MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

Kazakh National Research Technical University named after K.I. Satpayev

Institute of Geology, Oil and Mining

Department of Oil, Gas and Ore Geophysics

Raushanbek Diar Sultanuly

"Technology of NMR studies of uranium-containing reservoirs rocks in the exploration and development of hydrogenic uranium deposits in Kazakhstan"

DIPLOMA WORK

Specialty 5B070600 – "Geology and exploration of mineral deposits"

Almaty 2020

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ADMITTED TO DEFENCE
Head of the Department of Geophysics
Doctor of geol.-miner. sciences, professor

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"_____" _____2020y.

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Done by   Raushanbek D.S

Scientific supervisor
Tutor, Master of technical science

_____ Aliakbar Madiar Manarbekuly

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THE TASK
to complete the diploma work

Student <u>Raushanbek Diar Sultanuly</u>
Topic: <u>"Technology of NMR studies of uranium-containing reservoirs rocks in the exploration and development of hydrogenic uranium deposits in Kazakhstan"</u>
Approved by order of the Rector of the University <u>№762–b from "27" January 2020y.</u>
Submission deadline of the completed work   <u>"04" June</u> 2020 y.
Initial data for the diploma work: were selected during the completion
of industrial practice
Summary of the diploma work:
 a) Increasing the reliability of selection and evaluation of reservoir parameters and quality of water reservoirs in hydrogenic fields and, consequently, reducing the share of geological risk at the development stage
 b) improving the reliability of geological, geophysical and technological studies of hydrogen uranium deposits
 c) reduction of time and costs for petrophysical studies of stone and fluid material;
 d) operative issuance of opinions and recommendations and substantiation of management decisions on exploration and development of hydrogenic uranium deposits.
 The list of graphic material: are presented ____ slides of presentation work
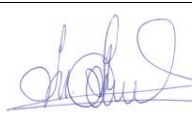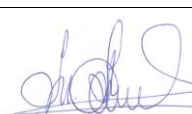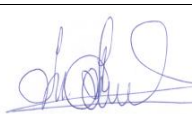 Recommended main literature: Kononenko I.Ya. Application of NMR Researches at Prospecting, Exploration and Development of Hydrogenic Uranium Deposits. M.

GRAPH
of diploma work preparation

Section Names, list of issues under development	Submission deadline to scientific supervisor	Notes
Petrophysical basis for determination of filtration-capacitive properties of rocks from the data of the pits	05.11.2019 – 13.11.2019	
Geological and information capabilities of rock sample study trenches for the extraction and evaluation of rock-collector parameters of hydrogenic uranium deposits with uwl	13.01.2020 – 24.01.2020	
Development of methods for integrated analysis of the results-the aim of these studies is to identify and assess the parameters of uranium collector rocks and the quality of waterproofing	02.04.2020 – 15.04.2020	
Analysis of the consolidated geological and petrophysical section of the togusken uranium deposit section, constructed according to the rock sample study pits, selected-from different wells	16.04.2020 – 04.05.2020	

Signatures
of the consultants and standard controller for the completed
diploma work with an indication of the sections of work
related to them

Section Names	Consultants, name, patronymic, surname (academic degree,title)	Date of signing	Signature
Petrophysical basis for determination of filtration-capacitive properties of rocks from the data of the pits	M.M.Aliakbar Master of technical science	15.01.2020	
Geological and information capabilities of rock sample study trenches for the extraction and evaluation of rock-collector parameters of hydrogenic uranium deposits with uwl	M.M.Aliakbar Master of technical science	06.02.2020	
Development of methods for integrated analysis of the results-the aim of these studies is to identify and assess the parameters of uranium collector rocks and the quality of waterproofing	M.M.Aliakbar Master of technical science	10.03.2020	
Analysis of the consolidated geological and petrophysical section of the togusken uranium deposit section, constructed according to the rock sample study pits, selected-from different wells	M.M.Aliakbar Master of technical science	15.04.2020	
Standard controller	M.M.Aliakbar Tutor	21.05.2020	

Scientific supervisor   Aliakbar M.M.

The student fulfilling the task   Raushanbek D.S.

Date   "_____"_____2020y.

ABSTRACT

The aim of the work was to develop methods for selecting and assessing reservoir rock parameters and the quality of uranium deposit waterproofing based on integrated analysis of the results of petrophysical magnetic resonance studies of rock samples.

The diploma deals with the basic principles of selection and evaluation of reservoir rock parameters and quality of waterproofing.

The possibilities of petrophysical NMR studies to solve the problems of selection and evaluation of reservoir rocks parameters and quality of water resonances in conditions of hydrogen uranium deposits are shown.

Methods of integrated analysis of petrophysical NMR research results of rock samples have been developed to assess heterogeneity and reservoir properties in the section of geological deposits of hydrogenated uranium deposits.

Petrophysical NMR studies of rock samples taken from different wells of the Togusken hydrogenous deposit were carried out using a Proton 20M relaxometer-based hardware and methodology complex.

Based on the data obtained as a result of NMR studies of rock samples taken from different wells, a consolidated geological and petrophysical section of the Togusken deposit rock deposits was built, where intervals of the reservoir rocks and their tires were identified and their quality was assessed.

The conclusion about favorable conditions for the development of the Togusken field was made on the basis of the analysis of the constructed composite geological and petrophysical section of the rocks deposits, which is characterized by an impermeable tire and an interval of rocks-collectors with high permeability.

АННОТАЦИЯ

Целью дипломной работы было разработать методики выделения и оценки параметров пород коллекторов и качества водоупоров урановых месторождений на основе интегрированного анализа результатов петрофизических магниторезонансных исследований образцов пород.

В работе рассмотрены основные принципы выделения и оценки параметров пород-коллекторов и качества водоупоров.

Показаны возможности петрофизических ЯМР исследований для решения задач выделения и оценки параметров пород-коллекторов и качества водоупоров в условиях гидрогенных месторождений урана.

Разработаны методики интегрированного анализа результатов петрофизических ЯМР исследований образцов пород с целью оценки неоднородности и коллекторских свойств в разрезе геологических отложений гидрогенных месторождений урана.

Выполнены петрофизические ЯМР исследования коллекции образцов пород, отобранных из разных скважин гидрогенного месторождения урана Тогускен с помощью аппаратурно-методического комплекса на базе релаксометра Протон 20М.

На основе данных, полученных в результате ЯМР исследований образцов пород, отобранных из разных скважин, построен сводный геологопетрофизический разрез отложений пород месторождения Тогускен, на котором выделены интервалы пород-коллекторов и их водоупоры и дана оценка их качеств.

Сделан вывод о благоприятных условиях разработки месторождения Тогускен на основе проведенного анализа построенного сводного геологопетрофизического разреза отложений пород, который характеризуется непроницаемым водоупором и интервалом пород-коллекторов с высокой проницаемостью.

АҢДАТПА

Дипломдық жұмыстың мақсаты - тау жыныстары үлгілерінің петрофизикалық магниттік-резонанстық зерттеулерінің нәтижелерін интеграцияланған талдау негізінде уран кен орындарының коллекторлары мен су тіректерінің сапасын анықтау және бағалау әдістемесін әзірлеу. Жұмыста коллектор-жыныстардың параметрлерін және су тіректерінің сапасын анықтау және бағалаудың негізгі принциптері қарастырылды. Уранның гидрогенді кен орындары жағдайында коллектор-жыныстардың параметрлерін және су тіректерінің сапасын анықтау және бағалау міндеттерін шешу үшін петрофизикалық ЯМР зерттеу мүмкіндіктері көрсетілді. Уранның гидрогенді кенорындарының геологиялық шөгінділері қимасында біртекті емес және коллекторлық қасиеттерді бағалау мақсатында жыныстар үлгілерін петрофизикалық ЯМР зерттеу нәтижелерін интеграцияланған талдау әдістемесі әзірленді. Протон 20М релаксометр базасында аппаратуралық-әдістемелік кешен көмегімен Тоғукен уранының гидрогенді кен орнының әртүрлі ұңғымаларынан алынған жыныстар үлгілерінің коллекциясын петрофизикалық ЯМР зерттеу орындалды.

CONTENT

INTRODUCTION

One of the most important conditions determining the suitability of hydrogen uranium deposits for underground well leaching (UWL) is a favorable hydrogeological environment. Favorable or unfavorable hydrogeological conditions determine the economics of the IAC process and in some cases the technical feasibility of this method. Water permeability of ores and rocks occupies a leading position among hydrogeological factors affecting the efficiency of underground leaching. Deposit mining is possible only when the productive horizon is composed of permeable rocks and is waterlogged. An important factor is the ratio of filtration properties of ores to host rocks. A favorable situation is when the ore rocks are more permeable than the host rocks. Therefore, when studying hydrogenic uranium deposits with UWL the priority tasks are to identify and evaluate permeable rocks and determine the quality of their tires.

The aim of the work was to develop methods for selecting and assessing reservoir rock parameters and the quality of uranium deposit waterproofing based on integrated analysis of the results of petrophysical magnetic resonance studies of rock samples.

At present, the main source of information for reservoir rocks assessment is well geophysical surveys. Evaluation of complex reservoirs from GWL data is complicated by the simultaneous influence of many geological and technological factors on the measured geophysical values. As a result, errors of geophysical parameters determination when using a complex of GWL increase, as errors due to individual types of measurements are added. It is particularly difficult to identify reservoirs of complex structure, which are an alternation of thin, different in lithology layers. In the sections of geological deposits of complex structure, which are characterized by frequent alternation of low-power formations, lithology variability, the presence of a significant amount of clay material of various compositions, GIS complex does not allow to clearly identify the rocks-collectors and recommend them for testing. When testing a large power packet of rocks, permeable intervals are tried to determine by results of laboratory core analysis or by hydrodynamic studies. In order to provide a reliable solution to the geological problems of assessment of complex reservoirs, it is necessary to supplement the main GIS complex with geophysical methods that are the least affected by these factors. One such method is nuclear magnetic resonance (NMR).

According to the NMR data, collectors are separated by their direct feature - the presence of free, mobile fluid in the rock. The basis for determining the filtration characteristics of the rock is the unique sensitivity of the method to the mobility of pore fluid. Measured nuclear-magnetic relaxation characteristics allow to determine pore distribution by size and to distinguish free and bound water.

When drilling into a new area, the GWL complex is based, as a rule, on an exhausted GWL complex that was used in a neighboring or similar field. In this case, the change of the geological section character requires clarification of previously found petrophysical dependencies and introduction of additional research methods

into the GWL complex. Therefore, operational analysis of core material plays an important role at the stage of prospecting and exploration works.

Sensitivity of NMR studies to the mobility of reservoir fluid allows us to identify those intervals of the geological deposit in the pore space of which there is a mobile fluid, and, therefore, to identify unambiguously rocks-collectors. Therefore, operational core investigations allow to significantly complement the GWL complex for reservoir extraction and to issue recommendations for their testing. A significant reduction in the labor intensity of NMR research is achieved through complex analysis, when the main petrophysical parameters are determined in a single measurement cycle on a single rock sample.

Determination of petrophysical parameters of rocks using NMR method is based on established petrophysical links between nuclear magnetic and collector and other properties of the studied rocks.

1 Petrophysical basis for determination of filtration-capacitive properties of rocks from the data of the pits

Geological and geophysical application of nuclear magnetic research of rocks and fluids in exploration and development of mineral deposits is based on fundamental laws and provisions of classical and quantum-mechanical theory of NMR, especially nuclear magnetic relaxation in hydrogen-containing fluids.

1.1 Physical bases of NMR applications for rock research

The essence of NMR is the resonant absorption/radiation of hydrogen-containing substance of electromagnetic energy at the transition between the zeeman (energy) levels of the nuclei of atoms having mechanical and magnetic μ moments.

Among rock-forming elements having such moments (C, O, H, etc.) the main practical interest in the application of NMR in geology and geophysics are hydrogen nuclei (protons). The high gyromagnetic ratio g (ratio of magnetic μ to mechanical moments) and the significant proton density in the main objects (water and aqueous solutions) with radio availability of the resonant spectrum predetermine the geological and information efficiency of proton magnetic resonance (PMR) application.

Hydrogen nuclei in a constant magnetic field with intensity But have potential energy:

$$E= -\mu \, H_0 \tag{1}$$

In this connection, for a proton with a nuclear spin moment (Spin I) there are $2I+1$ Zeeman levels. Between these levels there are spontaneous/spontaneous (SP) and forced/induced pedestrian movements (SP). The probability of a SP from the upper to the lower level at the DMR is usually small, in contrast to IPs that are excited by an external energy source such as an electromagnetic field. In this case, the quantum field energy must coincide with the energy gap between adjacent levels, and the field frequency must coincide with the so-called larmore frequency. When moving to a higher level, the hydrogen nucleus absorbs the energy quantum from the field, while in the opposite transition it emits a photon.

In PMR experiments, ensembles/systems of hydrogen nuclei usually participate, for which $I = 1/2$, and the probability of IP is proportional to the energy density of the electromagnetic field. Under normal conditions, the population of the nuclei at the lower level of N1 is greater than that of N2 at the upper level, and the thermodynamic equilibrium for the ratio of the population z- depends on field strength and temperature. Since the number of photon-absorbing transitions is greater than the number of photon-absorbing IPs with radiation, the energy is absorbed from the electromagnetic field and the NMR/PMR effect is observed under resonant conditions.

When a hydrogen-containing liquid (HCL) is placed in the magnetic field No, a nuclear magnetization of M occurs, the value of which is proportional to the nuclear magnetic susceptibility and intensity No. Dynamics and kinetics of the populations of the 2-level proton system due to IP changes in time, and the population difference is exponentially reduced to 0. After a certain time, - at N1 = N2, - the resonant absorption of energy of HL is stopped.

Relaxation processes in liquids cause the transition of the si-system of dipoles/spins, briefly derived from the thermal equilibrium, to the thermodynamic equilibrium state (TEE). Since the relaxation transitions of spins from the lower to the upper level (W1) and vice versa (W2) are different, the dipole system relaxes to the

TRS in an exponential law over time

$$T = \frac{1}{2 \times W} \cdot \text{ (where W is the average faithfulness)}$$

Changing the magnitude or direction of the No field changes the magnetisation value, and the subsequent process of restoring the equilibrium value of Mo is called relaxation and is characterized by spin lattice (longitudinal) and spin spin (transversal) relaxation times. At the same time, T2 time of spin-spin relaxation (SRR) is caused by the rate of energy exchange of nuclear moments (magnetic spins) inside the spin-spin system (e.g. water molecule), and T1 time of spin- lattice relaxation (SRR) - by the rate of exchange between spins and their environment. The change in orientation of vector M relative to the H0 field is accompanied by its precession near the field direction with resonance frequency:

$$\omega_0 = g \, H_0 \tag{2}$$

and energy transitions of spins.

To excite the precession in the NMR, an alternating electromagnetic field with a constant field H0 is applied, which most strongly affects the nuclear moments at a frequency close to the resonance one. The H1 field is formed using an inductance coil in a fluid sample placed inside it in a perpendicular direction to the But field. Changes in magnetic flux and thus E.E.S. at precession frequency ω_o in this coil are the observed NMR/PMR effect.

In magnetic resonance studies of rocks in the present time, mainly used impulse modification of the NMR / PMR, when the field H1 are applied to the investigated sample in the form of short pulses of resonant frequency, and the effects caused by nuclear spinami, observe, measure and record at intervals of time between these pulses. If the exposure time of the H1 field is small relative to the T1.2 relaxation time, then the rotation of the vector M at an angle f is equal:

$$f = g \cdot \text{H1} \cdot \text{tи} \tag{3}$$
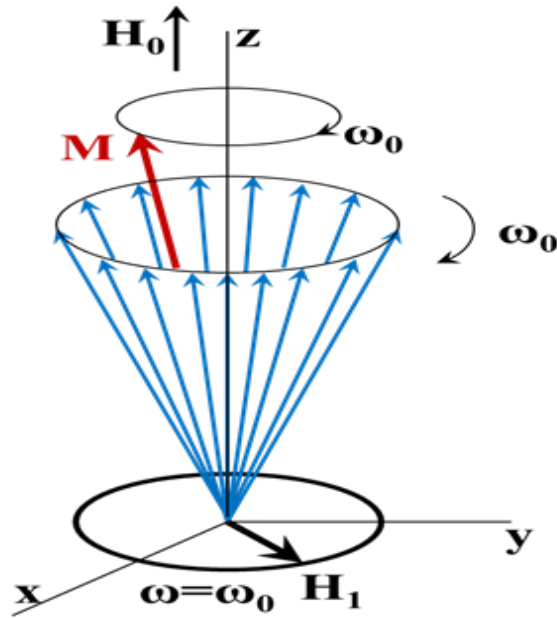
Figure 1.1 – Process of excitation of free induction signal under the action of radio frequency field H1

At f = π/2 vector M is rotated by 90 degrees relative to the H0 field direction by a radio-frequency pulse, after which the maximum amplitude of the free induction signal (FSS) of hydrogen nuclei is observed.

The amplitude of free induction signal from this liquid is described by equality:

$$U = 4\pi\text{- S- n- M0- Q,} \tag{4}$$

where Q, S and n are the quality, area and number of turns of the inductive coil, respectively. From this equality it follows that the amplitude of the SSI is pro-optional to the content of hydrogen nuclei in the sample of the fluid under study. Fading of SSI is basically caused by processes of spin-spin relaxation and inhomogeneity of a magnetic field in volume of the investigated sample.

For measurement of time of SRC the system of nuclear spins is deduced one way or another from SRC, after that the speed of setting of equilibrium value of longitudinal (spin-grid) component of nuclear magnetization M1 is determined. If relaxation processes in the spin system are characterized by one relaxation time, then in the initial mo-moment of time the longitudinal magnetization is described by the ratio:

$$M1(t) = M0 \ [1 - err \ (t/T1)] \tag{5}$$

This state is achieved by superimposing a 90º pulse-sa, after which an SSI is recorded with an amplitude proportional to the Mo value. When another 90-degree im-pulse is applied (after τ time), a SRI proportional to M1 is generated. Repeating the pulse sequence 90 - τ - 90 at different values τ, we can obtain the dependence of M1(t) and on its basis calculate the value of time T1.
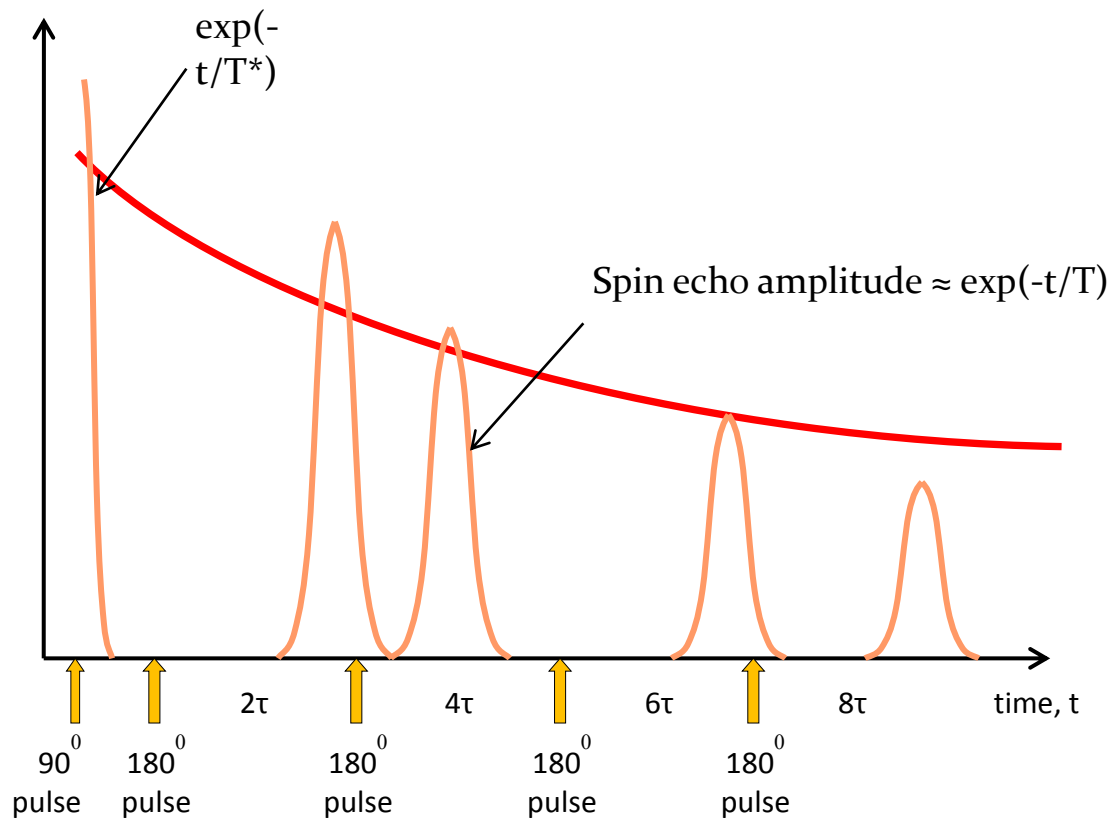
Figure 1.2 – Process of measurement of spin-spin relaxation time by multipulse spin echo method

To measure the time of the spin echo method (SEM) it is necessary to superimpose a sequence of one 90-degree and a series of 180-degree pulses on a sample. At the same time after 90-degree impulse there appears SSI, amplitude decrease of which is mainly caused by No field inhomogeneity. Since the free precession velocities of the vectors of magnetic moments of different nuclei are different, they decay with time. Under the influence of the 2nd 180-degree impulse, the vectors of magnetic moments are rotated at an angle of 180 degrees. As a result, the broken phase relations are gradually restored and after t time after the 2nd impulse vectors precess again in one phase. In this case, in the receiving coil of the inductance the SEM signal is excited. Between the subsequent 180-degree pulses, the SE signals are also generated, the amplitudes of which decrease with the time constant determined by spin-spin relaxation. Thus, the T2 time of spin-spin relaxation is determined by the time dependence of the SE amplitude:

$$A(t) = Ao \ exp \ (- \ t/T_2) \tag{6}$$

1.2 Petrophysical basis for NMR studies of rock samples

The amplitude of the free induction signal (FIS) from the pore liquid is described by the equality.

$$U = 4\pi\, S\, n\, Mo\, Q, \tag{7}$$

where Q, S and n - are quality, area and number of coils of inductance coil, respectively; Mo - is nuclear magnetisation.

According to the Curie's law, the nuclear magnetization of the sample:

$$\vec{M} = N\frac{\gamma^2 h^2 I(I+1)}{3K_B T}\vec{B}_0, \tag{8}$$

where K_B - Boltzmann's constant, T - absolute temperature, N - number of spins (hydrogen nuclei), γ - gyromagnetic ratio of the nucleus, h - Planck's constant, $\vec{B}_0$ - intensity of polarizing magnetic field.

Ability to determine the content of hydrogen nuclei (protons) in formation fluids predetermines the possibility of applying NMR research for quantitative estimates of liquids in samples and reservoirs. There is a proportional dependence between the value of the free induction signal (FIS) and the quantity of the road-containing liquid, which allows to estimate the quantity of pore liquid and determine the greatness of open, closed and total porosity of the rock-collector by the amplitude characteristics of FIS.

Usually under normal conditions aqueous molecules in free state are in isotropic thermal motion. For liquids in a large volume, relaxation times are determined by one time of correlation of molecular motion τc. Various physical and chemical factors (temperature, mineral and other impurities) have a significant influence on free water mobility and, consequently, on its relaxation characteristics. The influence of mineralization on the mobility and other properties of water molecules depends on the quantity and composition of min-neral salts in the water solution: as the content and charge of salt ions increase, the mobility of water molecules decreases.

When liquid molecules are adsorbed on a solid surface or are inside pores of a solid body, their thermal movement changes due to interaction of water molecules with pores walls. This thermal movement will be more anisotropic than the movement of molecules in a large volume. The degree of anisotropy of this movement depends on the nature of the solid surface and liquid molecules that are in the pore space.

According to the structural model of Bernal-Fauler, each molecule of water can form four tetrahedral bonds: two bonds are provided by the participation of hydrogen atoms in hydrogen bonds and two bonds are provided by an unseparated pair of oxygen electrons. The water molecules closest to the surface can form 3-4 bonds with it. These are the most firmly bonded water molecules. Subsequent layers of water molecules are oriented under the influence of surface forces. The movement of these

oriented molecules becomes less inhibited compared to the parietal water molecules, but more inhibited than the water molecules in the center of the pore. The retardation leads to the fact that the time of these molecules becomes longer than in the center of the pore, and therefore the longitudinal relaxation times are shorter.

The main effect of the porous medium on proton relaxation of the pore fluid is manifested in a decrease in its molecular mobility in the surface layer, i.e., in its increase. In the case when water is in the pore space of the rock, faster NMR relaxation is observed in comparison with its free state.

$$\frac{1}{T_1} = \frac{1}{T_{1B}} + \frac{1}{T_{1\text{Поверхн.}}},$$ (9)

Where T_{1B} - time of longitudinal relaxation of free water, $T_{1\text{Поверхн.}}$ - time of longitudinal relaxation of water protons on the surface of solid phase in rock.

Usually free water relaxation is negligibly small in comparison with surface relaxation. This dominant influence of the rock surface on NMR relaxation is that it provides a connection between longitudinal relaxation time T1 and pore size. The water protons closest to the solid surface have a high probability of magnetic relaxation. At the same time, the self-diffusion of water molecules tends to move non-relaxed protons to the surface and relaxed protons to the inside of the pores. In the case where this diffusion is fast compared to surface relaxation, it makes the magnetization homogeneous throughout the pore. The relaxation in the pore is then one exponential with a constant longitudinal relaxation time, which is given as

$$1/T_1 = \rho\, S/V,$$ (10)

where V and S - are respectively pore volume and surface area, ρ is the relaxation activity of the surface, i.e. the ability of the surface to cause relaxation of proton magnetisation and has a dimensional length / time.

The relaxation activity depends on two mechanisms. One mechanism represents the effect of granular surface on slowing down the mobility of adjoining water molecules. The other mechanism is the presence of paramagnetic atoms, i.e. atoms with non steamy electronic spin such as iron or manganese. Paramagnetic ions cause relaxation of electronic magnetization either through a much larger dipole of the electron compared to the proton, or through fluctuations of the electronic magnetic moment, which has its own longitudinal and transverse relaxations.

The second NMR relaxation characteristic is the time of transverse (spin-spin) relaxation T2, also associated with the pore size, but it is additionally affected by diffusion processes in an inhomogeneous constant magnetic field.

$$\frac{1}{T_2} = \frac{1}{T_{2B}} + \frac{1}{T_{2\text{Поверхн.}}} + \frac{1}{T_{2\text{Диффуз.}}},$$ (11)

where - T_{2B} time of transverse relaxation of free water; $T_{2\textit{Поверхн.}}$ - time of transverse relaxation of water protons on the surface of the solid phase of the rock; $T_{2\textit{Диффуз.}}$ - time of transverse relaxation of water protons associated with mo-lecular diffusion in an inhomogeneous constant magnetic field.

This additional variation makes the interpretation of T2 measurements more complicated in comparison with T1 measurements, and this is one of the reasons why much literature on rock NMR properties has until recently been focused on T1. However, in recent years, interest in studying the petrophysical relationships of time T2 has increased significantly. First of all, this is due to the use of the multi-pulse spin echo method, which allows to register the transverse relaxation curve in one measurement cycle. When using the multi-pulse method of SE, the observed rate of transverse relaxation is.

$$\frac{1}{T_2} \approx p\frac{S}{V} + \frac{2}{3}\gamma^2\tau^2 DG_0^{\;2}, \qquad (12)$$

where G_0 - magnetic field gradient, D - coefficient of self-diffusion of liquid, τ - interval between probing impulses. Influence of external magnetic field inhomogeneity when using multi-pulse SE method can be significantly reduced by reducing time interval τ.

In porous medium several phases of pore liquid usually coexist, each of which is characterized by its own content and mobility of molecules and, consequently, by proton relaxation rate. The multiphase nature of pore water is explained by the presence of superficial adsorption centers and different pore sizes. If the investigated rock has pores of different sizes, the measured relaxation curve from the investigated rock sample usually represents a sum of attenuation of signals from all pores.

$$U(t) = \sum_i A_i \exp(-t/T_{1i}), \qquad (13)$$

where A_i - the number of protons in pore i - size - corresponding to the constant attenuation times. By numerical solution of equality for A_i get dependence on A_i from T_1 which is called distribution and is interpreted as pore size distribution.

In rocks, the bound water in different states is characterized by different mobility, on the basis of which a qualitative and quantitative study of the residual water saturation of reservoirs is carried out. There are several views on the physical state of bound water in rocks. One of them, which has been dominated for a long time in foreign publications, is based on the assumption that bound and free water independently of each other make contributions to the nuclear magnetic relaxation curve and therefore can be divided by the value of the boundary relaxation time T1,2.

At the same time, the separate pore containing both free and bound water is characterized by only one relaxation time due to rapid diffusion between the phases of free and bound water.

2 Geological and information capabilities of rock sample study trenches for the extraction and evaluation of rock-collector parameters of hydrogenic uranium deposits with uwl

2.1 Analysis of geotechnological and hydrogeological conditions and tasks of uranium collector rocks extraction and evaluation

Despite significant differences in ore composition, properties, morphology of ore bodies and deposits and hydrogeological conditions, all deposits processed by the IAC method have common features. The efficiency of the IAP depends to a large extent on the capacity of the ore deposit and its ratio to the capacity of the productive (water-permeable) horizon, as well as the depth of the latter. The greater the capacity of the ore body t and its ratio to the capacity of the productive horizon M, the more favorable conditions for the ISP. Other factors being equal, there are unfavourable cases when $m/M < 1/10$, favourable at $m/M = 1/9-1/5$ and very favourable at $m/M = 1/4 - 1/1$.

IAC development is complicated by sections of ore deposits with sharply variable power over short distances. In this connection, study of spatial variability of ore deposit power and m/M ratio is one of the important tasks at the stage of deposit exploration. During exploration and development of hydrogenic uranium deposits with PSV on the basis of hydrogeological and petrophysical studies a number of other tasks should be solved:

- The possibilities and conditions for filtration of solutions by ore-substituting rocks are established;
- the internal structure of the orestimulating horizon has been studied;
- possibility of mutual influence of development of deposits and water intakes of underground water was assessed.
- The lithological composition and capacity of the water-switching rocks were determined;
- water depths of aquifers and groundwater levels, underlying and overlapping water reservoirs, reservoir and filtration properties of rocks of the ore-bearing horizon, permeability of ore and non-metallic rocks, presence of adjacent aquifers.

Knowing the patterns of carbonate and clay distribution in ores and host rocks helps to choose the mode of technological process and predict the efficiency of work at various stages of field operation by the PSV method.

The PSV method can be successfully used at deposits where the rock-forming minerals that make up the uranium ores are characterized by low solubility in the reagents used. These are primarily quartz, feldspars, mica and hydro mica. From aluminosilicates, which are part of uranium ores, the leaching process is significantly complicated by clay minerals, especially swelling clays.

For petrophysical studies, samples of undisturbed and disturbed rocks are taken from the core of hydrogeological wells along the entire ore horizon (subhorizon, cycle), from the upper and lower water bodies, as well as from all lithological differences of rocks developed in the section.

In case of increased (more than 20 m) capacity of the aquifer, differentiated assessment of capacitive and filtration properties of the section is made. Samples with undisturbed structure are taken to study water-physical properties of rocks, including permeability of ores and non-metallic rocks, as well as to substantiate lithologic-filtration types of rocks of the ore-bearing horizon. At each exploration profile, the network is 1600, less frequently. One engineering and geological well with full core sampling is drilled in the ore zone 800 m. Monoliths from ore deposits are selected at full capacity, including the upper and lower water bodies. At their considerable capacity (over 3 m), the monoliths are selected in a junction. The monoliths are selected from the supernatant sediments in a junction (3-10 m), but it is obligatory to test each lithological difference.

It has been established that permeability of sand and gravel rocks, which usually form a section of the productive horizons, depends on the content of clay-alumina particles and carbonates, the nature of their distribution in the rock. If clayey or carbonate components are present in the form of pellets, scraps, etc., they practically do not affect the permeability of rocks. If clayey-alumina particles or carbonates play the role of cementing agent, they can significantly reduce the permeability of sand and gravel rocks, and when certain concentrations are reached, make them impermeable. The values of the clayey and carbonate boundary values for the permeability separation of ore-destroying sediments should be specified for each specific deposit.

Visual and laboratory methods are used to assess the permeability of rocks and ores by their lithological composition. The core yield in a core pack is usually no more than 70%. In this case, core material losses usually occur in the most permeable rock differences, while clayey differences usually rise when drilling completely. Therefore, the results of core documentation of drilling wells can provide indicative (qualitative) information about water permeability of the studied section and tend to undersize it. It should be noted that in case of presence of the clay component in the form of isolated complexes or pellets, the particle size distribution analysis may overestimate the total clay content of rocks, and the results should be adjusted taking into account the visual documentation data.

Based on the results of the rock particle size distribution analysis, it is possible to determine the filtration coefficient of the rocks based on empirical formulas. The calculated values are approximate, as they do not fully take into account the natural occurrence, textures and structures of the rocks. However, experience shows that under conditions of simple structure of the ore-bearing horizon and homogeneity of rocks in terms of particle size composition, the use of empirical formulas for layer-by-layer calculation of the filtration coefficient of productive sediments gives results almost coinciding with those of calculations of the filtration coefficient based on the data of experimental pumping.

2.2 Relationship between permeability and filtration factors

When determining the filtration-intensive characteristics of hydrogen uranium deposits with PSV, the permeability of ore and host rocks is among the most important. At the same time it is of interest to estimate the ratio between permeability and filtration coefficients.

The ability of rocks to let water through due to the presence of cracks, pores and other voids is called their water permeability. It is determined by the filtration coefficient (or permeability coefficient), numerically equal to the rate of water filtration through the rock at a pressure gradient equal to one and measured in units of m/day (or cm/s).

The basic law of filtration associates the filtration flow rate with the head loss that characterises the energy consumption of the flow. It is assumed that in the main filtration area there is a linear relationship between flow rate and head drop (gradient), which is expressed by the following Darcy law formula:

$$Q = k \, \omega \, I, \tag{14}$$

where Q is the flow rate of a filtration flow with cross section ω at the head gradient I, representing the ratio of head loss ΔH to the filtration path length l; k is the proportional coefficient, called the filtration coefficient. Thus, according to Darcy law, the filtration flow is proportional to the cross-sectional area of the flow and the head gradient in the direction of motion.

The kinematic characteristic of the filtration flow is the filtration velocity v, which is the ratio of the flow to the cross-sectional area:

$$v = Q \, / \, \omega \tag{15}$$

By entering the filtration velocity, the Darcy Law can be represented as follows:

$$v = k \, I, \tag{16}$$

i.e. according to Darcy law the filtration speed is proportional to the pressure gradient.

From expression (2.3) it follows that the filtration coefficient has the dimension of velocity (in hydrogeological calculations usually [k] = m/day) and can be defined as filtration velocity at a single gradient of head. Filtration coefficient depends on pore space geometry and hydrodynamic properties of filtered fluid (density and viscosity).

When studying filtration of liquids with variable composition (in particular, when taking into account changes in water density and viscosity due to changes in mineralization and temperature), another form of Darcy law is more convenient, which directly takes into account the influence of fluid hydrodynamic properties.

Then the expression of the Darcy Law, should look:

$$v = kpr/\acute{\eta} * I,$$

where kpr is the permeability coefficient, which is a more accurate filtration characteristic of the pore medium than the filtration coefficient, as the kpr value should not depend on the hydrodynamic properties of the filter fluid. It should be kept in mind that this statement is true only in cases when the geometry of the pore medium does not change in the physical and chemical interaction of liquid and rock.

2.3 Factors affecting the permeability coefficient

As follows from the above conclusion, the permeability coefficient does not depend on the hydrodynamic properties of the filter fluid and, therefore, should be the same for different liquids, unless during the filtration process the pore space is reshaped or additional force fields appear.

A significant influence on filtration properties is caused by the heterogeneity of the structure of aquifers in the vertical direction. For reservoirs with pore and pore-crack permeability three main components with natural filtration heterogeneity can be distinguished.

The first component is inhomogeneity caused by changes in grain size by grain drops and spreads, as well as other facial substitutions.

The second component is vertical heterogeneity caused by formation of rocks. The filtration capacity of the reservoirs varies sharply from large values (tens of meters per day) to almost zero values at short distances (for example, thin alternation of sand and clay interlayers, presence of clay lenses, etc.) within one aquifer.

The third component is texture heterogeneity, which is observed within lithologically homogeneous layers or interlayers, which are inhomogeneous in texture features, which is typical for ore-bearing sediments. The texture heterogeneity is explained by the tendency of muddy and clayey lamellar-shaped particles to deposition on foliage during sedimentation, forming a scaly (tiled) texture of the sediment. As a rule, the water permeability of such formation in cross-layering is many times lower than in layering. The texture heterogeneity creates favorable conditions for ISP, especially in the presence of powerful aquifers.

To quantify the filtration heterogeneity, a filtration heterogeneity factor is sometimes used, showing what proportion of the payload volume is composed of sediments identical in permeability... This parameter becomes very valuable for practical purposes, when it is accompanied by a quantitative estimation of permeability of lithological differences in the pay zone (both in layering and in its vicinity).

For formation-porous deposits, to which the main volumes of uranium mining by the PSV method are connected at present, the classical case is that of a weakly dislocated gazelle formation composed of dissoluble chips (sands, sands, gravelites), which are bounded in soil and roof by continuous waterproofing (clay, marl, etc.).

The permeability of rocks is significantly influenced by porosity and pore space structure. At the same time, the nature of filtration significantly changes in case of incomplete water saturation of rocks and the filtration coefficient depends on relative humidity.

By moisture of a rock we mean the content in a sample of this or that amount of water, removed from it by drying at 100 - 1050C to a constant weight. Humidity is expressed as a percentage of the weight of the absolutely dry solid part of the sample.

By moisture content of rocks we mean their ability to contain and retain this or that amount of water. A distinction is made between the following types of moisture capacity: maximum molecular moisture capacity (Wm); capillary moisture capacity (Wk); total moisture capacity (Wt); maximum hygroscopic moisture capacity (Wh).

The maximum molecular moisture capacity of a rock is the maximum amount of hygroscopic and film water retained by the rock particles.

Capillary water content of sands is the maximum amount of water retained in capillary pores.

Total water content of the rock is the maximum amount of water retained by the rock when it is completely saturated with water. For clayey non- macroporous rocks, the full water content is usually the same as the capillary water content.

In the case of swelling clayey rocks, one should distinguish between the total moisture content of the given porosity and the moisture content of swelling or the maximum moisture content corresponding to the swelling sample.

Maximum hygroscopic moisture content or maximum hygroscopic capacity refers to the maximum amount of water that the rock absorbs from the air and releases heat. The most characteristic feature of this type of water in rocks is the lack of ability to dissolve salts. Maximum hygroscopicity is determined by drying the sample to a constant weight at a temperature of 105 - 110 ° C. The sample is preliminarily moistened under strictly defined conditions that prevent the rock from absorbing other types of bound water.

The water yield of sands is determined as the difference between total moisture content and maximum molecular moisture content.

2.4 Geological and information capabilities of NMR studies of rock samples for uranium collector rock assessment

The ultimate goal of GIS interpretation is to build lithological and petrophysical models from which the distribution of rocks and their physical properties in space can be represented. To solve these problems, various complexes of methods are used, which have proved themselves in one or another geological conditions.

Lithological dissection of the section based on the data of geophysical studies of wells is one of the most complex and often incorrect problems because the observed fields are not directly related to specific types of rocks, and depend mainly on the distribution of their physical properties. In turn, the physical properties of

rocks and their variability are determined by the conditions of sedimentation, di-, kata-, and epigenesis processes.

Studies of core samples play an important role in the construction of petrophysical dependencies, model substantiation, and determination of geological deposit parameters.

Prerequisites for informativeness and efficiency of NMR studies of rock and fluid samples for a reliable evaluation of FES and water-physical properties of uranium hydrogene deposits with PSV are the direct connection of the measured effects with rock porosity and sensitivity of NMR at the molecular level to the mobility of pore fluids. Since NMR measurements are simple, rapid, non-destructive and do not require special sample preparation, they can significantly improve the efficiency of studying productive deposits. This allows to study in operational mode all stone and fluid material coming from the wellhead of a drilling well, which provides not only average estimates of petrophysical parameters of reservoir rocks, but also individual formations and interlayers. This information is particularly important for the geological interpretation of well logging results.

Direct connection of the measured NMR signal amplitude with the hydrogen content of fluid in the pore space of the rock sample allows to determine its porosity regardless of the complexity of lithology. At the same time, estimates of total, open, closed and effective porosity on the same sample can be obtained, which significantly increases the geological representativeness and comparability of such definitions, their efficiency and cost-effectiveness.

NMR measurements of rock samples in the initial state immediately after their selection will allow to determine not only the degree of their humidity, i.e. the amount of water contained in the pore space of the rock, but also its energy state. Measured times of spin lattice T1 and spin-spin T2 relaxation depend on the degree of water molecules connection with solid skeleton, which allows to determine the moisture content of rocks.

The presence of clay material in the studied sandstones significantly reduces the measured relaxation times, which depend not only on the amount of clay but also on its type. As a result, NMR measurements of rock samples make it possible to estimate the clayiness of reservoirs and its type, which is important both for the evaluation of the FES and for planning the development project.

The sensitivity of the NMR method to fluid molecules mobility allows dividing water contained in the pore space of the rock into free and bound parts. It allows determining the effective power of the investigated geological sections, i.e. perspective thicknesses of those layers and interlayers through which aqueous solutions can be filtered.

As it was mentioned above, the most important characteristic of hydrogen rocks-collectors of uranium is their permeability. For a reliable assessment of rock permeability it is necessary to know a number of their petrophysical parameters: pore size, their tortuosity, physical and chemical properties of the skeleton, rheological properties of the fluid, etc. Most of these parameters can be estimated from NMR data of rock samples measurements.

3 Development of methods for integrated analysis of the results- the aim of these studies is to identify and assess the parameters of uranium collector rocks and the quality of waterproofing

3.1 Development of a methodology for identification and evaluation of uranium reservoir parameters based on NMR data of rock sample studies

The rocks of the productive horizon of sandstone deposits satisfy the following physical and geological model:
- the rocks composing the productive horizon are represented by sedimentary terrigenous sediments;
- each lithological difference consists of a sandy skeleton (quartz, feldspar), the pore space of which is filled with particles of clayey-aluminative fraction (particle size less than 0.05 mm) and water;
- salinity of water filling the free pores, from 0.5 to 6 g/l.

The capacitive properties of rocks reflect their capacity for water discharge or water saturation and are characterized by porosity. Porosity is defined as the ratio of the volume of voids in a rock to its entire volume and is expressed as a percentage. It can be defined by the porosity factor, numerically equal to the ratio of the volume of voids to the volume of the mineral skeleton, also expressed as a percentage. When assessing the technological properties of ore, we distinguish: total or absolute porosity, which determines the volume of all voids regardless of their shape and mutual relation; open porosity, which takes into account the volume of a part of voids, which are spatially connected with each other and provide the possibility of groundwater movement through this ore or rock; closed porosity, which is determined by the difference between total and open.

Supercapillary, or supercapillary, porosity (cavities larger than capillary ones > 0.5 mm), capillary porosity (sizes of rounded cavities from 0.0002 to 0.5 mm, crack-shaped cavities from 0.0001 to 0.25 mm), subcapillary porosity (cavities smaller than capillary ones < 0.0002 mm) are distinguished by the size of the cavities.

According to NMR data from rock samples, the porosity is determined directly by the amplitude of the measured free induction signal (FIC). The coefficient of total porosity is determined regardless of the lithology of the rocks by comparing the amplitudes of the measured rock sample and the standard sample:

$$Кп = Кпсо (Аи / Асо) / (Vсо / Vи), (\%),$$

where Кпсо is the porosity coefficient of the standard sample, Vи, Vсо and Аи, Асо and Ai are the volumes of the investigated and standard sample and the corresponding amplitudes of signals.

In the case where there is no closed porosity, the total porosity of the rock is equal to the open porosity. If there is a closed porosity in the investigated rock sample, its value is determined by measuring the SSI signal from the sample after its drying at 1050C to a constant weight.

The collector rocks in the section of the drilling well include those intervals of geological deposits, which are characterized by the ability to pass through the water solutions. In other words, the rock must contain free water in the pore space, not bound by the surface of the solid phase. Sensitivity of NMR studies to the mobility of reservoir fluid allows to identify those intervals of the geological deposit, in the pore space of which there is a mobile fluid, and, therefore, unambiguously identify the reservoir rocks. The amount of free water in the collector rock is determined by the effective porosity coefficient.

The following lithological types are usually singled out to characterize rocks of productive horizons, each of which is characterized by a certain range of particle fractions:

Table 2.1

Lithotypes	Particle size (diameter), mm
Clay-siltstone	less than 0.05 mm,
Very Small-grained Sand	From 0,05 to 0,1 mm,
Small-grained sand	from 0,1 to 0,25 mm
Middle-grained sand	From 0,25 to 0,5 mm
Coarse sand	From 0,5 to 1,0 mm
Gravel	More than 1,0 mm

If the mass fraction of clay-alumina particles exceeds 50%, the rock is identified as clay; sand is subdivided into fine, fine, medium and coarse grains depending on which of the fractions will exceed 50% of the mass fraction; if the mass fraction of gravel particles exceeds 50%, the rock is identified as gravel. If the mass fraction of any of the fractions does not exceed 50%, the rock is identified by fractions, the sum of mass fraction of the particles, which will exceed 50%. For example, if the sum of the mass fraction of fine and medium grained fractions exceeds 50%, the rock is identified as fine-medium grained sand, etc. If the sum of mass fractions of three or more sandy fractions exceeds 50%, the rock is identified as multi-grain sand.

Since there is a close relationship between the size of grains in the sands and the size of pores between them, a similar classification of rocks of productive horizons can be made according to NMR data of rock samples studies.

When assessing the quality of reservoir rocks, the most frequently used classification of porosity and permeability is the one used in the practice of geological work. (A.A.Khanin). Permeability of ore bodies is the main determinant of deposit classification. A distinction is made between deposits with high and limited pore, pore-crack and fracture permeability, with low and negligible pore-crack and fracture permeability. Deposits with ores permeable for solution leaching in their natural occurrence with filtration ratios exceeding 0.1 m/day.

Permeability of sand and gravel rocks, which usually form a section of the productive horizons, depends on the content of clay-alumina particles and carbonates, the nature of their distribution in the rock. If clayey or carbonate components are

present in the form of pellets, scraps, etc., they practically do not affect the permeability of rocks. If clayey-alumina particles or carbonates play the role of cementing agent, they can significantly reduce the permeability of sand-gravel rocks, and when certain concentrations are reached, make them impermeable. The values of clayey and carbonate boundary values for the permeability separation of ore-destroying sediments are specified for each specific deposit.

For rocks that include clay minerals that enter into physical and chemical interaction with water, the permeability depends significantly on the filter fluid composition. Thus, the permeability of sandstones for fresh water is lower than for salt water, and in pure sandstones this difference is relatively small, and in clayey sandstones it reaches orders of magnitude. In this case, the permeability depends not only on the content but also on the composition of clayey particles, and the effect of montmorillonite clay is noticeably greater, which is justified by the higher exchange capacity of such clays, actively developing their hydrate ionic diffuse salts.

Determination of permeability of rocks according to NMR data of rock samples is carried out as follows:

$$Кпр = С*Кпо4\ T1ср2$$

where C is the coefficient that depends on the rock type; Кпо is the coefficient of open porosity; T1cr is the average value of longitudinal relaxation time.

Exploration works on uranium should be oriented to obtaining information about heterogeneity of deposit structure, construction of its filtration model that is the initial data for designing the development. The main influence on fluid filtration processes in the reservoir body is the layer-by-layer and zonal heterogeneity of reservoirs. Permeable and impermeable rocks can be separated in the section of the ore-bearing horizon by lithologic-filtration types, as well as layer-by-layer values of the permeability coefficient in the section of wells can be determined using data from NMR studies of rock samples.

3.2 Development of a methodology for assessing the quality of water bodies

Rocks that are practically impermeable to water are called tyres (screens, waterproofing). These include clays, argillites, dense limestone, marl, rock salt, gypsum, anhydrides and some other dense rocks. Tires of several classes differ by a number of indicators. Tires of the highest class include rock salt, gypsum, anhydrites and plastic montmorillonite clays. The quality of tires is influenced by the homogeneity of the rock, mineralogical composition, absence of impurities and cracks. The presence of sand and siltstone particles in clays significantly reduces the shielding properties of tires. Tires of regional, zonal and local rank differ in size. The higher the homogeneity and thickness of a tire layer, the better its shielding properties.

At uranium deposits, clays most often act as waterproofing agents, which are divided into laminated and laminated tape structures. Mineral composition of clays is

usually mixed, that is, there are different types of clays (kaolinite, hydro mica, chlorite, etc.), but almost always in one or another amount of montmorrilonite is present.

Clay pores are divided into macropores (their effective radius exceeds 1 - 2 microns), transition pores with a radius interval of 0.015 to 2 microns and micropores with spradiuses less than 0.015 microns. Accordingly, the following limit types of clays are distinguished: non-porous, macroporous, transient and microporous. However, in practice clays have mixed structure, i.e. mixed porosity. In their structure, along with transient clays, there are micro- and macropores. The ratio between the pore volumes of the three types depends on the peculiarities of crystal and submicroscopic structure of natural clays.

One of the quality characteristics of clays is adsorption properties, which are determined by the interaction of pore water with a solid surface. Physically bound water is held on the surface of clay particles by molecular forces with noticeable binding energy, defined as the heat of wetting (sorption). A distinction is made between hard bound water and loosely bound water. Rigidly bound water is adsorbed (or hygroscopic), especially strongly bound water of the monomolecular layer at the clay-water interface. Critical characteristics of hard-bonded water are its reduced solubility and increased density. The amount of hard-bonded water depends on the mineralogical composition of the clay, the degree of its dispersion and the composition of exchange cations, and determines the hydrophilicity of the clay; it can be a classification sign. The adsorbed monomolecular layer of water favours the formation of water layers. The (or slightly) bound water is film (double-layer water) and capillary water. Film water forms a polymolecular layer of oriented dipole molecules, it moves along the clay from a particle with thicker film to a particle with less thicker film, not subject to gravity. Together with the capillary moisture, it has a reducing effect on the resistance of the clay. Clay minerals are characterized by an abundance of such water.

Thus, by the energy of interaction with a solid surface, the water of the clay pore medium can be divided into clay-bonded (strong bond) and capillary-bonded water (weak bond).

Depending on the type of clay, the specific surface area of the pore space changes greatly. Clay minerals of kaolinite composition are represented by particles with diameter 0.3-4 microns, thickness 0.05-2 microns and small specific surface area reaching 10-20 m2/year. Most of the bound water in kaolinites is formed in the area of capillaries and pores of small size.

Morphological peculiarity of chlorite particles is their chaotic arrangement, length to width ratio of 1:100 and small size of 0.1-2 microns in diameter (i.e. the particles have needle shape in the form of a brush), which promotes formation of specific surface equal to 200 m2/g. The bound water of the pore medium in chlorites belongs to the clay-bound type.

The clay-bonded type also includes water, which is contained in montmorillonite clays with a large specific surface. Montmorillonite is one of the

strongest adsorbents. Four layers of water are adsorbed in the inter-batch space of montmorrillonite.

Separation of water in clays into clay-bonded and capillary-bonded types can be done according to NMR data due to the dependence of relaxation times on the energy of interaction of water with the pore space surface. However, when conducting NMR studies of clay samples, one should bear in mind that most clays have the ability to swell. It is known that along with montmorrillonite kaolinite and hydro mica not only swell well, but also disperse in water. Therefore, they cannot be considered as hard sorbents in relation to water adsorption. They are characterized by intercrystalline swelling in contrast to the intercrystalline swelling inherent in montmorrillonite. The crystal lattice of kaolinite and hydro mica is rigid and does not change its parameters at humidification.

In the case of swelling clayey rocks should be distinguished between the full moisture content of the given porosity and the humidity of swelling or the maximum moisture content corresponding to a swollen sample. When the water content of the clay exceeds the adsorbed water, the inter-layer and inter-particle water are relatively free. As a result, the adsorption properties of clays are distorted according to NMR data. Measured relaxation times in water-saturated clays have overestimated values and, consequently, estimates of pore size and permeability coefficient will be overestimated. Therefore, a reliable assessment of adsorption properties of clays can be made from clay samples that are characterized by low water saturation.

4 Analysis of the consolidated geological and petrophysical section of the togusken uranium deposit section, constructed according to the rock sample study pits, selected-from different wells

The volume of rock samples examined by NMR method, taken from different wells of Togusken uranium deposit area, amounted to 62 samples. All the samples received for testing were in a friable state. Before NMR measurements the samples were formed in measuring containers in the form of cylinders with diameter 30 mm and height 30 mm. Since the samples had low humidity due to drying, they were saturated with mineralized aqueous solution. Samples were saturated by gradual impregnation with a syringe of aqueous solution.

NMR studies of the prepared rock samples were performed using a hardware-methodical complex based on a Proton 20M relaxometer. When determining the porosity of rock samples, calibration was carried out using standard samples of moisture volume fraction (GSO 2468-82).

Table 4.1 shows the magnetic resonance characteristics and petrophysical parameters determined by NMR measurements of selected rock samples. The sequence of numbers of investigated rock samples is shown in the table depending on the depth of their selection in wells.

Table 4.1 – Results of NMR studies of rock samples at Togusken field

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Ср)	Т1', мс %	Т1'', мс %	Т1''', мс % Т1ср, мс	Т2ср, мс	Кпр, мД	Кгл, %
1.	371	153,6-153,7	1031	Clay greenish-gray	176,6	35	0	100	Ср= 0,07	2,3 (100)				0,24	–
2.	347	155,9-156,0	241	Clay (a mixture of cherry and yellow-brown)	172,4	47,5	0	100	0,04	1,5 (100)				0,34	–
3.	345	156,1-156,2	141	Clay reddish-brown	158,4	43,0	0	100	0,02			Т1ср=0,7		0,05	–
4.	342	156,7-156,8	11	Clay (mixture of brown-red and green)	192,2	37,3	0	100	Ср.=0,06			Т1ср=1,9		0,21	–
5.	371	158,0-158,1	1041	Brown-red clay	134,1	43	0	100	Ср.= 0,03	0,9				0,09	–
6.	344	158,3-158,4	91	Clay (a mixture of grey and yellow ochre)	216,9	37,4	0	100	0,04			Т1ср=1,3		0,10	–
7.	357	158,4-158,5	561	Cherry-red clay	210,3	29,4	0	100	0,04	1,23 (100)	–	–	0,93 (100)	0,04	–

№ №	well number	square Interv.	№ sample	description	ССИ T2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Cp)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	T2ср, мс	Кпр, мД	Кгл, %
8.	364	158,4-158,5	781	Cherry-red clay	154,2	43,2	0	100	0,04			T1ср=1,2	0,57	0,15	–
9.	342	159,4-159,5	21	Sand clay.	200,2	28,6	0	100	Ср.=0,07	2,0 (100)				0,08	–
10.	351	161,1-161,2	451	grey-green.	185,2	29,6	0	100	1-st 0,21 2-nd 0,06 Ср. = 0,07	7,0 (24)	1,9 (76)	T1ср=2,3		0,1	–
11.	373	161,4-161,5	1171	Clay sand gray grey	177,6	44,5	0	100	0,03			T1ср=0,9		0,1	–
12.	342	161,7-161,8	31	Cherry-gray clay	320,3	38,7	3,4	91,2	1-st 0,36 2-nd 0,13 Ср. =0,19	11,8 (47,8)	4,2 (52,2)	T1ср=6,1		2,5	17,9
13.	344	161,8-161,9	101	Sand fine-grained gray clay	225,0	38,3	5,3	86,1	1-st 0,69 2-nd 0,18 Ср. = 0,28	22,3 (47,2)	5,8 (52,8)	T1ср=8,9	5,02	5,1	17,0
14.	368	162,2-162,3	891	Sand fine grained yellow, clayey	200,7	34,8	4,2	87,8	1-st 1,15 2-nd 0,17 Ср. = 0,22	37,1 (26,1)	5,5 (73,9)	T1ср=7,1	2,78	2,2	18,3

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Ср)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	T2ср, мс	Кпр, мД	Кгл, %
15.	364	163,8-163,9	791	Sand fine-grained yellow	195,0	38,6	5,5	85,8	1-st 1,66 2-nd 0,22 Ср. = 0,30	53,7 (30,3)	7,2 (69,7)	T1ср=9,8	3,32	6,4	16,9
16.	348	165,1-165,2	291	Sand fine-grained gray, clayey	248,3	34,5	4,8	86,8	1-я 1,59 2-я 0,23 Ср. = 0,28	51,2 (21,5)	7,3 (78,5)	T1ср=8,9	5,74	3,4	18,2
17.	344	165,7-165,8	111	Fine grain gray sand	237,3	40,0	3,8	90,2	1-я 0,68 2-я 0,15 Ср. = 0,20	21,9 (35,2)	4,7 (64,8)	T1ср=6,5	3,81	3,2	17,3
18.	342	166,5-166,6	41	Fine grain white sand	232,9	35,4	2,3	93,4	1-я 0,3 2-я 0,09 Ср.= 0,12	9,8 (32,9)	2,8 (64,1)	T1ср=3,7		0,6	19,3
19.	345	166,7-166,8	161	The sand is finely grained yellow,	272,4	39,0	7,1	81,8	1-я 1,35 2-я 0,28 Ср. = 0,41	43,5 (38,4)	9,1 (61,6)	T1ср=13,1	3,74	11,8	16,0
20.	347	166,9-164,0	261	Sand fine-grained yellow	263,7	36,6	3,1	91,6	1-я 0,56 2-я 0,14 Ср.= 0,19	17,9 (30)	4,6 (70)	T1ср=6,0		1,9	18,6
21.	374	167,0-167,1	1131	Fine grain sand, motley color	185,2	30,3	1,4	95,3	1-я 0,26 2-я 0,08 Ср. = 0,11	8,5 (32)	2,5 (68)	T1ср=3,2		0,3	21,2

№ №	well number	square Interv.	№ sample	description	ССИ T2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Ср)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	T2ср, мс	К_пр, мД	К_гл, %
22.	371	167,5-167,6	1051	Sand medium-grained grey	438,9	33,7	15,7	53,4	1-я 1,78 2-я 0,66 Ср.= 0,92	57,6 (45,3)	21,2 (54,7/)	T1ср=29,7		34,1	11,3
23.	357	169,6-169,7	581	Sand medium grained white	335,6	25,0	13,5	54,2	1-я 3,59 2-я 0,59 Ср. = 0,73	115,7 (23,8)	18,9 (76,2)	T1ср=23,6	11,4	6,5	13,0
24.	374	170,4-170,5	1141	Sand medium-grained grey	302,9	31,4	14,3	54,3	1-я 1,88 2-я 0,60 Ср.= 0,87	60,9 (46,1)	19,3 (53,9)	T1ср=28,2	13,1	23,2	11,9
25.	342	171,3-171,4	51	Sand medium grained white mixed with black	425	35,1	8,3	76,3	1-я 2,74 2-я 0,51 Ср. = 0,63	88,5 (22,7)	16,5 (77,3)	T1ср=20,3		18,8	15,8
26.	371	172,9-173,0	1061	Sand medium-grained grey	378,9	32,5	9,2	71,8	1-я 1,7 2-я 0,38 Ср.= 0,51	54,5 (31,9)	12,3 (68,1)	T1ср=16,4		9,3	15,5
27.	372	173,6-173,7	1081	Clay blue-wateau gray	216,9	40,7	0	100	0,08			T1ср=2,6	1,80	0,56	–
28.	345	175,3-175,4	171	Sand medium grained white	281,9	31,8	15,1	55,4	1-я 5,61 2-я 0,62 Ср. = 0,84	181,0 (28,8)	20,1 (71,2)	T1ср=27,0	13,81	22,4	12,1

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Ср)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	T2ср, мс	Кпр, мД	Кгл, %
29.	344	175,6-175,7	121	Sand medium-grained grey	258,6	40,5	6,4	84,2	1-я 1,73 2-я 0,29 Ср. = 0,36	55,9 (24,4)	9,2 (75,6)	T1ср=11,6	4,91	10,8	16,0
30.	371	175,7-175,8	1071	Sand medium grained white	322,8	39,1	7,7	80,3	1-я 0,83 2-я 0,12 Ср.= 0,29	26,8 (34,7)	6,9 (65,3)	T1ср=9,3		6,1	15,6
31.	373	175,7-175,8	1191	Sand medium-grained grey	284,4	31,1	8,0	74,2	1-я 1,65 2-я 0,32 Ср. = 0,47	53,2 (40,0)	10,2 (60,0)	T1ср=15,1	9,24	6,4	16,4
32.	353	176,4-176,5	461	Sand medium sulphur grey (monolith)	342,5	27,9	14,1	49,4	1-я 6,7 2-я 1,33 3-я 0,4	216,6 (25,6)	43,0 (43,2)	12,9 (31,2) T1ср=28,		14,6	11,4
33.	365	176,6-176,7	861	Sand medium-grained grey	391	33,2	15,3	53,8	Ср = 0,88			T1ср=28,4	17,2	29,4	11,5
34.	349	176,7-176,8	361	Sand medium-grained grey	278,0	27,0	14,9	44,9	1-я 3,33 2-я 0,74 Ср. = 1,17	107,5 (47,5)	23,9 (52,5)	T1ср=37,9	13,75	22,9	10,5
35.	368	177,3-177,4	901	Sand medium-grained grey	352,3	21,2	5,6	73,6	1-я 2,92 2-я 0,39 Ср. = 0,50	94,3 (25,3)	12,5 (74,7)	T1ср=16,0	6,47	1,6	18,6

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. µm Average size Ср)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	Т2ср, мс	Кпр, мД	Кгл, %
36.	362	178,1-178,2	831	Sand medium grained white (mixed with	474	37,7	7,8	79,4	Ср.= 0,51			T1ср=16,4	10,1	16,3	15,8
37.	347	179,7-179,8	271	Sand medium-grained grey	577,6	34,3	24,2	27,4	1-я 7,1 2-я 1,78 Ср.= 2,7	229,5 (45,7)	57,3 (54,3)	T1ср=87,2		315,7	5,8
38.	374	180,5-180,6	1151	Clay gray	173	40,0	0	100	0,06	1,9 (100)	–	–	0,95 (100)	0,28	–
39.	372	183,4-183,5	1091	Sand fine gray	308.5	28,6	9,9	65,3	1-я 1,56 2-я 0,45 Ср. = 0,61	50,2 (37,8)	14,5 (62,2)	T1ср=19,8	8,46	7,9	14,9
40.	371	183,8-183,9	1111	Sand medium grained white	310,4	34	8.8	74,1	1-я 1,15 2-я 0,29 Ср.= 0,41	37,2 (39)	9,3 (61)	T1ср=13,1		6,9	15,6
41.	364	183,9-184,0	801	Sand medium gray	269,1	25,1	3,9	74,7	1-я 4,66 2-я 0,36 Ср. = 0,48	150,3 (27,5)	11,5 (72,5)	T1ср=15,4	6,29	2,8	17,9
42.	361	184,0 - 184,1	751	Sand medium-grained grey	330	34,2	8,4	75,4	Ср.= 0,54			T1ср=17,3	11,3	12,3	15,9

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. µm Average size Ср)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	T2ср, мс	Кпр, мД	Кгл, %
43.	353	185,2-185,3	471	Sand fine gray	246,9	40,8	11,4	72,1	1-я 3,63 2-я 0,70 3-я 0,23	117,2 (20,7)	22,5 (46,0)	7,5 (33,3) T1ср=15,	6,3	18,7	13,7
44.	349	185,2-185,3	371	Sand fine gray	336,5	29,2	19,7	32,6	1-я 5,44 2-я 1,09 Ср. = 1,58	175,6 (39,0)	35,1 (61,0)	T1ср=51,0	24,40	56,8	7,4
45.	346	185,6-185,7	211	Sand medium-grained grey	272,9	35,7	4,9	86,3	1-я 0,63 2-я 0,20 Ср.= 0,27	20,4 (36,3)	6,6 (63,7)	T1ср=8,8	5,1	3,8	17,8
46.	370	186,5-186,6	951	Clay greenish-gray	147,9	43,9	0	100	0,04			T1ср=1,3	0,08	0,19	–
47.	366	186,7-186,8	841	Sand medium-grain grey (wet)	467	33,4	18,1	45,6	Ср.= 1,16			T1ср=37,3	18,7	51,9	9,7
48.	363	187,5 - 187,6	811	Sand medium-grained grey	391	26,9	4,8	82,3	Ср.= 0,4			T1ср=12,9	7,3	2,6	19,2
49.	362	187,6 - 187,7	731	Sand medium grained white, dry	349	15,2	1,4	90,5	Ср.= 0,19			T1ср=6,3	4,7	0,07	24,6

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Ср)	Т1', мс %	Т1'', мс %	Т1''', мс % Т1ср, мс	Т2ср, мс	Кпр, мД	Кгл, %
50.	370	192,0-192,1	1001	Sand medium-grained grey	233,2	27,6	18,3	33,8	1-я 5,72 2-я 0,82 Ср. = 1,47	184,6 (52,0)	26,3 (48,0)	Т1ср=47,5	9,63	39,2	7,8
51.	357	193,2-193,3	611	Sand mixed grey	311,7	26,4	9,0	65,8	1-я 3,77 2-я 0,80 3-я 0,27	121,6 (24,5)	26,0 (55,3)	8,6 (20,2) Т1ср=21,	11,3	6,7	15,5
52.	345	193,3-193,4	181	Sand is grainy and white	292,4	25,3	3,6	85,2	1-я 1,15 2-я 0,25 Ср. = 0,33	37,2 (28,0)	8,2 (72,0)	Т1ср=10,5	6,07	1,4	20,4
53.	361	194,4 - 194,5	761	Sand medium grained white	327	32,3	4,5	86,1	Ср. = 0,28			Т1ср=9,1	6,5	2,7	18,6
54.	360	194,4-194,5	711	Sand medium-grained grey	247,4	33,2	3,8	88,4	1-я 0,93 2-я 0,17 Ср. = 0,21	29,9 (25,2)	5,5 (74,8)	Т1ср=6,9	4,06	1,8	18,9
55.	368	194,4-194,5	931	Clay gray	141,4	43,3	0	100	0,04			Т1ср=1,3	0,06	0,18	–
56.	372	197,1-197,2	1101	Fine grain white sand	309,7	30,7	16,2	47,3	1-я 3,19 2-я 0,69 Ср. = 0,98	102,9 (38,0)	22,3 (62,0)	Т1ср=31,8	10,37	26,90	11,6

№ №	well number	square Interv.	№ sample	description	ССИ Т2*, мкс	Кпо, %	Кпэф, %	Кво, %	Pore sizes. μm Average size Cp)	T1', мс %	T1'', мс %	T1''', мс % T1ср, мс	T2ср, мс	Кпр, мД	Кгл, %
57.	373	202,0-202,1	1201	Fine grain white sand	315,1	35,0	6,0	82,9	1-я 0,74 2-я 0,27 Ср. = 0,38	23,9 (46,7)	8,6 (53,3)	T1ср=12,3	8,13	6,8	17,2
58.	371	203,2-203,3	1121	Sand medium grained white	379,1	35,3	4.4	87,4	1-я 0,53 2-я 0,17 Ср.= 0,25	17,0 (46,7)	5,5 (53,3)	T1ср=8,0		3,0	18,1
59.	374	205,8-205,9	1181	Sand is medium-grained, with an admixture of k/z.	485,3	35,9	4,3	87,9	1-я 0,48 2-я 0,21 Ср. = 0,32	15,6 (60,5)	6,7 (39,5)	T1ср=10,3		5,3	18,0
60.	348	205,9-206,0	351	Sand medium-grained grey	273,1	32,2	5,5	82,8	1-я 2,54 2-я 0,29 Ср. = 0,38	81,9 (27,7)	9,2 (72,3)	T1ср=12,2	5,55	4,8	18,0
61.	346	206,1-206,2	231	Sand fine-grained gray, clayey	235,7	33,7	1,95	94,2	1-я 0,24 2-я 0,09 Ср.= 0,12	7,7 (47,8)	2,7 (52,2)	T1ср=3,9		0,6	20,0
62.	374	209,5-209,6	1161	Sand fine-grained gray, clayey	435,2	22,5	0,9	96,1	1-я 0,23 2-я 0,09 Ср. = 0,12	7,3 (49,2)	2,7 (50,8)	T1ср=3,9		0,1	23,8

According to the data presented in Table 4.1, a consolidated geological and petrophysical section of the Togusken uranium deposit was constructed. The name "summary" is due to the fact that the studied rock samples were taken from different wells.

Figure 4.1 shows a summary tablet of petrophysical parameters Kpo (coefficient of open porosity), Kpaf (coefficient of effective porosity and Kpr (coefficient of permeability) depending on the depth of sampling of the studied rock samples.

Figure 4.2 shows a summary tablet of petrophysical parameters Quo (coefficient of residual or bound water saturation) and Kgl (coefficient of volumetric clayiness) depending on the depth of sampling of studied rocks.

The presented figures reflect geological deposits, which lie in the depth range of 153.6 - 209.6 m. The upper part of geological sediments in the depth interval of 153.6 - 161.5 m is represented by clays. In the lower part (depth interval 161.7 - 206.0 m) are mainly sands with varying degrees of clayiness, which are collector rocks, which at four depths (173.6; 180.5; 186.5 and 194.4 m) are separated by clay interlayers. In the lowermost part of the section there are fine clay sands with sharply deteriorated collector properties, which may belong to the transition zone from collector rocks to reservoirs. Samples of rocks (Nos. 231 and 1161) in this part of the section are characterized by low values of coefficients of effective porosity and permeability and increased content of clay material.

Clays of the upper part of the section belong to different types and have mixed mineralogical composition. Different types of clays have different specific surface values and are characterized by different adsorption properties.

Figures 4.3 and 4.4 show the time spectra of longitudinal relaxation-

The results of NMR measurements of rock samples Nos. 1171 and 1031, representing two types of clays with different specific surfaces. At a larger specific surface, water molecules are more strongly bound to the surface of pores and less mobile, which decreases the measured time of T1. Comparison of spectra presented in Figures 4.3 and 4.4 shows that peak values of T1 times in specimens No. 1171 and 1031 are equal to 0.9 ms and 2.3 ms, respectively. Consequently, sample No. 1171 has a larger specific surface and is a stronger sorbent.

Judging by magnetic resonance relaxation times (T1cr = 0.7 - 2.3 ms), the clays of the upper part of the section have different adsorption properties, but are mainly rather strong sorbents. Having very small size of micropores (0.02 - 0.07 microns) the presented clays are characterized by negligibly small permeability. Given the considerable power of the clays (7.9 m) in the upper part of the section, they create a tire for the underlying collector rocks, which has high shielding properties.
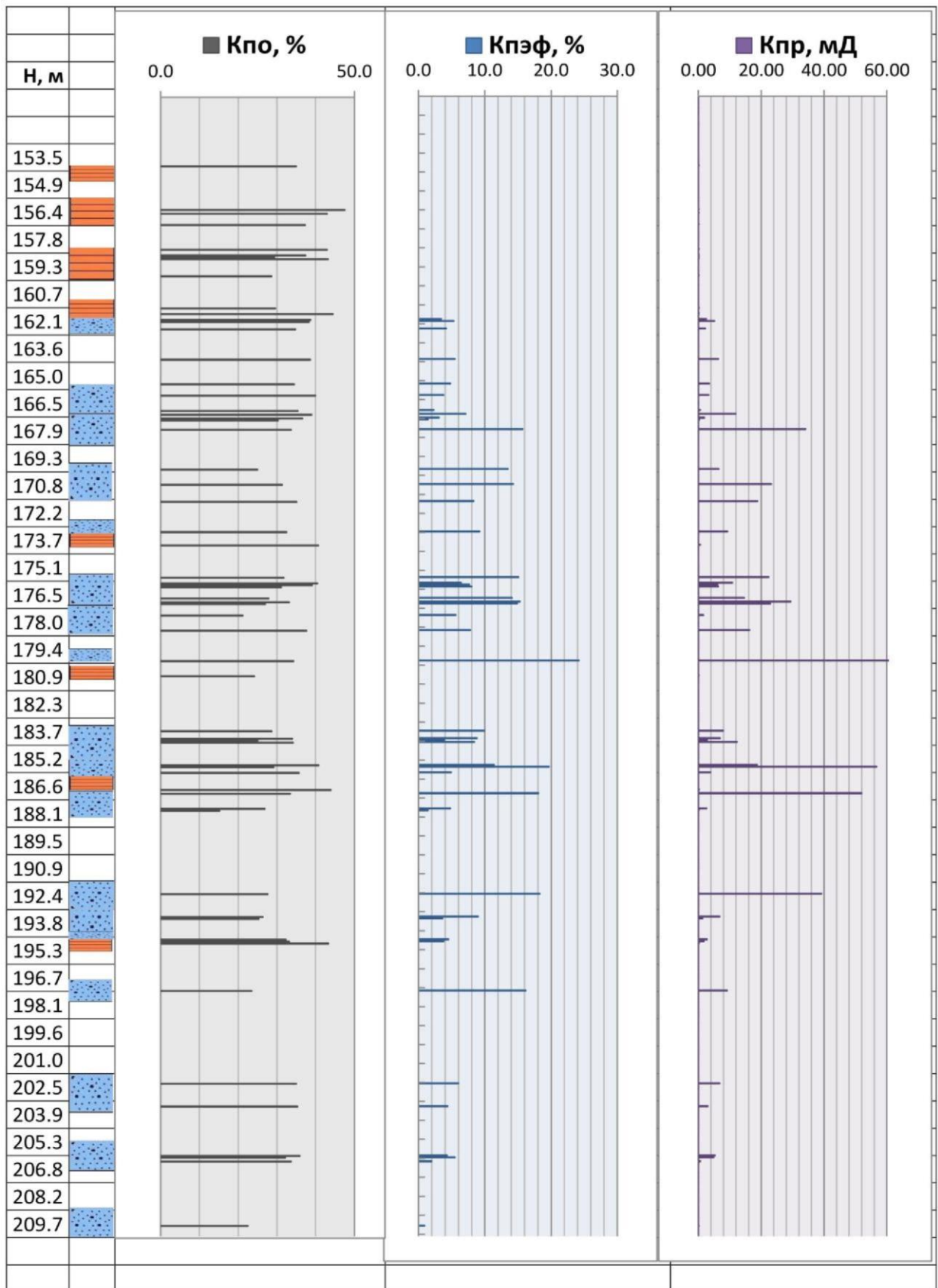
Figure 4.1 – Summary tablet of the Kpo, Kpaf and Kpr parameters depending on the sampling depth.

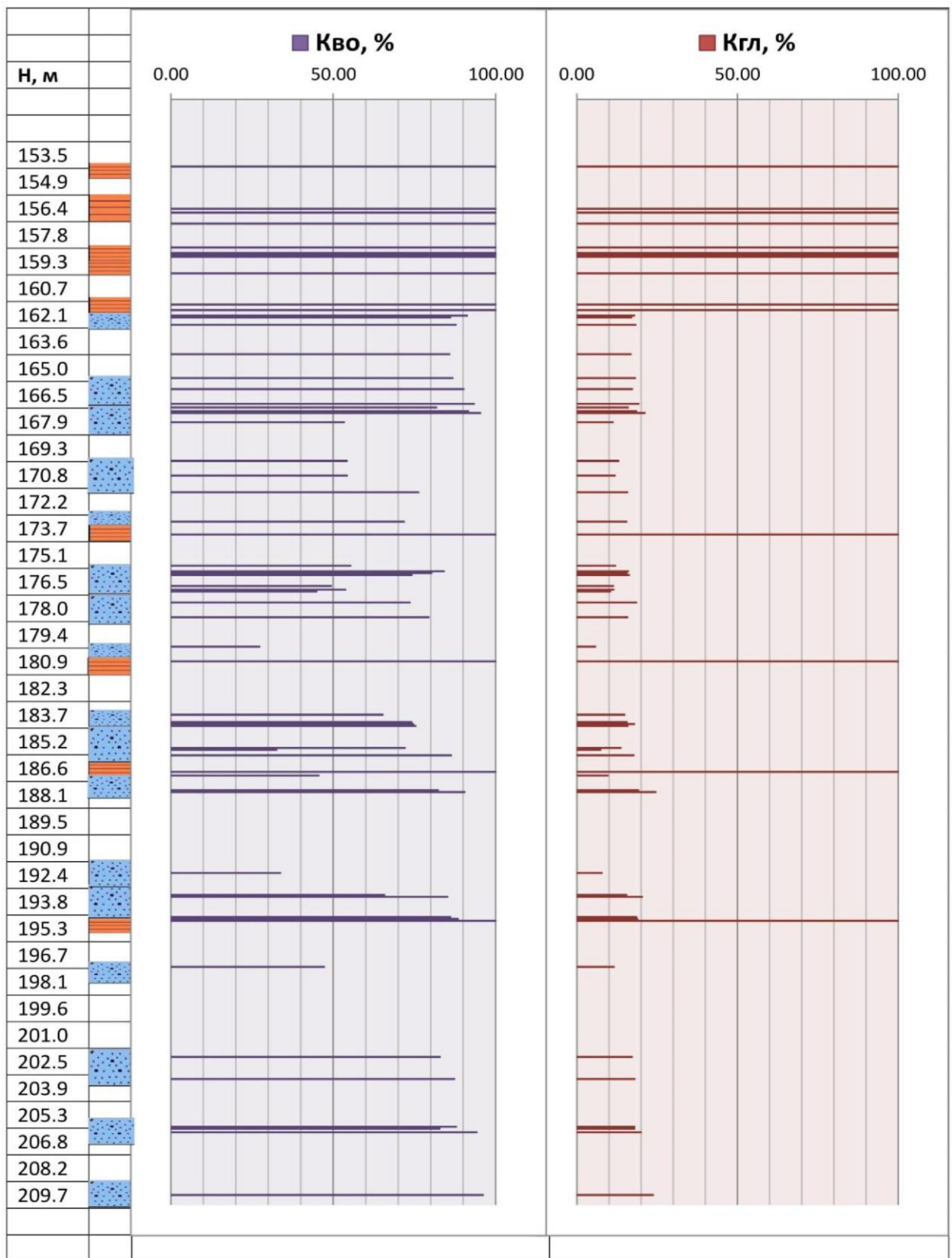Legend: ▭ - Clay   ▦ - collector rocks

Figure 4.2 – Summary tablet of Quo and Kgle parameters depending on the sampling depth.

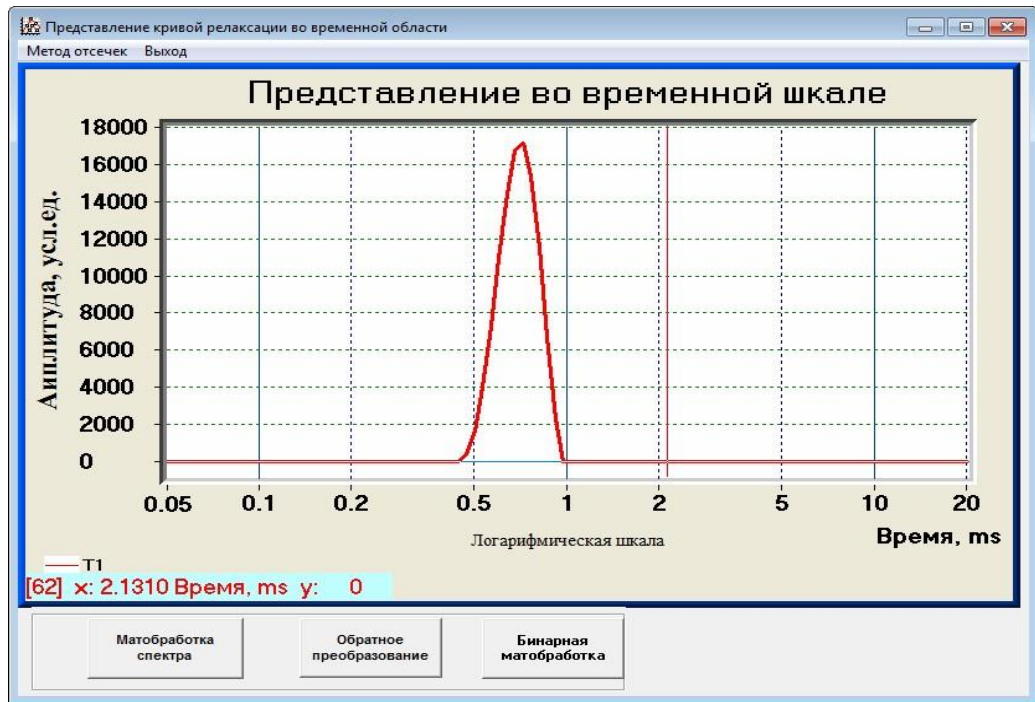Legend: ▭ - Clay   ▦ - collector rocks

Figure 4.3 – Spectral distribution of T1 longitudinal relaxation times obtained by NMR measurement of rock sample No 1171
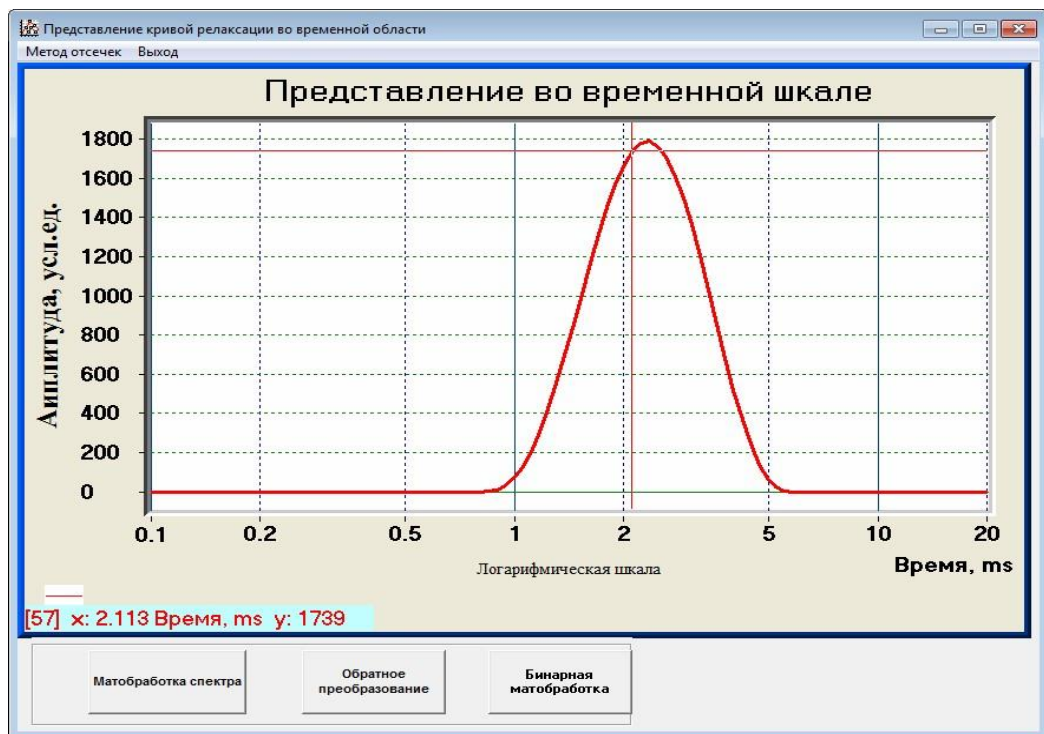

Figure 4.4 – Spectral distribution of longitudinal relaxation times T1 obtained by NMR measurement of rock sample No 1031

The depth interval of 161.7 - 209.6 m, where the sands lie, mainly belongs to collector rocks. Geological sediments in this depth interval, judging by petrophysical parameters, are characterized by considerable heterogeneity. The filtration and

capacitance properties (FEC) of the collector rocks vary over a wide range. The coefficient of open porosity Kpo, which reflects the pore space capacity of the rock, varies from 21.2 to 40.8%, averaging 32 - 37%. The Kpef effective porosity coefficient, which determines the share of free (moving) water in the collector rock pores, is in the range of 1.95 - 24.2%.

Figures 4.5 and 4.6 show spectral distributions of T1 longitudinal relaxation times obtained from NMR measurements of rock samples Nos. 371 and 111, whose collector properties differ significantly. Figure 4.5 shows the spectrum consisting of two separate parts reflecting shares of pore water with different mobility. The left part with peak value T1 = 35 ms characterizes water with less mobility, determined by the influence of clay material. The right part with peak value T1 = 175 ms reflects water with greater mobility that is connected with interaction of water molecules with sand grains. Since sample No. 371 has a small content of clay material (volume clay content coefficient Kgl = 7.4%), the share of bound water is 32.6%. As a result, at Kpo = 29.2%, this rock sample has Kpef = 19.7% and Kpr = 56.8 mD, i.e. it is characterized by high FES.

Sample 111 is characterized by a continuous spectrum with two peaks of T1 = 4.7 and 22 ms, which is shown in Figure 3.6. Most of the spectrum refers to T1 times, which have low values, which are typical for bound water molecules. Since sample No. 111 contains significant amounts of clay material (Kg = 17.3%), the share of bound water is 90.2% of the pore volume. Therefore, at Kpo = 40%, the effective porosity coefficient was only 3.8% and Kpr = 3.2 mD, i.e. sample No. 111 has low collector properties.

The permeability of rocks is closely related to the effective porosity, which determines the amount of free water in the pore space of rocks. This is confirmed by the dependence of the permeability coefficient Kpf on the effective porosity coefficient Kpf, which is shown in Fig. 4.7. The correlation coefficient was 0.74. The presented graph of dependence shows that at Kpaf < 5% the permeability coefficient does not exceed several units of mD. On the contrary, at Kpaf > 10% permeability of rocks-collectors increases to tens of units of DM. Sample 271 has the highest FEC in this range, its values of Kpaf = 24.2% and Kpr = 315 mD.

Since the area of specific surface of clayey particles significantly prevails over that of sandstone and siltstone, the volume of bound water in the pore medium of the collector rocks increases with the growth of clayey material. This leads to a strong dependence of sand permeability on its clayiness. Figure 4.4 shows the dependence of the permeability coefficient of KPR on the volume clayiness coefficient of the studied samples of rocks Kgl. The correlation coefficient was 0.84. The presented chart shows that the most permeable are collector rocks with volume clayiness not exceeding 10%. At KgL = 10 - 15% permeability coefficient remains in the range of 35 - 10 mD and only at KgL > 15% permeability decreases to units of mD. If the volume clay content coefficient of the rock samples exceeds 20%, their permeability becomes negligibly low.
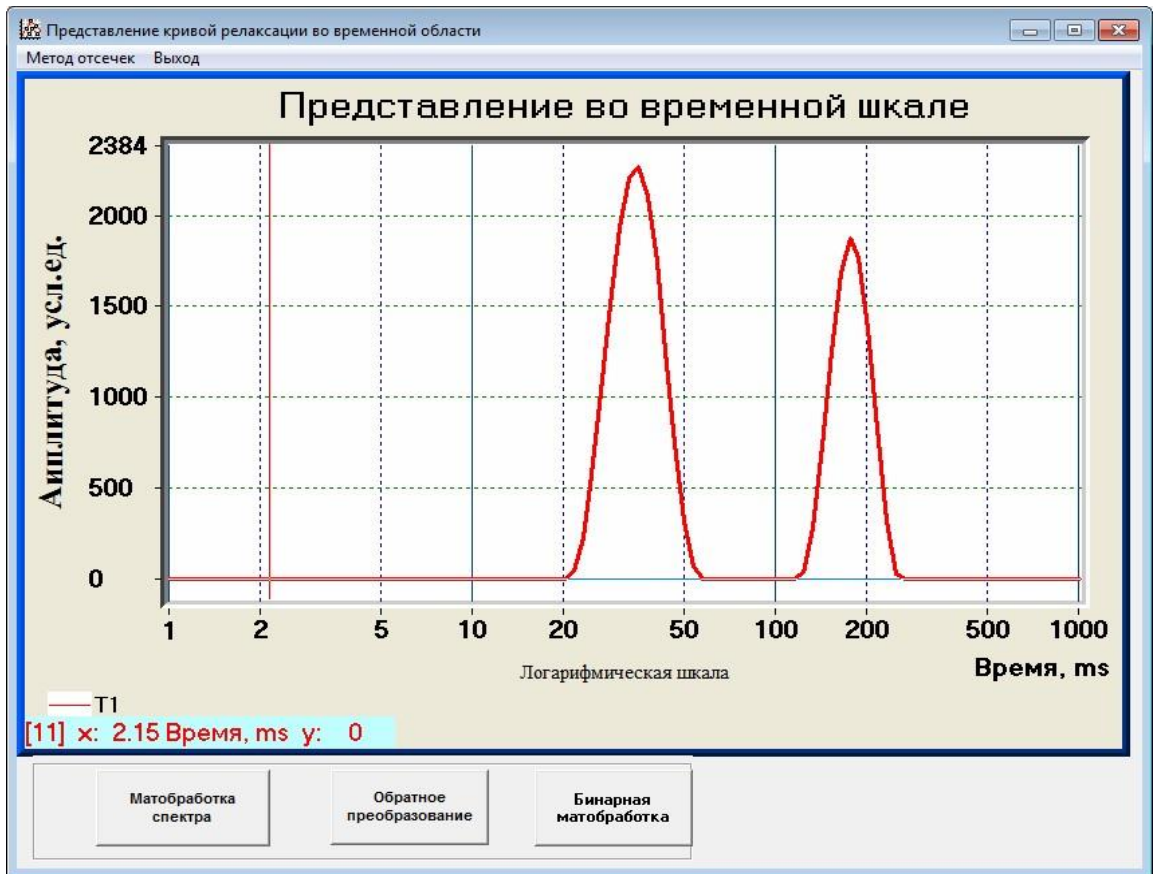
Figure 4.5 – Spectral representation of T1 longitudinal relaxation times obtained by NMR measurement of rock sample No. 371

Figure 4.6 – Spectral representation of T1 longitudinal relaxation times obtained by NMR measurement of rock sample No 111
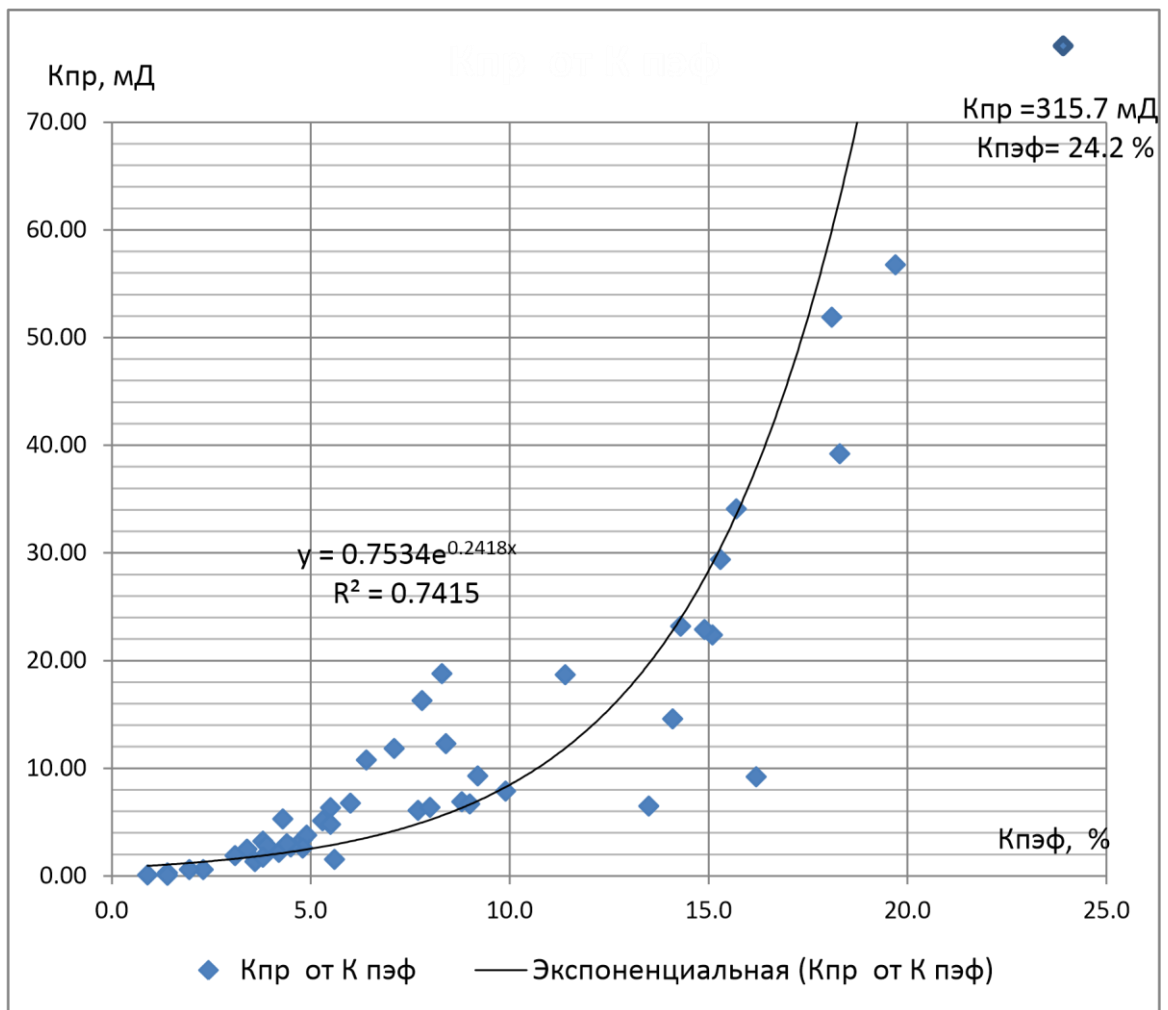
Figure 4.7 – Graph of the dependence of the coefficient of permeability of Kpr on the coefficient of effective porosity of Kpaf, based on the results of NMR measurements of rock samples taken from the Togusken field
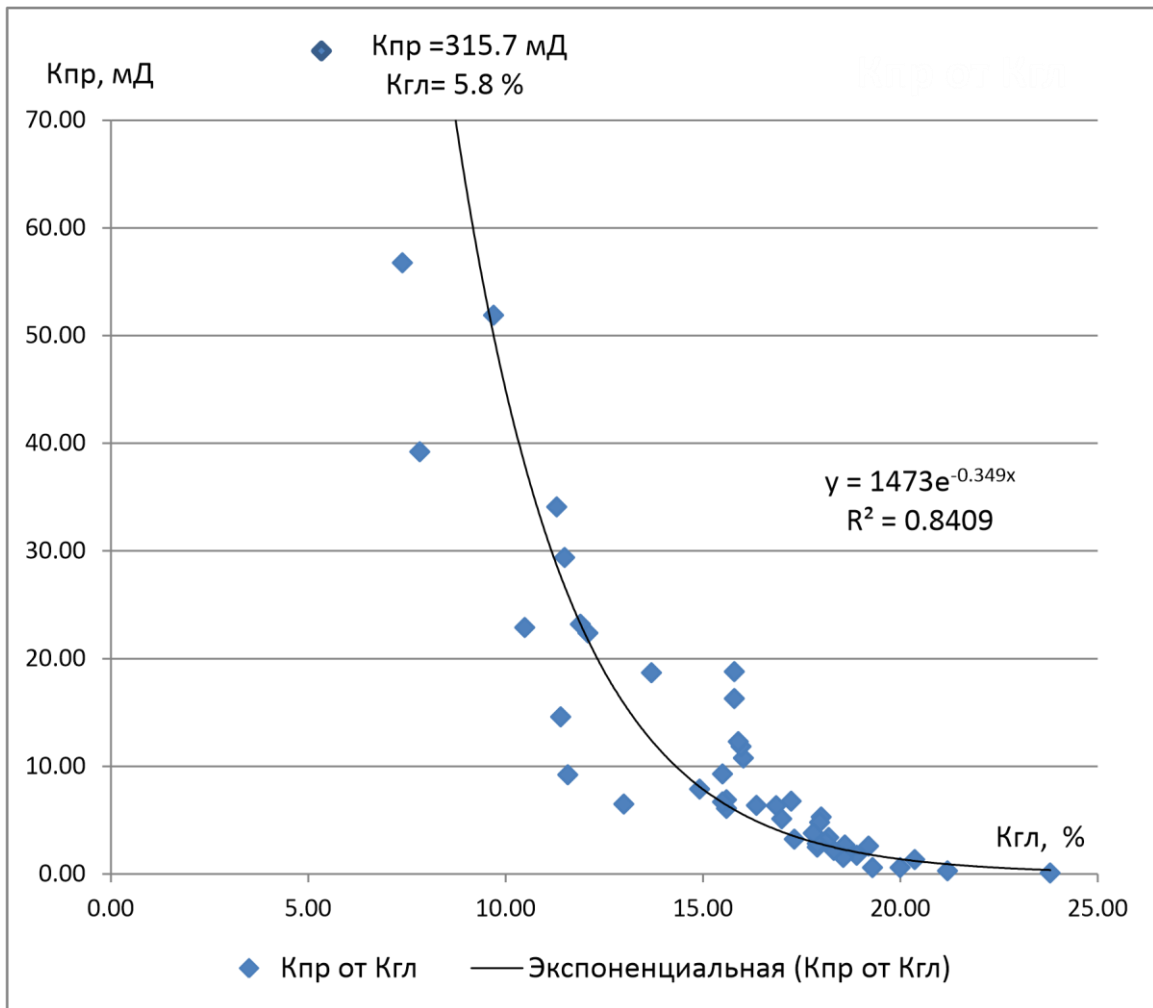
Figure 4.8 – Graph of the dependence of the permeability coefficient of Kgp on the volume clay strength coefficient of Kgp, based on the results of NMR measurements of rock samples taken from the Togusken deposit.

The analysis of the constructed consolidated geological and petrophysical section of the Togusken deposit rocks, which is characterized by an impermeable tire and an interval of rocks-collectors with high permeability, allows to draw a conclusion about favorable conditions for the development of this deposit.

CONCLUSION

Petrophysical nuclear magnetic studies of selected and prepared 62 rock samples from different wells of Togusken field allowed to determine their filtration-volume properties (FEC). The physical prerequisites for the effectiveness of these studies were the direct connection of measured NMR characteristics with the amount of hydrogen-containing pore liquid of rock samples and unique sensitivity at the molecular level to the mobility of this liquid.

As a result of NMR studies, the main petrophysical parameters of rock samples were determined:

- Kpo open porosity coefficient;
- the coefficient of effective porosity of Kpaf, reflecting the share of free (moving) water in the pore space of the rock;
- the coefficient of residual (bound) water saturation of the rock Quo;
- pore size distribution;
- volume clay density coefficient Kg; - permeability coefficient Kpf.

The developed methods of integrated analysis of the results of petrophysical NMR studies of rock samples allowed identifying collector rocks and water reservoirs, assessing their parameters and heterogeneity in the section of geological deposits of the Togusken hydrogenous uranium deposit.

According to the data obtained as a result of petrophysical NMR studies, which are presented in Table 4.1, a consolidated geological and petrophysical section of the Togusken deposit rocks was constructed. In the constructed geological and petrophysical section, the upper clay interval (depths of 153.6 - 209.6 m) and the lower sand interval (depths of 161.7 - 209.6 m), which mainly relate to rocks collectors, were identified.

Clays of the upper interval belong to different types and have mixed mineralogical composition. Clay samples have large specific surfaces and are characterized by high adsorption properties, i.e. they are strong sorbents. At the size of micropores 0.02 - 0.07 microns, the clay samples studied have negligible permeability. As the power of clays of the upper interval of the section is 7.9 m, they create a tire with high shielding properties for the lower interval of permeable rocks.

Geological deposits in the lower interval of depths, judging by petrophysical parameters, are characterized by considerable heterogeneity. The filtration and capacitance properties of the collector rocks vary over a wide range. The coefficient of Kpo open porosity, which reflects the pore space capacity of the rock, varies from 21.2 to 40.8%, averaging 32 - 37%. The Kpaf effective porosity coefficient is in the range of 1.95 - 24.2%.

The coefficient of permeability Kpf of selected collector rocks is closely related to the coefficient of effective porosity Kpef and the coefficient of bulk clayiness Kp.

This is confirmed by the corresponding dependencies shown in Figures 4.7 and 4.8. With increasing Kpef, the permeability coefficient increases and, on the contrary, with increasing Kpef, the permeability coefficient drops markedly.

The analysis of the constructed composite geological and petrophysical section of the Togusken deposit rocks, which is characterized by an impermeable tire and an interval of rocks-collectors with high permeability, allows to draw a conclusion about favorable conditions of this deposit development.

In general, petrophysical NMR studies of rock samples showed their effectiveness and prospects for use at the stage of geological exploration, as they allow to significantly reduce costs at the expense of:

1. Reduction of expenses for transportation of core material to the laboratory, if the studies are conducted directly in the field conditions.

2. Reductions in laboratory and analytical work.

3. Increasing the reliability of selection and evaluation of reservoir parameters and quality of water reservoirs in hydrogenic fields and, consequently, reducing the share of geological risk at the development stage

Feasibility study and mining enterprise project.

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