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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылыметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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CLAY AND CARBONATE COMPOSITION OF HYDROGENIC URANIUM HORIZONS: PROBLEMS AND PROSPECTS OF THEIR INVESTIGATION BY GEOPHYSICAL METHODS

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Abstract. *Relevance.* This study provides a detailed analysis of the specific clay and carbonate content characteristics in ore-bearing horizons of hydrogenic uranium deposits within the Chu-Sarysu province, hosted mainly by sandstones of varying grain sizes. A comprehensive understanding of the distribution and quantitative features of these parameters is crucial for geological interpretation, including determining the shape, dimensions, and position of uranium ore bodies. It is also highly relevant for field development using in-situ leaching (ISL), where efficiency strongly depends on high leaching solution mobility. Clay and carbonate minerals significantly affect the permeability and filtration properties of sandstones, reducing the migration efficiency of natural and technological fluids. *Objective.* To analyze the physical foundations and assess the capabilities of well-logging, electrical, and seismic methods for reliably predicting clay/carbonate content and the overall filtration properties of ore horizons, aiming to overcome the limitations of labor-intensive laboratory core analysis. *Methods.* These challenges were addressed by analyzing the physical foundations and assessing the capabilities of well-logging methods. Special emphasis was placed on identifying the physico-

geological foundations of electrical and seismic methods, as well as delineating contrasts in electrical and density properties to evaluate geophysical methods for predicting rock filtration properties. *Conclusions.* The results identified key limitations caused by insufficient completeness and detail in studying rock physical properties, resulting in a shortage of specialized petrophysical data required for reliable interpretation of well-logging and inter-well geophysical data. Based on this analysis, major problems and promising future research directions were defined to enhance the accuracy, reliability, and information content of geophysical methods across all stages of geological and technological operations on hydrogenic uranium deposits.

Keywords: hydrogenic uranium deposits, ore horizons, clay content and carbonate content of rocks, geophysical methods

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ГИДРОГЕНДІ КЕНОРЫНДАРДАҒЫ УРАН ҚАБАТТАРЫНЫҢ САЗДЫЛЫҒЫ МЕН КАРБОНАТТЫЛЫҒЫ: ОЛАРДЫ ГЕОФИЗИКАЛЫҚ ӘДІСТЕРМЕН ЗЕРТТЕУДІҢ ПРОБЛЕМАЛАРЫ МЕН ПЕРСПЕКТИВАЛАРЫ

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Аннотация. *Өзектілігі.* Шу-Сарысу провинциясының гидрогенді уран кенорындарындағы рудалы горизонттарды құрайтын әртүрлі түйіршікті құмдар мен құмтастардың саздылығы мен карбонаттылығы жан-жақты зерттелді. Бұл таужыныстардағы саз және карбонат минералдарының болуы олардың өтімділігі мен фильтрлік қасиеттеріне елеулі әсер етіп, табиғи және технологиялық сұйықтықтардың миграциясын төмендетеді. Саздылық пен карбонаттылықтың таралуы мен сандық сипаттамаларын анықтау геологиялық интерпретация үшін, соның ішінде уранкенді денелердің пішінін, өлшемін және қимадағы орналасуын болжауда маңызды. Себебі, өңірдегі уран кенорындары генезисі бойынша гидрогенді типтегі қабаттық-инфильтрациялық рудаланумен сипатталады. Сонымен қатар, осы генетикалық типтегі кенорындарды жерасты ұңғымалық шаймалау (ЖҰШ) тәсілімен игеру кезінде де зерттеу нәтижелері өзекті. Өйткені үдерістің тиімділігі шаймалау ерітінділерінің рудалы горизонттардағы жоғары қозғалғыштығына тәуелді. *Мақсаты.* Зерттеулер саздылық пен карбонаттылықты анықтаудың дәстүрлі зертханалық әдістерімен салыстырғанда өнімділігі жоғары ұңғымалық геофизикалық әдістердің физикалық негіздерін талдауға және олардың мүмкіндіктерін бағалау арқылы жүргізілді. *Әдістері.* Зертханалық әдістер көлемді жұмысты – әртүрлі тереңдік пен қалыңдықтағы кен горизонттарынан таужыныстардың репрезентативті үлгілерін алуды – қажет етеді. Жұмыста электрлік және сейсмикалық әдістердің физикалық-геологиялық негіздеріне ерекше назар аударылды. Таужыныстардың электрлік және тығыздық қасиеттеріндегі айырмашылықтарын анықтау геофизикалық әдістердің кен горизонттарының фильтрлік қасиеттерін сенімді болжаудағы әлеуетін бағалауға мүмкіндік берді. *Қорытынды.* Алынған нәтижелер кенді горизонттардағы таужыныстардың физикалық қасиеттері туралы деректердің толық еместігін және геофизикалық зерттеулерді сенімді интерпретация жасауға қажетті мамандандырылған петрофизикалық мәліметтердің жеткіліксіздігін көрсетті. Талдау негізінде гидрогенді уран кенорындарындағы геологиялық-технологиялық жұмыстардың әртүрлі кезеңдерінде ұңғымалық геофизикалық (сейсмикалық және электрлік) әдістерді қолданудың негізгі проблемалары және олардың дәлдігін, сенімділігін және мәліметтілігін арттыруға бағытталған болашақ зерттеулердің перспективалы бағыттары белгіленді.

Түйін сөздер: гидрогенді уран кенорындары, рудалы горизонттар, таужыныстардың саздылығы мен карбонаттылығы, геофизикалық әдістер

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ГЛИНИСТОСТЬ И КАРБОНАТНОСТЬ УРАНОВЫХ ГОРИЗОНТОВ ГИДРОГЕННЫХ МЕСТОРОЖДЕНИЙ: ПРОБЛЕМЫ И ПЕРСПЕКТИВЫ ИХ ИЗУЧЕНИЯ ГЕОФИЗИЧЕСКИМИ МЕТОДАМИ

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Аннотация. *Актуальность.* Исследование посвящено анализу глинистости и карбонатности рудоносных горизонтов гидрогенных месторождений урана Чу-Сарысуской урановорудной провинции, сложенных преимущественно разнозернистыми песчаниками. Всестороннее изучение пространственного распределения и количественных характеристик этих параметров имеет важное значение для геологической интерпретации, включая определение формы, размеров и пространственного положения урановых рудных тел. Глинистость и карбонатность пород также существенно влияют на эффективность разработки месторождений методом подземного скважинного выщелачивания (ПСВ), поскольку определяют подвижность выщелачивающего раствора, проницаемость и фильтрационные свойства песчаников. Повышенное содержание глинистых и карбонатных минералов может ограничивать миграцию природных и технологических растворов и снижать эффективность извлечения урана. *Цель.* Проанализировать физические предпосылки и оценить возможности каротажных, электрических и сейсмических методов для достоверного прогнозирования глинистости, карбонатности и фильтрационных свойств рудоносных горизонтов, а также определить пути преодоления ограничений, связанных с трудоёмким лабораторным исследованием керна. *Методы.* Проведён анализ физических основ и диагностических возможностей методов геофизических исследований скважин. Особое внимание уделено физико-геологическому обоснованию применения электрических и сейсмических методов, а также выявлению различий в электрических, плотностных и упругих свойствах пород, связанных с изменением их

глинистости, карбонатности и фильтрационных характеристик. Рассмотрены возможности использования каротажных и межскважинных геофизических данных для косвенной оценки состава и проницаемости рудоносных песчаников. *Результаты*. Установлено, что достоверность геофизического прогнозирования глинистости, карбонатности и фильтрационных свойств рудных горизонтов ограничивается недостаточной изученностью физических свойств пород и дефицитом специализированных петрофизических данных. Показано, что электрические, плотностные и упругие параметры могут использоваться в качестве косвенных индикаторов минерального состава и фильтрационных характеристик песчаников, однако их интерпретация требует учёта литологической неоднородности, минерализации пластовых вод, пористости и степени цементации пород. *Выводы.* Основными проблемами остаются недостаточная полнота и детальность изучения физических свойств пород, а также отсутствие репрезентативных петрофизических зависимостей, необходимых для надёжной интерпретации каротажных и межскважинных геофизических данных. Перспективными направлениями дальнейших исследований являются формирование специализированной петрофизической базы, комплексирование электрических, сейсмических и каротажных методов, а также разработка многопараметрических моделей прогнозирования глинистости, карбонатности и фильтрационных свойств рудоносных горизонтов. Реализация этих направлений позволит повысить точность, надёжность и информативность геофизических исследований на всех этапах геолого-технологических работ на гидрогенных месторождениях урана.

Ключевые слова: гидрогенные месторождения урана, рудные горизонты, глинистость и карбонатность пород, геофизические методы, фильтрационные свойства; геофизические исследования скважин; подземное скважинное выщелачивание

Introduction. The majority of Kazakhstan's uranium reserves are concentrated in hydrogene, tabular infiltration-type deposits, primarily hosted within the coformational sand-clay sequences of the Shu-Sarysu and Syrdar'ya rift-sedimentary basins (Figure 1). These basins consist of Mesozoic-Cenozoic sand-clay sediments that contain uranium mineralization of the roll-front type, characterized by the curved geometry of the oxidation-reduction boundary. Roll-front uranium bodies typically occur within sandstones exhibiting high permeability. In this context, sedimentary texture, the alternation of sand and clay layers, and the presence of carbonates and organic matter collectively control the position of the redox front, the intensity of uranium precipitation, and the current technological properties of the ore-bearing strata. For instance, in the Shu-Sarysu region, six sand-clay sequences have been identified, with sand-dominant intervals reaching 50-70 m in thickness and separated by low-permeability clay interbeds (Petrov et al., 2008; Franz, 2009; Aizhulov et al., 2023).

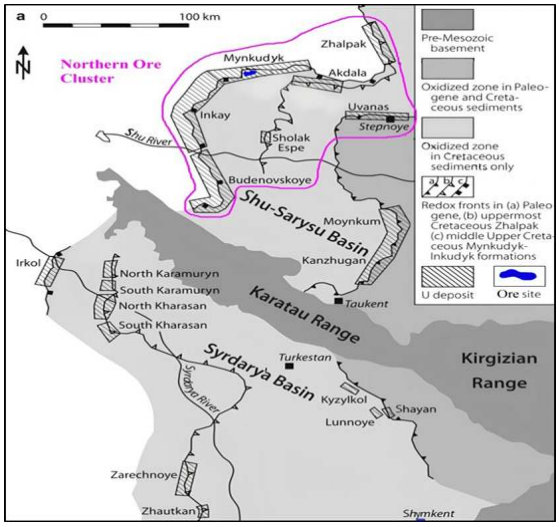

Figure 1. Location of the study area (Franz J. Dahlkamp, 2009), modified.

The clay content and carbonate content of uranium-bearing horizons are of critical importance – both from a geological perspective (the genesis, morphology, and localization of uranium deposits) and from the standpoint of in-situ leaching (ISL) technology used for the development of uranium deposits. An increase in the proportion of clay and carbonate minerals elevates the acid-neutralizing capacity of the host rocks and diminishes the permeability of formation waters and leaching solutions (Jiang Guoping, Zhao Lixin, 2021; Tong Zhang et al., 2023). For instance, the addition of 10% bentonite (montmorillonite, smectite) to quartz sand has been shown to reduce its hydraulic conductivity by four orders of magnitude (Vorontsov, 2022).

At present, the clay and carbonate contents of rocks in Kazakhstan's uranium deposits are determined exclusively through laboratory analyses of technological samples extracted from boreholes. Meanwhile, the vast majority of geological, mining, and technological tasks are addressed more efficiently through the use of geophysical data (Mwenifumbo and Mwenifumbo, 2013; Sharapatov et al., 2023; Kun Xiao et al., 2024).

In the evaluation of filtration properties of hydrocarbon reservoir rocks, gamma-ray logs (GR) are commonly employed, as clays exhibit relatively high natural radioactivity and their concentration correlates with GR responses (Kopeev et al., 2020). However, due to the anomalously high radioactivity of uranium-bearing horizons, radiometric logging methods cannot be applied to estimate their clay and carbonate contents. This limitation necessitates the examination of other physical properties of the rocks and the establishment of quantitative, potentially multifactorial, direct or indirect relationships between clay and carbonate parameters and geophysical field measurements under in situ conditions. Developing physical criteria for the informativity of individual or integrated logging methods requires

analyzing contrasts in acoustic and electrical properties, which govern the sensitivity of the measured parameters to variations in clay content and carbonate composition (Sharapatov, 2024).

Methods and materials. The study was conducted using empirical datasets obtained from deposits of the Northern Ore Cluster within the Shu-Sarysu uranium province. Processing, analysis, and synthesis of field-based geological and geophysical observations, as well as laboratory investigations of core samples, were carried out (Figure 2).

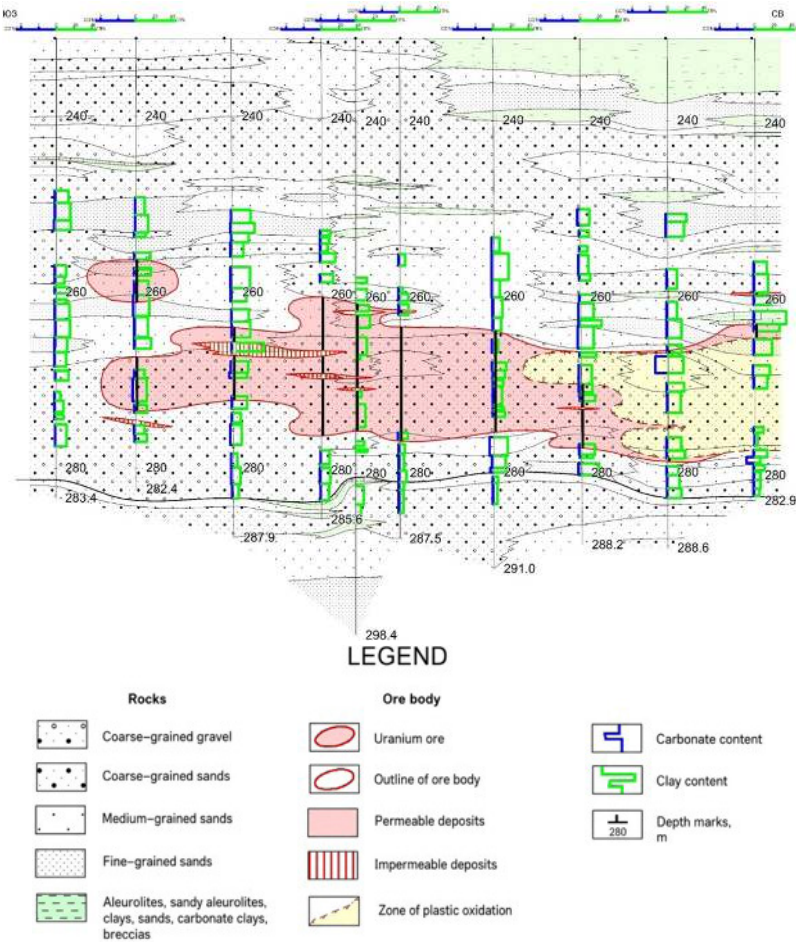

Figure 2. Technological profile showing the filtration properties of rocks in the Inkudyk ore horizon (depth interval 249.3-284.6 m).

The gical composition of clays is not constant. Although clay minerals constitute the primary component, various impurities are also present and influence the final chemical composition. In the analyzed technological-profile samples, the clay

minerals of the sandstone units within the ore-bearing horizon are predominantly represented by kaolinite and montmorillonite in varying quantitative proportions (Figure 3). The clay content of the uranium horizon ranges from 2.9 to 45%, with a mean value of 12.14±1.31 and a standard error of approximately 0.66.

The database is highly reliable and includes survey results from 40 boreholes located along seven profiles. The analysis included 581 samples collected exclusively from Inkudyk ore (productive) horizons 1 and 2, with a total thickness of 746.9 meters. Subsequently, during the uranium deposit development stage, the study area was divided into seven balance blocks, further confirming the representativeness and practical significance of the resulting database.

Carbonate minerals in the analyzed samples are represented by dolomite and calcite. According to the chemical analysis, CO_2 content ranges from <0.10 to 0.25% (Table 1). Aggregate cemented structures of varying composition were identified within the gravel-sand fractions of samples Y1 and Y4. The medium- and fine-grained sand fractions contain aggregate clusters composed of detrital grains bound by carbonate cement, as well as numerous aggregates of mixed carbonate-clay composition.

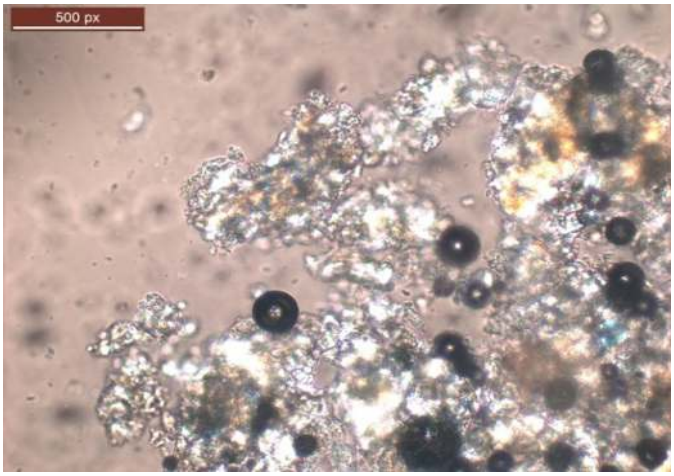

Figure 3. Form of clay occurrence – kaolinite (translucent, slightly whitish, with a soft sheen) in the sands of the ore horizon: sample Y3; fraction 0.1-0.05 (nicoli "+"; magnification 630x).

Table 1. Example of results of mineralogical tests of ores at a temperature of 15-25°C, humidity < 80%

№	Well	Sample	Total Fe, %	or Oxidized Fe, %	or Total reduced Fe, %	Organic carbon, %	**CO_2, %**	Total sulfur, %	Sulfate sulfur, %	Sulfide sulfur, %
1	X	Y1	0.95	0.41	0.54	0.029	**0.14**	<0.10	<0.20	<0.10
2		Y2	0.84	0.34	0.50	0.120	**<0.10**	0.16	<0.20	0.16
3		Y3	3.44	2.48	0.96	0.830	**0.11**	<0.10	<0.20	<0.10
4		Y4	0.82	0.39	0.43	0.044	**0.25**	<0.10	<0.20	<0.10

According to the results of the semiquantitative X-ray fluorescence analysis, the silt-grade fraction of the sands contains 1.6 to 2.6% carbonates (dolomite and calcite). The clay-grade fraction of the samples contains 1.8 to 4.5% carbonates (dolomite and calcite). Siderite is present only in trace amounts.

The selection of informative electrical and seismic methods for assessing clay content and carbonate composition in sandstone-hosted uranium horizons requires establishing the physico-geological foundations of their application by identifying contrasts in the electrical properties and densities (seismic-wave velocities) of the studied rocks. A sandy medium containing 15% water exhibits markedly lower specific electrical resistivity (SER, Ω·m) compared to dry sand. At the same time, the presence of approximately 10% carbonate minerals slightly increases resistivity relative to clean wet sand, thereby compensating a portion of the reduction caused by water saturation (Heying Hou et al., 2023). Following the same trend, carbonate minerals moderately reduce the magnitude of electrochemical activity, polarizability, and dielectric permittivity (Table 2).

Table 2. Effect of humidity, clays, carbonates on the electrical characteristics of sands.

No	Property	*Sands of variable grain size, natural moisture 15%	Influence	
			*Clays (12.14%)	*Carbonates (10%)
1	Type of conductivity	Electrolytic (pore water)	Ionic (bound-water films)	Electrolytic (water in fractures/cavities)
2	Sensitivity to moisture	Strong	Weak	Very strong
3	Specific electrical resistivity, Ω·m	7.8 (6.6-10.1), based on logging data	**+10-30%	+5-15%
4	Electrochemical activity	Noticeably increased	+5-15% or - moderate	- moderate
5	Polarizability, %	Noticeably increased	Up to +30%	- moderate
6	Dielectric permittivity	Up to +25%	Up to +20%	- moderate

*The values presented here and throughout the text correspond to average parameters of uranium-bearing horizons within the study area.

**The symbols "+" and "-" indicate an increase and decrease, respectively, in the electrical properties of the rocks.

With an increase in clay-mineral content in digital sand models (for example, 0 → 3.95 → 7.26 → 16.86%) and under otherwise identical conditions, the specific electrical resistivity decreases markedly (Weichao Yan et al., 2018). Clay minerals introduce additional surface conductivity and enhance ionic activity; therefore, an increase in electrochemical activity may be expected. However, if clay reduces water mobility, the effect may become insignificant or even lead to a decrease (Emelianov et al., 2024). Increasing moisture content leads to higher electrochemical activity and polarizability due to enhanced ion mobility.

To calculate specific electrical resistivity under the defined conditions, a modified generalized equation for sedimentary rocks is applied:

$$\rho = A \cdot \mathrm{W}^{-m}$$

where

ρ – denotes specific electrical resistivity,

W – is moisture content expressed in weight percent,

A and m – are empirical parameters dependent on sediment texture and mineralogical composition.

The parameters A and m are subsequently adjusted to account for clay content and carbonate composition: for example, clays lead to a decrease in A (meaning that resistivity becomes lower for the same value of W), whereas carbonates result in an increase in A (Cesar and Navarro et al., 2025).

For dielectric permittivity, an empirical relationship of the following form can be applied:

$$\varepsilon^B = \varepsilon_c + B \cdot W$$

where

B – is a coefficient dependent on mineral composition;

W – is the moisture content,

ε^B, ε_c – represent the dielectric permittivities of wet and dry sands, respectively.

For the application of electromagnetic methods, it is essential to analyze the complex dielectric permittivity of the studied rocks:

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

where

ε' – «the real component» that governs the propagation velocity of the electromagnetic wave in rocks, expressed as: $\mathrm{V} = \frac{\mathrm{c}}{\sqrt{\varepsilon'}}$, c ≈ 0.3 m/ns – representing the speed of light in vacuum. An increase in ε' results in a reduction of wave velocity;

ε'' – «imaginary» component, which controls wave absorption and attenuation. The attenuation coefficient – α, dB/m: expresses the exponential decay of the signal with distance and is related to the specific electrical conductivity $1/\rho$ (the inverse of resistivity), S/m, and to the loss tangent

$$tg\delta = \varepsilon''/\varepsilon',\ \varepsilon'' = \left(\frac{1}{\rho}\right) \cdot \frac{\varepsilon_0}{\omega},$$

ω - is the angular frequency of the electromagnetic field (MHz). The constant $\varepsilon_0 = 8.8541878128 \cdot 10^{-12}$ characterizes the ability of vacuum to transmit an electric field.

Under average geological conditions and for the typical physical parameters of the ore-bearing horizons in the study area ε' values for clays and carbonates are approximately 4-6, whereas for sands they range from about 3 to 5. This results in only a weak contrast in wave-propagation velocity V, often falling within the

uncertainty of field measurements. In contrast, ε'' and $1/\rho$ (electrical conductivity) contribute directly to the attenuation coefficient (α, dB/m), which provides the primary contrast. When the electromagnetic field traverses clay-rich zones, the attenuation increases sharply, by a factor of 3-10. Clays, including kaolinite-rich varieties, consistently exhibit higher ε'' (losses) and higher 1/ρ (related to water in the diffuse double layer and mineralogical effects) compared with sands containing 15% moisture (Parkhomenko et al., 2022).

To refine the applicability of seismic wave-based methods, the factors influencing variations in the density of the host rocks – sand-dominated units – were examined. This approach is justified by: a) the existence of a reliable quantitative relationship between density and seismic-wave velocity, and b) the substantially larger volume of density data available for the study area.

The analysis of rock density (σ, g/cm^3) was carried out for the Inkudyk and Mynkudyk ore-bearing horizons, which are the most representative units within the study area. As in the assessment of electrical properties, the analysis employed the most common parameter sets obtained from industry laboratories during technological evaluations of ore-bearing horizons from different zones and deposits: for the Inkudyk horizon, sand units exhibit densities of σ = 1.98 and 2.02 g/cm³ at moisture levels of W = 14.8 and 15%, respectively. For the Mynkudyk horizon, the corresponding densities are σ = 2.03, 1.99, and 1.97 g/cm³ at moisture contents of W = 14.5, 15, and 14.8%, respectively.

The influence of moisture on the density of sands is moderate and can be expressed as $\Delta\sigma/\Delta W \approx$ 0,01-0,02 g/cm³ per 1% moisture (for moisture levels up to approximately 20%). For clays, the effect is strong: $\Delta\sigma/\Delta W \approx$ 0,015-0,025 g/cm³ per 1% moisture, valid up to the average moisture level characteristic of the ore-bearing horizons in the study area. For carbonates, the effect is weak, amounting to: $\Delta\sigma/\Delta W \approx$ 0,002-0,004 g/cm³ per 1% moisture.

The analysis of the influence of clay content and carbonate composition on sand density at W = 15 % demonstrated that, in combination, these components generally increase bulk density. Their effect is governed by their structural role within the sand matrix. For example, when clays (≈12%) act as a pore-filling material between sand grains, they increase density more substantially. Carbonates (≈10%), in contrast, tend to reduce density because their relatively high porosity lowers the overall bulk density of the mixture (Badee, 2020).

Results. The analysis of the physical properties of the rocks, including their electrical and seismic-wave characteristics, demonstrated the high potential of two geophysical techniques for detailed investigation of ore-bearing horizons: the radio-wave sounding method (RWS) and/or crosshole seismic tomography (CST) (Figures 4 and 5). Furthermore, there is a clear need for pilot methodological studies aimed at selecting optimal modifications of these methods and observation geometries adapted to the specific geological conditions of individual deposits.

In the RWS method, it is possible to record (1) the signal amplitude, which is used to calculate the apparent attenuation coefficient α, and (2) the arrival time

of the impulse or phase, which is used to determine velocity V and subsequently the apparent dielectric permittivity ε. This enables the detection of contrasts in attenuation between host rocks and target intervals and thus provides the capability to illuminate the interwell space with electromagnetic waves (Shapovalov et al., 2022).

The registration of analogous parameters for seismic waves, the independence of CST from heterogeneously absorbing near-surface layers, and its wide investigative radius (Oshkin et al., 2017), together with the proximity of sources and receivers to the target interval and the availability of various observation geometries in both methods, collectively enable the effective solution of geological and technological tasks during the development of hydrogene-type uranium deposits.

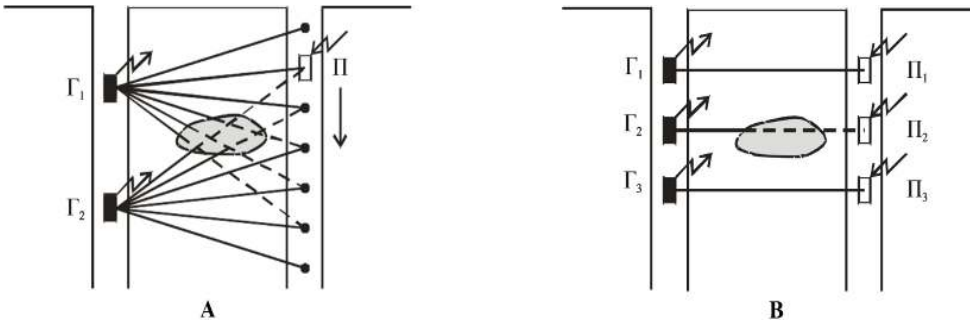

Figure 4. Observation systems for work using the RWS method: A – fan, B – synchronous.

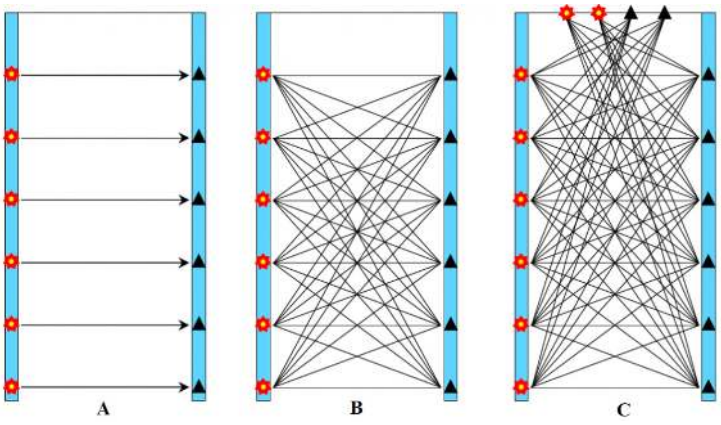

Figure 5. Types of CST: A – parallel scanning; B – tomographic scanning; C – tomographic scanning with the addition of data from sources and receivers located on the surface (Oshkin et al., 2017).

Discussion. The principal advantage of employing geophysical methods to assess clay content and carbonate composition lies in the ability to obtain data directly under in situ conditions, offering significantly greater operational

efficiency compared with laboratory analyses of extracted samples. The review and analysis of the electrical and density characteristics of rocks from uranium-bearing horizons indicate that such investigations must be conducted with a more targeted and thematic focus. Existing datasets on the physical properties of these rocks do not adequately account for the specific effects of clay content and carbonate composition on geophysical field responses, which complicates the interpretation of corresponding logs and field measurements.

Conclusion.

1) Geological prerequisites exist for the application of physical field methods as an effective tool for evaluating the filtration properties of ore-bearing horizons in uranium deposits.

2) At the development stage of uranium deposits, both the physical foundations and the technical capabilities are available to address geological and technological tasks through the investigation of interwell space using geophysical techniques.

3) To select an optimal geophysical method, determine its potential modifications, and develop a data-acquisition strategy, further detailed examination of the physical properties of the ore-bearing rocks is required, including electrical characteristics for radio-wave sounding and density or seismic-wave velocity for crosshole seismic tomography.

4) The results of additional thematic investigations of the physical properties of the uranium-bearing horizons can be employed as interpretive parameters for geophysical fields and subsequently as criteria within a data library designed for training artificial intelligence models (Sharapatov and Saduov et al., 2025).

References

Aizhulov D.Y., Shayakhmetov N.M., Kaltayev A. (2018) Quantitative Model of the Formation Mechanism of the Rollfront Uranium Deposits. Eurasian Chemico-Technological Journal. – Vol. 20. – No. 3. – P. 213-221. https://doi.org/10.18321/ectj724 (in Eng.).

Badee Alshameri (2020) Maximum dry density of sand-kaolin mixtures predicted by using fine content and specific gravity. SN Applied Sciences. – No. 2. – P. 1693. https://doi.org/10.1007/s42452-020-03481-9 (in Eng.).

Cesar Augusto Navarro Rubio, Mario Trejo Perea, Hugo Martínez Ángeles, José Gabriel Ríos Moreno, Roberto Valentín Carrillo-Serrano and Saúl Obregón-Biosca. (2025) Predictive Model of Electrical Resistivity in Sandy, Silty and Clayey Soils Using Gravimetric Moisture Content. E-ISSN 2673-4117, Published by MDPI. – No. 6. – P. 317. https://doi.org/10.3390/eng6110317 (in Eng.).

Franz J. Dahlkamp (Editor). (2009) Uranium Deposits of the World, Asia. Springer-Verlag Berlin Heidelberg. – 494 p. ISBN 978-3-540-78558-3 https://link.springer.com/referencework/10.1007/978-3-540-78558-3 (in Eng.).

Heying Hou, Wei Han, Tianxiang Li, Haiyuan Wang, Xiaolong Du, Zhe Liu and Linhao Wang. (2023) Experimental Study on the Electrical Resistivity Characteristics of Uniformly Graded Calcareous Sand. Applied Sciences. Published by MDPI. – No. 13. – P. 11467. E-ISSN 2076-3417, https://doi.org/10.3390/app132011467 (in Eng.).

Jiang Guoping, Zhao Lixin. (2021) Study on Application of Mixed Organic Acid in In-situ Leaching of High Carbonate Sandstone Uranium Deposit [J]. Atomic Energy Science and Technology. – No. 55. – P. 380-388. ISSN 1000-6931. https://doi.org/10.7538/yzk.2021.zhuankan.0166 (in Eng.).

Kopeev K.N., Borisenko G.T., Sharapatov A., Akhmetzhanov A.Zh. (2020) Izucheniye petrofizicheskikh svyazey dlya sovershenstvovaniya metodiki interpretatsii dannykh GIS yurskikh

otlozheniy Mangyshlaka [Studying petrophysical relationships to improve the well logging data interpretation technique for Jurassic sediments of Mangyshlak]. Scientific and Technical Bulletin "Karotazhnik". – No. 1 (301). – P. 46-56. ISSN 1810-5599. https://karotazhnik.ru/ntv-karotazhnik/arhiv-vypuskov/ (in Russ.).

Kun Xiao, Yichen Xu, Yaxin Yang, Xudong Hu, Qibin Luo, Zhongyi Duan, Changwei Jiao, Mengshi Chen & Dening Yin. (2024) Study on Logging Identification of Sandstone-Type Uranium Deposits Based on Ensemble Learning… Nuclear Science and Engineering. – P. 1246-1262. https://doi.org/10.1080/00295639.2024.2437916 (in Eng.).

Mwenifumbo C.J., Mwenifumbo A.L. (2013) Geophysical logging methods for uranium geology and exploration. Geological Survey of Canada, Publisher: Natural Resources Canada. – No. 4. – 43 p. ISBN 978-1-100-21750-5. https://doi.org/10.4095/292248 (in Eng.).

Oshkin A.N., Ragozin N.A., Ignatev V.I., Konkov A.I. and Ermakov R.Y. (2017) Cross-Hole Shooting on Longitudinal and Shear Waves… EAGE 13th Conference and Exhibition Engineering Geophysics. – P. 1-7. https://doi.org/10.3997/2214-4609.201700415 (in Eng.).

Parkhomenko E.I., Keller G.V., Editors. (2012) Electrical Properties of Rocks/ Monographs in Geoscience. Publisher: Springer New York, NY. – 314 p. eBook. ISBN 978-1-4615-8609-8. https://doi.org/10.1007/978-1-4615-8609-8 (in Eng.).

Petrov N.N., Berikbolov B.R., Aubakirov X.B., Vershkov A.F., Lukhtin V.F., Plekhanov V.N., Chernyakov V.M., Yazikov V.G. (2008) Uranovyye mestorozhdeniya Kazakhstana (ekzogennyye). Izdaniye vtoroye [Uranium deposits of Kazakhstan (exogenous). Second edition] . – Almaty. – 320 p. ISBN 5-628-01763-9. (in Russ.).

Shapovalov V., Vasilchenko A., Yavna V., Kochur A., Okost M. (2022) Ground-Penetrating Radar Method for Studying Water Drainage in Sand Layers. Fluids. – No. 7. – P. 379. ISSN: 2311-5521. https://doi.org/10.3390/fluids7120379 (in Eng.).

Sharapatov A., Assirbek N., Samanbetov N. (2023) Otsenka effektivnosti metodov elektrokarotazha pri izuchenii germetichnosti obsadnykh kolonn v skvazhinakh uranovykh mestorozhdeniy [Evaluation of the efficiency of electric logging methods when studying tightness of casing strings in wells of uranium deposits]. Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering. – Vol. 334. – No. 10. – P. 7-15. ISSN:2500-1019. E-ISSN:2413-1830. https://doi.org/10.18799/24131830/2023/10/4336. (in Russ.).

Sharapatov A., Saduov A., Assirbek N., Abdyrov M., Zhumabayev B. (2025) Prediction of rare and anomalous minerals using anomaly detection and machine learning techniques. Applied Computing and Geosciences. – Vol. 26. – P. 100250. ISSN: 2590-1974, https://doi.org/10.1016/j.acags.2025.100250 (in Eng.).

Sharapatov A, Assirbek N., Saduov A., Abdyrov M., Zhumabayev B. (2024) Consolidated geological and geophysical characteristics of uranium deposit rocks and prospects for their utilization (Shu-Sarysu province, Kazakhstan). News of the National Academy of Sciences of the Republic of Kazakhstan, «Halyk» Private Foundation, Series of geology and technical sciences. – Vol. 6 (467). – P. 210-229. ISSN 2518-170X (Online) https://doi.org/10.32014/2024.2518-170X.471 (in Eng.).

Tong Zhang, Xin Yang, Liang Yuan, Xuebin Su, Zhiming Du, Yihan Yang, Ming Tang, Chuanfei Zhang, Peng Qiao, Bingzhang Li. (2025) Investigation on evolution characteristic of dynamic pore and reactive transport of leaching solute in uranium-bearing sandstone during in-situ alkaline leaching mining: An in-situ LF-NMR leaching experiment. Nuclear Engineering and Technology, Publisher: Korean Nuclear Society. – Vol. 57. – No. 12. ISSN 17385733. https://doi.org/10.1016/j.net.2025.103864 (in Eng.).

Viacheslav Emelianov, Zeyu Zhang, Andreas Weller, Matthias Halisch, Konstantin Titov. (2024) Surface conductivity of clays. Geophysical Journal International. – Vol. 238. – No. 2. – P. 1013-1026. ISSN 1365-246X. https://doi.org/10.1093/gji/ggae201 (in Eng.).

Vorontsov P.Y. (2022) Vliyaniye veshchestvennogo sostava rud i vmeshchayushchikh porod na protsess dobychi i vyshchelachivaniya urana metodom podzemnogo skvazhinnogo vyshchelachivaniya (PSV) na mestorozhdeniyakh plastovo-infil'tratsionnogo tipa [An effect of the material composition of ores and host rocks to the uranium mining and leaching process by the method of in-situ leaching

(ISL) at reservoir-infiltration-type deposits. Problems of mineralogy, petrography, and metallogeny]. – No. 25. – P. 34-45. ISBN 978-5-7944-3864-7. https://doi.org/10.17072/chirvinsky.2022.34 (in Russ.).

Weichao Yan, Jianmeng Sun, Jinyan Zhang, Weiguo Yuan, Li Zhang, Likai Cui, Huaimin Dong. (2018) Studies of electrical properties of low-resistivity sandstones… Journal of Geophysics and Engineering. – Vol. 15. – No. 1. – P. 153-163. ISSN: 1742-2140. https://doi.org/10.1088/1742-2140/aa8715 (in Eng.).