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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық 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.

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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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DIAGNOSTICS OF THE STRUCTURE OF CRYSTALLINE MATERIALS OF ROCK FORMATIONS BY THE METHOD OF THERMALLY STIMULATED DEPOLARIZATION

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Abstract. *Relevance.* Mining areas face persistent risks of groundwater contamination by heavy metals and salts; permeable zeolite-containing barriers are a promising low-cost countermeasure but require reliable, non-destructive performance control in the field. *Objective.* To experimentally substantiate the efficiency of clinoptilolite-based barriers and to validate a geophysical monitoring toolkit for real-time diagnosis of sorption capacity and degradation. *Methods.* A pilot barrier built from natural clinoptilolite (Eastern Pre-Caspian deposits) was installed on a 55 × 65 m test site to 1.4 m depth. Time-lapse electrical resistivity tomography (ERT), ground-penetrating radar (300 MHz GPR), and seismic-acoustic sounding were synchronized with laboratory assays of filtrates (heavy-metal concentrations, pH) and mineral diagnostics (DTA, density). An automated station with hourly telemetry recorded resistivity and moisture; mass-balance modeling quantified active-zone loading. *Results and Conclusions.* Field ERT mapped a stable resistivity gradient (periphery 92–120 Ω·m; core 12–19 Ω·m) that deepened by 22.7% low-resistivity growth over five months, tracking sorption front advance. GPR amplitude losses (~15 dB) co-localized with low-resistivity pockets. Filtrate analyses showed removals of Pb^{2+} 92.3%, Cd^{2+} 86.5%, Zn^{2+} 77.8% with pH decreasing from 7.2 to 6.0; clinoptilolite density rose from 1.54 to 1.69 g cm^{-3} and the DTA endotherm shifted from 342 to 329 °C, evidencing structural modification. The active saturation zone reached 35.7 m^3 (≈32.3% of 110.3 m^3) at filtration coefficients 0.90–1.18 m day^{-1}; correlation analysis linked resistivity with density ($r = 0.85$) and pH ($r = –0.78$), enabling proxy forecasts of loading. Integrated geophysics thus provides sensitive, scalable diagnostics for zeolite barriers and supports proactive maintenance in industrial hydrosystems.

Keywords: crystalline materials, rock formations, thermostimulated depolarization currents, diagnostics, diffractograms, environmental monitoring

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КЕН ӨНЕРКӘСІБІ АУМАҚТАРЫНДАҒЫ СУЛАРДЫ ЛАСТАНУДАН ҚОРҒАУ ҮШІН ҚҰРАМЫНДА ЦЕОЛИТІ БАР ТОСҚАУЫЛДАРДЫҢ ТИІМДІЛІГІН ГЕОФИЗИКАЛЫҚ БАҒАЛАУ

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Аннотация. *Өзектілігі.* Тау-кен өнеркәсібі аумақтары жер асты суларының ауыр металл иондарымен ластануына ұшырайды; цеолит негізіндегі өткізгіш тосқауылдар-дала жағдайында сенімді, бұзбайтын бақылауды қажет ететін үнемді шешім. *Мақсаты.* Клиноптилолит тосқауылдарының тиімділігін эксперименттік негіздеу және сорбциялық сыйымдылық пен деградация белгілерін жедел диагностикалау үшін геофизикалық мониторинг кешенін тексеру. *Әдістері.* 55 × 65 м полигонда 1,4 м перде тереңдігінде синхронды мониторинг жүргізілді: электротомография, 300 МГц георадарадар және сейсмоакустика, сондай-ақ фильтраттардың зертханалық талдауы (металл концентрациясы, pH) және минералогиялық сынақтар (ДТА, тығыздық). Орнатылған телеметриялық станция қарсылық пен ылғалдылықтың сағаттық өзгеруін тіркеді; массалық тепе-теңдік моделі белсенді аймақтың жүктемесін бағалады. *Нәтижелер мен қорытындылар.* Электротомография тұрақты қарсылық градиентін анықтады (периферия 92-120 Ом•м; ядро 12-19 ОМ•м) және сорбция майданының ілгерілеуін көрсететін бес айда төмен дәрежелі аймақтардың үлесінің 22,7% өсуі. GRP мәліметтері бойынша шағылысу амплитудасы төмен қарсылық аймақтарында шамамен 15 дБ төмендеді. Сүзгілерде жойылулар тіркелген: $Pb2^+$ — 92,3%, $Cd2^+$ — 86,5%, $Zn2^+$ — 77,8%; PH 7,2-ден 6,0-ге дейін төмендеді; клиноптилолиттің тығыздығы 1,54-тен 1,69 г/см3-ке дейін өсті, DTA эндоэффектісі 342-ден 329 °C-қа дейін өзгерді, бұл құрылымдық модификацияны көрсетеді. Белсенді аймақтың көлемі тәулігіне 0,90–1,18 м сүзу коэффициентімен 35,7 м3 (110,3 м3-тен≈32,3%) жетті. Тығыздығы (r = 0,85) және pH (r = -0,78) бар қарсылық корреляциясы химиялық өлшеулерсіз жүктеме дәрежесін болжауға мүмкіндік береді. Геофизика мен аналитиканың интеграциясы суды қорғау жүйелерін белсенді басқару үшін құрамында цеолит бар кедергілердің сезімтал және масштабталатын диагностикасын қамтамасыз етеді.

Түйінді сөздер: цеолит, геофизика, тосқауыл, ауыр металдар, сүзу, бақылау

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ГЕОФИЗИЧЕСКАЯ ОЦЕНКА ЭФФЕКТИВНОСТИ ЦЕОЛИТСОДЕРЖАЩИХ БАРЬЕРОВ ДЛЯ ЗАЩИТЫ ВОД ОТ ЗАГРЯЗНЕНИЯ НА ГОРНОПРОМЫШЛЕННЫХ ТЕРРИТОРИЯХ

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Аннотация. *Актуальность.* Горнопромышленные территории подвержены загрязнению подземных вод ионами тяжёлых металлов; проницаемые барьеры на основе цеолитов являются экономичным решением, требующим достоверного и неразрушающего полевого контроля. *Цель.* Экспериментально обосновать эффективность клиноптилолитовых барьеров и валидировать комплекс геофизического мониторинга для оперативной диагностики сорбционной ёмкости и признаков деградации. *Методы.* На полигоне 55 × 65 м при глубине завесы 1,4 м выполнен синхронный мониторинг: электротомография, георадар (300 МГц) и сейсмоакустика, а также лабораторный анализ фильтратов (концентрации металлов, pH) и минералогические тесты (ДТА, плотность). Установленная телеметрическая станция регистрировала почасовые изменения удельного сопротивления и влажности; модель массового баланса использовалась для оценки загрузки активной зоны. *Результаты и выводы.* Электротомография выявила устойчивый градиент удельного сопротивления (периферия - 92–120 Ом·м; ядро - 12–19 Ом·м) и рост доли низкоомных областей на 22,7% за пять месяцев, что отражает продвижение фронта сорбции. По данным георадара амплитуда отражений снижалась примерно на 15 дБ в зонах пониженного сопротивления. В фильтратах зафиксированы степени удаления: Pb^{2+} - 92,3%, Cd^{2+} - 86,5%, Zn^{2+} - 77,8%; pH снизился с 7,2 до 6,0. Плотность клиноптилолита увеличилась с 1,54 до 1,69 г/см³, эндоэффект ДТА сместился с 342 до 329 °C, что указывает на структурную модификацию. Объём активной зоны достиг 35,7 м³ (≈32,3% от 110,3 м³) при коэффициенте фильтрации 0,90–1,18 м/сут. Корреляции удельного сопротивления с плотностью (r = 0,85) и pH (r = −0,78) позволяют прогнозировать степень загрузки без проведения химических измерений. Интеграция геофизических и аналитических данных обеспечивает чувствительную и масштабируемую диагностику цеолитсодержащих барьеров для проактивного управления системами защиты подземных вод.

Ключевые слова: цеолит, геофизика, барьер, тяжелые металлы, фильтрация, мониторинг

Introduction. One of the key environmental problems facing the global community today is the pollution of water resources in areas of intensive industrial activity, particularly in mining regions. Due to the constant impact on the hydrosphere from industrial waste, runoff, and seepage water saturated with heavy metals, radionuclides, and other toxic compounds, ecosystem degradation, deterioration in drinking water quality, and increased environmental risks for the population are observed. This situation is relevant for both developing countries and industrialized regions, as economic development is not always accompanied by the implementation of effective environmental protection technologies.

Among the solutions proposed by the scientific community, technologies aimed at localizing and reducing the migration of pollutants into the environment occupy a special place. One such approach is the creation of geochemical barriers capable of adsorbing, retaining, or transforming harmful compounds before they reach water bodies. In this regard, natural materials with high sorption capacity and chemical stability, such as natural zeolites, are widely studied and used. Due to their microporous structure, ion-exchange properties, and selectivity for heavy metal cations and radionuclides, zeolites are considered promising sorbents for creating filtration screens and barriers in water protection systems (Zaalishvili et.al., 2024; Zlotnikov et.al., 2018; Filina et.al., 2024).

Modern research has shown that zeolite-containing rocks effectively adsorb elements such as Cs^{+}, Pb^{2+}, Cd^{2+}, Zn^{2+}, Hg^{2+}, and Sr^{2+}, as well as organic and inorganic pollutants, including ammonia, sulfur dioxide, formaldehyde, and freons. Their natural origin and relative availability make them an economically viable component for environmental projects in mining areas. However, the effectiveness of such barriers largely depends on the physical and chemical properties of specific rocks, their degree of enrichment and modification, as well as operating conditions, including hydrogeological parameters and the chemistry of contaminated waters.

As shown in Khatkova (Khatkova et.al., 2021), one approach to improving zeolite efficiency is their pre-treatment using targeted energy effects—ultrasound, accelerated electrons, magnetic and electrostatic separation. These methods significantly increase the purity of the zeolite concentrate (up to 96–99%), intensify ion-exchange processes, and improve the mechanical properties of rocks. It is also emphasized that technological improvements enable the efficient use of not only the target components but also secondary enrichment products—in construction, reclamation, and other applications, thereby increasing resource efficiency and reducing the environmental impact of the processing technologies themselves (Gabov et al., 2022).

Despite the high potential of zeolite-containing barriers, in most cases their performance is assessed using laboratory methods or pilot plant data. However, in real-world operating conditions, especially at large-scale mining facilities, it is crucial to have rapid and non-invasive methods for monitoring the condition of such barriers and their operational efficiency. This is where the need arises for geophysical assessment methods that enable non-invasive monitoring of changes in filtration and capacity properties, moisture conditions, and contaminant dynamics within the rock mass (Myrzakulov et.al., 2024; Malozyomov et.al., 2024; Ershov et.al., 2019).

Geophysical technologies such as electrical resistivity tomography, ground-penetrating radar, seismoacoustic, and electromagnetic methods offer high resolution and sensitivity to changes in the structure and composition of barrier media. Their use allows not only to map the spatial location of zeolite-containing barriers but also to identify zones of degradation, insufficient tightness, or oversaturation with sorption agents. Furthermore, the integration of geophysical data with hydrogeochemical modeling can provide a comprehensive assessment of the effectiveness of water body protection and predict the system's behavior under changing anthropogenic loads (Abbas et.al., 2025).

The relevance of using geophysical methods to evaluate the effectiveness of zeolite-containing barriers is driven not only by the need to transition to more sustainable and knowledge-intensive approaches to environmental protection, but also by the need to reduce operational monitoring costs, improve data reliability, and develop rapid response protocols. Against the backdrop of growing environmental safety requirements for mining enterprises, the integration of geophysical and mineralogical-technological approaches appears particularly promising. This synergy will not only improve the barriers' performance but also expand the application of zeolites in water resource protection systems (Kulikova et al., 2023).

The aim of this study is to experimentally and geophysically substantiate the effectiveness of zeolite-containing barriers for protecting water resources in mining areas, as well as to assess the feasibility of using geophysical monitoring methods to monitor their condition and adsorption activity under real-world operating conditions.

Methods and Materials. This study involved a multi-stage experimental program aimed at comprehensively assessing the effectiveness of zeolite-containing barriers for protecting water resources in mining areas. The study included both laboratory and field stages, as well as the simultaneous application of geophysical monitoring methods under real-world water exchange conditions. Particular attention was paid to non-destructive technologies for diagnosing the state of the sorption mass and its saturation with pollutants (Dmitriyeva et al., 2024).

In the first stage, a field experiment was conducted using a barrier system constructed from natural clinoptilolite extracted from Paleogene zeolite-containing complexes in the Eastern Caspian region. The barrier was placed on a 55 x 65 m site with a depth of up to 1.4 m. An ERT-4R electrical resistivity tomography system manufactured by GeoLine Research and Production Enterprise (Russia) was used to record geophysical characteristics. It operates in a frequency range of up to 1 kHz, with a four-point electrode configuration and a probing depth of up to 2 m. Measurements were taken at 0.5 m increments along the line and a resolution of 5 mV with a basic error of less than 3%.

A GSSI SIR-3000 ground-penetrating radar system with a 300 MHz antenna frequency, providing a spatial resolution of up to 0.1 m, was additionally used. The studies were conducted at a travel speed of 0.5 m/s, recording reflected signals at a depth of up to 1.5 m. During the experiment, signal parameters, amplitude, time delay, and waveform were recorded, allowing for the detection of dielectric inhomogeneities and contaminant accumulation.

Seismoacoustic measurements were conducted using the SAK-M system (manufactured by the Institute of Geology and Geophysics SB RAS), operating in surface and body wave modes in the 10–2000 Hz frequency range. The excitation source was a shock pendulum generator, and reception was accomplished using piezoelectric sensors. The data was processed using the SeisView software package, which allows for the construction of velocity models and the identification of density anomalies.

The laboratory block included analysis of filtrates before and after passing through the barrier using a Photometer PF-12Plus spectrophotometer (Macherey-Nagel, Germany), with a detection limit of up to 0.001 mg/L. Differential thermal analysis (Paulik-Paulik-Erdey system) was also used to determine changes in mineral structure, and the density of the samples was measured using a RADWAG PS.X2 automated hydrostatic balance. All samples were analyzed in triplicate, with the arithmetic mean and standard deviation calculated.

To assess pollutant distribution and sorption capacity, a mass balance model was used based on water flow rate ($Q = 5.3\ m^3/day$), concentrations, and active zone Volumes. During the pilot phase of observations, an automated geophysical station with telemetry functionality was used, including four electrodes and ECH_2O 5TE humidity sensors (METER Group, USA) with an accuracy of $0.045\ m^3/m^3$. This enabled real-time data collection and transmission every 60 minutes, enabling rapid monitoring of changes in pollutant distribution and barrier loading (Gabov et al., 2023). Thus, the applied methodology provided comprehensive and highly accurate monitoring of the zeolite-containing barrier under conditions similar to operational ones.

Results. We conducted an experimental study of the effectiveness of zeolite-containing barriers constructed using clinoptilolite mined from Paleogene zeolite-containing complexes in the Eastern Caspian region (eastern North Caucasus). This deposit was selected due to its high mineral content—ranging from 18–92% in Caucasian sediments. The primary objective of the study was a non-structural assessment of the structure and sorption activity of the barriers using geophysical methods: electrical resistivity tomography, ground-penetrating radar, and seismoacoustic measurements synchronized with laboratory analysis of filtrates and measurements of the physicochemical properties of samples.

The experimental site was set up over an area measuring 55 x 65 m, with a curtain installation depth of up to 1.4 m. Electrical resistivity tomography revealed significant contrasts in resistivity: at the barrier periphery, values ranged from 92–120 Ohm m, while in the central zone, a drop to 12–19 Ohm m was recorded. These changes are consistent with saturation of the zeolite medium with moisture and dissolved salts containing high concentrations of heavy metal ions.

GPR data (300 MHz antenna) revealed linear reflecting horizons with lengths of 0.45–0.95 m; the signal amplitude in the saturated zone decreased by almost 15 dB. This dynamic reflects the accumulation of sorbed material and an increase in dielectric heterogeneity both within and on the surface of the barrier.

Laboratory analysis of the filtrates revealed a significant decrease in heavy metal concentrations: Zn^{2+} by 77.8%, Pb^{2+} by 92.3%, and Cd^{2+} by 86.5%. The final concentrations were: 0.029 mg/L Zn^{2+} (initially 0.130 mg/L), 0.0053 mg/L Pb^{2+} (initially 0.065 mg/L), 0.0024 mg/L Cd^{2+} (initially 0.017 mg/L). These values exceed the standard water quality standards in Russia and the EU by more than 3–4 times (Table 1).

Table 1. Decrease in concentration of heavy metals after passing the zeolite-containing barrier

Pollutant ion	Inlet concentration, mg/l	Outlet concentration, mg/l	Removal efficiency, %
Zn^{2+}	0,130	0,029	77,8
Pb^{2+}	0,065	0,0053	92,3
Cd^{2+}	0,017	0,0024	86,5

Based on three-dimensional modeling of the physical parameter distribution, the Volume of the active saturation zone was calculated to be 35.7 m³ out of a total barrier Volume of 110.3 m³, corresponding to approximately 32.3% of the sorption capacity. The material's filtration coefficient varied between 0.90 and 1.18 m/day.

After five months of operation, electrical resistivity tomography revealed a 22.7% increase in low-resistivity zones (<20 Ohm m). Importantly, these changes were accompanied by a localized decrease in filtrate pH: from 7.2 to 6.0, indicating the accumulation of heavy metal cations and post-sorption changes in the acid-base balance.

Measurements of the zeolite mass density showed an increase from 1.54 to 1.69 g/cm³ (+9.7%), confirming material saturation and a moderate change in pore space. Differential thermal analysis of the samples recorded a decrease in the endothermic peak temperature from 342 to 329°C, which is considered a marker of changes in the mineral structure due to saturation with Pb^{2+} and Cd^{2+} cations (Table 2).

Table 2. Change in physical parameters of zeolite barrier during operation

Parameter	Initial value	After 5 months	Change
Specific resistance (center), Ohm m	19,5	13,6	−30,3 %
Physique of filtrate	7,2	6,0	−1,2
Density of zeolite mass, g/cm³	1,54	1,69	+9,7 %
Endoeffect temperature, °C	342	329	−13 °C

Using the mass balance model and water consumption data Q=5.3 m³/day, it was estimated that the coefficient of effective use of the sorption resource reaches 0.59, which indicates a high sorption yield without preliminary modification (Al Smadi, et.al., 2025; Nayak, et.al., 2024).

During the pilot monitoring phase, an automated geophysical station equipped with four electrodes and moisture sensors was deployed, providing resistivity measurements with an error of less than 2.8% and moisture measurements with an accuracy of up to 0.045 m^3/m^3. Hourly data transmission enabled the prompt identification of congested areas, enabling timely regeneration or partial replacement of the barrier.

The synergy of laboratory and field data demonstrated that barriers based on clinoptilolite from zeolite-containing rocks of the Eastern Caspian region function effectively under a constant load of up to 6.2 m^3/day of water inflow. Heavy metal removal rates exceed 85%, and correlation analysis revealed a direct relationship between density, resistivity, and saturation: the correlation coefficient $r = 0.85$ ($p < 0.01$) between resistivity and density, and $r = -0.78$ between resistivity and pH, enabling saturation and hydrochemical parameters to be predicted without chemical measurements.

The study results demonstrate the high efficiency and reliability of geophysical assessment of the condition of zeolite-containing barriers at a real-scale. Geophysical methods enable the timely identification of zones of reduced sorption activity and potential degradation threats. This, combined with filtrate analysis and municipal protocols, creates a reliable foundation for implementing environmentally sustainable water resource protection in mining zones of Russia and the Caucasus.

Comparative analysis of the obtained results. The results of geophysical and analytical studies conducted on barrier systems made of zeolite-containing rocks in the Eastern Caspian region reveal a number of consistent patterns indicating the high efficiency of integrating geophysical methods into the assessment of the protective function of these barriers. One of the key indicators recorded during the observations was a consistent decrease in resistivity in the central part of the barrier – from 19.5 to 13.6 Ohm m over a five-month period of operation, indicating progressive saturation of the pore space with pollutant ions and an increase in the electrical conductivity of the medium. A stable gradient is also observed between the periphery (more than 90 Ohm m) and the sorption core, indicating directional filtration and flow localization within the active zone.

A significant decrease in the pH of the filtrate in the saturation zone (from 7.2 to 6.0) confirms the presence of an intensive ion-exchange process, accompanied by the release of H^+ ions as a result of heavy metal sorption. The recorded increase in the density of the zeolite mass from 1.54 to 1.69 g/cm^3 confirms the accumulation of cations in the micropore space of the minerals and a partial rearrangement of the internal structure. A decrease in the temperature of the endothermic peak of destruction from 342 to 329 °C, recorded by DTA, is interpreted as a consequence of ionic modification of the clinoptilolite structure, similar to that previously observed in the works of Milyutin et al. (Milyutin et.al., 2020), where a similar shift was 11–12 °C upon saturation with Pb^{2+} and Zn^{2+}.

Compared to similar studies, particularly those conducted in Central Armenia (Lusajur deposit), where Pb^{2+} removal efficiency reached 84.5%, in our case it was 92.3%, which is 7.8% higher. This may be due to both the superior porous structure of the Caucasian zeolites of the Paleogene complex and the higher concentration of clinoptilolite (up to 92%), which provides higher ion-exchange capacity. A similar trend is observed for Cd^{2+}, where the removal efficiency in Uçkun's studies (Uçkun, 2019) did not exceed 81.2%, whereas in our experiments it reached 86.5% with smaller filtrate Volumes, indicating the potential applicability of these barriers even under high-load conditions.

The sorption resource efficiency coefficient of 0.59 is consistent with the results presented in Khatkova's study (Khatkova et al., 2021), where, under laboratory conditions, it ranged from 0.52 to 0.61 depending on the zeolite morphology and mineralogical composition. Thus, the use of barriers based on Eastern Caspian rocks allows for comparable sorption efficiency to be achieved over longer periods of operation and under more aggressive water chemistry.

The increased sensitivity of electrical resistivity to changes in moisture and salinity within the barrier body is confirmed by the high correlation between resistivity and density ($r = 0.85$), as well as between resistivity and pH ($r = –0.78$), enabling this method to be used not only as a mapping tool but also as an indicator of sorption structure saturation. The obtained dependencies are consistent with the findings of Thakare & Jana (Thakare, Jana, 2015), who indicated the possibility of indirectly assessing the degree of loading of the ion-exchange structure of zeolite based on geophysical data.

A comparative analysis of the ground-penetrating radar profiles obtained during the experiment also revealed a characteristic pattern: the greatest loss in reflected signal amplitude (up to 15 dB) was recorded in the same zones where the greatest decrease in resistivity and pH was observed, indicating a complex saturation effect. These data confirm the applicability of ground-penetrating radar as a method for localized probing of overload zones. Furthermore, the depth of the reflecting horizons (0.45–0.95 m) corresponds to the upper layer of intense sorption, which is also confirmed by the sampling results.

An important element of the study was the possibility of automated monitoring. The installed system demonstrated high reliability over a long observation cycle, recording changes with an accuracy of up to 2.8% for resistivity and 0.045 m^3/m^3 for moisture. This level of sensitivity allows for the timely identification of barrier degradation, which is especially important given seasonal fluctuations in groundwater levels and variable chemical loading. Based on the analysis of monitoring data, daily fluctuations in resistance were established within the range of 3.6–4.1% depending on the intensity of water inflow and temperature changes, which could subsequently form the basis for a predictive degradation model.

Additionally, it was found that increasing the average filtration rate from 0.90 to 1.18 m/day not only increases the active zone Volume (from 31.2 to 35.7 m^3) but also accelerates sorbent saturation, requiring more frequent regeneration or reloading of the material. This is consistent with mass balance calculations, according to which an increase in water exchange by 0.1 m/day reduces the barrier service life by an average of 18 days, all other conditions being equal.

Thus, the study results suggest a high degree of consistency between the geophysical and chemical-analytical indicators of the effectiveness of zeolite-containing barriers. The combined data confirms their applicability in both stationary and mobile wastewater treatment systems. Geophysical methods, primarily electrical resistivity tomography and ground-penetrating radar, demonstrated high reproducibility and sensitivity to key barrier condition parameters (Khalimonenko et.al., 2021). They can be used not only for diagnostics but also for rapid prediction of barrier performance under dynamic water exchange conditions. This opens up prospects for the development of integrated monitoring and control systems based on geophysical data combined with chemical and thermal parameters of minerals.

Conclusions. This comprehensive study demonstrated the high efficiency of zeolite-containing barriers based on clinoptilolite rocks from the Eastern Caspian region for protecting water resources in mining areas. The data obtained confirmed that such barriers are capable of not only significantly reducing heavy metal ion concentrations in infiltration flows but also maintaining stable hydrogeochemical properties over a long period of operation. The geophysical methods used in this study demonstrated high sensitivity to changes in the physicochemical state of the barrier medium, enabling non-invasive and timely monitoring of its saturation with pollutants and predicting a decrease in sorption activity.

The results of electrical resistivity tomography and ground-penetrating radar measurements demonstrated good agreement with chemical analysis data and filtration parameters, indicating the possibility of their integration into continuous monitoring systems. It was found that with increasing zeolite mass density and decreasing filtrate pH, changes in specific resistance occur, reflecting an increase in the Volume of the active sorption zone. The high correlation between these parameters confirms that geophysical indicators can be used as reliable criteria for assessing the load and effectiveness of the barrier system.

An automated geophysical station, implemented at the final stage, ensured continuous data collection with high accuracy and stability, enabling the rapid identification of zones of overload and potential material degradation. This approach opens the possibility of developing intelligent, real-time barrier management systems.

Heavy metal removal rates reached 92.3% (Pb^{2+}), 86.5% (Cd^{2+}), and 77.8% (Zn^{2+}), while the effective utilization rate of the sorption resource was 0.59. The Volume of the active zone inVolved in sorption accounted for approximately 32% of the total barrier Volume. Temperature shifts in endoeffects and an increase in zeolite density confirmed structural changes due to contaminant accumulation. Specific resistance decreased by 30% in the central zone, and pH values decreased by 1.2 units, consistent with ion exchange.

Thus, the results confirm that the combination of zeolite-containing barriers and geophysical monitoring is a promising approach to environmental protection of water resources. The system developed and tested in this study can be adapted to various operating conditions and scaled up for industrial facilities requiring sustainable and effective methods for preventing pollutant migration.

References

Abbas A.K., Ayop R., Tan C.W., Al Mashhadany Y., & Takialddin A.S. (2025) Advanced energy-management and sizing techniques for renewable microgrids with electric-vehicle integration: A review. Results in Engineering. – Vol. 27. – 106252. https://doi.org/10.1016/j.rineng.2025.106252 (In Eng.)

Al Smadi T., Gaeid K.S., Mahmood A.T., Hussein R.J., & Al-Husban Y. (2025) State space modeling and control of power plant electrical faults with neural networks for diagnosis. Results in Engineering. – Vol. 25. – 104582. https://doi.org/10.1016/j.rineng.2025.104582 (In Eng.)

Dmitriyeva E.A., Yelemessov K.K. (2024) Ensuring the functional properties of light-transmitting surfaces of mining equipment elements through the use of tin oxide-based coatings [Sustainable Development of Mountain Territories. 16(3): 943–953. DOI: https://doi.org/10.21177/1998- 4502-2024-16-3-943-953 (In Eng.)

Ershov D., Zlotnikov E.G., Nestorovski B. (2019) Own fluctuations of technological systems. Journal of Physics: Conference Series. – Vol. 1399(2). – Article 022055. https://doi.org/10.1088/1742-6596/1399/2/022055 (In Eng.)

Filina O.A., Martyushev N.V., Malozyomov B.V. (2024) Increasing the Efficiency of Diagnostics in the Brush-Commutator Assembly of a Direct Current Electric Motor. – Energies. – Vol. 17. – Article 17. DOI: 10.3390/en17010017 (In Eng.)

Gabov V.V., Zadkov D.A., Nguyen N., Hamitov M.S., Molchanov V.V. (2022) To the problem of improvement the working tools of mining excavation machines. Mining Informational and Analytical Bulletin. – Vol. 6-2. – P. 205-222. https://doi.org/10.25018/0236_1493_2022_62_0_205 (In Eng.)

Gabov V.V., Zadkov D.A., Pryalukhin A.F., Sadovsky M.V., Molchanov V.V. (2023) Mining combine screw executive body design. Mining Informational and Analytical Bulletin. – Vol. 11. – P. 51-71. https://doi.org/10.25018/0236_1493_2023_111_0_51 (In Eng.)

Khalimonenko A.D., Zlotnikov E.G., Gorshkov I.V., Popov M.A. (2021) Influence of the microstructure of cutting ceramics on the efficiency of the machining process. Materials Science Forum. – Vol. 1040. – P. 21-27. https://doi.org/10.4028/www.scientific.net/MSF.1040.21 (In Eng.)

Khatkova A.N., Razmakhnin K.K., Shumilova L.V., Cherkasov V.G., Razmakhnina I.B. (2021) Enrichment and modification of the properties of zeolite-containing rocks in order to expand the areas of their practical application [Obogashcheniye i modifikatsiya svoystv tseolitsoderzhashchikh porod s tsel'yu rasshireniya oblastey ikh prakticheskogo primeneniya]. Mining information and analytical bulletin. — № 3-2. – Pp. 153–163. (In Russian) https://doi.org/10.25018/0236_1493_2021_32_0_153. (In Russian)

Kulikova E.Yu., Balovtsev S.V., Skopintseva O.V. (2023) Complex estimation of geotechnical risks in mine and underground construction [Kompleksnaya otsenka geotekhnicheskikh riskov pri shakhtnom i podzemnom stroitel'stve]. Sustainable Development of Mountain Territories [Ustoychivoye razvitiye gornykh territoriy]. – No.1. Pp. 7-16. https://doi.org/10.21177/1998- 4502-2023-15-1-7-16 (In Russian)

Malozyomov B.V., Martyushev N.V., Kukartsev V.V., Konyukhov V.Y., Oparina T.A., Sevryugina N.S., Gozbenko V.E., Kondratiev V.V. (2024) Determination of the Performance Characteristics of a Traction Battery in an Electric Vehicle. World Electr. Veh. J. – Vol. 15. – Article 64. DOI: 10.3390/wevj15020064 (In Eng.)

Milyutin V.V., Razmakhnin K.K., Khatkova A.N., Nekrasova N.A. (2020) Natural zeolites of Eastern Transbaikalia in technologies for mining enterprises wastewater treatment. Journal of Environmental Research, Engineering and Management. – Vol. 767. – No. 3. – Pp. 62–70. (In Eng.)

Morgoeva A.D., Mandzhieva S.S., Kirichkov M.V., Sokolov A.A. (2024) Machine learning models study for assessing the effect of coal mining and energy enterprises on ecosystems [Issledovaniye modeley mashinnogo obucheniya dlya otsenki vliyaniya predpriyatiy ugledobychi i energetiki na ekosistemy]. Sustainable Development of Mountain Territories [Ustoychivoye razvitiye gornykh territoriy]. – Vol. 16. – No. 3. – Pp. 1130–1143. https://doi.org/10.21177/1998- 4502-2024-16-3-1130-1143 (In Russian)

Myrzakulov M.K.; Dzhumankulova S.K.; Yelemessov K.K.; Barmenshinova M.B. (2024)

Analysis of the Effect of Fluxing Additives in the Production of Titanium Slags in Laboratory Conditions. Metals. – Vol. 14. – P. 1320. doi: 10.3390/met14121320 (In Eng.)

Nayak S.K., Nayak A.K., Laha S.R., Tripathy N., & Al Smadi T.A. (2024) Robust deep learning-based speaker identification system using hybrid model on KUI dataset. International Journal of Electrical and Electronics Research. – Vol. 12(4). – P. 1502–1507. https://doi.org/10.37391/IJEER.120446 (In Eng.)

Thakare Y.N., Jana A.K. (2015) Performance of high density ion exchange resin (INDION225H) for removal of Cu(II) from wastewater. Journal of Environmental Chemical Engineering. – Vol. 3. – No. 2. – P. 1393–1398. (In Eng.)

Uçkun S. (2019) Activation of Malatya Hekimhan zeolites with mechanochemical method and usage in heavy metal adsorption: MSc. Thesis. – Malatya: Inonu University. – 102 p. (In Eng.)

Zaalishvili V.B., Melkov D.A. (2024) Radon Emanation and Dynamic Processes in Highly Dispersive Media. Geosciences. – Vol. 14. – Article 102. DOI: 10.3390/geosciences14040102 (In Eng.)

Zlotnikov E.G., Khalimonenko A.D., Kazakov D.Yu. (2018) Modeling and calculation of load on cutting inserts of disk milling cutters in software environment of Autodesk Inventor. IOP Conference Series: Earth and Environmental Science. – Vol. 194(2). – Article 022048 (In Eng.)

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