ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ
АКАДЕМИЯСЫ» РҚБ

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»

N E W S

OF THE NATIONAL ACADEMY
OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN

SERIES

OF GEOLOGY AND TECHNICAL SCIENCES

3 (471)

MAY – JUNE 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *Геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылына 6 рет.

http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*

Периодичность: 6 раз в год.

http://www.geolog-technical.kz/index.php/en/

CONTENTS

Geology

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 3. Number 471 (2025), 252–267

https://doi.org/10.32014/2025.2518-170X.524

UDC 553.632

© Zh.K. Tukhfatov[1*], M.K. Jexenov[2], Y.K. Bektay[3], G.S. Turysbekova[3], B.N. Shiderin[3], 2025.
[1]OGPA "Dossormunaygaz" JSC "Embamunaygaz", Atyrau, Kazakhstan;
[2]Atyrau University named after Kh. Dosmukhamedov, Atyrau, Kazakhstan;
[3]Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan.
E-mail: zh.tuhfatov@kmgep.kz

EXPLORATION STUDIES FOR RAW CHEMICAL MINERAL RESOURCES IN THE CASPIAN BASIN SALT DOMES

Tukhfatov Zhassulan — candidate of geological and mineralogical science, OGPA "Dossormunaygaz" JSC "Embamunaygaz", Atyrau, Kazakhstan, E-mail: zh.tuhfatov@kmgep.kz https://orcid.org/0009-0007-3301-9997;
Jexenov Makhambet — candidate of Geographical Sciences, Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan, E-mail: ddm85@mail.ru; https://orcid.org/0000-0002-1741-3931;
Bektay Yerkin — candidate of Technical Sciences, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, E-mail: erbekta@gmail.com; https://orcid.org/0000-0002-5304-5021;
Turysbekova Gauhar — candidate of Technical Sciences, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, E-mail: ipgauhartas@gmail.com; https://orcid.org/0000-0003-1085-6470;
Shiderin Bauyrzhan — postdoctorant, Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan, E-mail: b.shiderin@satbayev.university; https://orcid.org/0000-0002-5511-334X.

Abstract. The article describes in detail the history of research in the field of mining magnesium salts, boron ores and potash ores, as well as the characteristics of potential regions of Kazakhstan for mining these ores. Historical data of exploration works and their results for the period from 1960 to 2011 are presented. Various sources of minerals and rocks, as well as their properties and composition, are shown. A reliable mineral resource base for the production of boric and potassium salts in Western Kazakhstan has been created. Boron-potassium salts are previously unexplored new types of mining and chemical raw materials that have no analogues in world practice. They are widespread on an industrial scale on the globe only in halogen formations of the Kungurian stage of the Lower Permian of the Caspian Basin and are a complex raw material containing boron, potassium, magnesium, bromine and table salt. The exploration of borate ores and potassium salts in the

Caspian Basin continues to be an important national economic task, due to the development of borate ores in the Inder salt-dome structure, which made it possible to continue exploration work on borate ores in the dome X. Due to the expansion of agricultural production and the ever-growing need for potassium worldwide, this study is of great importance. Fertilizer production accounts for a significant portion of global potassium production, and it can also be used in other areas such as pharmaceuticals, glass, ceramics, food and detergent industries.

Keywords: Potassium, magensium, boron ores, potash exploration, geological survey, salt domes, exploration well.

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant No. AP14870189)

© Ж.Қ. Тухфатов[1*], М.Қ. Джексенов[2], Е.Қ. Бектай[3], Г.С. Тұрысбекова[3], Б.Н. Шидерин[3], 2025.

[1]НГДУ «Доссормұнайгаз» АҚ «Ембімұнайгаз», Атырау, Қазақстан;
[2]Х. Досмұхамедов атындағы Атырау университеті, Атырау, Қазақстан;
[3]Қ.И. Сәтбаев атындағы Қазақ ұлттық ғылыми-зерттеу техникалық университеті, Алматы, Қазақстан.
E-mail: zh.tuhfatov@kmgep.kz

КАСПИЙ МАҢЫ ОЙПАТЫ ТҰЗДЫ КҮМБЕЗДЕРДІҢ БІРІНДЕГІ ТАУ-ХИМИЯЛЫҚ ШИКІЗАТТАРДЫ БАРЛАУ ЖҰМЫСТАРЫ

Тухфатов Жасулан Қасимұлы — геология және минералогия ғылымдарының кандидаты, «Эмбамұнайгаз» АҚ, «Доссормұнайгаз» МГӨБ, Атырау, Қазақстан, E-mail: zh.tuhfatov@kmgep.kz, https://orcid.org/0009-0007-3301-9997;
Джексенов Махамбет Құдайбергенович — география ғылымдарының кандидаты, Х. Досмұхамедов атындағы Атырау университеті, Атырау, Қазақстан, E-mail: ddm85@mail.ru, https://orcid.org/0000-0002-1741-3931;
Бектай Еркін Қалдыбайұлы — техника ғылымдарының кандидаты, Қ.И. Сәтбаев атындағы Қазақ ұлттық ғылыми-зерттеу техникалық университеті, Алматы, Қазақстан, E-mail: erbekta@gmail.com, https://orcid.org/0000-0002-5304-5021;
Турысбекова Гаухар Сейтхановна — техника ғылымдарының кандидаты, Қ.И. Сәтбаев атындағы Қазақ ұлттық ғылыми-зерттеу техникалық университеті, Алматы, Қазақстан, E-mail: ipgauhartas@gmail.com, https://orcid.org/0000-0003-1085-6470;
Шидерин Бауыржан Нурланулы — постдокторант, Қ.И. Сәтбаев атындағы Қазақ ұлттық ғылыми-зерттеу техникалық университеті, Алматы, Қазақстан, E-mail: b.shiderin@satbayev.university, https://orcid.org/0000-0002-5511-334X.

Аннотация. Бұл жұмыста калий, магний тұздары және бор рудаларын алу үшін Қазақстан аймақтарының барлау тарихы мен сипаттамасы егжей-тегжейлі көрсетілген. Әртүрлі тау жыныстары мен минералды көздер және олардың қасиеттері мен құрамдары көрсетілген. Нәтижелер. Х тұзды күмбезінің өлшемі мен құрамы анықталды. Күмбез аймағында назар аударарлық борат кендері, борлы калий-магний тұздары анықталды. 475-525 м тереңдіктегі тұз қабаты үш аймақтың тау жыныстарымен бейнеленген және төменгі, жоғарғы галиттік аймақты және өнімді борлы қондырғыны қамтиды. Жартастың қалыңдығы 9,0 м. Бор оксидінің мөлшері 2,75%, калий 13,1%. Сульфатты қабат жоғарғы хемогенді-шөгінді қабаттан және төменгі элювиальды қабаттан тұрады. Бұл қабаттағы бор мөлшері бораттар: гидроборацит, ашарит, борацит және пинноит болуымен анықталады. Сульфатты қабаттың қалыңдығы 294,0-ден 441,0 м-ге дейін ауытқиды. Ғылыми жаңалық. 1960-1962 және 1988-1992 жылдардағы барлау бұрғылауының қолда бар материалдары негізінде элювиальды бораттардың ірі кен орындары бар перспективалы тұзды күмбез X анықталды. Оның өлшемі мен құрамы анықталды. Морфологиялық және құрылымдық талдау принциптерін басшылыққа ала отырып, біз X күмбезінің тұзды айнасының геологиялық-литологиялық картасын құрастырып, оның негізгі құрылымдық элементтерін бөліп көрсеттік. Практикалық құндылық. Тұз күмбезі X құрамында калий, калий-магний және бор-калий тұздарының көп мөлшері бар. Сондай-ақ бортұзды кендердің кең таралуы, бұл X тұзды күмбезінде кен өндіруді дамыту үшін жаңа аумақтарды ашу бойынша геологиялық барлау жұмыстарын жалғастыруға мүмкіндік береді. Күмбездің орталық бөлігінде ең ықтимал бай кен орындары элювиальды бораттар болып табылады, олардың кен орындары ашылуы мүмкін және шеткері жерлерде өнеркәсіптік қызығушылық объективтерімен ұсынылуы мүмкін.

Түйін сөздер: калий тұздары, магний тұздары, бор тұзы кендері, геолог-барлау жұмыстары, барлау ұңғымасы.

© Ж.К. Тухфатов[1], М.К. Джексенов[2], Е.К. Бектай[3], Г.С. Турысбекова[3], Б.Н. Шидерин[5], 2025.

[1]НГДУ «Доссормунайгаз» АО «Эмбамунайгаз», Атырау, Казахстан;
[2]Атырауский университет имени Х. Досмухамедова, Атырау, Казахстан;
[3]Казахский национальный исследовательский технический университет им. К.И. Сатпаева, Алматы, Казахстан.
E-mail: zh.tuhfatov@kmgep.kz

ПОИСКОВЫЕ РАБОТЫ НА ГОРНОХИМИЧЕСКОЕ СЫРЬЕ В ОДНОМ ИЗ СОЛЯНЫХ КУПОЛОВ ПРИКАСПИЙСКОЙ ВПАДИНЫ

Тухфатов Жасулан Қасимович — кандидат геолого-минералогических наук АО «Эмбамунайгаз», НГДУ «Доссормунайгаз», Атырау, Казахстан, E-mail: zh.tuhfatov@kmgep.kz, https://orcid.org/0009-0007-3301-9997;

Джексенов Махамбет Кудайбергенович — кандидат географических наук, Атырауский университет имени Х. Досмухамедова, Атырау, Казахстан, E-mail: ddm85@mail.ru, https://orcid.org/0000-0002-1741-3931;

Бектай Еркин Калдыбаевич — кандидат технических наук, Казахский национальный исследовательский технический университет им. К.И. Сатпаева, Алматы, Казахстан, E-mail: erbekta@gmail.com, https://orcid.org/0000-0002-5304-5021;

Турысбекова Гаухар Сейтхановна — кандидат технических наук, Казахский национальный исследовательский технический университет им. К.И. Сатпаева, Алматы, Казахстан, E-mail: ipgauhartas@gmail.com, https://orcid.org/0000-0003-1085-6470;

Шидерин Бауыржан Нурланулы — постдокторант, Казахский национальный исследовательский технический университет им. К.И. Сатпаева, Алматы, Казахстан, E-mail: b.shiderin@satbayev.university, https://orcid.org/0000-0002-5511-334X.

Аннотация. В статье подробно описана история исследований в области поисков и разведки магниевых солей, боросолевых руд и калийных солей, а также характеристики потенциальных регионов Казахстана для добычи этих руд. Результаты. Определены размеры и содержание соляного купола X. На площади купола, можно выявить заслуживающие вниманию боратовые руды и бороносные калийно-магниевые соли. Соляная толща на глубинах 475-525м представлена породами трех зон и заключает в себе нижнюю, верхнюю галитовую зону и продуктивную бороносную пачку. Мощность породы 9,0 м. Содержание окиси бора составляет 2,75 %, а калия 13.1 %. Сульфатная толща сложена из верхней хемогенно-осадочной и нижней элювиальной. Бороносность этой толщи определяется наличием боратов: гидроборацита, ашарита, борацита и пинноита. Мощность сульфатной толщи колеблется от 294,0 до 441,0 м. Научная новизна. По имеющимся материалам поискового бурения 1960- 1962,1988- 1992 годов был определен перспективный соляной купол X, который содержит крупные залежи элювиальных боратов. Руководствуясь принципами морфолого-структурного анализа, нами была составлена геолого-литологическая карта соляного зеркала купола X с выделением основных структурных его элементов. Были определены его размеры и содержание. Практическая ценность. В соляном куполе X заключено большое количество ресурсов калийных, калийно-магниевых и борно-калийных солей. А также широкое распространение боросолевых руд, что дает возможность продолжить поисковые работы по обнаружению новых площадей развития для производства руд на соляном куполе X. В Центральной части купола наиболее вероятно богатые залежи, элювиальных боратов, их залежи могут быть вскрыты и по периферии, где они могут быть представлены линзами, представляющими промышленный интерес.

Ключевые слова: калийные соли, магниевые соли, боросолевые руды, геологоразведочные работы, разведочные скважины.

Introduction. The salt formations in the Caspian Depression and Aktobe Trans-Ural region have substantial reserves of potassium and magnesium salts, quantified in billions of tons of K_2O and $MgCl_2$. Currently, 95 formations in the Kazakh segment of the salt-bearing basin are identified to exhibit potassium mineralization to varied extents, with 50 deemed promising. Regarding potassium and magnesium salt resources, only four sites are designated as deposits: Zhilyan, Inder, Satimola, and Chalkar. The initial three have been comprehensively examined, whilst one is now undergoing research and assessment. Kazakhstan Potash Company starts exploration of potash deposits according to the company. They obtained subsoil use rights for Zhilyan and Chalkar in 2011. In 2014, Reuters reported on its plans to invest $3.8 billion in deposits and potash production in Kazakhstan (https://

amm.kz/en/press-center/news/news-blog/907-kazakhstan-potash-company-starts-exploration-of-potash-deposits)

Table 1 Areas of potash exploration and development in eastern Europe and Asia (Wynn, 2016)

Country	Mine production by year			
	2021	2022	2023	2024
Canada	14000	14,600	13,500	15000
Russia	8000	6800	9000	9000
Belarus	7100	4000	4500	7000
China	6000	6000	6000	6000
German	2300	2700	2600	3000
Jordan	1600	1640	1700	1800
Israel	2300	2450	2330	2400
Chile	900	1100	600	750
United States	480	430	390	420

Kazakhstan possesses substantial reserves of potassium and magnesium salts to support the mining and processing industries in fulfilling the agriculture sector's demand for potassium fertilizers in the global market (Bocharov, 2004:350). By recovering this mineral resource Kazakhstan might ascend to the top five global leaders in agricultural fertilizer output. However, the potassium recovery from minerals/rocks is very complicated due to the uniform distribution of potassium throughout the crystal structure (Sandeep, 2020: 2).

Presently, Kazakhstan occupies the second position in the CIS countries, the fourth in Asia, and the seventh globally regarding assessed boron reserves among 11 nations with substantial boron ore deposits.

As a result of geological exploration, prospecting, and scientific research conducted from 1960 to 2011 (with interruptions), a reliable mineral resource base for the production of boron and potassium salts has been established in Western Kazakhstan. Boron-potassium salts represent previously unstudied new types of mining and chemical raw materials, with no analogs in global practice. They are distributed on an industrial scale around the globe only in the halogenic formations of the Kungur tier of the Lower Permian of the Caspian Basin and are a complex raw material containing boron, potassium, magnesium, bromine, and table salt. The search for borate ores and potassium salts in the Caspian Basin remains an important economic task, due to the development of borate ores in the Inder salt dome structure, which made it possible to continue exploration work on borate ores in the dome of the X dome in 1960-1962 and 1988-1992. The salt dome structure X is located in the central part of the Caspian Basin, within the West Kazakhstan region of the Republic of Kazakhstan.

Figure 1. Area of geological exploration for boron-potassium salts.

Tectonics

The described territory is located in the central part of the Caspian Basin, which represents the deeply submerged southeastern part of the Russian Platform. In the tectonic structure of the platform cover, four structural complexes can be distinguished: sub-salt, salt, supra-salt, and cover. The first sub-salt structural complex includes Paleozoic rocks up to the Lower Permian Kungurian stage (Khalturina, 1985:205). The rock of this complex is not exposed anywhere in the central part of the Caspian Depression, so its structure can only be inferred from seismic profiling data.

The second salt structural complex is represented by a thickness of hydrochemical sediments from the Lower Permian. In the area of the salt domes, Mesozoic and Paleogene rocks are highly displaced and reflect the tectonics of the salt core. Here, local concordances, breaks, reductions in thickness, pinch-outs of individual horizons, and a sharp increase in dip angles towards the dome caps are observed. In the inter-dome zones, the rocks of this complex lie almost horizontally. Dome X is the largest salt uplift identified within the basin. The studied salt dome X, in terms of its size and morphology, belongs to the type of hidden salt domes, where the salt core is exposed by a cover of younger deposits, and older deposits are pierced by the salt body during the growth of the salt dome.

The salt massif has quite steep slopes. A particularly sharp descent is noted in the western part, where the dip angles reach 40°. To the southeast, the slopes of the salt massif are more gentle, with dip angles not exceeding 18-20°. According to seismic survey data, the following structural elements and slopes can be distinguished in the salt massif: southwestern, northwestern, northern, eastern, southeastern, and southern. All of them are separated from each other by salt outcrops. The width of the dome, according to seismic map data, ranges from 14 to 40 km, with an area of about 200 sq. km. A characteristic feature is the development of powerful sulfate thicknesses on the dome crests. During the formation of the dome, the sulfate thickness in the form of a horizontal "cap" rose at different speeds, with the underlying plastic salt masses, being relatively less local, breaking into separate blocks (Diarov, 2000:82).

According to available data, the dome's vault is divided into two major blocks: the northeastern part and the southwestern part, which extend parallel to each other along the entire length of the dome. The dividing strip is formed by drilled wells No. 28, 4, and 36. The northeastern block has a slight interruption in the strip of drilled wells No. 66, 68, and 20, which apparently formed as a result of tectonic phenomena. The southwestern block is significantly lower compared to the northeastern one, which was mainly influenced by the subsidence of the salt layer, as indicated by geological cross-sections showing a gradual deepening of the salt mirror to the southwest. This block is considered tectonically the most stable, having experienced the least active uplift during the overall development of salt tectogenesis in the dome area. Within its limits, the thickness of the sulfate layer is predominant (up to 209m in well No. 30).

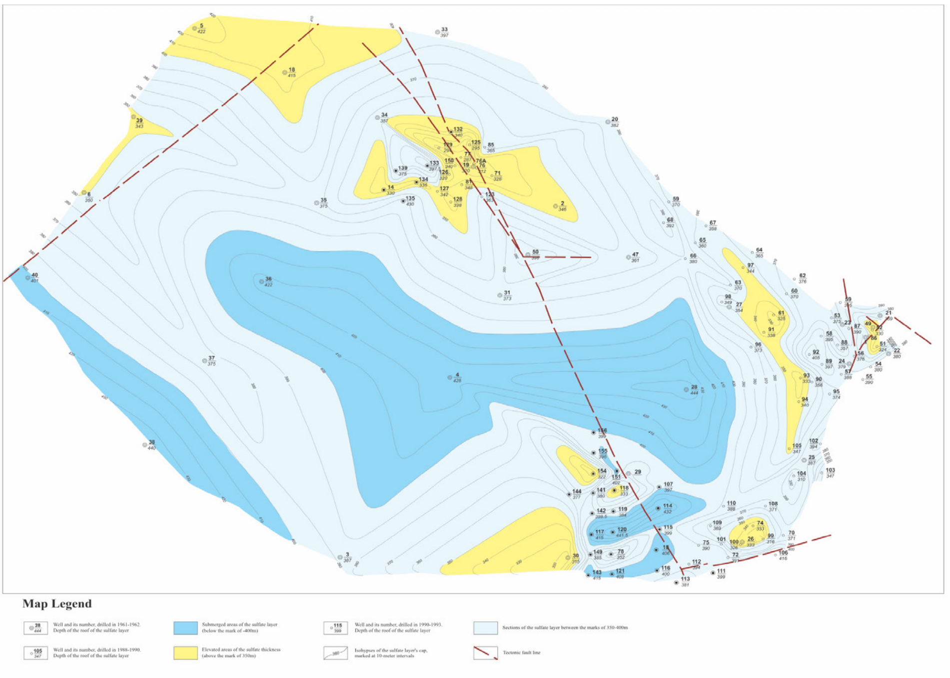

Figure 2. Schematic geological map of sulfate thickness on structure X.

Similar to the more well researched Satimola, the salt dome X formed unevenly, pulsing in both space and time. Individual portions accelerated or decelerated at different times in relation to the linked ones, all against the background of the salt masses' overall forward motion. Anticlinal structures were clearly created inside the dynamically elevating portions of the salt mass. When the overlaying deposits reached the erosional incision, they fractured because they were much more stiff than the salts. Eluvium from the salt rocks—the so-called gypsum cap—formed intensely when chemogenic deposits appeared in the leaching zone, which caused the sulfate layer to thicken noticeably (Diarov, 1981:100). The Upper Permian to Lower Cretaceous was the most active time period for gypsum cap formation, and the Paleogene is also discernible in some places that correspond to the anticlinal uplifts of the salt masses. The nearly total lack of overlaying terrigenous deposits from the Upper Permian, Triassic, Jurassic, and Paleogene in the section serves as evidence for this. In some blocks, deposits of the lower (well No. 19, 34, 77, 99) or upper (well No. 1, 5, 6, 23, 30, 39, 74, 77, etc.) horizons are found in the section. At the same time, the chalk deposits preserved from erosion within some of these blocks are characterized by minimal thickness values

Basin internal structure

We have created a geological-lithological map of the salt mirror of dome X, emphasizing its primary structural components, based on our experience on the Inder and Satimola domes and the morpho-structural analysis principles. Polyhalite and anhydrite are among the potassium, potassium-magnesium, and boron-potassium salts that make up the dome. It has been shown that there are more insoluble residues (clay, borate sulfates) than potassium salt. In regions where boron-potassium salts emerge onto the salt mirror during their washing, this has greatly accelerated the creation of eluvial formations. A more potent gypsum layer is currently forming on the salt mirror as a result of the prolonged leaching of salts by groundwater, which is manifested in the morphology of the sulfate layer rocks as ridges and mounds. (Diarov, 1983:153) These salts and anhydrites are potassium, potassium-magnesium, and boron-bearing. Individual anticlinal formations within the dome component of the salt massif X, Bagyrlaiskaya, Kodzhinskaya, and Vostochnaya, can be identified by a combined study of the relief and isopachy of the sulfate layer rocks and the lithology of the salt rocks themselves. The anticlinal folds' axes undulate along the strike and are extended parallel to the dome wing.

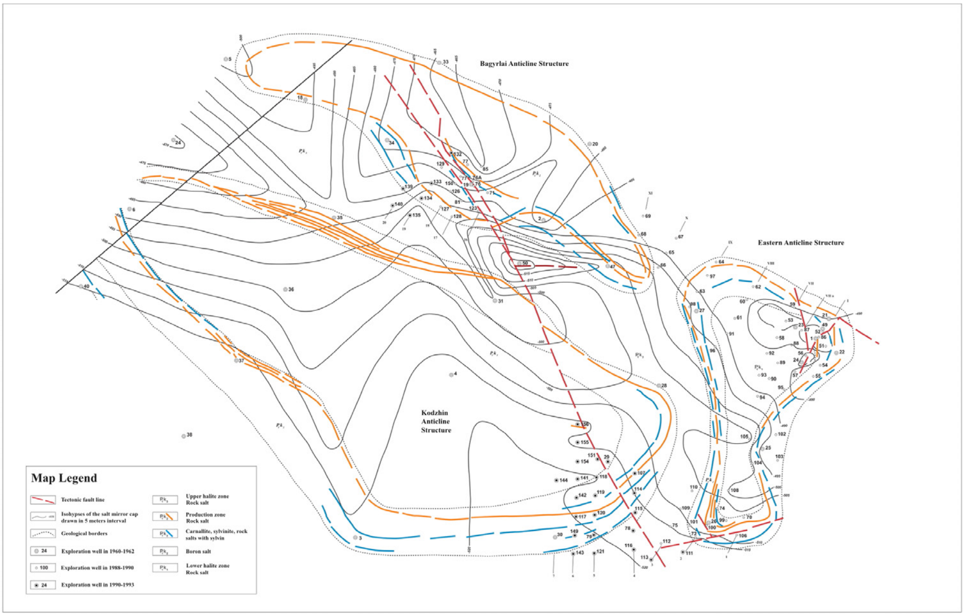

Figure 3. Schematic geological-lithological map of the salt mirror structures X.

Because of the unique composition and structure of the boron-potassium salt layers, the outcrops of productive salt horizons on the salt mirror control the position of the identified anticlinal structures. This means that the wings of the identified structures are made up of potassium and boron-potassium salts everywhere. The layers of potassium and boron salts in the productive zone along the strike are complicated by hinges, diving towards the general dip of the anticlinal structure, and isoclinal folds of different orders (Tihvymskyi, 1985:25). The anticlinal structure of Bagyrla is extended from northwest to southeast, spanning 10 km and measuring 1.5 to 2.5 km in breadth. The long to short axis has a 4:1 ratio. The exploration wells No. 5, 18, 34, 19, 2, and 47 establish the southwest wing of the structure. This section's northeast wing, which is exposed by wells No. 20 and 33, is configured similarly to the outer wing. There are two faults that cross the wing from southeast to northwest. The Kodzhinskaya anticline structure is elongated from the northwest to the southeast over a distance of 13 km with a width of 2–5 km. Boron-potassium and potassium salts of the fold wings are revealed by wells No. 30, 3, 37, 6, 35, 31, 50, and 28. The southeastern wing is intersected by a fault that extends from the Bagyrla Anticline over a distance of 13 km and fades in the southern part of the dome. The eastern anticline structure is elongated from north to south over a distance of 6.5 km with a width of 1.5–3.2 km. The northern and southern wings are complicated by tectonic faults and cut through all layers of potassium and boron salts. Boron-potassium and potassium salts of the wings are found in wells No. 26, 25, 1, and 27. On the dome, adjacent synclinal structures are located next to the highlighted anticline structures, elongated in the northeastern direction. The core of these formations consists of younger salt deposits. To the north of the work area near the village of Krugly, due to the growth of the eponymous dome, the Ural River deviates to the east from its main direction. In the southern part of the local uplift, a tectonic fault can be traced, along which movement occurred in recent times.

Materials. Potassium salt. A list of potash minerals and its potash content is shown in Table 2. Where, carnallites, sylvinites, and polyhalites are found among the several regions within the investigated dome where wells have been found. The potassium salts that are most prevalent in the vicinity of structures X and Lebyazhinsky are carnallite. It usually combines with halite, but it also occasionally combines with bischofite, kieserite, and sylvite. The potassium level of the salts varies from 13.11% (well No. 20) to fractions. The deposits reach a thickness of 66 meters (well No. 35).

Table 2 Different potash minerals with approximate K2O content [Sandeep, 2020: 4]

Minerals	Chemical formula	K_2O (approx.; %)
Orthoclase	$KAlSi_3O_8$	16
Mica (muscovite)	$KAl_2(AlSi_3O_{10})(OH)_2$	8–12
Nepheline syenite Kainite	$Na_3KAl_4Si_4O_{16}$	5–7
Langbeinite Carnallite	$MgSO_4 \cdot KCl.3H_2O$	19
Microcline Polyhalite	$MgSO_4.K_2SO_4$	22
Alunite	$KCl \cdot MgCl_2 \cdot 6H_2O$	17
Feldspar	$KAlSi_3O_8$	15–17
Glauconite	$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$	16
Sylvite	$K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 4Al(OH)_3$	11
	KAlSi3O8	5–14
	$(K,Na)(Fe^{3+,}Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$	4–8
	KCl	63

Magnesium salts. The chemical composition in #2 (interval 556.0–560.5 m) of structure X, which is represented by bischofite and kieserite (well 22), is as follows:

- Cl -19.2%, Mg -11.05%, K -1.94%, Na -11.7%, and Ca -0.61%
- The insoluble residue is 0.57, Ḃ is 0.023%, and SO_4 is 43.24%.

Kieserite, halite, and individual grains of carnallite and polyhalite make up these rocks.

Well No. 44 encountered the bischofite rock at the Lebyazhinskaya structure between 623 and 625 m and 634 and 645 m. In certain locations, the kieserite rock dominates the bischofite rock in the 635.3–636.0 m period. The following was revealed by the examination of the rock from the 635.0–636.0 m interval:

- Ca -0.19%, CI -14.13%, Mg -15%, and SO_4 -31.19%.

The content is determined as follows based on several samples taken from different points in the rock's bischofite layer:

- Mg— about 11.6%, CI (around 33–34%).

Rock salt is widely distributed in the dome and contains at least 90% sodium chloride. The deposits of rock salt have not been assessed, and the reserves have not been calculated.

Borates. Borate ores in the sulfate layer have been encountered by many wells. They are represented by hydroboracite, ascharite, boracite, and less frequently, pinnoite. The ore-forming minerals are hydroboracite and ascharite. The maximum content of conditional ores (with borate content accepted as equal to 3% B_2O_3) is 10m (well 76a). In the salt layer, borates were noted by five wells, but the B_2O_3 content in them usually does not exceed 1.0%, except for well No. 9, located near the isthmus connecting X and Lebyazhinsky. Here, in the interval of 516.0–518.5 m and 518.5–519.5 m, the B_2O_3 content in rock salt in the anhydrite rock is 12.70 and 1.92%, respectively.

The widespread occurrence of borate brines in the central part of the Caspian Lowland within the salt domes, including structure X and their outcrops on the salt mirror cut, has led to the formation of eluvial borate ores in the gypsum cap, facilitating the discovery of new areas for the development of borate ores with boron oxide content of 9-12%. (Lysicin,1983,300) This situation allows for the continuation of exploration work to discover new areas for the development of eluvial boron ores in the gypsum layer of the salt dome X. In this regard, the exploration projects were designed to identify eluvial borate deposits in the gypsum layer with boron content of 9-12%. The selection of objects for exploration was justified by previous work on dome X in 1960-1962 and 1988-1992. As a result of these exploration works conducted by the Inder Geological Exploration Expedition in 1960-1962, a fairly wide boron-bearing capacity of hydrochemical deposits was established on this structure. In 12 of the previously drilled wells, boron manifestations were noted, including seven wells in the gypsum layer and five wells in the salt layer. The boron oxide content in the gypsum ranges from 9.0 to 38.40%. The thickness of the ore bodies is 1.0-9.0m. The boron content in the gypsum layer is represented by veins, nests, and inclusions of ulexite and asharite. As a result of exploration work from 1988 to 1990, industrial-grade borate ores were discovered in the gypsum layer by wells No. 76a, 77, and 100 on the dome structure. The exploration revealed rich boron-bearing rocks in different intervals with following boron oxide content shown in table below.

Table 3 Discovered boron bearing rock intervals with boron composition

Well No.	Intervals, m	Boron oxide content B_2O_3 %
76a	426-429	0.63 – 2.24
	428.0-436.0	4.26 – 28.48
	436.0 – 438.0	0.78 – 7.37
77	441.0-446.0	2.08 to 31.68
100	440.0 - 443.5	1.2 to 3.41

The boron-bearing rocks are represented by gypsum and gypsum-clay rocks with lenses and inclusions of hydroboracite and asharite. The salt layer has been exposed by wells at depths between 475 m and 525 m. The salt layer primarily constitutes the Kodzhinskaya and Bagyrlaiskaya anticlines and is characterized by rocks from three zones: the lower halite, productive boron-bearing, and higher halite. The deposits of the lower halite zone have been disclosed by wells No. 151, 154, 155, and 156, characterized by gray and light gray rock salt with fine- and medium-sized crystals. The color is mostly attributable to the presence of several mineral impurities. Rock salt accompanied by anhydrite is the most prevalent. Potassium-magnesium minerals are infrequently found in rock salt. Carnallite and sylvite inclusions in rock salt are seen in well No. 156 within the depth range of 516.0-525.0 m. Mineralization in rock salt within mountainous regions is exceedingly uncommon. The productive salt layer consists of rock salt including two strata: a lower layer rich in boron and an upper layer abundant in potassium. They were encountered by twelve exploration wells: No. 107, 114, 115, 118, 119, 120, 130, 133, 134, 139, 142, and 149. The majority of these wells found rock salt, however only well No. 135 discovered carnallite rock with 1.32% potassium within the depth range of 475.5-483.0 meters. Beyond the productive horizon is the upper halite formation, characterized by light gray, polycrystalline, huge rock salt. Exploratory wells No. 78, 111, 113, 116, 121, and 135 encountered them. The structural characteristics of the salt core of the X dome are dictated by the existence of three principal anticline structures (Bagyrlaiskaya, Kodzhinskaya, and Vostochnaya), within which the rocks of the lower boron-bearing package of the salt layer are exposed at the salt mirror. The extensive anticlines are clearly complicated by higher-order folds, the mapping of which presents significant challenges at the present stage of research. The anticipated outcrops of the boron-rich layer within the salt thickness at the flanks of these anticlines represent the most prospective regions for the exploration of eluvial borate deposits in structure X. The sulfate thickness is situated directly on the salt mirror. It has been identified through drilling at depths of 294.0 to 441.0 m, with a thickness varying from 42.0 to 242.0 m. The sulfate thickness of the dome exhibits genetic heterogeneity. The upper section comprises relatively well-preserved chemogenic-sedimentary carbonate-sulfate deposits, which finalize the phases of halogenic sedimentation in the Caspian region, whereas the lower section consists of eluvial formations resulting from the leaching of the salt strata, referred to as the gypsum cap. (Diarov, 2000: 68) The considerable thickness of the eluvial layer across extensive regions signifies the intensity and longevity of the salt leaching process, whereas pronounced thickness discrepancies in neighboring areas, along with the characteristics of the superjacent terrigenous Upper Permian-Cenozoic deposits—marked by a blocky, irregular pulsation in the formation of the salt dome—are noted. The cover layer consists of fine-grained, thick gypsum in shades of gray and dark gray, underlain by a layer of anhydritized gypsum. The layer thickness varies between 10.0 and 82.0 meters. The gypsum cap consists of polycrystalline gypsum interspersed with layers of greenish and grayish-green clays (1.0-7.0 m), gypsum clays (5.0-52.0 m), and anhydrite-gypsum rocks ranging from 5 to 15 m in thickness. Gypsum constitutes the primary rock type that forms the gypsum cap. Their hues are light gray, gray, and dark gray. The thickness varies from 32.0 to 160.0 meters. Boron minerals, including ascharite, hydroboracite, and ulexite, are present in gypsum. At the interface of the eluvial layer and rock salt, there exists an anhydrite layer with a thickness ranging from 2.0 to 8.0 meters. This is a gray, light gray rock with a bluish hue, characterized as cryptocrystalline. Boron-containing gypsum formations were identified in six wells: No. 115, 116, 142, 149, 154, and 155, located on the Kodzhinskaya anticline. The boron concentration is indicated by the presence of asharite and hydroboracite inclusions. Their thickness varies from 1.0 to 9.0 meters. The boron oxide concentration varies from 0.4% to 1.71%. Boron-bearing gypsum was discovered in two wells, No. 133 and 134, on the Bagyrla anticline, occurring in two and seven intervals, respectively, with thicknesses ranging from 1.0 to 7.0 meters. The boron oxide concentration varies from 0.41% to 2.75%. A cover layer consisting of terrigenous rocks from the Triassic, Neogene, and Quaternary deposits is situated above. (Iarzhemskyi, 1984: 70)

Investigate indications.

The exploratory indicators employed in the quest for borate ores under the sulfate layer of dome X were as follows:

1. The superficial presence of the sulfate layer of the dome from the terrestrial surface. Genetic relationship of eluvial borate deposits with outcrops on the salt mirror of boron-potassium strata within the salt thickness:
2. The correlation of boron-potassium and potassium salts with a singular producing layer of the salt massif:
3. The positioning of boron-potassium horizons and their eluviation (borates) within the sulfate layer on the flanks of isoclinal salt formations.
4. The presence of eluvial borates within the robust development of keprok local structures is linked to the swift creation of eluvial deposits in regions where boron-potassium salts appear on salt mirrors during erosion

Methods. Chemical analysis tasks.

To achieve a comprehensive qualitative evaluation of borates, boron-potassium and potassium salts, and rock salt, the entire core recovered from these rocks was subjected to sectional sampling. Samples were extracted by bisecting the core along its longitudinal axis. One portion underwent additional processing, while the remaining portion was designated for storage. The section lengths for borates, boron-potassium, and potassium salts ranged from 0.5 to 1.0 meters; for rock salt, from 2.0 to 10 meters; and for anhydrites, from 0.5 to 3.0 meters. Sample processing was conducted mechanically utilizing the AC-150 x 80 jaw crusher, the AV 200 x 125 roller crusher, and the 60-DR type disc pulverizer, encompassing crushing, mixing, and reduction. Screens with apertures ranging from 5.0 to 0.25 mm were employed for sifting. (Filko, 1990, 7)

The reduction was executed through quantization with the Richards-Chechet formula ($Q = rd^2$) with uniformity coefficients:

- Rock salt and anhydrite — 0.1;
- Potassium and boron-potassium salts — 0.3;
- Borates, boron clays, and gypsum — 0.3.

The initial weight of the sample varied between 1.2 and 19.0 kg, while the final weight ranged from 100 to 185 g. A total of 406 samples were collected and analyzed using the designated method. Among these, 384 samples were comprised of boron-containing gypsum and anhydrites, whereas 22 samples were of rock and potassium salts.

The analytical work encompassed chemical and mineralogical-petrographic examinations of the stone material throughout the process. Chemical investigation was conducted on boron-bearing rocks from the gypsum layer, as well as potassium and boron-potassium salts. A total of 406 samples were examined for a condensed analysis to ascertain the chemical composition of the rocks. Among these, there are 384 samples from the gypsum layer and 22 samples from the salts. Ten percent of all samples undergo internal control analysis. External control was not conducted. In the gypsum layer samples, only the concentrations of boron oxide, magnesium oxide, and water (H_2O) were ascertained. Rock, potassium, and boron-potassium salts underwent a diminished analysis to ascertain K, Cl, Br, B_2O_3, and H_2O content. The chemical laboratory conducted chemical analyses and internal control assessments (Diarov, 1993:9).

Results and discussion. Salt dome X, similar to the renowned boron ore deposits of Inder and Satimola, is situated within the developmental zone of the boron-bearing carnallite-sylvite-halite lithological-facial complex of the Permian halogenic formation in the Central Caspian region. The dome is categorized as medium in size and characterized as buried and breached in microstructural type. The geological and geophysical analysis is inadequate, particularly concerning the salt layer, which hinders the comprehension of the internal structure of the salt core and, subsequently, the identification of the most effective approach for undertaking exploration activities for eluvial borates.

Based on the data from exploratory drilling performed between 1960-1962 and 1988-1992, the location of the dome, in proximity to established borate deposits, clearly suggests that X is a viable site for discovering substantial eluvial borate deposits. The exploratory wells conducted on the dome failed to locate borate ores within the gypsum cap; nonetheless, 8 of the 28 wells intersected boron-bearing gypsum containing non-industrial-grade boron anhydrite. This suggests that it is highly feasible to locate significant borate ores and boron-containing potassium-magnesium salts in the dome region. The salt thickness identified by exploratory wells at depths of 475-525 meters comprises rocks from three zones, including a lower and upper halite zone, as well as a productive boron-bearing formation. The productive zone consists of rock salt containing interlayers and inclusions of carnallite and sylvite. The thickness of the rock measures 9.0 meters. The boron oxide concentration is 0.04%, while the potassium concentration is 1.17%. The sulfate layer comprises two components: the upper chemogenic-sedimentary layer and the bottom eluvial layer. The productive eluvial section of the sulfate layer (gypsum cap) markedly differs from the sedimentary layer regarding structure, composition, constituent rocks, and their structural-textural characteristics, which are wholly dictated by the conditions of its formation. Eluvial layer is composed of polycrystalline gypsum, interspersed with clays and clayey gypsum. The boron concentration of this layer is dictated by the existence of borates: hydroboracite, asharite, boracite, and pinnoite. The sulfate layer thickness varies between 294.0 and 441.0 meters. According to the consolidated mechanism for the production of eluvial borate deposits, the most attractive region for exploration is the central portion of the structure (the dome). The enormous quantity of exploratory wells drilled at the periphery, notwithstanding the considerable thickness of the eluvial layer, substantiates this assertion. Rich concentrations of eluvial borates are most likely located in the central region of the dome, with additional deposits potentially found throughout the perimeter, represented by lenses of industrial significance. (Bocharov, 2004, 340)

Conclusion. In regard to the research results, the following recommendations are presented:

1) The examination of eluvial borates within the dome of X appears promising, particularly in its center region, namely within the Kodzhinskaya and Bagyrlaiskaya anticlines.

2) During exploratory drilling, take into account the pronounced dip angles of productive salt formations, as the eluvial borate formations show a band-like configuration in plan view, requiring quick adjustments to the diameters of the well network when actual material is extracted.

3) Persist in exploration activities for novel deposits of boron-potassium salts on the upper portion of dome X utilizing a 2.0 × 2.0 km grid with a well depth of 1200 m.

4) Perform comprehensive seismic analysis on the dome's vault, and the identified promising regions should be identified utilizing geophysical techniques (CMPV method - correlation method of wave refraction) to investigate the morphology of salt formations. Prior research indicates that the eluvium of productive rocks shows up in the subterranean topography of sulfate layer rocks, characterized by ridges and crests, with relative elevations compared to other relief forms varying from 20 to 140 meters. The placement of potassium and boron-potassium salts appears to be revealed in the subsurface topography of the sulfate-bearing rocks

References

Bocharov V.M., Khalturina I.I. On the issue of the formation of various complexes of potassium-magnesium salts of the Caspian halogen formation. Structure and conditions of formation of potassium salt deposits. Novosibirsk: Nauka (1981), – P.127-144 Search, exploration, and evaluation of boron deposits. Moscow. Nedra, 1983. – P. 325. (in Eng.).

Bocharov V.M., Tukhvatov K., Mineral and chemical raw materials of the Northern Caspian "Geology of the Caspian and Aral Sea Regions" - Almaty: Kazakh Geological Society "KazGEO", (2004), – P. 347-356. (in Eng.).

Diarov M.D., Zakonov A.N., Tukhvatov K., Features of the mineral composition of boron-bearing zones in the salt masses of the Caspian Depression. Journal of "Geology and Geochemistry of Fossil Fuels,"Lviv, (1993), №2. (in Eng.).

Diarov M.D., Serikov T. Patterns of formation of boron salt deposits. Almaty, (2000), –P. 56-82. (in Eng.).

Diarov M.D., Tukhvatov K., Utarbayev G.S. Main patterns of halogenic boron accumulation in Earth's history // Main problems of salt accumulation Nauka, (1981). –P. 100-112. (in Eng.).

Diarov M.D., Utarbayev G.S Searching criteria for halogenated borate deposits. Sovet geology, (1991) №5, –P. 13-16.

Filko A.S The state of the mineral resource base of the agro-industrial complex of the USSR and the main directions of its development. Forecasting and exploration of mining and chemical raw materials. Nedra, (1990). –P. 5-14. (in Eng.).

https://amm.kz/en/press-center/news/news-blog/907-kazakhstan-potash-company-starts-exploration-of-potash-deposits

Iarzhemskyi, I. Boron-bearing halogenated rocks. Novosibirsk, Nauka, (1984), 73 p. (in Eng.).

Jeff Wynn and Greta J. Orris, Geology and Undiscovered Resource Assessment of the Potash-Bearing Central Asia Salt Basin, Turkmenistan, Uzbekistan, Tajikistan, and Afghanistan, Scientific Investigations. 2016. Report 2010–5090–AA (in Eng.).

Jexenov, Makhambet K., Tukhfatov, Zhassulan K., Bektay, Erkin K., Abdinov, Rauan Sh, Turysbekova, Gauhar S., News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. DOI 10.32014/2024.2518-170X.428 STRUCTURAL-TECHTONIC AND MINERALOGICAL STRUCTURE OF INDER LIFTING FIELD, MINING AND CHEMICAL RAW MATERIALS IN ATYRAU REGION http://www.geolog-technical.kz/assets/20241209/3.%2032-48.pdf (in Eng.).

Khalturina I.I., Bocharov V.M., Avrova N.P. Boronates of the Caspian Halogen Formation and Their Genesis. KazNIINTI. (1985). №845. 205 p. (in Eng.).

Sandeep Kumar Jena. A Review on Potash Recovery from Different Rock and Mineral Sources Mining, Metallurgy and Exploration, 2020. (in Eng.).

Tihvinskyi I.N. Main problems of developing the raw material base of mineral salts in the USSR. Natural soda and dawsonite occurrencess in the USSR. Nauka, (1985). –P.25-35 (in Eng.).

U.S. Geological Survey, Mineral commodity summaries 2016 to 2019. Prepared by Stephen M. Jasinski (in Eng.).

Dzhaksenov M.K., Ismagilov F.R., Akhmetov S.M., Diarov M.D., Bektai E.K. Utilizaciya serovodorodsoderzhashchih neftezavodskih gazov [Utilization of hydrogen sulfide-containing refinery gases]. News of NAS RK, Almaty, Chemistry and Technology series No.5, 2020, –P.64-70. (COXON) https://doi.org/10.32014/2020.2518-1491.81 (in Russ.).

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of Sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of Sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайтах:

www:nauka-nanrk.kz

http://www.geolog-technical.kz/index.php/en/

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*

Редакторы: *Д.С. Аленов, Ж.Ш.Әден*

Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 15.06.2025.

Формат 70х90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.

14,5 п.л. Заказ 3.

РОО «Национальная академия наук РК»

050010, Алматы, ул. Шевченко, 28, т. 272-13-19