Original article
EDN: AYNKYU
DOI: 10.21285/2686-9993-2026-49-2-3

A review of potential oil and gas accumulation zones in the northern regions of Western Yakutia for regional geological study

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Abstract. The article considers potential oil and gas accumulation zones in the northern regions of Western Yakutia. The subthrust zone of the periphery of the Verkhoyansk folded structures is of particular interest for oil and gas exploration, especially on the Kitchansky protrusion and adjacent sections of the Verkhoyanskaya Arc, including the northern margin of the Aldan branch up to the Tompon depression, as well as within the northwestern Verkhoyansk cover. Within the study area, it is proposed to consider potential oil and gas accumulation zones located along migration pathways and at their ends as forecasting objects, highlighting the most likely directions of hydrocarbon movements. From the perspective of the potential for non-anticlinal trap formation in the lower part of the Permian deposits, the region adjacent to the northern slope of the Yakut Arch is of interest. Permian and Triassic deposits resting directly on the crystalline basement represent a promising complex. The mudstones of the Nedjelinskaya formation are likely to serve as a cap rock. For regional geological work, it is proposed to consider promising oil and gas objects within the Kitchanskaya and Yakutskaya oil and gas accumulation zones. This work is aimed at the study of the geological structure of the junction zone of the southeastern part of the Predverkhoyansky trough, the northern slope of the Aldan anteclise and the southern side of the Vilyui syneclise, the nature of structural and lithological relationships, the areal distribution of stratigraphic complexes within the sedimentary cover, the identification of oil and gas promising reservoirs and zones of potential oil and gas accumulation, the refinement of oil and gas prospects and estimation of predicted hydrocarbon resources. It is assumed that quantitative oil and gas accumulation will belong to traps of a predominantly non-anticlinal (stratigraphic) type.

Keywords: promising oil and gas bearing objects, Western Yakutia, oil and gas accumulation, trap, Yakut arch

Funding. The work was carried out within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation (FWRS-2025-0036).

For citation: Nikolaeva M.V., Ivanov A.G., Berdyev S.S. A review of potential oil and gas accumulation zones in the northern regions of Western Yakutia for regional geological study. *Earth sciences and subsoil use.* 2026;49(2):?-?. https://doi.org/10.21285/2686-9993-2026-49-2-3.

Научная статья
УДК 551.243.8:552.578.2

Обзор потенциальных зон нефтегазонакопления на территории северных районов Западной Якутии для проведения региональных геологических работ

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Резюме. В статье рассмотрены потенциальные зоны нефтегазонакопления на территории северных районов Западной Якутии. Определенный интерес для поисков нефти и газа представляет поднадвиговая зона периферии Верхоянских складчатых сооружений, особенно на Китчанском выступе и смежных участках Верхоянской дуги, включая северную окраину Алданской ветви вплоть до Томпонской впадины, а также в пределах северо-западного Верхоянского покрова. В пределах территории работ предложено в качестве объектов прогнозирования рассматривать потенциальные зоны нефтегазонакопления, находящиеся на пути миграционных потоков и в их окончаниях с выделением наиболее вероятных направлений движения углеводородов. С точки зрения возможности формирования неантиклинальных ловушек в нижней части пермских отложений интересен район, тяготеющий к территории северного склона Якутского свода. В качестве перспективного комплекса выступают отложения пер-

ми и триаса, залегающие непосредственно на кристаллическом фундаменте. Покрышкой предположительно могут служить аргиллиты неджелинской свиты. Для проведения региональных геологических работ предлагается рассмотреть нефтегазоперспективные объекты в пределах Китчанской и Якутской зон нефтегазонакопления. Целевым назначением данных работ является изучение геологического строения зоны сочленения юго-восточной части Предверхоянского прогиба, северного склона Алданской антеклизы и южного борта Вилюйской синеклизы, характера структурного и литологического взаимоотношения, площадного распространения стратиграфических комплексов осадочного чехла, выделения нефтегазоперспективных резервуаров и зон возможного нефтегазонакопления, уточнения перспектив нефтегазоносности и оценки прогнозных ресурсов углеводородов. Предполагается, что количественное нефтегазонакопление будет принадлежать ловушкам преимущественно неантиклинального (стратиграфического) типа.

Ключевые слова: нефтегазоперспективные объекты, Западная Якутия, нефтегазонакопление, ловушка, Якутский свод

Финансирование. Работа выполнена в рамках государственного задания Министерства науки и высшего образования Российской Федерации (FWRS-2025-0036).

Для цитирования: Николаева М.В., Иванов А.Г., Бердыев С.С. Обзор потенциальных зон нефтегазонакопления на территории северных районов Западной Якутии для проведения региональных геологических работ // Науки о Земле и недропользование. 2026. Т. 49. № 2. С. ?–?. https://doi.org/10.21285/2686-9993-2026-49-2-3.

Introduction

The sedimentary section within the study area of Western Yakutia is represented by a broad stratigraphic range of promising complexes. The primary objects of study are the commercially hydrocarbon-bearing deposits from the Riphean to the Jurassic–Cretaceous, which constitute the largest volumetric part of the sedimentary cover in the study area. In the northwestern regions, Ordovician, Silurian, and Devonian deposits may also be hydrocarbon-bearing, although they have currently been insufficiently studied in detail [1].

The commercial significance of accumulations contained in Riphean deposits has been confirmed within Yakutia, in the Berezovskaya depression. A gas-condensate pool has been established in the interval of the Torginskaya Formation of the Riphean at the Bysakhtakh field. Furthermore, within the Yurubcheno-Tokhomskaya zone, fairly large hydrocarbon accumulations have been identified, generally confirming the high potential of the Riphean sequences [2].

Sedimentary basin areas are subdivided into zones of predominant hydrocarbon generation and zones of predominant hydrocarbon accumulation. The former typically include large and medium-sized negative plical structures, within which thick sequences of sedimentary rocks accumulate, generating hydrocarbons. The petroleum potential of a reservoir is critically dependent on the intensity of hydrocarbon generation and accumulation processes [3]. Hydrocarbons generated within negative structures migrate toward adjacent uplifts. The presence of sealing cap rocks and migration pathways ensures the movement of hydrocarbons toward piezometric minima along the flanks of uplifts. The features of the structural framework of potentially productive complexes exert a significant influence on the distribution of migrating hydrocarbons [4].

This article presents recommendations for regional geological studies of the northern territories of Western Yakutia.

Materials and methods

The Predverkhoyansk petroleum province, confined to the western margin of the Verkhoyansk fold-thrust system, represents a promising but poorly studied region of Eastern Siberia in terms of petroleum potential. The geological structure of the territory is determined by a complex combination of platform and fold-deformed structures, which governs the specifics of hydrocarbon accumulation and localization [5].

The sedimentary cover of the Predverkhoyansk petroleum province is composed mainly of terrigenous and terrigenous-carbonate deposits of the Riphean, Vendian, Paleozoic, and Mesozoic, with thicknesses locally exceeding 8–10 km. The most promising in terms of petroleum potential are the Lower and Middle Paleozoic complexes, represented by alternating sandstones, siltstones, and carbonate rocks with favorable reservoir properties [6].

The identification of potential oil and gas accumulation zones is based on an integrated analysis of structural-tectonic, lithological-facies, and geochemical factors [7].

Within the Predverkhoyansk petroleum province, several structural zones are distinguished, differing in the degree of deformation of the sedimentary cover. In the western part of the province, relatively weakly disturbed platform structures prevail, represented by gentle anticlinal uplifts and monoclines. These structures can serve as favorable objects for the formation of classical anticlinal traps, especially in combination with lithological screening. Approaching the frontal part of the Verkhoyansk fold-thrust belt, the intensity of deformation increases, which is expressed in the development of linear folds and tectonically screened blocks [6–8].

Thrust structures, widely developed in the eastern and central parts of the Predverkhoyansk petroleum province, are of particular importance for petroleum potential. Within such structures, accumulations can form in uplifted fold limbs, thrust wedges, and tectonically screened traps, where thrust surfaces act as fluid seals.

An important element of the structural control of oil and gas accumulation is the junction zones of thrusts with subvertical faults. In these zones, conditions are created for the concentration of deformations, the formation of local structural traps, and the intensification of vertical and lateral hydrocarbon migration. Faults of various kinematics can serve a dual function: as migration pathways for fluids at early stages and as sealing elements at late stages of tectonic development [9–11].

Faults play a significant role in the localization of hydrocarbon accumulations: on the one hand, they facilitate the migration of fluids from deep generation centers, and on the other hand, they can act as seals, forming tectonic traps. Thrust structures are of particular importance, within which accumulations can form in allochthonous blocks with preserved reservoir properties [12].

Thus, potential oil and gas accumulation zones within the Predverkhoyansk petroleum province are confined to structurally complicated areas of the foredeep and the frontal part of the fold-thrust belt, where source rocks, effective reservoirs, and reliable traps are combined. Further refinement of the petroleum prospects of the region requires detailed seismic surveys, parametric drilling, and comprehensive geochemical studies.

The geochemical prerequisites for the petroleum potential of the Predverkhoyansk petroleum province are associated with the presence of thick Cambrian and Ordovician source rock sequences, represented by organogenic-clayey and carbonate-clayey rocks. The organic matter content in these deposits reaches 2–5%, and the kerogen is predominantly of types II–III, which determines a mixed oil and gas generation trend [12].

Hydrocarbon generation kitchens are localized mainly in the deep parts of the foredeep and subthrust zones, where the combination of elevated temperatures and pressure favored active generation of gas and gas-condensate fluids [13]. Subsequently, hydrocarbons migrated predominantly along faults and zones of tectonic fracturing associated with thrusts and related faults. Thus, structural elements acted not only as traps but also as main pathways for vertical and lateral migration.

Potential oil and gas accumulation zones within the Predverkhoyansk petroleum province are formed as a result of the close interaction of structural and geochemical factors. The most promising areas are those where thrust-fold structures are combined with zones of maximum realization of the generation potential of source rocks and favorable conditions for hydrocarbon migration and accumulation.

In predicting potential oil and gas accumulation zones within the Predverkhoyansk petroleum province, direct and indirect indicators of the presence of hydrocarbons, recorded from geological-geophysical and geochemical studies, are of great importance. Given the limited deep drilling data, such indicators allow a substantial refinement of the prospects of individual structural elements and local features.

Direct indicators of hydrocarbon saturation include shows of hydrocarbon gases and bitumoids in the sedimentary cover section. In several areas of the Predverkhoyansk petroleum province, gas shows have been recorded in fractured sand-

stones and carbonate rocks of Paleozoic age, as well as the presence of dispersed bitumoids in organogenic-clayey sequences. Bitumoid impregnations, asphaltenes, and resinous substances indicate processes of migration and partial destruction of hydrocarbon accumulations and are considered indicators of source rock potential and active fluid dynamics [14, 15].

The combination of direct and indirect indicators of hydrocarbon presence makes it possible to identify the most promising oil and gas accumulation zones, confined to anticlinal uplifts of platform type, thrust-fold structures, and subthrust traps.

Of particular interest for oil and gas exploration is the subthrust zone of the periphery of the Verkhoyansk folded structures, especially on the Kitchansky protrusion and adjacent sections of the Verkhoyansk Arc, as well as within the northwestern Verkhoyansk cover [16].

Within the latitudinal branch of the Predverkhoyansk trough, from the perspective of the potential for non-anticlinal trap formation in the lower part of the Permian deposits, the area adjacent to the northern slope of the Yakut Arch is of interest, where Permian rocks rest on granitic-gneisses of the crystalline basement at depths exceeding 3,000 m. Despite the considerable depth of burial and proximity to the folded region, the Permian sequence, in terms of catagenesis, falls into the zone of moderate alterations; the exposed section is more clayey than in the Vilyui syneclise, reservoir beds are of relatively small thickness (up to 20–25 m), and the siltstone-clayey interbeds separating them locally reach thicknesses of up to 100 m [17].

The prospects for petroleum potential of Jurassic and Cretaceous deposits are evidenced by the results of testing the Namskaia reference well, where nine intervals were tested in the Lower Cretaceous – Lower Jurassic section (1,631–3,003 m). From all intervals, inflows of mineralized water with dissolved gas were obtained, with a maximum gas flow rate of up to 1000 m³/day.

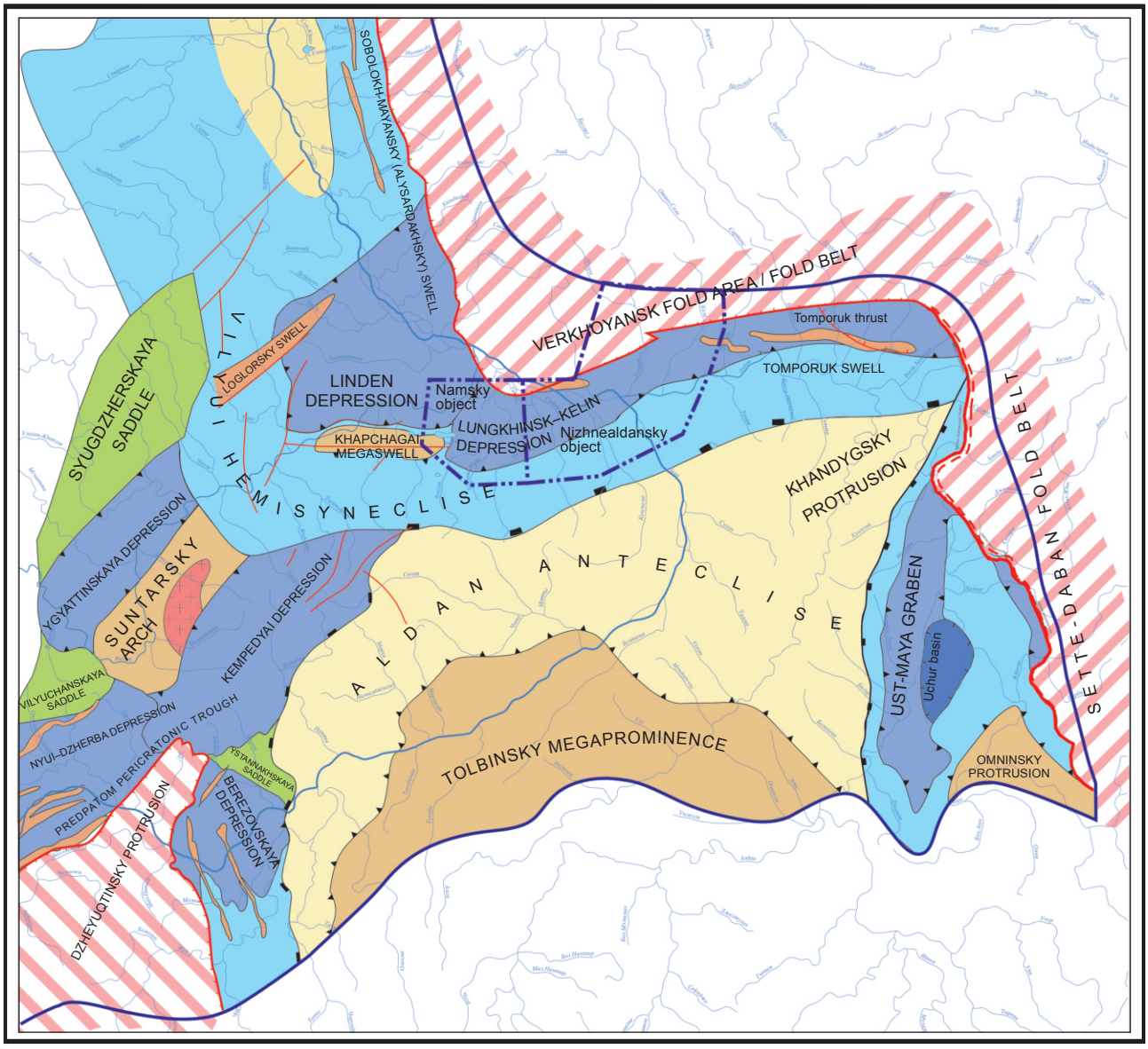
Results and discussion

The platform margin of the folded framing, which is promising for the discovery of large hydrocarbon accumulations in lithologically and stratigraphically screened traps of the basal horizons, is proposed to be initially studied in the area of the left bank of the latitudinal course of the Aldan River by conducting regional work within the latitudinal (Aldan) branch of the Predverkhoyansk trough. The figure shows the proposed objects for regional study.

Namsky prospect. The proposed study area is located within the junction zone of the southeastern marginal part of the Vilyui syneclise and the Aldan branch of the Predverkhoyansk trough, and is confined to the western half of the Lunkhinsko-Kelinskaya depression.

From the west, the area is bounded by the contour of the Yuzhno-Vilyuisky regional study area (Andreevskaya 2, Bayskaya 1, Yuzhno-Nedzhelinskaya 251 wells); the northwestern boundary runs along the axial line of the eastern periclinal closure of the Khapchagai megaswell up to the Ust-Vilyui and Sobo-Khainskoye fields. The northeastern boundary extends from the Sobo-Khainskaya area to the Namskaia reference well along the left bank of the Lena River. The area covers 21,368 km².

Within the study area, the basement lies at depths from 4 km in the south to 12–15 km in the northern subsided part. The sedimentary cover is represented predominantly by two depositional complexes: the lower Vendian–Cambrian and the upper Upper Paleozoic–Mesozoic [18]. Within the study area, the platform-adjacent and fold-adjacent domains are distinguished. The platform-adjacent domain is characterized by a gentle subsidence of the Permian–Mesozoic deposits with increasing thickness of the complex toward the Predverkhoyansk trough. The fold-adjacent domain is characterized by steeper dip of the rocks and the development of tectonic faults of Verkhoyansk strike, of thrust origin. Exploratory drilling was carried out within the Bergeinskaya and Oloy structures. The main prospects are associated with the Permian–Triassic sedimentary complex, which is predominant and occurs at depths accessible for drilling. Indications of oil saturation in Upper Jurassic deposits have been established in the Bergeinskaya and Oloy areas at depths down to 3,800 m. In addition, during testing of the Oloy well, two oil



Proposed targets for regional study:
1 – boundaries of the work area; 2 – boundaries of oil and gas provinces and regions;
3 – regional deep faults; 4 – administrative boundaries; 5 – fold-slip fault zone;
6 – crystalline basement outcrops
Предлагаемые объекты для регионального изучения:
1 – границы района работ; 2 – границы нефтегазоносных провинций и областей;
3 – региональные глубинные разломы; 4 – административные границы;
5 – зона складчато-сдвиговых дислокаций; 6 – выходы кристаллического фундамента

shows in the form of oil films were obtained from Lower Cretaceous deposits. In the Namskaia reference well, inflows of formation water with a high content of dissolved gas were obtained from Jurassic deposits. In Yuzhno-Nedzhelinskaya well No. 251, weak gas inflows were obtained from Upper Permian deposits.

The Yuzhno-Nedzhelinskaya structure was prepared in 1961 on the conventional horizon D (lower part of the Cretaceous deposits). In 1967, during the revision of geological and geophysical materials, structural mapping was performed on the Triassic–Permian horizon. Morphologically, the structure represents a structural nose, within

which a local fold of northeastern strike is contoured along the -3,600 m isohypse. The area is 14 km², with an amplitude of about 50 m. Based on the structural mapping performed in 2014 on the Triassic–Permian horizon, a structural nose was mapped. In the vertical section along profile line 130202, it appears as an anticlinal bend throughout all deposits of the sedimentary cover.

In 1977, the structure was drilled. Based on testing of Yuzhno-Nedzhelinskaya well No. 251 in the depth interval 4,155–4,159 m (Taragayskaya sequence), a minor gas inflow with a flow rate of 1,000 m³/day was obtained [19].

One of the interesting structural features within the study area is the Baysky protrusion. The Bayskaya structure was prepared and transferred for drilling in 1974 on seismic horizon J33 (Bergeinskaya Formation of the Upper Jurassic). As a result of the 2014 mapping along line PR130202, the Baysky bend was mapped on the lower structural stage. On the structural map of the Triassic–Permian horizon, it appears as a structural cape, the axial part of which extends from Bayskaya to the Yuzhno-Nedzhelinskaya well [10]. To refine the structure of these features, an additional set of geological and geophysical works is required, with the survey line network tied to previously completed and ongoing works in the Yakutskaya and Nizhnealdanskaya areas.

The recommended scope of seismic surveys is 2,000 km. The target objective is to study the geological structure of the junction zone between the Aldan branch of the Predverkhoyansk trough and the Vilyui syneclise in order to identify promising targets and to localize predicted hydrocarbon resources.

Nizhnealdansky prospect. The study area covers 14,257 km². It is located within the fold-adjacent zone of the Aldan branch of the Predverkhoyansk trough (Nizhne-Aldanskaya depression). The fold-adjacent zone is characterized by the development of tectonic faults of Verkhoyansk strike and steeper dip of deposits into the trough.

The inferred oil and gas accumulation zone combines linear subthrust structural traps formed parallel to the front of thrusting of the Verkhoyansk folded domain onto the Mesozoic cover of the platform. The bottomhole of the Nizhnealdanskaya well, drilled in the central part of the trough on the flank of the Tompon depression, is located in the basal part of the Batylykskaya Formation of Cretaceous deposits at a depth of 3,003 m. The thickness of Mesozoic deposits in the most subsided parts of the Predverkhoyansk trough is presumably up to 7,000 m.

The sedimentary cover of the Nizhne-Aldanskaya depression, according to parametric drilling, is represented by Paleozoic, Mesozoic, and Cenozoic deposits. Basement rocks were penetrated by the Ivanovskaya well at a depth of 3,508 m and are represented by micaceous-quartz schists and quartzites. The prospects for petroleum potential of Jurassic and Cretaceous deposits are evidenced by the results of testing the Namskaia reference well [20].

The main fluid seals of the Predverkhoyansk trough are siltstone-clayey rocks with interbeds of tuffs of the Nedzhelinskaya, Tagandzhinskaya, and Monomskaya formations of Early Triassic age and their equivalents; mudstones of the Suntarskaya Formation of Early Jurassic age and their clayey equivalents.

The recommended scope of seismic surveys is 800 km. The target objective is to study the geological structure of the study area in order to estimate prospective resources, identify promising targets within the zone of thrust development, localize predicted hydrocarbon resources, and identify new oil and gas accumulation zones.

Conclusion

Thus, the features of the geological evolution of the marginal parts of the Upper Paleozoic–Mesozoic sedimentary basin of the Siberian Platform (the Predverkhoyansk and Leno-Anabar troughs) allow them to be considered as a promising regional zone of potential oil and gas accumulation, with a fairly wide development of unconformities of various stratigraphic range and areal extent, which has developed along the entire structural perimeter. It is quite expected that here the predominant quantitative oil and gas accumulation will belong to traps of a predominantly non-anticlinal (stratigraphic) type.

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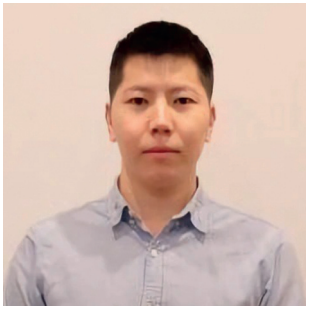

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Conflict of interests / Конфликт интересов

The authors declare no conflict of interests.
Авторы заявляют об отсутствии конфликта интересов.

The final manuscript has been read and approved by all the co-authors.
Все авторы прочитали и одобрили окончательный вариант рукописи.

Information about the article / Информация о статье

The article was submitted 24.04.2026; approved after reviewing 05.05.2026; accepted for publication 19.05.2026.
Статья поступила в редакцию 24.04.2026; одобрена после рецензирования 05.05.2026; принята к публикации 19.05.2026.