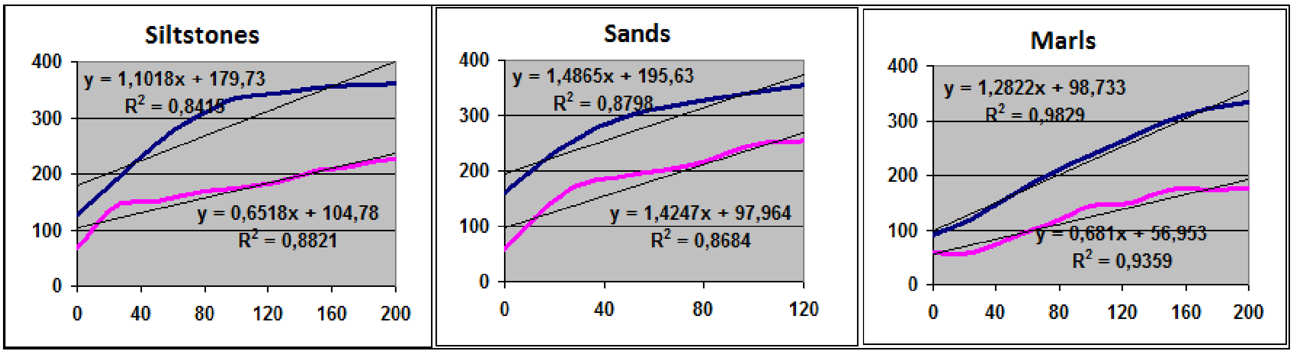

Fig. 3. Variations in hardness and yield strength of sands, siltstones and marls at various values of geo-pressure

According to the papers (Иманов, 2011, 2012) it is noted that aleurites under pressures up to 25 MPa fractured elastically and plastically. In this case, the hardness and yield stress of aleurites under atmospheric conditions equal 58.8 and 42.7 × 10^7 N / m^2. From fig. 3 follows that the trend of increasing hardness and yield strength of silts with increasing pressure is described by linear functions: Y = 1.487 x + 195.6 and Y = 1.425 x + 97.96, respectively.

The hardness and yield stress of clays in atmospheric conditions are, respectively, 23.88 and 7.98 • 10^7 N / m^2, and at an all-round pressure between 25-50 MPa, respectively, 31.84 and 19.1 • 10^7 N / m^2.

At values of the all-round pressure between 25-50 MPa, the clays passed into a plastic state and did not collapse.

The yield point for aleurites increased at all-round pressure from 0.1 to 200 MPa from 42.7 to 114.3 × 10^7 N / m^2, i.e. 2.6 times, and for clays from 7.98 to 55.8 • 10^7 N / m^2, i.e. 6.9 times.

Siltstones, calcareous sandstones and marls are elastically plastic at all-round pressure of 25 MPa, and at all-round pressure of 150 MPa they pass into a plastic state.

Siltstones, calcareous sandstones and marls are elastically plastic at all-round pressure of 25 MPa, and at all-round pressure of 150 MPa they pass into a plastic state.

Calcareous sandstones and marls remain elastic-plastic up to a pressure of 200 MPa.

With a growth of the all-round pressure from 0.1 to 122 MPa, the hardness of the studied siltstones increased 2.2 times, i.e., an increase in hardness was observed from 159.84×10^7 N / m^2 to 357.75×10^7 N / m^2. Under similar experimental conditions, with a uniform increase in pressure from 25 to 200 MPa, the yield stress increased from 162.18 to 320 × 10^7 N / m^2 (i.e., approximately 2.0 times).

The hardness of the investigated sandstones in the process of increasing the total pressure from 1 to 200 MPa increased from 126.5 to 361.9 * 10^7 N / m^2 and the yield stress in the range of 25-200 MPa increased from 141.6 to 226.4 * 10^7 N / m^2, or 2.8 and 1.6 times, respectively.

An increase in the hardness of sandstone with an increase in the all-round pressure from 0.1 to 100-120 MPa occurs in basically the same way. So, in particular, with an increase in the total pressure in the specified range, the hardness of sandstones increased from 126.5 to 333.9 * 10^7N / m^2. However, with an increase in pressure from 165 to 200 MPa, the hardness of sandstones increased by 28 × 10^7 N / m^2. This means that the hardness of sandstones increases insignificantly – only up to 7 • 10^7 N / m^2. The trend of increasing hardness and yield strength of sandstones with increasing pressure up to 25 MPa is described by linear functions: Y = 1.102 x + 179.7 and Y = 0.652 x + 104.8, respectively (Fig. 3).

The hardness of marls with an increase in the total pressure from 0,1 to 200 MPa increases from 89.9 to 333.9 × 10^7 N / m^2, or 3.6 times. At the same time, the yield point in the pressure range from 25 to 200 MPa increased from 57.6 to 175.3 10^7 N / m^2, i.e. 3 times. In marls, the trend of increasing hardness and yield strength with increasing pressure up to 25 MPa is described by linear functions: Y = 1.282 x + 98.73 and Y = 0.681 x + 56.95, respectively (Fig. 3).

However, it should be noted that, despite the above data, in general, the hardness of rocks does not increase indefinitely with an increase in all-around pressure. In practice, the curves of the dependence of hardness on uniform pressure, starting from 200 MPa, gradually flatten out (this is especially noticeable on the curves of the hardness of sandstone).

In general, the observed process illustrates the structural resistance of matters to deformation, which is characteristic of most solids and rocks as well. This stability, in addition to the initial reservoir properties of reservoir rocks, also depends on various types of deformation processes – from elastic deformation to plastic fracture, arising during the development and within massive's filtration of fluids. These processes, in turn, cause secondary changes in reservoir properties of fluid saturated reservoir rocks.

So, in the case of plastic destruction of the formation, a change within pore space can occur in the side of an increase in the specific surface of the particles, and this, on the one hand, leads to a decrease in the formation pressure, because it is known:

$$P=F/S,$$

where F – load (in-situ pressure); S – pore surface area (total surface of rock-forming particles).

As a result, a condition arises of abnormally low reservoir pressures. This particular case reflects the idea of oil and gas-saturated systems as porous or fractured media characterized by a chaotic distribution of rock-forming grains, the shape and size of capillaries and cracks (Gurbanov et al., 2021; Запивалов и др., 2009; Левчук, Букреева, 1976). For such type of media, the effective reservoir pressure is one of the fundamental factors of in-situ migration and further unimpeded hydrocarbon recovery (Glover, 2016; Романовский, 1976). This process arises as a response of the fluid, contained in the pores of the rock to the rock pressure (lithostatic pressure), exerted by the common weight of the overlying rock strata.

The numerical value of the effective reservoir pressure is estimated as

$$\mathbf{P_{ef} = P_m - P_{for}}$$

where P_m – mountain pressure and P_{for} – formation pressure.

In addition to the indicated rock and reservoir pressures in the subsoil, one more component is considered – hydrostatic pressure, determined by the density and height of the liquid column at the corresponding depths. The depth values of lithostatic and hydrostatic pressures are generally characterized by gradients of lithostatic and hydrostatic pressures (Гасанов, 2021; Kerimov et al., 2020; Gurbanov et al., 2021). One of the ways of determination of the lithostatic pressure gradient is based on the rate of sedimentation, which calculates the degree of compaction and the bulk density of rock grains (Olsson, 1999; Bjorlykke, 2006).

An example of the possible changing in the lithostatic and hydrostatic gradient over depth is shown in Fig. 4, from which it follows that the hydrostatic pressure gradient is equal 10.5 kPa / m, and the lithostatic gradient is about twice as large and is about 22.6 kPa / m.

To identify and take into account the influence of the dominant fractions in various reservoirs, the studied samples were divided by the name of the rocks into 4 groups: clayey-silty sands, clayey-sandy siltstones, sandy-clayey siltstones and clayey sandy loam (Table 1).

The results of the change in the content of fractions, depending on the depth, are illustrated in the form of circular diagrams of changes in porosity, fractional composition and mechanical compaction of deposits. The resulting visual images alow to establish the patterns of compaction of the pore space of productive formations in depth and reflect relationship between the specific surface and the pore space and oil saturation. The results of the generalizations are based on statistical estimates of the degree of influence of individual fractions (including the dominant ones) on the porosity value in various types of reservoir rocks.

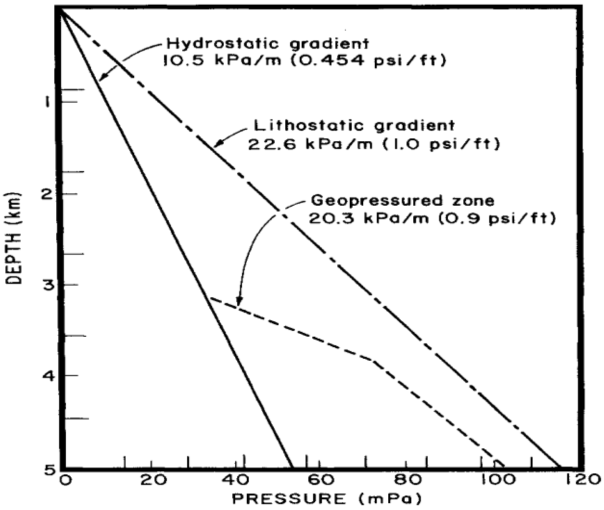

Fig. 4. Change in the average gradient along the depth and the zone of increased pressure (Glover, 2016).

According to the composition of the fraction (grain size), the samples are divided into four groups: pelitic fraction (up to 0.01 mm), siltstone fraction (0.055 mm), fine-grained sand (0.175 mm) and medium-grained sand (0.25 mm) fractions.

The results obtained in our studies of the distribution of fractions under the identified groups of rocks are shown in Fig. 5. As follows from the consideration of these data, the composition of the first group of rocks (clayey-silty sands) is dominated by a fraction with a grain size of 0.175 mm. The other two fractions, with a grain size of 0.055 and 0.01 mm, take approximately the same volume, and lastly coarse grains (0.25 mm) constitute an insignificant part of the volume and may not be taken into account.

In general, the amount of fraction that makes up the majority in all groups of rocks (0.055 mm), as well as the fraction with a grain size of 0.175 mm leads to an increasing of porosity in clayey sandy siltstones.

Table 1

Average values of data on fractional composition, porosity, specific surface area of pore space and oil and gas content for the studied groups of rocks (Гасанов, 2021; Левчук, Букреева, 1976).

Rock groups (number of probes)	**Fractions, mm%**				**Poro sity, %**	**Special surface of porosity**	**Oili-ness, %**
	0.25	**0.175**	**0.055**	**0.01**			
Clayey silty sands (14)	2.44	54.13	28.01	15.31	25.62	1266	15.2
Clayey-sandy siltstones (6)	0.39	27.49	55.54	16.58	25.04	1725	16.74
Sandy clayey siltstones (3)	0.37	12.43	60.41	26.90	23.07	1851	15.18
Clayey sandy loam (5)	0.68	39.38	43.91	16.59	24.56	1611	17.53

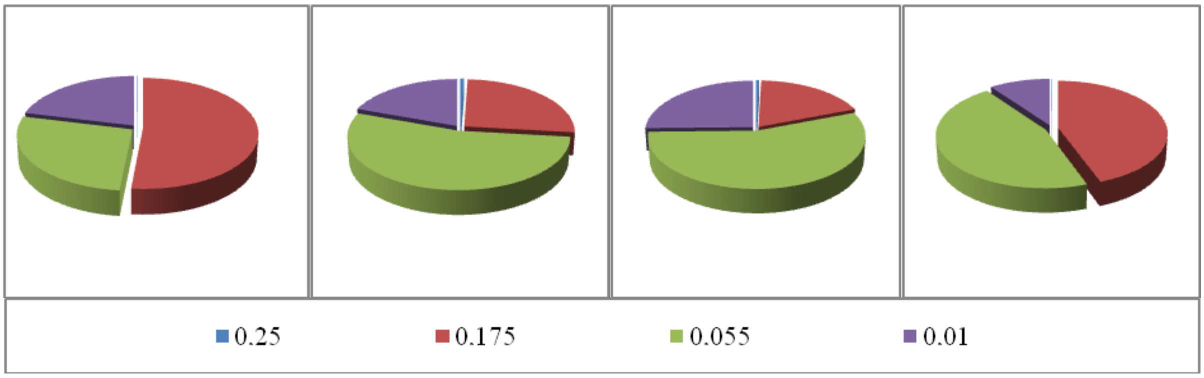

Fig. 5. Distribution of fractions in rock groups (from left to right): clayey-silty sands, clayey-sandy siltstones, sandy-clayey siltstones and clayey sandy loam

Finally, in the latter group, the majority of fractions (0.055 mm) in clayey sandstones and the minority of fractions (0.175 mm) have the opposite effect on porosity, as in clayey siltstones. Thus, an increase in the amount of the main (0.055) fraction in this group of rocks leads to a decrease in porosity, and an increase in the amount of a 0.175 mm fraction leads to an increase in porosity.

Conclusions:

Concerning of main tasks of researches of the modeling practice of the multimodal distribution of intergranular porosity and theoretical generalizations of the data of particle size analysis of cores of one of the known oil and gas fields in Azerbaijan, which is at the stage of long-term processing were considered.

Together with that in-depth regularities of the pore space compaction for saturated reservoirs were established.

Also the relationship between the specific surface of the pore space and oil saturation was determined. The common results obtained are based on statistical assessments of the degree of influence of individual fractions (including dominant fractions) on the value of porosity in various types of reservoir rocks.

According to the data obtained, an increase of the content of the dominant fraction, as well as the 0.175 mm fraction in clayey-sandy siltstones, leads to an increasing in porosity. But in the group of sandy-clayey siltstones, the influence of both the dominant (0.055 mm) and the larger fraction (0.25 mm) on the porosity value is negative. Finally, in sandy loams and in clayey-silty sands, the influence on the porosity of the dominant (fine 0.055 mm) and subordinate fractions (larger 0.175 mm) had an opposite character. So, an increase in the content of the predominant (fine – 0.055 mm) fraction in sandy loams leads to a decreasing in porosity and an increasing in the content of a coarser fraction (0.175 mm) leads to increases of porosity.

Evaluation of the mechanical stability and stability of the pore space of productive reservoirs made it possible to draw up functional dependences of the change in hardness and yield strength with increasing all-round pressure.

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УСЛОВИЯ СТАБИЛЬНОСТИ ПОРИСТОСТИ НЕФТЕНАСЫЩЕННЫХ КОЛЛЕКТОРОВ ПРИ ГЛУБОКОМ ЗАЛЕГАНИИ

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Резюме. Основные нефтяные коллекторы, расположенные в терригенно-осадочных породах, состоят из структурированной матрицы с текстурно-организованным поровым пространством. В свою очередь, типичная структурированная матрица состоит из минеральных зерен разного размера, которые выглядят как хаотические системы. В данной статье представлен подробный аналитический обзор результатов гранулометрического анализа кернов из скважин одного из известных нефтяных месторождений Азербайджана. Исследованы наиболее типичные для региона продуктивные коллекторы, содержащие пелитовые, алевритовые, мелкозернистые и среднезернистые песчаные фракции. Результаты изменения содержания фракций в зависимости от глубины представлены в виде круговых диаграмм изменения пористости, фракционного состава и механического уплотнения отложений. В результате исследований установлены закономерности уплотнения порового пространства продуктивных пластов по глубине и взаимосвязь между удельной поверхностью порового пространства и нефтенасыщенностью. Полученные результаты основаны на статистических оценках степени влияния отдельных фракций (в том числе доминирующих) на величину пористости в различных типах пород-коллекторов. В частности, из полученных данных следует, что увеличение содержания как доминирующей фракции, так и фракции 0.175 мм в глинисто-песчаных алевролитах приводит к увеличению пористости, а в группе песчано-глинистых алевролитов эффект по пористости как доминирующей (0.055 мм), так и более крупной (0.25 мм) фракций отрицателен. Наконец, в супесях влияние на пористость доминирующей (мелкая 0.055 мм) и подчиненной (более 0.175 мм) фракций, а также в группе глинисто-алевритовых песков имеет противоположный характер. Так, увеличение содержания мелкой (0.055 мм) фракции в супесях приводит к снижению пористости, а увеличение содержания более крупной фракции (0.175 мм) увеличивает пористость.

Ключевые слова: *межзерновая пористость, терригенные коллекторы, упаковка зерен, гранулометрический анализ, доминирующие фракции*

DƏRİNLİYƏ GÖMÜLMÜŞ NEFTDOYMLU KOLLEKTORLARIN MƏSAMƏLİLİYİNİN DAYANIQLIĞI

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Xülasə. Terrigen-çökmə süxurlarda yerləşən əsas neft tutumlu kollektorları, toxumalı məsamə sahəsi olan strukturlaşdırılmış matrisdən ibarətdir. Öz növbəsində, tipik strukturlaşdırılmış matris, xaotik sistemlərə bənzəyən müxtəlif ölçülü mineral dənələrdən ibarətdir.Bu məqalədə Azərbaycanda tanınan neft yataqlarından birinin quyularındakı kern nümunələrində dənələr ölçüsü analizinin nəticələrinin ətraflı analitik icmalı verilir. Bölgə üçün pelit, lil, incə dənəli və orta dənəli qumlu fraksiyaları olan ən tipik məhsuldar kollektorlar araşdırılmışdır. Dərinlikdən asılı olaraq dənələr fraksiyaların tərkibindəki dəyişikliklərin nəticələri məsaməlilik, fraksiya tərkibi və çöküntülərin mexaniki sıxılma dəyişikliklərinin dairəvi diaqramları şəklində təqdim olunur.Nəticədə məhsuldar kollektorların məsamələrinin dərinlikdə sıxılma qanunauyğunluqları və məsamə sahəsinin spesifik səthi ilə neft doyumluğu arasındakı əlaqə quruldu. Alınan nəticələr, ayrı-ayrı dənələr fraksiyaların (dominant olanlar da daxil olmaqla) müxtəlif növ süxurlarında məsaməlilik dərəsinə təsirinin statistik qiymətləndirmələrinə əsaslanır.Xüsusilə əldə edilən məlumatlardan məlum olur ki, gilli-qumlu siltlərdə həm dominant fraksiyanın, həm də 0.175 mm fraksiyanın tərkibindəki artım məsaməliliyin artmasına səbəb olur, lakin qumlu-gilli lil süxurları qrupundakı həm dominant fraksiyanın (0.055 mm) həm də daha böyük ölçülü hissəciklərin (0.25 mm) məsaməliyə təsiri mənfidir. Nəhayət, qumlu lillərdə dominant (0.055 mm) və ikinci dərəcəli fraksiyaların (0.175 mm-dən çox), həmçinin gilli-lilli qumlular qrupunun məsaməliyinə təsiri əks xarakter daşıyır. Beləliklə, qumlu lillərdə incə (0.055 mm) dənələrin tərkibindəki artım məsaməliliyin azalmasına səbəb olur amma daha iri dənələrin (0.175 mm) artımı məsaməliliyi artırır.

Açar sözlər: *qranulalararası məsamə, terrigen kollektorlar, dənələrin qablaşdırması, qranulometrik analiz, dominant fraksiyalar*