МАРКШЕЙДЕРСКОЕ ДЕЛО. ГОРНОПРОМЫШЛЕННАЯ ГЕОЛОГИЯ

DOI: 10.21440/0536-1028-2026-5-69-77

Uranyl ion and organic compounds in shales

Mehpara K. Ismayilova[1], Niiaz G. Valiev[2], Maral H. Aliyeva[3], Maksim S. Lebzin[2]*
[1] Institute of Physics of the Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan
[2] Ural State Mining University, Ekaterinburg, Russia
[3] Azerbaijan State Oil Industry University, Baku, Azerbaijan
e-mail: az_ma@mail.ru

Abstract

Introduction. *In natural conditions, uranium exists in two valence states, tetravalent and hexavalent, and occurs only in the form of oxides such as uraninite (nasturan, pitchblende and uranium black), or in the form of uranyl ion, which forms salts with oxygen-containing acids. Uranium has a high affinity for organic compounds, which leads to its concentration in sediments rich in organic compounds. There is a direct relationship: the higher the content of organic carbon in shales, the higher the uranium content in them.*

The research objective *is to describe the mechanism of uranyl ion accumulation through its binding to organic compounds in marine sedimentary basins and assess the potential of using uranyl ions as photoredox catalysts.*

The research results. *Organic compounds serve as a "trap" for uranyl ion migrating in marine basins, concentrating it from seawater. The practical value of uranyl ion cations as photoredox catalysts in chemical reactions has been demonstrated. The excited state of uranyl ion cations has a high oxidizing ability. Uranium is reduced to a tetravalent state and sorbed by organic compounds.*

Conclusions. *An increased level of total organic carbon is usually associated with an increase in uranium content. Organic compound functions as a sorbent and reducing agent; a decrease in its content leads to lower uranium concentration. In the marine environment, uranium moves to the deposition zone. In the absence of oxygen, uranium passes into the hexavalent form, after which it is absorbed by organic compounds in a reducing geochemical environment.*

Keywords: *uranyl ion; organic compounds; gamma activity; complex raw materials; sorbent; reducing agent; environment.*

Introduction. The world population is growing steadily as well as its needs for energy. In 150–200 years humanity is going to face an energy shortage, so science is looking for a solution, trying to obtain alternative sources of energy [1, 2]. Green nuclear energy is the foundation of the energy sector of the future. The energy of the atomic nucleus it the very source capable of providing for humanity due to enormous energy reserves contained within. Currently, the main nuclear fuel is uranium (U) and, to some extent, thorium (Th). It should be noted that only a small portion of uranium is used in reactors, while most of it is used as a strategic military raw material. All known reserves of uranium and thorium in the world can provide humanity with nuclear energy for 5–10 thousand years [1].

Natural uranium is divided into two categories: enriched and depleted. The uranium enrichment process involves increasing the concentration of the U-235 isotope from the initial 0.72% to a maximum level of 94%. Depleted uranium that contains less than 0.7% uranium-235 (usually 0.1–0.3%) is the main tailing of the enrichment process. Depleted uranium is the tailing (primarily uranium-238) remained after separation of the uranium-235 and uranium-234 isotopes from natural uranium. Natural uranium contains about 99.27% uranium-238, 0.72% uranium-235, and 0.0055% uranium-234 [3, 4].

In natural conditions, uranium is present in the forms U^{4+} and U^{6+} and found only as UO_2 oxides (uraninite and its varieties, nasturan, pitchblende, and uranium black) or as the uranyl ion UO_2^{2+}, which forms salts of oxygen acids [5–9]. Since organic compounds are most typical of argillaceous deposits, they become the main concentrators of uranium during its transport in the surface medium. Peat, coal, and carbonaceous rock matter are effective sorbents for uranium precipitation [1, 10–13].

Shales, rich in organic compounds, typically have high uranium contents. The effect of uranium irradiation on the evolution and generation of hydrocarbons in organic compounds has attracted considerable attention and is to be taken into account as well as its effect on the assessment of uranium-rich shale resource [3, 14–18]. Uranium and organic compounds in shales, particularly black shales, are closely related geochemically. Black shales are sedimentary rocks with a high organic compounds content in which uranium accumulates during the formation of deposits associated with hydrothermal activity. This process is particularly noticeable in sedimentary layers rich in organic compounds [3, 15–17]. The weighted mean uranium content in black shales is approximately 13±2 g/t. In some cases, for example, in the dictyonema shales occurring in the Baltic region, the uranium concentration can significantly exceed its typical values common for most sedimentary rocks, such as limestones [6, 7, 9, 10].

The research objective is to characterize the uranium accumulation process. The mechanism of uranium accumulation is as follows: in marine conditions, uranium (in dissolved form) is transported to a sedimentation basin. In anaerobic (oxygen-free) conditions, typical for black shale formation, uranium is reduced to U^{4+} and is sorbed by organic compounds or precipitated as sparingly soluble compounds [3, 16].

Results. Not all organic compounds effectively concentrate uranium. Humic and sapropelic components (amorphous organic compounds) are the most active, while inert organic compounds (terrigenous organic compounds) are less effective. Black shales are considered a complex mineral raw material from which uranium can be mined together with other minerals. Uranium-238 accounts for over 99% of total natural uranium [10].

Black shales are the subject of investigation aimed at finding a new type of uranium deposits that could become a significant reserve for the nuclear energy sector. Black shale formations often contain supra-clarke contents of uranium and other metals that are considered syngenetic. Black shales, which are rich in organic compounds, are typically thin-layered sedimentary argillaceous rocks of marine origin typically formed under conditions of oxygen deficit in bottom waters and in the upper sediment layer [6, 9, 10]. In the Earth's crust, the thorium-to-uranium ratio significantly exceeds that figure in bed rock (massive rock) because thorium accumulates in indestructible rock fragments, while mobile uranium migrates more easily (Table 1). The content of radioactive elements in sedimentary rocks (uranium – $3{,}2 \cdot 10^{-4}$; thorium – $1{,}1 \cdot 10^{-3}$) is directly related to their origin. Organogenous sediments show the highest concentrations, due to the presence of organic carbon, phosphates, and other compounds that actively

precipitate uranium. At the same time, chemogenic deposits, such as gypsum or rock salt, are characterized by low levels of radioactivity. Among igneous rocks, acidic varieties (uranium – $3{,}5 \cdot 10^{-4}$; thorium – $1{,}8 \cdot 10^{-3}$) have the highest radioactivity, while ultrabasic rocks (uranium – $3 \cdot 10^{-7}$; thorium – $5 \cdot 10^{-7}$) have the lowest values. In crystalline rocks, radioactive elements partly occur in accessory minerals (allanite, zircon, monazite, apatite, sphene, and others) and are also present as oxides not chemically bound to specific minerals. Young deep-sea marine sediments show significant accumulation of ionium (an isotope of thorium, element in the radioactive decay series), which are tens of times higher than its equilibrium content in uranium. This is due to chemical properties of ionium, which facilitate its precipitation from water along with sediments, as compared to uranium, which remains in a dissolved state [14, 19].

Table 1. Concentrations of uranium and thorium in sedimentary rocks with the standard radioactivity level within the continental part of the Earth's crust

Таблица 1. Концентрация урана и тория в осадочных породах со стандартным уровнем радиоактивности в пределах континентальной части земной коры

Rock	The content of elements, g/t		Th / U
	U	Th	
Terrigenous (sandy-argillaceous)			
Conglomerates, gravelstones	2.40	9.0	3.7
Sandstone, siltstones	2.90	10.4	3.6
Argillites, shales. clays	4.00	11.5	2.4
Quartz conglomerates	6.30	31.0	5–10
Carbonaceous shales	>10–20	15.0	<1.0
Siliceous			
Siliceous shales, quartzites	1.70	2.2	1.2
Argillaceous-siliceous shales	2.80	6.2	2.2
Carbonate			
Limestones	1.60	1.8	1.1
Marls	2.80	2.5	0.9
Dolomites	3.70	2.8	0.8
Saline			
Anhydrites	1.00	1.0	1.0
Rock salt	0.90	1.0	1.1
Coal	3.40	4.8	1.4
Upper layers of the continental crust			
Sands and sandstones	2.30	7.8	3.4
Clays and shales	4.50	10.0	2.2
Carbonate	2.10	2.4	1.1
Siliceous	5.00	3.4	0.7
Evaporites	0.68	0.7	1.0
Sedimentary rock in general	3.40	7.7	2.3
Clark	2.50	9.3	3.7

Dictyonema shales of the Baltic basin represent low-quality fuel and low-grade uranium raw material and are currently not mined because of low uranium recovery [9, 10]. Uranium is the main ore mineral in dictyonema shales whose significant natural resources account for the enormous uranium reserves, even with its low concentration in rock. Other

metals are considered minor components. Uranium occurs in several forms: up to 10% of the total amount is present as nasturan; up to 30% is associated with organic compounds; a significant portion (30–40%) is believed to be in the silicate and phosphate components of dictyonema shales. One variety of uraninite is nasturan, a mineral containing a mixture of tetravalent and hexavalent uranium. Nasturan and argillaceous matter in coal are closely intergrown with each other.

Within the geological section of the formation, the highest uranium concentrations are in layers with the highest organic compounds content.

In recent years, the unique complex composition of the dictyonema shales has been studied in detail: deficient dispersed elements (rhenium, scandium, rubidium, and cesium), rare earth metals, non-ferrous metals (in addition to vanadium and molybdenum, also zinc and copper), and precious metals (gold and platinum group metals) have been identified, with their contents corresponding to the lower threshold values for commercial ore types [5, 6, 10].

Organic compounds and ancient sedimentation conditions play a key role in the formation of uranium mineralization in the dictyonema shales. Dictyonema sediments accumulated in shallow marine conditions, in a reducing hydrogen sulfide environment of interstitial waters. The mean concentration of uranium in the formation increases as its thickness decreases to one meter or less [6, 9, 10].

The Kaibolovo-Gostilitsy prospecting area is a unique deposit of currently off-balance uranium ores. It has the potential to replenish the mineral resource base of the nuclear industry, on condition of complex extraction of not only uranium, but also vanadium, molybdenum, rare earth elements [9], rhenium, platinum group metals, and other minerals. Exploration therefore must be accompanied by technological research aimed at comprehensive extraction of uranium and associated valuable components from the dictyonema shales and phosphorites of the Pakerort horizon of the Baltic Sea basin [12].

Organic compounds played a significant role in the course of blue-green algae growth by absorbing metals and many other microelements and accumulating them within; and also, subsequently, uranium and other metals were sorbed by dead organic compounds in bottom sediments. Consequently, a decrease in the number of organic compounds leads to a decrease in uranium concentration. The correlation of uranium content is as follows: negative with calcium –0.28; with manganese –0.32; with phosphorus –0.1. So, neither silicate nor phosphate components of dictyonema shales can contain significant amount of uranium, and the alkaline conditions of the environment apparently did not contribute to its precipitation [15–18, 20–22].

In the interstitial waters of the paleobasin, where sedimentation occurred, a reducing hydrogen sulfide environment clearly prevailed. This is indicated by the presence of iron, sulfur (up to 3% or more), and organic compounds (about 10%) in the dictyonema shales, which contributed to the precipitation of many elements in the sulfide form as well as to the reduction of hexavalent uranium [6, 10].

The predicted uranium resources of the Kaibolovo-Gostilitsy area remain significant and are estimated at 220,000–300,000 t (including the interbedded member). Therefore, this deposit is not simply large, but unique in terms of uranium reserves [12]. The organic component of shale represents a strongly oxidized variety of highly carbonized organic compounds. Table 2 shows the distribution of uranium in organic shales (after centrifugal analysis) [19].

The content of uranium in fractions shows a linear increase with increasing ignition loss, which characterizes the number of organic compounds in the fractions in this case [19].

The main mechanism for uranium accumulation in sedimentary rocks is the diffusion of the $UO_2(CO_3)_3^{-4}$ complex from an aqueous environment, followed by uranium reduction and its sorption or precipitation as independent minerals, primarily uraninite. Many aspects related to uranium accumulation in black shale phosphates remain unclear. Researchers propose different hypotheses for uranium accumulation: it can replace calcium in the crystal lattice of apatite or calcite, and also bind to organic compounds through sorption mechanisms [10, 18, 20]. The excited state of uranyl cations UO_2^{2+} is characterized by high oxidizing capacity [17–18, 20–22].

Table 2. Distribution of uranium, molybdenum and vanadium by fractions of different specific weight (carbonized organic compound)

Таблица 2. Распределение урана, молибдена и ванадия по фракциям различного удельного веса (карбонизованного органического вещества)

Specific weight for a fraction	Fraction yield, %	Ignition loss, %	Uranium, %	Vanadium, %	Molybdenum, %
< 2.1	7.7	59.1	0.18	0.34	0.09
2.1–2.2	50.1	27.7	0.09	0.23	0.07
2.4–2.5	23.8	18.9	0.06	0.18	0.03
2.5–2.6	18.4	13.9	0.05	0.44	0.06

The use of uranyl nitrates as powerful photoredox catalysts in chemical reactions plays an important role in thermal catalysis and structural chemistry. Uranyl cations UO_2^{2+} have proven to be ideal photoredox catalysts in chemical reactions under visible light. The excited state of uranyl cations UO_2^{2+} achieved by irradiation with visible light is characterized by a long fluorescence lifetime and high oxidizing capacity [20]. Interestingly, the ground and excited states of uranyl cations UO_2^{2+} are chemically inert relative to oxygen molecules, which prevents undesirable transformations of reactive oxygen species. Scientific papers have summarized the latest advances in the field of photoredox transformations carried out using uranyl nitrates [20–22].

Conclusions. The Earth's crust contains 1014 tons of uranium, but the main problem is that it does not form large deposits. Black shales are the most important geochemical reservoir of uranium with organic compounds being the key agent for its concentration.

Uranium and organic compounds are closely related geochemically. This syngenetic relationship (formed simultaneously with the rock) is caused by the processes of sedimentation and diagenesis. It has been shown that high total organic carbon content typically correlates with increased uranium concentrations.

Organic compound acts as a sorbent and reducing agent; a decrease in the number of organic compounds leads to a decrease in uranium concentration. In marine conditions, uranium is transported to sedimentation basins. In anaerobic conditions, uranium is reduced to U (IV) and sorbed by organic compounds under reducing geochemical conditions.

Uranium accumulation in black shales is a complex multi-stage process. The key factor of the process are organic compounds, especially in reducing marine conditions. The main mechanism is the diffusion of dissolved uranium from the aquatic environment, its reduction to the tetravalent state, and sorption by amorphous humic and sapropelic components or precipitation as sparingly soluble minerals such as nasturan.

The dictyonema shales of the Baltic basin deserve special attention. Despite being low-quality as a fertile material, they contain enormous uranium resources – from 220,000 to 300,000 t in the Kaibolovo-Gostilitsy area alone. These off-balance ores become economically feasible only with complex extraction of valuable associated components of vanadium, molybdenum, rhenium, scandium, rare earths, and precious metals.

Modern studies have revealed an additional aspect of uranium geochemistry: the photoredox catalytic properties of uranyl cations UO_2^{2+}. Their excited state, stable relative to molecular oxygen, opens up prospects for uranyl nitrates in chemical reactions under visible light. However, in the context of geological processes, this property highlights the chemical activity of uranium in its oxidized form, which in natural conditions converts to its reduced form only in the presence of organic compounds and a hydrogen sulfide environment.

As a result, black shale formations remain a priority in the search for new types of uranium deposits. In order to transfer from off-balance resources to commercial reserves it is essential to improve the technologies of integrated metal extraction and study the mechanisms of uranium interaction with organic compounds both during sedimentation and catagenesis. Only the integration of geochemical, mineralogical, and technological research will make it possible to realize their potential as a viable reserve for nuclear energy.

REFERENCES

1. Neruchev S. G. *Uranium and life in the history of the Earth.* St. Petersburg: VNIGRI Publishing; 2007. (In Russ.)

2. Miroshnichenko I. V., Glushkova T. A., Talalai A. G., Shinkariuk I. E. State reference materials of composition and properties of radioactive ore bodies. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering.* 2025; 5: 48–65 (In Russ.) DOI: 10.21440/0536-1028-2025-5-48-65

3. Marchenko V. I., Zhuravleva G. I., Dvoeglazov K. N., Savilova O. A. Behavior of plutonium and neptunium in nitric acid solutions containing hydrazine and technetium ions. *Khimicheskaia tekhnologiia = Chemical Technology.* 2008; 9(2): 61–67. (In Russ.)

4. Rakishev B. R., Mataev M. M., Kenzhetaev Z. S. *Analysis of mineralogical composition of sediments in in-situ leach mining of Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal).* 2019; 7: 123–131. (In Russ.) DOI: 10.25018/0236-1493-2019-07-0-123-131

5. Klyucharev D. S., Soesoo A. A possible model of the interaction of organic carbon and rare earth metals on the example of dictyonema shales. *Razvedka i okhrana nedr = Prospect and Protection of Mineral Resources.* 2021; 10: 75–79. (In Russ.)

6. Vyalov V. I., Dyu T. A., Shishov E. P. Uranium and rare-earth elements in Dictyonema shales of the Baltic basin (Kaibolovo-Gostilitsy area). *Georesursy = Geo resources.* 2024; 26(1): 3–19. (In Russ.) DOI: 10.18599/grs.2024.1.3

7. Iakovlev V. L., Kornilkov S. V., Kravchuk I. L., Nevolina E. M. On the mechanism of occurrence and development of hazardous production situations in open-pit coal mining. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering.* 2025; 6: 69–78. (In Russ.) DOI: 10.21440/0536-1028-2025-6-69-78

8. Rogov M., Shchepetova E., Zakharov V. A. Late Jurassic-earliest Cretaceous prolonged shelf dysoxic-anoxic event and its possible causes. *Geological Magazine.* 2020; 157(10): 1622–1642. (In Russ.) DOI: 10.1017/S001675682000076X

9. Vyalov V. I., Larichev A. I., Balakhonova A. S. Ore genesis of dictyonemic shales and obolov sandstones of the Baltic basin. *Regionalnaia geologiia i metallogeniia = Regional Geology and Metallogeny.* 2013; 55: 87–98. (In Russ.)

10. Mikhailov V. A., Chernov V. Ia., Kushnerenko V. K. Dictyoneme shales of the Baltic basin are a promising object of industrial development for uranium and other minerals. In: *Materials on the geology of deposits of uranium, rare and rare-earth metals: Proceedings.* 2006. Iss. 149. P. 92–98. (In Russ.)

11. Sarychev G. A., Denisenko A. P., Smirnov K. M. et al. *Complex processing method of carbon-silicic black-shale ores*. Patent RF no. 2477327; 2013. (In Russ.)

12. Kulikova E. Yu., Balovtsev S. V., Skopintseva O. V. Geotechnical risk management in mine and underground construction. *Ustoichivoe razvitie gornykh territorii = Sustainable Development of Mountain Territories*. 2025; 17(1): 556–563. (In Russ.) DOI: 10.21177/1998-4502-2025-17-1-556-563

13. Goroshko V. M., Gilmanova G. Z. Uranium potential of structural-stratigraphic disconformity zones between platform and metamorphic units of Aldan shield Idyumkhaikan dome. *Rudy i metally = Ores and Metals*. 2018; 2: 14–24. (In Russ.)

14. Shumilin M. V. Unconventional sources of uranium and their potential role in the future. *Mineralnye resursy Rossii. Ekonomika i upravlenie = Mineral Recourses of Russia. Economics and Management.* 2016; 4: 24–26. (In Russ.)

15. Ismailova M. K., Aliieva M. G., Valiev N. G., Lebzin M. S. The role of radiation in the formation of petroleum hydrocarbons. *Izvestiia Tulskogo Gosudarstvennogo Universiteta. Nauki o Zemle = Proceedings of the Tula State University. Earth Sciences.* 2026; 1: 14–19. (In Russ.)

16. Savelyeva O. L., Savelyev D. P., Filosofova T. M. Uranium and yttrium accumulation in the bone debris incarbonaceous rocks of the Kamchatsky mys peninsula. *Vestnik KRAUNTs. Nauki o Zemle = Bulletin of Kamchatka Regional Association "Educational Scientific Center". Earth Sciences*. 2019; 2(42): 77–83. (In Russ.) DOI: 10.31431/1816-5524-2019-2-42-77-83

17. Hanna S. L., Farha O. K. Energy–structure–property relationships in uranium metal-organic frameworks. *Chemical Science.* 2023; 6(14(16)): 4219–4229. DOI: 10.1039/d3sc00788j

18. Barluzzi L., Giblin S. R., Mansikkamäki A., Layfield R. A. Identification of oxidation state +1 in a molecular uranium complex. *Journal of the American Chemical Society.* 2022; 144(40): 18229–18233. DOI: 10.1021/jacs.2c06519

19. Rozhkova E. V., Razumnaia E. G., Serebriakova M. B. The role of sorption in the concentration of uranium in sedimentary rocks. *Iadernye goriuchie i reaktornye metally = Nuclear Fuels and Reactor Metals.* 1959. P. 13–32 (In Russ.)

20. Deqing Hu, Xuefeng Jiang. Perspectives for uranyl photoredox catalysis. *Synlett.* 2021; 32(13): 1330–1342. DOI: 10.1055/a-1493-3564

21. Martin C. R., Leith G. A., Shustova N. B. Beyond structural motifs: the frontier of actinide-containing metal-organic frameworks. *Chemical Science.* 2021; 12(21): 7214–7230. DOI: 10.1039/D1SC01827B

22. Hanna S. L., Debela T. T., Mroz A. M., Syed Z. H., Kirlikovali K. O., Hendon C. H., Farha O. K. Identification of a metastable uranium metal-organic framework isomer through non-equilibrium synthesis. *Chemical Science.* 2022; 13(44): 13032–13039. DOI: 10.1039/D2SC04783G

Received 30 April 2026

Information about the authors:

Mehpara K. Ismayilova – PhD (Chemical sciences), leading researcher, Institute of Physics of the Ministry of Science and Education of the Republic of Azerbaijan. E-mail: ismayilovamehpara@gmail.com; https://orcid.org/ 0000-0003-3619-6482

Niiaz G. Valiev – DSc (Engineering), Professor, Head of the Department of Mining, Ural State Mining University; Editor-in-Chief of Minerals and Mining Engineering. E-mail: gtf.gd@m.ursmu.ru; https://orcid.org/0000-0002-5556-2217

Maral H. Aliyeva – PhD (Engineering), Associate Professor of the Department of Geology and Development of Mineral Deposits, Azerbaijan State Oil Industry University. E-mail: maral.aliyeva.5252@mail.ru; https://orcid.org/0009-0004-4740-451X

Maksim S. Lebzin – PhD (Engineering), senior researcher, Research laboratory for reclamation of disturbed lands and technogenic objects, Ural State Mining University. E-mail: az_ma@mail.ru; https://orcid.org/0000-0001-5959-135X

УДК 553.495:552.57 DOI: 10.21440/0536-1028-2026-5-69-77

Уранил-ион и органические вещества в сланцах

Исмаилова М. К.[1], Валиев Н. Г.[2], Алиева М. Г.[3], Лебзин М. С.[2]

[1] Институт физики Министерства науки и образования Азербайджана, г. Баку, Азебайджан.

[2] Уральский государственный горный университет, г. Екатеринбург, Россия.

[3] Азербайджанский государственный университет нефти и промышленности, г. Баку, Азебайджан.

Реферат

Введение. *В природных условиях уран существует в двух состояниях: четырехвалентном и шестивалентном. В природе этот элемент встречается исключительно в виде оксидов, таких как уранинит (настуран, урановая смолка, а также урановая чернь), либо в форме*

уранил-иона, который образует соли с кислородсодержащими кислотами. Уран обладает высоким родством с органическими веществами, что приводит к его концентрированию в богатых ими осадочных породах. Существует прямая связь: чем выше содержание органического углерода в сланце, тем выше в нем содержание урана.

Цели исследования *– описание механизма накопления уранил-иона за счет его связывания с органическим веществом в морских осадочных бассейнах и оценка возможности использования уранил-ионов в качестве фоторедокс-катализаторов.*

Результаты исследования. *Органическое вещество служит «ловушкой» для уранил-иона, мигрирующего в морских бассейнах, концентрируя его из морской воды. Продемонстрирована практическая ценность катионов уранил-иона в качестве фоторедокс-катализаторов в химических реакциях. Возбужденное состояние катионов уранил-иона обладает высокой окислительной способностью. Уран восстанавливается до четырехвалентного состояния и сорбируется органическим веществом.*

Выводы. *Повышенный уровень общего органического углерода, как правило, связан с увеличением содержания урана. Органическое вещество выполняет функции сорбента и восстановителя; снижение количества органического вещества ведет к уменьшению концентрации урана. В морской среде уран перемещается в зону осадконакопления. При отсутствии кислорода уран переходит из шестивалентной формы в четырехвалентную, после чего поглощается органическим веществом в условиях восстановительной геохимической среды.*

Ключевые слова: *уранил-ион; органические вещества; гамма-активность; комплексное сырье; сорбент; восстановитель; окружающая среда.*

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Неручев С. Г. Уран и жизнь в истории Земли. СПб.: ВНИГРИ, 2007. 326 с.

2. Мирошниченко И. В., Глушкова Т. А., Талалай А. Г., Шинкарюк И. Е. Государственные стандартные образцы состава и свойств радиоактивных рудных тел // Известия высших учебных заведений. Горный журнал. 2025. № 5. С. 58–65. DOI: 10.21440/0536-1028-2025-5-58-65

3. Марченко В. И., Журавлева Г. И., Двоеглазов К. Н., Савилова О. А. Поведение плутония и нептуния в азотно-кислых растворах, содержащих гидразин и ионы технеция // Химическая технология. 2008. Т. 9. № 2. С. 61–67.

4. Ракишев Б. Р., Матаев М. М., Кенжетаев Ж. С. Исследование минералогического состава осадкообразований в условиях скважинной добычи урана // ГИАБ. 2019. № 7. С. 123–131. DOI: 10.25018/0236-1493-2019-07-0-123-131

5. Ключарев Д. С., Соесоо А. Возможная модель взаимодействия органического углерода и редкоземельных металлов на примере диктионемовых сланцев // Разведка и охрана недр. 2021. № 10. С. 75–79.

6. Вялов В. И., Дю Т. А., Шишов Е. П. Уран и редкоземельные элементы в диктионемовых сланцах Прибалтийского бассейна (Кайболово-Гостилицкая площадь) // Георесурсы. 2024. № 26(1). С. 3–19. DOI: 10.18599/grs.2024.1.3

7. Яковлев В. Л., Корнилков С. В., Кравчук И. Л., Неволина Е. М. О механизме возникновения и развития опасных производственных ситуаций в условиях открытой угледобычи // Известия высших учебных заведений. Горный журнал. 2025. № 6. С. 69–78. DOI: 10.21440/0536-1028-2025-6-69-78

8. Rogov M., Shchepetova E., Zakharov V. A. Late Jurassic-earliest Cretaceous prolonged shelf dysoxic-anoxic event and its possible causes // Geological Magazine. 2020. No. 157(10). P. 1622–1642. DOI: 10.1017/S001675682000076X

9. Вялов В. И., Ларичев А. И., Балахонова А. С. Рудогенез диктионемовых сланцев и оболовых песчаников Прибалтийского бассейна // Региональная геология и металлогения. 2013. № 55. С. 87–98.

10. Михайлов В. А., Чернов В. Я., Кушнеренко В. К. Диктионемовые сланцы Прибалтийского бассейна – перспективный объект промышленного освоения на уран и другие полезные ископаемые // Материалы по геологии месторождений урана, редких и редкоземельных металлов: информ. сб. 2006. Вып. 149. С. 92–98.

11. Способ комплексной переработки углерод-кремнеземистых черносланцевых руд: пат. 2477327 Рос. Федерация; заявл. 05.09.2011; опубл. 10.03.2013. Бюл. №. 17. 13 с.

12. Куликова Е. Ю., Баловцев С. В., Скопинцева О. В. Управление геотехническими рисками в шахтном и подземном строительстве // Устойчивое развитие горных территорий. 2025. Т. 17. № 1. С. 556–563. DOI: 10.21177/1998-4502-2025-17-1-556-563

13. Горошко В. М., Гильманова Г. З. Урановоносность зон структурно-стратиграфических несогласий между платформенными и метаморфическими образованиями Идюмо-Хайканского купола Алданского щита // Руды и металлы. 2018. № 2. С. 14–24.

14. Шумилин М. В. Нетрадиционнные источники урана и их возможная роль в будущем // Минеральные ресурсы России. Экономика и управление. 2016. № 4. С. 24–26.

15. Исмаилова М. К., Алийева М. Г., Валиев Н. Г., Лебзин М. С. Роль радиации в формировании углеводородов нефти // Известия ТулГУ. Науки о Земле. 2026. Вып. 1. С. 14–19.

16. Савельева О. Л., Савельев Д. П., Философова Т. М. Накопление урана и иттрия костным детритом в углеродистых породах п-ова Камчатский мыс // Вестник КРАУНЦ. Науки о Земле. 2019. № 2. Вып. 42. С. 77–83. DOI: 10.31431/1816-5524-2019-2-42-77-83

17. Hanna S. L., Farha O. K. Energy–structure–property relationships in uranium metal-organic frameworks // Chemical Science. 2023. No. 6. Vol. 14(16). P. 4219–4229. DOI: 10.1039/d3sc00788j

18. Barluzzi L., Giblin S. R., Mansikkamäki A., Layfield R. A. Identification of oxidation state +1 in a molecular uranium complex // Journal of the American Chemical Society. 2022. No. 144(40). P. 18229–18233. DOI: 10.1021/jacs.2c06519

19. Рожкова Е. В., Разумная Е. Г., Серебрякова М. Б., Щербак О. В. Роль сорбции в концентрации урана в осадных породах // Ядерные горючие и реакторные металлы. 1959. С. 13–32.

20. Deqing Hu, Xuefeng Jiang. Perspectives for uranyl photoredox catalysis // Synlett. 2021. No. 32(13). P. 1330–1342. DOI: 10.1055/a-1493-3564

21. Martin C. R., Leith G. A., Shustova N. B. Beyond structural motifs: the frontier of actinide-containing metal-organic frameworks // Chemical Science. 2021. No. 12(21). P. 7214–7230. DOI: 10.1039/D1SC01827B

22. Hanna S. L., Debela T. T., Mroz A. M., Syed Z. H., Kirlikovali K. O., Hendon C. H., Farha O. K. Identification of a metastable uranium metal-organic framework isomer through non-equilibrium synthesis // Chemical Science. 2022. No. 13(44). P. 13032–13039. DOI: 10.1039/D2SC04783G

Поступила в редакцию 30 апреля 2026 года

Сведения об авторах:

Исмаилова Мехпара Камил – кандидат химических наук, ведущий научный сотрудник Института физики Министерства науки и образования Азербайджана. E-mail: ismayilovamehpara@gmail.com; https://orcid.org/ 0000-0003-3619-6482

Валиев Нияз Гадым оглы – доктор технических наук, профессор, заведующий кафедрой горного дела Уральского государственного горного университета; главный редактор издания «Известия вузов. Горный журнал». E-mail: gtf.gd@m.ursmu.ru; https://orcid.org/0000-0002-5556-2217

Алиева Марал Гасан – кандидат технических наук, доцент кафедры геологии и разработки месторождений полезных ископаемых Азербайджанского государственного университет нефти и промышленности. E-mail: maral.aliyeva.5252@mail.ru; https://orcid.org/0009-0004-4740-451X

Лебзин Максим Сергеевич – кандидат технических наук, старший научный сотрудник научно-исследовательской лаборатории рекультивации нарушенных земель и техногенных объектов Уральского государственного горного университета. E-mail: az_ma@mail.ru; https://orcid.org/0000-0001-5959-135X

Для цитирования: Исмаилова М. К., Валиев Н. Г., Алиева М. Г., Лебзин М. С. Уранил-ион и органические вещества в сланцах // Известия высших учебных заведений. Горный журнал. 2026. № 5. С. 69–77 (In Eng.). DOI: 10.21440/0536-1028-2026-5-69-77

For citation: Ismayilova M. K., Valiev N. G., Aliyeva M. H., Lebzin M. S. Uranyl ion and organic compounds in shales. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering.* 2026; 5: 69–77. DOI: 10.21440/0536-1028-2026-5-69-77