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Study of petrophysical parameters of productive series by use of well data

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The progress of existing geophysical techniques for the last years led to a wider scope of the problems resolved using this set of tools. The tools allow tackling pivotal tasks such as the study of lithology in a geological section, correlation, evaluation of saturation, porosity, permeability, and clay fraction, and outlining of oil-gas and water-saturated layers. Complications emerging while resolving these problems directly depend on the petrophysical parameters of reservoir layers. For instance, similar values of resistivity in oil and water layers result in high value of clay fraction and variation of porosity in a wide range and this complicates distinguishing the oil and water layers. On the other hand, it is known that an increase of cementing clay amount in reservoirs causes drop of porosity ($K_{por.}$) and increase of residual water saturation.

This paper is devoted to design of models defining correlation between petrophysical parameters of reservoir layers by use of integrated well data and establishing regression equations from these parameters' distributions. Models of variation of porosity, permeability, clay fraction and oil and gas saturation through the sections of wells were also designed. They made it possible to evaluate filtration-capacity characteristics and establish correlation between petrophysical parameters of reservoir layers and gain information about this field.

The bar graph was drawn for permeability coefficient variation through studied reservoirs in Qirmaky suite (QD-1, QD-2, QD-3, QD-4) by use of sections of wells conditionally marked as 1, 2, 3, and 4 in the Balakhany field.

Analysis of the constructed histograms allows us to classify the studied collector layers according to their permeability. Of the 17 layers studied in section of well 1, only Layer 17 has very good permeability, the other 16 are of good permeability; all 17 layers of well 2 have good permeability characteristics; of the 17 layers of well 3, Layer 3 is of poor permeability, layers 6, 7, and 14 have average permeability, and the rest are of good permeability; all 12 layers of well 4 have good permeability.

The study target is Qirmaky suite (QD-1, QD-2, QD-3, QD-4) of the Productive Series in Balakhany field.

Key words: water saturation, permeability, effective porosity, clay fraction, regression equation, petrophysical model.

Introduction: Balakhany-Sabunchy-Ramana oil field is the largest compared to other fields in Azerbaijan. The field has specific oil burial environment. Despite the absence of gas «caps» the oil field is characterised by high oil output. Study of Productive Series sediments have been fulfilled by use of geophysical data acquired both from the surface and from wells. These sediments consist of alternation of sand, sandstone and clay. The most sandy part is observed in Qirmakyalty suite. One of the major production targets

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in the section of Productive Series is Qirmaky suite (QD) — IQD_1, IQD_2, IQD_3, IQD_4, $IIQD_1$, $IIQD_2$, $IIQD_3$, $IIQD_4$, $IIQD_5$ [Kerimova, Khalilova, 2020].

Complications in prediction of productivity of reservoir layers directly relates to their petrophysical characteristics. High percentage of clay presence in the field and wide range of porosity variation causes similar resistivity values of oil and water saturated layers, and this as a result complicates distinction of oil and water layers [Pashayev et al., 2018; Seyidov, 2019].

It is known that resistivity value of oil and gas layer depends primarily on its water saturation. On the other hand, high presence of cementing clay amount in reservoirs causes decrease of porosity ($K_{por.}$) and increase of residual water saturation [Seyidov, Kerimova, 2018; Ladenko, Savenok, 2021].

Methods. Integrated well data have been applied for evaluation of petrophysical parameters of reservoir layers and the results are shown in Tables 1, 2 [Kerimova, 2014; Mukhtarova, Nasibova, 2021]. We have also designed the models reflecting correlation between defined petrophysical parameters and established the regression equations for statistical distribution of these parameters. Designed models made it possible to study filtration-volumetric characteristics of reservoir layers and correlation between petrophysical parameters, and as a consequence to gain knowledge about this field [Abdelaziz, 2016; Burikova et al., 2020].

The study target was Qirmaky suite (QD-1, QD-2, QD-3, QD-4) of Productive Series by use of well data acquired from Balakahny field.

Results. One of the models designed for the area reflects the correlational dependence between effictive porosity of reservoir layers and permeability. Permeability and porosity coefficients of productive layers are the major dynamic parameters of reservoirs and depend on some features. These parameters are characterised by intensive and dynamic interrelation [Abdullatif et al., 2021].

Fig. 1 displays correlation between permeability and effective porosity coefficients evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) analysed in section of well 1 in Balakhany field (wells are numbered conditionally for this study).

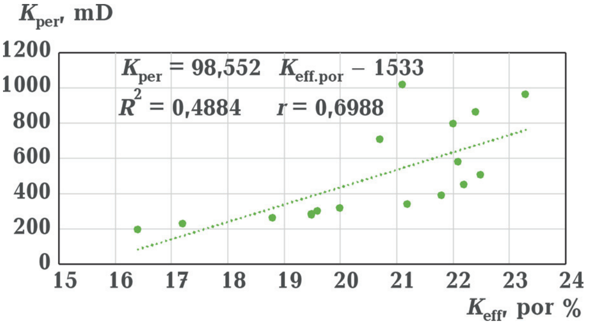

Fig. 1. Correlation between permeability and effective porosity coefficients evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 1 in Balakhany field.

It must be noted that the regression equation $K_{perm.}$=99.5523$K_{eff.\ por.}$−1533 characterized by high (r=0.6988) coefficient of correlation between effective porosity and permeability has been established. This correlational dependence is also important for outlining lithotypes in the section. It can be seen from the figure that the porosity of lithotype with permeability value of 194 mD is 16.5 %, lithotype of 962 mD permeability is 23 % and porosity of lithotype with 1016 mD value of permeability is evaluated as 21 %.

In a similar way, the correlational dependence has been established between effective porosity and permeability of reservoir layers of Qirmaky suite for section of well 2 in Balakhany field.

Fig. 2 displays the correlation established for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) by analysis of section of well 2 in Balakhany field. Established equation $K_{perm.}$= =38.48$K_{eff.\ por.}$−187.97 displays good correlation (r=0.6514) between effective porosity and permeability in Qirmaky suite. It can be seen from Fig. 2 that porosity of lithotype with permeability 361 mD is evaluated as 19 %, the porosity is 23 % for lithotype with 611 mD permeability, porosity is 18 % for lithotype with 534 mD permeability.

It must be noted that other valuable pa-

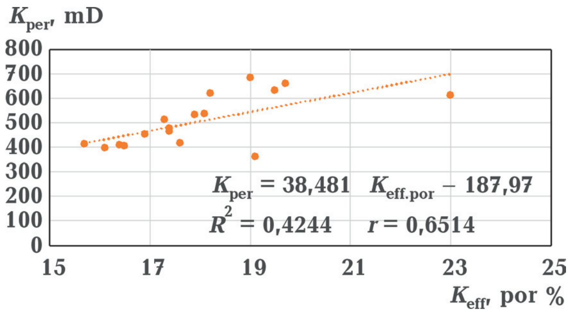

Fig. 2. Correlation between permeability and effective porosity coefficients evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 2 in Balakhany field.

rameters have been taken into account while designing porosity models. In addition, calculations made by use of the equations demonstrated that if allocation of pores between particles are not taken into account, it is not possible to establish relation between permeability and porosity.

We have also established the correlation between water saturation coefficient and permeability coefficient of productive reservoirs in Qirmaky suite (Fig. 3).

Analysis of correlational dependence allows to outline two zones, the zone of clay reservoirs with $K_{perm.}$<200 mD and the zone with poor clay presence with permeability value $K_{perm.}$>200 mD. This classification of layers can be explained by drop of the amount of cementing clay in rocks due to higher permeability coefficient at the low value of water saturation coefficient.

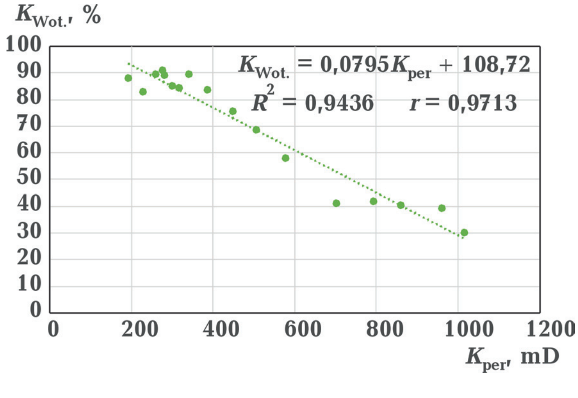

Fig. 3. Correlational dependence between water saturation coefficient and permeability coefficient evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 1 in Balakhany field.

Drop of percentage of cementing clay presence in rock pores is related to good sorting of large-grained sandstone. Fig. 3 analysis allows to infer good and inverse correlation r=0.9713 between water saturation coefficient and permeability coefficient, which is characterised by regression equation K_w= =–0.0795$K_{perm.}$+108.72.

In a similar way the correlational dependence has been established between water saturation coefficient and permeability coefficient of productive reservoirs of Qirmaky suite (QD-1, QD-2, QD-3, QD-4) for sections of well 2 (Fig. 4).

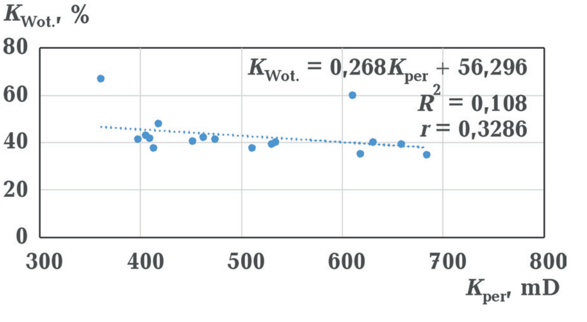

Fig. 4. Correlational dependence between water saturation coefficient and permeability coefficient evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 2 in Balakhany field.

It can be inferred from Figure 4 that very weak and inverse correlation r=0.3286 exists between water saturation coefficient and permeability coefficient in Qirmaky suite in well 2 and it is characterised by regression equation K_w=–0.0268$K_{perm.}$+56.296.

Based on Table 1 we have established the correlational dependence between water saturation coefficient and clay fraction coefficient of reservoir layers in Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 1 in Balakhany field (Fig. 5).

It is known, that pelite fractions play not only the role of cementing matter within the pores, but they are also involved in forming of a rock structure by clays. The coefficient of residual water saturation of clay rocks is the sum of water on the surface of clay and pore water between the particles of rock skeleton [Yin et al., 2020; Arkoprovo…, 2021].

It can be seen from Fig. 5, that in Qir-

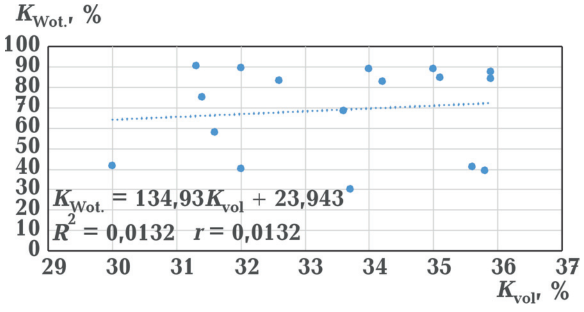

Fig. 5. Correlational dependence between water saturation coefficient and clay fraction coefficient evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 1 in Balakhany field.

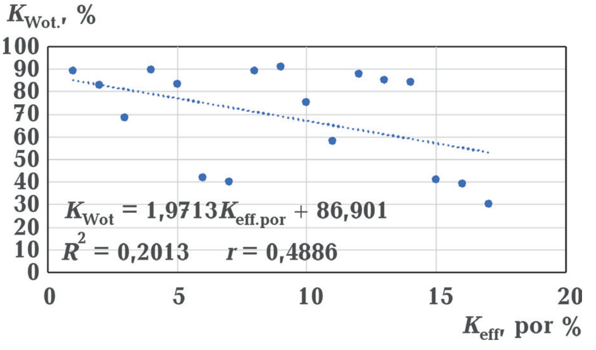

Fig. 7. Correlational dependence between water saturation coefficient and effective porosity coefficient evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4), well 1 in Balakhany field.

maky suite the very weak correlation is observed between coefficients of water saturation of layers and clay fraction, described by r=0.0132 and regression equitation K_w= =–1.3493$K_{clay.}$+23.943.

Similarly, the correlational dependence of water saturation coefficient and clay fraction of productive reservoirs in Qirmaky suite (QD-1, QD-2, QD-3, QD-4) was also established for well 2 (Fig. 6). Based on analysis of the figure we may infer the existence of good and inverse correlation between these two parameters characterised by r=0.5 coefficient and regression equation K_w=–0.8244$K_{clay.}$+69.324.

Within the framework of this study we have also established correlational dependence between water saturation and effective porosity coefficients for reservoir layers in Qirmaky suite for well 1 in Balakhany field (Fig. 7).

Fig. 7 makes it possible to infer the existence of weak correlation r=0.4886 between coefficients of water saturation and effective porosity of Qirmaky suite. The correlation is described by regression equation K_w= =–1.9713$K_{ef.\ por.}$+86.901.

In a similar way, we have established correlational dependence between water saturation and effective porosity coefficients for productive reservoir layers of Qirmaky suite (QD-1, QD-2, QD-3, QD-4) in section of well 2 in the study area (Fig. 8).

The bar graph was drawn for permeability coefficient variation through studied reservoirs in Qirmaky suite (QD-1, QD-2, QD-3, QD-4) by use of sections of wells conditionally marked as 1, 2, 3 and 4 in Balakhany field (Fig. 9).

It can be seen from the figure that the highest value of permeability coefficient in section of well 1 is within layer 17 and its value is 1016 mD, the lowest value is 194 mD within layer 12, the highest value of permeability co-

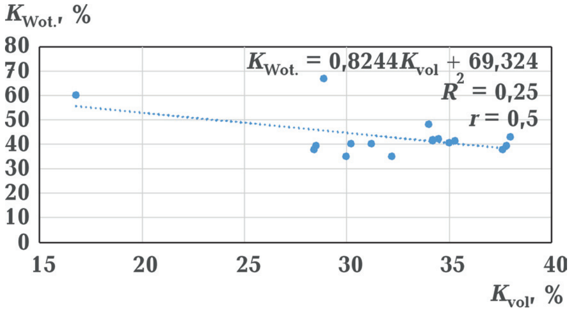

Fig. 6. Correlational dependence between water saturation coefficient and clay fraction coefficient evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) for well 2 in Balakhany field.

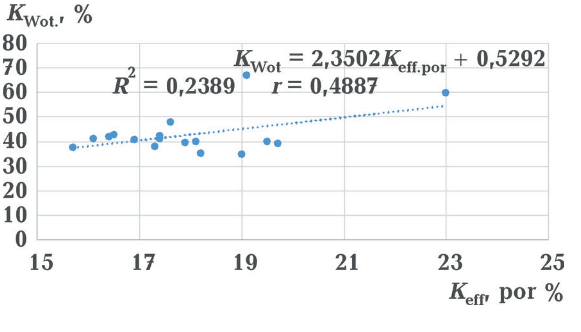

Fig. 8. Correlational dependence between water saturation and effective porosity coefficients, evaluated for Qirmaky suite (QD-1, QD-2, QD-3, QD-4), well 2 in Balakhany field.

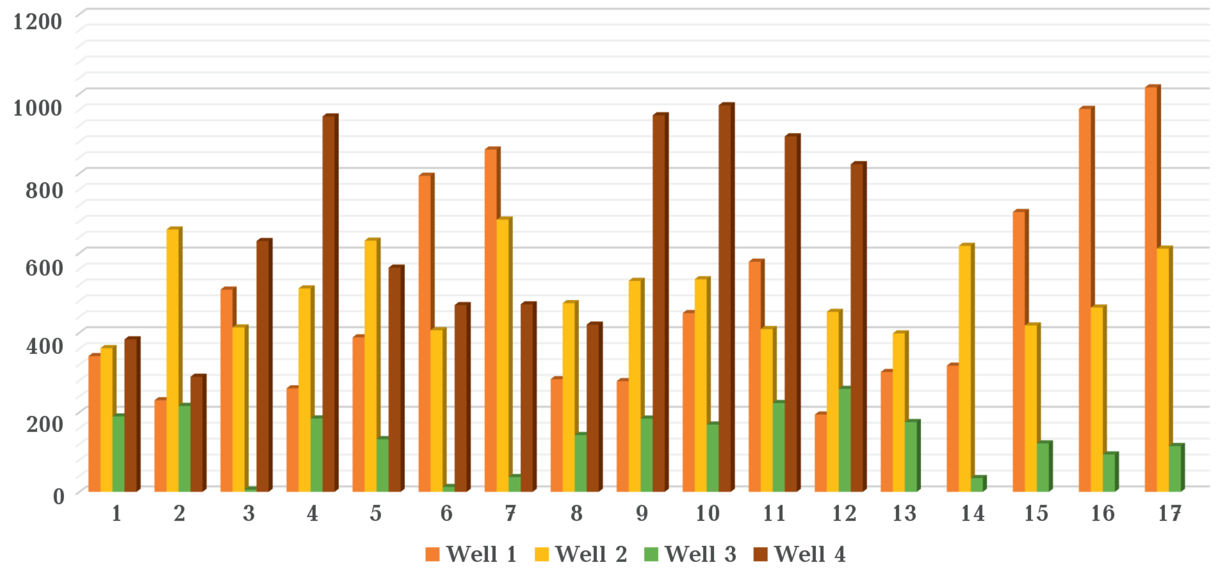

Fig. 9. Permeability variation through reservoir layers of Qirmaky suite (QD-1, QD-2,QD-3, QD-4), Balakhany field.

efficient in section of well 2 is within layer 7 and its value here is 684 mD, while the lowest value 361 mD is within layer 1. The highest value of permeability coefficient in section of well 3 is within the layer 12 and its value is 259 mD, while the lowest value is 5.5 mD in the layer 3. For well 4 the highest value of permeability coefficient is 971 mD within layer 10, and the lowest value is 298 mD, observed within layer 2. Thus, of 17 layers studied in section of well 1, the layer 17 is the one with best permeability while the other 16 layers are with good permeability; all 17 layers studied in well 2 are featured by good permeability; in section of well 3 the layer 3 is characterised by poor permeability, layers 6, 7 and 14 by average permeability while the other thirteen layers are described as having good permeability; all 12 layers studied in section of well 4 can be described as reservoirs with good permeability. The Table 3 displays average values of porosity, clay fraction and oil saturation, evaluated for the studied reservoir layers by use of various methodological approaches and equations [Kerimova, Aliyev, 2022].

By use of values indicated in the Table 3 we have designed spatial models of petrophysical parameters variation through the layers (Fig. 10—12).

According to the 3D model reflecting porosity variation in reservoirs of Qirmaky suite

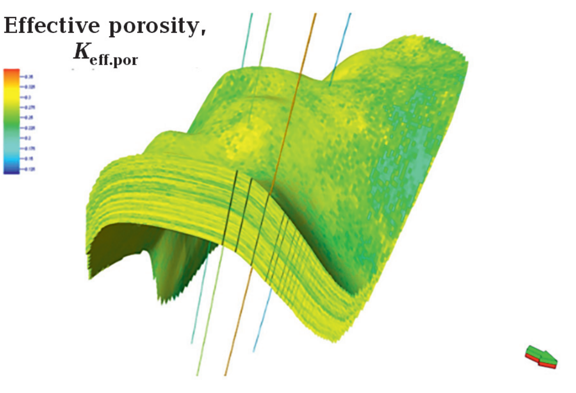

Fig. 10. 3D model displaying porosity variation in Productive Series in sections of wells 1, 2, 3 and 4 in Balakhany field.

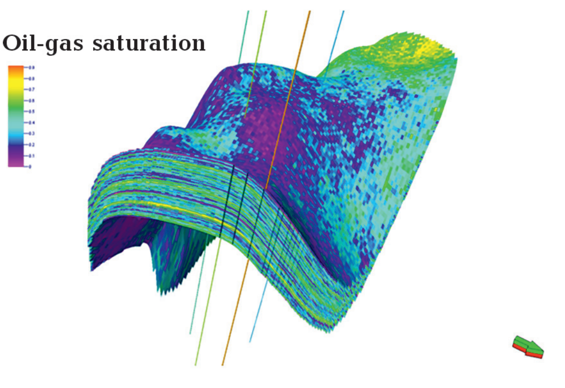

Fig. 11. 3D model displaying variation of oil and gas saturation coefficient in Productive Series in sections of wells 1, 2, 3 and 4 in Balakhany field.

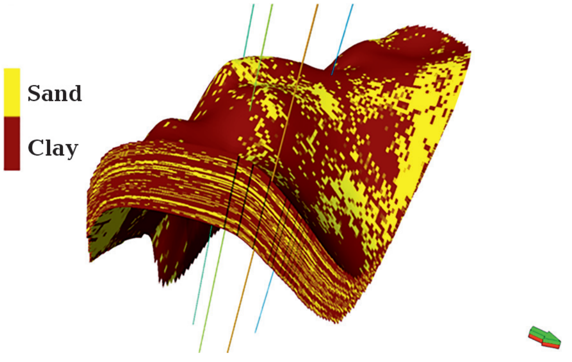

Fig. 12. 3D model displaying variation of reservoir properties in Productive Series for wells 1, 2, 3 and 4 in Balakhany field.

(QD-1, QD-2, QD-3, QD-4) of Productive Series, the average porosity value in section of well 1 is 20 %, in well 2 is 18 %, in well 3 is 18.5 % and in well 4 it is 20.5 % respectively (Fig. 10).

Fig. 11 shows the model of variation of oil and gas saturation coefficient. From 3D model it can be seen that the average value of oil and gas saturation in Qirmaky suite (QD (QD-1, QD-2, QD-3, QD-4)) in the section of well 1 is 29.25 %, while this value increases for well 2 up to 55.75 %, for well 3 that is 49.25 % and for well 4 is 50.75 % respectively.

Fig. 12 displays the model of clay fraction variation across the studied wells. According to 3D model the average value of the bulk clay in Qirmaky suite (QD (QD-1, QD-2, QD-3, QD-4)) in well 1 is 33.5 %, in well 2 is 31.25 %, in well 3 is 29.25 % and in well 4 the value is 32.25 % respectively. Analysis of clay fraction values in studied well sections makes it possible to infer that the lithology of Qirmaky suite consists of sand, aleurolite and clay. The 3D model clearly shows the highest clay presence in Qirmaky suite.

Conclusion. The following are the conclusions made in our study:

1. The values of permeability, clay fraction, porosity and oil and gas saturation have been evaluated by use of well data from Balakhany field. In section of well 1 (wells are numbered conditionally for this study) the oil and gas presence is observed in 5 layers out of 17 and the water presence is in 12 layers; in well 2 the oil and gas presence is observed in 15 layers and water in 2 layers; in section of well 3, the oil and gas presence is observed in 22 layers while water is identified in 8 layers; 9 of 12 layers in well 4 are with oil and gas presence while 3 layers were evaluated as water reservoirs.

2. The correlational dependences have been established between water saturation coefficient and effective porosity, water saturation coefficient and clay fraction, effective porosity and permeability for reservoir layers of Qirmaky suite in wells 1 and 2 in Balakhany field. The appropriate regression equations have also been established.

3. Bar graph of variation of permeability coefficient through layers have been drawn for Qirmaky suite (QD-1, QD-2, QD-3, QD-4) for wells 1, 2, 3 and 4 drilled in Balakhany field. According to the permeability coefficient:

– of 17 layers studied in section of well 1 the layer 17 is only one with very good permeability, the other 16 layers are of good permeability;

– all 17 layers studied in well 2 are with good permeability characteristics;

– of 17 layers studied in well 3 the layer 3 is of poor permeability while layers 6, 7 and 14 are featured by average permeability, the other thirteen layers are of good permeability;

– all 12 layers analyzed in section of well 4 have good permeability.

1. Based on gathered data the 3D models of porosity, oil-gas saturation and porosity have been designed by use of Petrel software. According these models, the average porosity value in section of well 1 is 20 %, in well 2 is 18 %, in well 3 is 18.5 % and in well 4 is 20.5 % respectively. The average value of oil and gas saturation in well 1 is 29.25 %, in well 2 is 55.75 %, in well 3 is 49.25 % and in well 4 is 50.75 % respectively. The average value of clay fraction in well 1 is 33.5 %, in well 2 is 31.25 %, in well 3 is 29.25 % and in well 4 is 32.25 % respectively. The clay fraction values make the basis to infer the lithology consisting of sand, aleurolite and clay in Qirmaky layer in wells studied in Balakhany field.

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Дослідження петрофізичних властивостей відкладів продуктивної товщі на підставі комплексу свердловинних даних

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Останніми роками розвиток існуючих геофізичних методів зумовив розширення кола завдань, вирішуваних за допомогою цього комплексу інструментів. З використанням наявного набору інструментів вивчаються основні завдання, такі як вивчення літології в геологічному розрізі, кореляція, оцінювання насиченості, пористості, проникності, глинистої фракції та оконтурювання нафтогазонасичених і водонасичених шарів. Ускладнення, що виникають під час вирішення цих завдань, безпосередньо залежать від петрофізичних параметрів пластів-колекторів. Наприклад, близькі значення питомого опору в нафтових та водоносних пластах призводять до високого значення глинистої фракції та зміни пористості в широких межах, що ускладнює виділення нафтоносного та водоносного пластів. Між тим відомо, що збільшення кількості цементуючої глини в колекторах викликає зменшення пористості ($K_{пор.}$) і збільшення залишкової водонасиченості.

Стаття присвячена побудові моделей, що визначають взаємозв'язок між петрофізичними параметрами пластів-колекторів з використанням інтегрованих свердловинних даних та побудові рівнянь регресії з використанням статистичного розподілу цих параметрів. У рамках дослідження побудовано моделі зміни пористості, проникності, глинистої фракції та нафтогазонасиченості по розрізах свердловин. За цими моделями оцінено фільтраційно-ємнісні характеристики, виявлено кореляцію між петрофізичними параметрами пластів-колекторів й отримано відомості про це родовище. Побудовано гістограму зміни коефіцієнта проникності колекторів кірмакінської світи (КС-1, КС-2, КС-3, КС-4) за розрізами свердловин, умовно позначених як 1—4 у родовищі Балахани.

Аналіз побудованих гістограм дав змогу класифікувати досліджені шари колектору за їхньою проникністю. Отже, із 17 шарів, досліджених у розрізі св. 1, тільки 17-й шар має дуже хорошу проникність, решта 16 шарів — хорошу проникність; всі 17 шарів розрізу свердловини 2 мають хороші характеристики проникності; у розрізі свердловини 3 шар 3 має погану проникність, тоді як шари 6, 7 і 14 характеризуються середньою проникністю, решта 13 пластів мають хорошу проникність; всі 12 проаналізованих пластів у розрізі свердловини 4 мають хорошу проникність.

Об'єктом вивчення є кірмакінська світа (КС-1, КС-2, КС-3, КС-4) продуктивної товщі родовища Балахани.

Ключові слова: водонасиченість, проникність, ефективна пористість, об'ємна глинистість, рівняння регресії, петрофізична модель.