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IMPROVEMENT IN THE COMPLEX OF STUDYING THE DYNAMICS CHANGES IN WATER-OIL CONTACT (WOC) AND GAS-WATER CONTACT (GWC) USING RESULTS OF NEUTRON AND ELECTRIC METHODS

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The purpose of this work is to substantiate the optimal complex geological and geophysical studies of filtration and capacitive characteristics of reservoir rocks with difficult geological cross-sections in order to prevent the flooding of productive layers and monitor the dynamics of change for water-oil and gas-water contacts. **Methodology.** The research methodology consists of the analysis and generalization from results of geological and geophysical studies of oil and gas geological deposits; construction petrophysical interconnections permeability coefficients with the coefficients of granular and absolute porosity at the gas and gas condensate deposits in Sarmatian tiers gas and gas-condensate deposits; substantiation of the reflection of high permeable rocks from the results of geophysical complex studies; determination of current values for gas-water contacts (GWC), and determination of oil-and-gas extraction coefficients. **Results.** By results of neutron methods it is possible to obtain the most reliable diagnostic information about the nature of reservoir saturation, gas saturation coefficients, and also to monitor the dynamics of changes in the position of the GWC and WOC. According to the obtained data, it is possible to predict and prevent the risk of flooding in productive rocks. **Scientific novelty.** For the first time, the relationship between the distribution of water saturation coefficient reservoir rocks and the equilibrium of capillary and gravitational forces in geological sections gas fields and hydrocarbons division into separate zones. In addition, the petrographic dependences of critical values of water saturation coefficient (K_s*) were obtained from the coefficient of porosity in Jurassic and Neogene deposits. **Practical value**. The obtained scientific results allow the restudy of the stage of deposits within the open oil and gas fields to determine with a great degree of reliability the dynamics of changes in water-oil and gas-water contacts.

Key words: flooding of productive rocks; water-oil contact; gas-water contact; neutron method.

Introduction

The problems that have arisen in the fuel and energy complex of Ukraine are largely due to a decrease in the production of gas-condensate and oil due to the flooding of productive layers. Typical technological and methodical methods of carrying out geological and geophysical methods, both at the stage of searches and at the stage of deposit development, in each individual case, need to be improved. Taking into account the fact that the geological structure of the search areas in different Ukraine territories is characterized by features and characteristics peculiar to them only because of the deposits' formation and their overlapping of the overlay rocks. An extremely urgent task is to establish the peculiarities structure of matrix reservoir rocks that fulfill the geological sections, and the justification of their filtration and capacitive characteristics.

Purpose

The purpose of this work is to substantiate the optimal complex geological and geophysical values for filtration and capacitive characteristics of the reservoir rocks with difficult geological cross-sections in order to prevent the flooding of productive layers and to monitor the dynamics of change of water-oil and gas-water contacts.

Methodology

The experience and results of geological and geophysical works carried out on gas and gas-condensate deposits in the northwest part of the Krukenytska depression showed that the determination of ways for water entering into the reservoir, as well as the determination of the position and dynamics of the change for GWC, is an extremely difficult task. In most cases, this situation is due to significant clayeyty, cracking and cavity of rocks, and the type of cement in their matrix. This has a significant effect on the results of the complex geophysical investigations and the geological structure of Neogene deposits explored in the gas-condensate fields of the search areas. In addition, there is a presence of rift building having significant affect extending along the Krakovetskyi fault from the Polish-Ukrainian border, with a range from several kilometers to ten kilometers, [Krupskyi, 2001].

The formation of the Neogene system is represented by the alohtonnyh sediments of Otnanian tier, the Sambor subzone, and the autochthonous deposits (Carpathian, Baden and Sarmatian tiers) of the Kosivsko-Ugerska subzone [Fedoryshyn, et al., 2002; 2014].

The features of such a structure include the presence of alohtonic and autochthonous sediments within it, the thickness of which varies depending on belonging to the Sambir or Kosiv-Uner subzone. Capacity varies from 600 to 1690 m.

Autochthonous deposits that fill Neogene deposits of gas and gas-condensate fields lie on the blurry surface of the Mesozoic era, reflected in their structure, mineralogical composition, type of cement, and filtration-capacitive characteristics. Basically it is the deposits of Helvetian, Baden, and Sarmatian tiers with which the deposits of gas and condensate are associated in the Neogene system cross-section.

It should be noted that the reflection of the above sediments in the geophysical fields is also ambiguous, which greatly complicates the interpretation of well researched results in the process of exploration and extraction of hydrocarbons.

Based on the foregoing, it can be seen that the standard methodological and technological methods used in the course of geophysical well logging (GWL) do not always allow solving the problems set for determining the reasons of decreased hydrocarbon production.

In particular, the insufficient efficiency of the results of geophysical well logging is noted in assessing the nature of saturation reservoir rocks with the complex structure of the abovementioned rocks, and monitoring the dynamics of changes in WOC and GWC during the development of the deposit. This is especially true for the so-called “waterfowl” oil and gas deposits.

The definition of the position of WOC and GWC for this type of deposit is complicated by the fact that in this case two different problems are solved, namely:

– setting the WOC position;

– setting the GWC position.

On the example of analysis of the results of geophysical studies for geological sections with complex structure in oil and gas condensate deposits in Western Siberia, it is evident that the change in the composition of fluid by height is identical regardless of whether it is a reservoir deposit or a massive [Serjenga, 2007]. In most cases, the law of water saturation changes by height in depositsonly “one” what?law?) (Fig.1). From the figure it can be seen that the distribution of water-saturation by height of the deposit is mainly determined by the equilibrium of capillary and gravitational forces acting on the formation fluids. The value of the coefficient water saturation in rock defined in the core material allowed to establish four characteristic zones in hydrocarbon deposit with complex structure:

– the first zone is boundary saturated with the condition ($K_w = K_{w,b}$), where K_w – coefficient of water saturation; and $K_{w,b}$ – coefficient of the boundary value of bound water, above which free water appears.

– the second zone is undersaturated with water with the condition $K_{w,b} < K_w < K_w^*$, where K_w^* is the limiting value of the water saturation coefficient, below which pure oil will be obtained;

– the third zone is transitional, where $K_w^* < K_w < K_w^{**}$, where K_w^{**} is the limiting value of the water saturation coefficient above which pure water will be obtained;

– completely saturated water, where $K_w = 1$.

The establishment of boundaries above these zones is carried out in the process of monitoring the dynamics of changes in water-oil, water-gas, and oil-gas contacts using the results of geophysical studies in wells.

As for the notion of water-oil contact, it should be noted that there is no strictly unambiguous interpretation of it in industrial and scientific activities. This is due to the fact that the transition from the oil-saturated section to the water-saturated section of collector occurs gradually, and in this connection the contact is not clear. Such a phenomenon can be explained by the influence of capillary forces on the distribution of water in the void of the oil saturated collector.

The upper boundary of the transition zone is the area of maximum water-saturated collection, and the bottom is the roof of the water-saturated section reservoir rock.

WOC is carried out at a depth where the resistance of rock (ρ_r) is equal to some definite critical value (ρ_r^{cr}) [Savostianov, 1984; Fedoryshyn, et al., 2004]. In most cases, WOC is determined by electrometric data.

Comparing the critical values of specific electric resistance value (SER) of the unchanged reservoir section and its water saturation coefficient to the measured electric resistance of rock (ρ_r) allows preliminary estimation of the nature of rock saturation that characterizes the boundary above which during the test will receive industrial inflow of hydrocarbons. For this purpose, two methods are used to determine the SER and the water saturation coefficient. The first method of determining ρ_r^{cr} i K_w^{cr} – is based on the statistical analysis of values ρ_r i K_w determined by direct testing of productive and non-productive layers. This was based on the results from obtained data, and the construct of statistical graphs of the distribution, of the oil and gas-saturated reservoirs, which during the test were given an industrial oil or gas stream, and for collectors that received pure water with signs of oil or gas (water-saturated rock-collectors). By combining the distribution curves of parameters obtained in the study for two types of collectors (productive and non-productive) represented in a single scale, it received a point of intersection on the regression line, which corresponds to a certain value ρ_r^{cr} or K_w^{cr}. The disadvantage of this method is that the results (main parameters) of the test are obtained at the final stage of field exploration. The second method for determining parameters ρ_r^{cr} and K_w^{cr} is more versatile at the base, where it lies with petrophysical interconnections established by experimental study of core samples in conditions close to the reservoir. This method involves the use of phase-permeability data for oil, gas, and water ($K_{per.o.}$, $K_{per.g.}$, $K_{per.w.}$) taking into account the coefficients of oil-gas saturation and water saturation (K_{go}, K_w). According to the results of core capillarization, the values of critical water saturation (K_w^{cr}) are obtained from which an anhydrous oil inflow will be obtained [Taujnianckyi, et al., 2003, Fedoryshyn & Vytvytska, 2010].

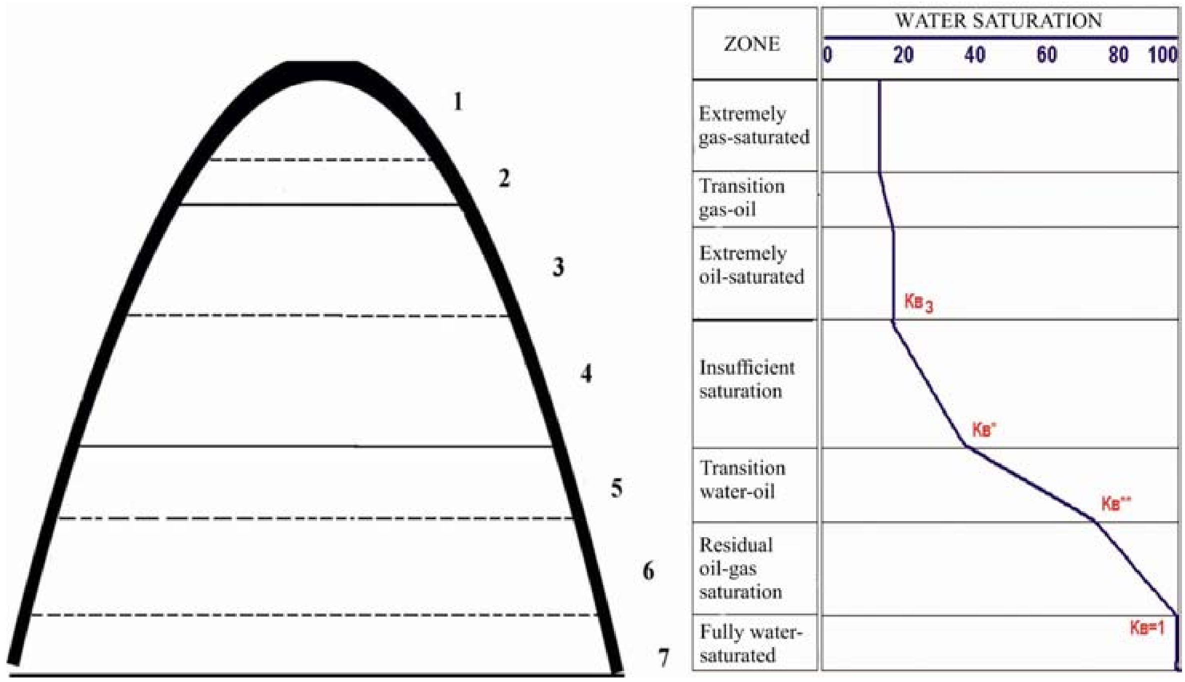

Fig. 1. The distribution of fluids and the nature of changes of water saturation in collectors by height for oil and gas condensate deposit in Western Siberia [Serjenga, 2007]

Experimental capillarometric core investigations selected from the deposits of the Jurassic system Harampurske oil and gas field have been carried out and allowed the construction of the petrophysical dependence of critical water saturation values K_w^* from the coefficient of rock porosity. As can be seen from Fig. 2, all layers that fulfill the Upper, Middle, and Lower Jurassic epochs are characterized by identical and similar structural and lithological characteristics. Using the constructed dependence for layers with different porosity we determine the limit value of their productivity. Given this value, we calculated the volume of its volumetric moisture:

$$\omega_m = K_p \cdot K_w^* \quad (1)$$

where K_p – coefficient of open porosity; K_w^* – limit value of water saturation coefficient.

Results

Constructing the dependence $\omega_w = f(\rho_p)$ we carry out the transition to the critical values of specific electrical reservoir resistance (SER). Taking into account that the geological structure of gas and gas-condensate deposits is complex, in each individual case the ρ_r^{cr} will be different from other values, and its value will be determined by the physical and filtration-capacitive parameters of reservoir rocks. Thus, the obtained critical values of ρ_r^{cr} and K_w^{cr} are clarified at the stage of drilling (studying) the field and allow with high reliability determination of the position of GWC and WOC.

However, it should be noted that the use of only the above parameters to determine the position of GOC is not enough, considering the complex geological structure of the cross-section and the technological conditions for the disclosure of productive layers. In most cases neutron methods are used to determine the boundaries of the productive formation, in particular, the repeated neutron logging (RNL). Repeated studies of neutron logging are carried out in cased wells where the processes of breaking the penetration zone occur, with the consequence of changing the effect of the gas reservoir saturation on the geophysical data. In most cases, the effects of gas influence the date of neutron methods during the breakdown of the penetration zone, and are equal to the errors of apparatus measurements.

Taking into account that the breakdown of the penetration zone for productive rocks in terrigenous sediments occurs from two or three months to several years depending on their filtration-capacitive parameters, the change in position of WOC and GWC occurs in wide limits. Geological and technological factors have a significant influence on this process. Such factors include the complex lithologic-stratigraphic and tectonic structure of geological deposits that fill it, and the presence of tectonic faults which determine the various changes in GWC. The second factor is characterized by a change in filtration-capacitive parameters of productive layers. To this factor can be attributed also the technical error of determining the depth of rocks due to lack of informativeness for well geophysical instruments, as well as the extension of the cable. All of the above factors lead to errors in the process of determining the absolute depth of the lithologic-stratigraphic unit of rocks and as a consequence the position of interfluid contacts. See Fig. 2.

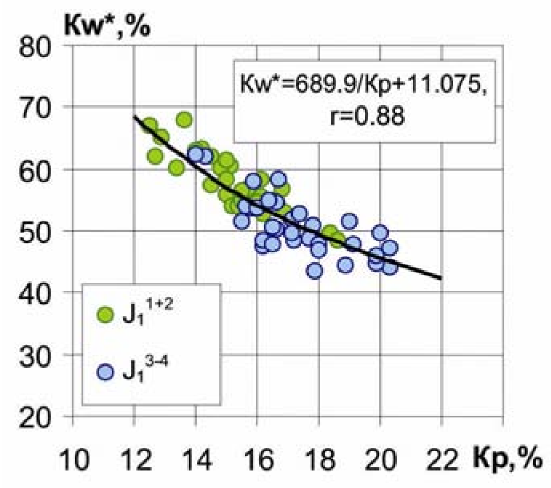

Fig. 2. Standard dependence of critical water saturation value K_w^* from K_p for the layers of the Jurassic horizon [Serjenga, 2007]

On the example of correlation scheme for Jurassic sediments at north-eastern part Harampurske field, it is clear that the lithologic-stratigraphic deposits discovered by the well № 321 differ significantly in their depth, in particular the thickness of productive rocks, as well as the nature of their saturation (Fig. 3). The analysis of results of geophysical well logging allows us to conclude that the wells 311R, 330R are drilled in one tectonic unit, and the well 301R revealed similar deposits in another tectonic block. In correlation scheme, it clearly distinguished the different depths of occurrence for stratigraphic layers J_1-1, J_1-3, J_1-4. By absolute marks, this oil reservoir is located 30 m deeper than in wells 311R and 330R. According to the results of the test from productive reservoir J_1-1 in the range 2902.0–2906.0 m, an inflow of condensate with debit 21.01 m^3/ day, gas 327 th.m^3 / day was received. At that time, tests of this formation in well 330R range from 2864.0–2867.0 and allow the condensate to flow 10.7 m^3/ day and gas 14.8 th.m^3/ day [Serjenga, 2007; Krasnozhon & Kozachenko, 2007; Dunn, et al., 2002].

Determination of the position of gas-water contact (GWC) in the above-mentioned Jura deposits is problematic due to both the tectonic features of the geological structure and the low efficiency of geophysical methods, the results of which are displayed in different ways in separate blocks of stratigraphic sections. In this regard, for determining GWC and GOC within the search fields with complex geological structure, in most cases relied on the results of testing the productive layers after their reopening by perforation.

Taking into account that WOC and GOC are the boundary surfaces in the transition zone of oil or gas deposits, it is proposed to use in the process of monitoring the dynamics of change GWC a complex of nuclear-physical methods, in particular the neutron-gamma logging, re-neutron logging, and also in the process of drilling, carrying out electric resistant methods and the self-potential method. Determination of the boundary of water-oil and gas-water contacts by the results of most neutron methods is based on the anomalous neutron properties of chlorine, which is contained in formation waters. Such effect is characteristic for all terrigenous deposits, irrespective of which tectonic block and which field they are located. However, it is necessary to obtain bench marking of neutron research in front of water, gas, and oil reservoirs. It should also be noted that pulsed neutron methods, in particular pulsed neutron-neutron logging (PNNL), are characterized by a much greater sensitivity to the content of chlorine in rocks and allows the determination of the position of WOC and GWC in the cross-section where the mineralization of reservoir waters is 40-50 g/l, and in some cases 20–30 g/l [Allen, et al., 1991; Coates, et al., 1999; Fedoryshyn, et al., 2014].

Practical value

The obtained scientific results allow restudy of the stage of deposits within the open oil and gas fields to determine with a great degree of reliability the dynamics of changes in water-oil and gas-water contacts.

Conclusions

Thus, according to the results of neutron methods it is possible to obtain the most reliable diagnostic information about the nature of reservoir saturation, gas-oil saturation coefficient, and also to monitor the dynamics of changes in the position of GWC and WOC. According to the obtained data, it is possible to predict and prevent the risk of flooding productive layers. See Fig. 3.

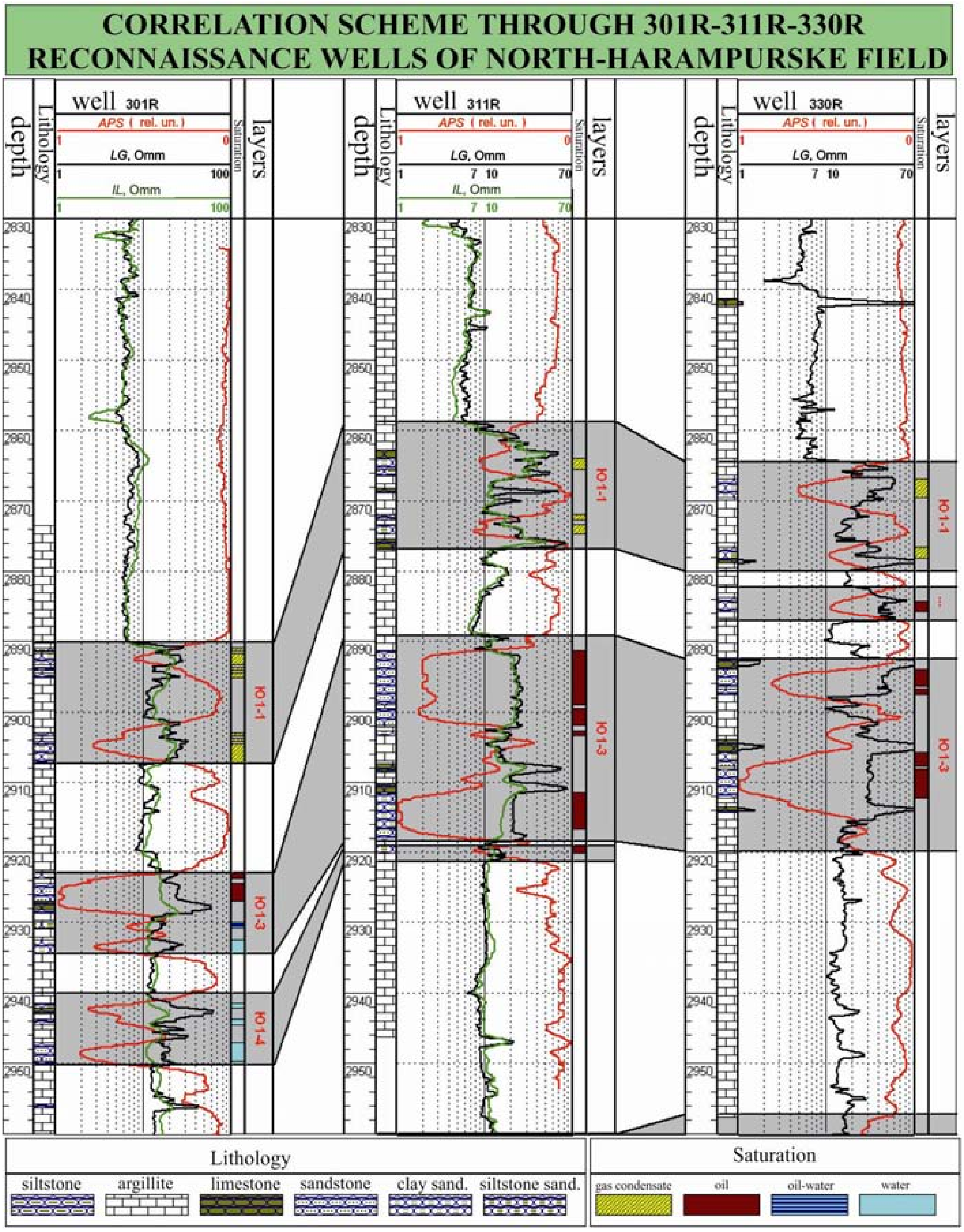

Fig. 3. Geological and geophysical cross-section of the eastern part of the northern deposit at Harampurske field [Serjenga, 2007].

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УДОСКОНАЛЕННЯ КОМПЛЕКСУ ВИВЧЕННЯ ДИНАМІКИ ЗМІНИ ВОДОНАФТОВОГО КОНТАКТУ (ВНК) ТА ГАЗОВОДЯНОГО КОНТАКТУ (ГВК) ЗА РЕЗУЛЬТАТАМИ НЕЙТРОННИХ ТА ЕЛЕКТРИЧНИХ МЕТОДІВ

Мета. Метою роботи є обґрунтувати оптимальний комплекс геолого-геофізичних досліджень фільтраційних та ємнісних характеристик гірських порід складно-побудованих геологічних розрізів із метою запобігання обводнення продуктивних пластів та моніторингу динаміки зміни водонафтових, газоводяних контактів. **Методика.** Методика досліджень полягає в аналізі та узагальненні результатів геолого-геофізичних досліджень із вивчення геологічної будови розрізів нафтогазових та газових родовищ; побудови петрофізичних взаємозв’язків коефіцієнтів проникності з коефіцієнтами гранулярної та абсолютної пористості порід-колекторів газових та газоконденсатних родовищ; обґрунтування відображення високопроникних порід у результатах геофізичних комплексних досліджень; визначення поточних значень газоводяних контактів (ГВК) та встановлення коефіцієнтів нафтогазовилучення. **Результати.** За результатами нейтронних методів можна отримати найдостовірнішу діагностичну інформацію про характер насичення пласта, коефіцієнта газонафтонасичення, а також проводити моніторинг динаміки зміни положення ГВК і ВНК. За отриманими даними можна передбачити і запобігти ризик обводнення продуктивних порід-колекторів. **Наукова новизна.** Вперше встановлено взаємозв’язок розподілу коефіцієнта водонасиченності порід-колекторів із рівновагою капілярних та гравітаційних сил у геологічних розрізах газових родовищ та поділ покладів вуглеводнів на окремі зони. Окрім цього отримано петрографічні залежності критичних значень коефіцієнта водонасиченності ($К_в$*) від коефіцієнта пористості юрських та неогенових відкладів. **Практична цінність**. Отримані наукові результати дозволяють на етапі довивчення покладів у межах відкритих родовищ нафти і газу визначати з великим ступенем достовірності динаміку зміни водонафтових та газоводяних контактів.

Ключові слова: обводнення продуктивних пластів, водонафтовий контакт, газоводяний контакт, нейтронний метод.

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