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The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.

The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

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Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

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

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

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

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

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

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

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

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

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©Zhanbatyrov A.A.[*1], Tukhfatov Zh.K.[2], Bektay E.K.[3], Turisbekova G.S.[3], Zhanbatyrov N.A.[1], 2026.
[1]LLC "Tackop Inter", Astana, Kazakhstan;
[2]NGDU "Dossormunaigas", JSC "Embamunaigas", Atyrau, Kazakhstan;
[3]Satbayev University, Almaty, Kazakhstan.
E-mail: zaaz1953@mail.ru

CURRENT STATE OF POTASH ORE DEVELOPMENT IN THE CASPIAN LOWLANDS OF THE REPUBLIC OF KAZAKHSTAN: PROBLEMS AND SOLUTIONS

Zhanbatyrov Arun — Candidate of Technical Sciences, LLP Tackop Inter, Astana, Kazakhstan, E-mail: zaaz1953@mail.ru, https://orcid.org/0009-0002-8845-931x;
Tukhfatov Zhasulan — Candidate of Geological and Mineralogical Sciences, NGDU "Dossormunaigas", JSC "Embamunaigas", Atyrau, Kazakhstan, E-mail: zh.tuhfatov@kmgep.kz, https://orcid.org/0009-0007-3301-9997;
Bektai Erkin — Candidate of Technical Sciences, Satbayev University, Almaty, Kazakhstan, E-mail: erbekta@gmail.com, https://orcid.org/0000-0002-5304-5021;
Turusbekova Gauhar — Candidate of Technical Sciences, Satbayev University, Almaty, Kazakhstan, E-mail: ipgauhartas@gmail.com, https://orcid.org/0000-0003-1085-6470;
Zhanbatyrov Nurlan — Master's Student, LLP Tackop Inter, Astana, Kazakhstan, E-mail: nuriksam@mail.ru, https://orcid.org/0009-0002-1565-1802.

Abstract. The article analyzes the current state of preparation for the development of potash and potash-bearing ores in the Pre-Caspian Depression. In 2023, a 25-year license (with the possibility of extension) for the extraction of mineral resources was obtained for the Satimola deposit. “Taskor Inter” LLP developed and approved a Mining Operations Plan for the underground extraction of 25 million tons of potash and potash-bearing ores per year.

Results. Using the Satimola structure as an example, the central site has been selected as the primary object for development, which in turn makes it possible to obtain relevant and comprehensive geological information, ensure degassing of the rock mass, and significantly reduce drilling costs.

For the underground development of potash deposits, it is necessary to train qualified specialists at both higher and intermediate levels - from the study of

mineral raw materials to the justification of technological parameters for extraction and processing (Baryakh A.A et al, 2022). It is proposed to organize such training at the S. Utebayev Atyrau University of Oil and Gas (Zhanbatyrov A.A et al, 2024).

Scientific novelty: The proposed innovative method for preparing a solid mineral deposit for industrial development by underground mining has been implemented at the Satimola structure within the project "Mining Operations Plan for Ore Extraction at the Satimola Deposit."

Practical value. The authors propose conducting additional studies of the mining-geological, mining-technical, hydrogeological, geotechnical conditions, as well as gas-dynamic phenomena, using modern research methods and scientific instruments.

Keywords: boron-bearing structures, boron-potash salts, carnallite-kieserite rocks, boron minerals - hydroboracite, caliborite, boracite.

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©Жанбатыров А.А.*[1], Тұхфатов Ж.К.[2], Бектай Е.Қ.[3], Тұрысбекова Г.С.[3], Жанбатыров Н.А.[1], 2026.

[1]«Tackop Inter» ЖШС, Астана, Қазақстан;
[2]«Ембімұнайгаз»АҚ, «Досормұнайгаз» МГӨБ, Атырау, Қазақстан;
[3]Сәтбаев Университеті, Алматы, Қазақстан.
E-mail: zaaz1953@mail.ru

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ КАСПИЙ МАҢЫ ОЙПАТЫНДАҒЫ КАЛИЙ КЕНДЕРІН ИГЕРУДІҢ ҚАЗІРГІ ЖАҒДАЙЫ: МӘСЕЛЕЛЕРІ МЕН ШЕШУ ЖОЛДАРЫ

Жанбатыров Арун — техника ғылымдарының кандидаты, «Tackop Inter» ЖШС, Астана, Қазақстан,
E-mail: zaaz1953@mail.ru, https://orcid.org/0009-0002-8845-931x;
Тухфатов Жасұлан — геология-минералогия ғылымдарының кандидаты, «Доссормұнайгаз» МГӨБ, «Ембімұнайгаз» АҚ, Атырау, Қазақстан,
E-mail: zh.tuhfatov@kmgep.kz, https://orcid.org/0009-0007-3301-9997;
Бектай Еркін — техника ғылымдарының кандидаты, Сәтбаев университеті, Алматы, Қазақстан,
E-mail: erbekta@gmail.com, https://orcid.org/0000-0002-5304-5021;
Турусбекова Гаухар — техника ғылымдарының кандидаты, Сәтбаев университеті, Алматы, Қазақстан,
E-mail: ipgauhartas@gmail.com, https://orcid.org/0000-0003-1085-6470;
Жанбатыров Нурлан — магистрант, "Tackop Inter" ЖШС, Астана, Қазақстан,
E-mail: nuriksam@mail.ru, https://orcid.org/0009-0002-1565-1802.

Аннотация. Мақалада Каспий маңы ойпатындағы калий және калий құрамды кендерді игеруге дайындықтың қазіргі жағдайына талдау жасалған. 2023 жылы Сатимола кен орнында 25 жыл мерзімге (ұзарту мүмкіндігімен) пайдалы қазбаларды өндіруге лицензия алынған. «Таскор Inter» ЖШС жерасты тәсілімен жылына 25 млн. тонна калий және калийқұрамды кен өндіруге арналған Тау-кен жұмыстарының жоспарын жасап, келісімнен өткізді.

Боркұрамды кендер мен калий кендерінің маңызды техникалық айырмашылығын атап өткен жөн: су әсерінің қауіптілігі. Қазақстанда тәжірибе тек боркұрамды кендерді өндірумен шектеледі.

Нәтижелері. Сатимола құрылымын мысалға ала отырып, орталық учаске бірінші кезекте игеру нысаны ретінде таңдалған, бұл өз кезегінде өзекті және толық геологиялық ақпарат алуға, тау жыныстары массивін дегазациялауға және бұрғылау шығындарын айтарлықтай төмендетуге және жерасты жаәне жерасты жағдайында жүргізілетін барлау нәтижелері бойынша жаңа деректер алу тиімді игеру мен өнеркәсіптік қауіпсіздікті қамтамасыз етуге мүмкіндік береді.

Калий кен орындарын жерасты тәсілімен игеру үшін минералдық шикізатты зерттеуден бастап өндіру және өңдеу технологиялық параметрлерін негіздеуге дейінгі барлық кезеңдерге қажетті жоғары және орта буын мамандарын дайындау үшін, С.Өтебаев атындағы Атырау мұнай және газ университеті базасында ұйымдастыру ұсынылады.

Ғылыми жаңалығы. Жерасты тәсілімен қатты пайдалы қазбалар кен орнын өнеркәсіптік игеруге дайындаудың ұсынылып отырған инновациялық әдісі Сатимола құрылымында «Сатимола кен орнында рудаларды өндіруге арналған Тау-кен жұмыстарының жоспары» жобасында енгізілген.

Практикалық құндылық. Авторлар кен орнын игерудің тау-геологиялық, тау-техникалық, гидрогеологиялық, геотехникалық жағдайларын және газ-динамикалық құбылыстарын қазіргі заманғы зерттеу әдістері мен ғылыми құралдар негізінде қосымша зерттеуді ұсынады.

Түйін сөздер: тырмалау құрылымдары, бор-калий тұздары, карналлит-кизерит жыныстары, бор минералдары-гидроборацит, калиборит, борацит

©Жанбатыров А.А.[1*], Тухфатов Ж.К.[2], Бектай Е.К.[3], Турысбекова Г.С.[3], Жанбатыров Н.А.[1], 2026.
[1]ТОО «Tackop Inter», Астана, Казахстан;
[2]НГДУ «Доссормунайгаз» АО «Эмбамунайгаз», Атырау, Казахстан;
[3]Satbayev University, Алматы, Казахстан.
E-mail: zaaz1953@mail.ru

СОВРЕМЕННОЕ СОСТОЯНИЕ ОСВОЕНИЯ КАЛИЙНЫХ РУД ПРИКАСПИЙСКОЙ НИЗМЕННОСТИ РЕСПУБЛИКИ КАЗАХСТАН: ПРОБЛЕМЫ И РЕШЕНИЯ

Жанбатыров Арун — кандидат технических наук, ТОО «Tackop Inter», Астана, Казахстан, E-mail: zaaz1953@mail.ru, https://orcid.org/0009-0002-8845-931x;
Тухфатов Жасұлан — кандидат геолого-минералогических наук, НГДУ «Доссормунайгаз», АО «Эмбамунайгаз», Атырау, Казахстан,
E-mail: zh.tuhfatov@kmgep.kz, https://orcid.org/0009-0007-3301-9997;
Бектай Еркін — кандидат технических наук, Satbayev University, Алматы, Казахстан,
E-mail: erbekta@gmail.com, https://orcid.org/0000-0002-5304-5021;
Турусбекова Гаухар — кандидат технических наук, Satbayev University, Алматы, Казахстан,
E-mail: ipgauhartas@gmail.com, https://orcid.org/0000-0003-1085-6470;
Жанбатыров Нурлан — магистрант, ТОО «Tackop Inter», Астана, Казахстан,
E-mail: nuriksam@mail.ru, https://orcid.org/0009-0002-1565-1802.

Аннотация. *Актуальность***.** В статье проведён анализ современного состояния готовности к освоению калийных и калийсодержащих руд Прикаспийской впадины. В 2023 году получена лицензия на добычу полезных ископаемых на месторождении Сатимола сроком на 25 лет с возможностью продления. ТОО «Taskor Inter» разработало и согласовало План горных работ по подземной добыче 25 млн тонн калийных и калийсодержащих руд в год. Следует отметить важное технологическое различие между борсодержащими и калийными рудами, связанное с повышенной опасностью воздействия воды. В Казахстане практический опыт ограничивается преимущественно добычей борсодержащих руд. *Результаты*. На примере структуры Сатимола показано, что центральный участок выбран в качестве приоритетного объекта разработки, что позволяет получать актуальную и полную геологическую информацию, осуществлять дегазацию массива горных пород, существенно снижать затраты на бурение, а также получать новые данные в процессе подземной разведки. Это обеспечивает повышение эффективности разработки и уровня промышленной безопасности. Для освоения калийных месторождений подземным способом рекомендуется создание образовательной и научной базы на базе Атырауский университет нефти и газа имени С. Утебаева для подготовки специалистов высшего и среднего звена, необходимых на всех этапах - от изучения минерального сырья до обоснования технологических параметров добычи и переработки. *Научная*

новизна. Предлагаемый инновационный подход к подготовке месторождения твёрдых полезных ископаемых к подземной разработке реализован в структуре Сатимола в рамках проекта «План горных работ по добыче руд на месторождении Сатимола». *Практическая ценность*. Авторами обоснована необходимость дальнейшего комплексного изучения горно-геологических, горно-технических, гидрогеологических, геотехнических условий и газодинамических процессов разработки месторождения с применением современных методов исследований и научных инструментов.

Ключевые слова: бороносные структуры, борно-калийные соли, карналлит-кизеритовые породы, борные минералы - гидроборацит, калиборит, борацит

Introduction. More than 100 years ago, Kazakhstan began and successfully develops hydrocarbon raw materials within the Caspian Basin. The Republic of Kazakhstan has no practical experience in underground mining of potash and potash-containing ores. The current state of readiness for the development of potash and potash-containing ores in the Caspian basin raises reasonable concerns, which may negatively affect the implementation of projects to create and develop the potash industry in the Republic of Kazakhstan in the future. The results of this approach can be seen in Uzbekistan and Turkmenistan during the development of the Garlyk and Tyubegatan fields. The world literature contains materials on the study of the Earth's potassium basins: - The Nepean deposit of potash salts and the Lena-Kirenga potassium-bearing basin of Precambrian age. - Starobinskoye deposit of the Verkhnedevonsky potassium-bearing formation. - Petrikovskoye potassium-bearing deposit of the Upper Devonian age. -The Saskatchewan potassium deposit of the Middle Devonian age. - Cane Creek potash deposit (USA) of medium-carboniferous age. - Verkhnekamskoye deposit of potash salts of the Kungursky stage of the Lower Permian - Verkhnepechorsky basin of potash salts of the Kungurian stage of the Lower Permian, - The Caspian potassium-bearing basin of the Kungurian stage of the Lower Permian. - The Stasfurt potassium-bearing basin of the Upper Permian (Zechstein) age. - The Central European Tsechstein circulatory basin of the Permian age. - Zechstein of Poland of the Late Permian age of potassium salts. - The Kaliningrad (Nivenskoye) potassium deposit of the Permian period. - The Delaware potassium-bearing basin of Late Permian age. - Yorkshire potassium deposit of Late Permian age. - The Central Asian potash basin is confined to the Upper Jurassic and Lower Cretaceous halogen formations. - Industrial accumulations of Paleogene-age potash salts in northern Spain. - The Upper Rhine potassium-bearing basin of tertiary age. - The Precarpathian potassium-bearing basin of Miocene age.

Object of the study. Of the above-mentioned potassium-bearing basins, only in the Caspian salt basin of the Kungurian stage of the lower Permian large-scale industrial deposits of boron-potassium salts unknown to early science were

discovered. The length of the basin is 1000 km, the width is 550 km, and the area is 600 thousand km2. Figure 1 shows a forecast map of borates and potash salts in the Caspian basin. The "Central potassium-boron province" has been identified in the potassium-bearing basin. Its length is 400 km, its width is 250 km (Zhanbatyrov et al, 2025).

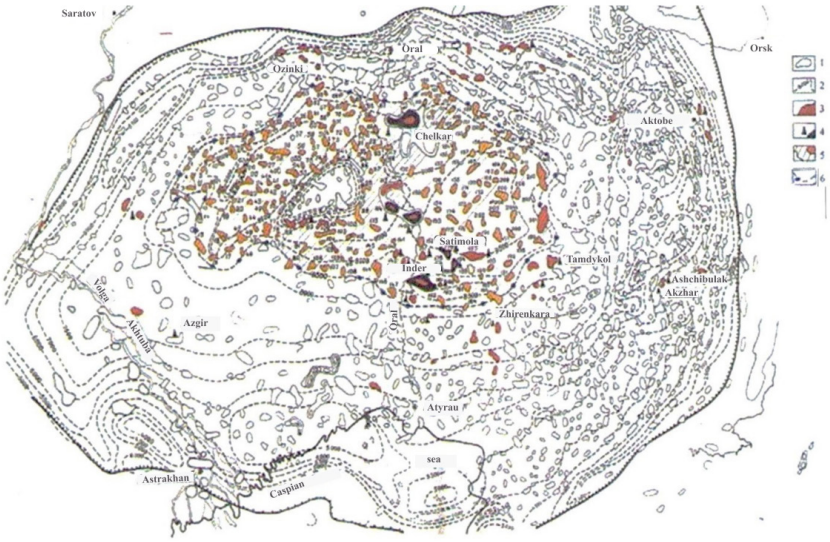

Figure 1. Forecast map of borates and potash salts of the Caspian lowland. Symbols: 1-contours of domes based on gravimetric and seismic work; 2-stratoisohypses of the salt litter; 3-potassium structures; 4-rake structures; 5 - salt structures of the zone promising for boron and potassium; 6-contours of the central potassium-Boron province.

The object of the study were: 1. Indersky salt massif, located in the southern part of the Central potassium-boron province. The vault area of the structure is 250 km2, the salt layer lies at a depth of 55 meters. (Tukhfatov et al, 2024)

Among boron-potassium and potash salts, there are silvinites, silvin-carnallite, carnallite silvinites, kieserite, boracite-halite-kieserite, carnallite-kieserite, carnallite, bischofite-carnallite, bischofite-halite, preobrazhenskite-bischofite-halite and bischofite rocks.

2. The Satimolinsky salt massif, located closer to the center of the Central potassium-boron province of the Caspian Basin. The vault area of the structure is 270 km2 and the gypsum layer lies at a depth of 240-250 meters. Potassium and boron-potassium salts of the Satimol structure are composed of polyhalite silvinites, kainite, kieserite-kainite, kainite-polyhalite-carnallite, carnallite-kieserite, kieserite-carnallite rocks with boracite, preobrazhenskite, caliborite, caliborite-preobrazhenskite, preobrazhenskite-caliborite and preobrazhenskite-sulfoborite-caliborite rocks.

3. The Satimolinsky salt massif, located closer to the center of the Central

potassium-boron province of the Caspian Basin. The vault area of the structure is 270 km2 and the gypsum layer lies at a depth of 240-250 meters.

Boron-potash salts of the Chelkara salt massif are characterized by complex lithological compositions. Productive breeds are mostly polymineral. Boracite, caliborite, and preobrazhenskite are primarily used.

Main content. The study of potash and boron-potash salts has been carried out for several decades at the Atyrau University of Oil and Gas named after Safi Utebayev under the supervision of Academician of the National Academy of Sciences of the Republic of Kazakhstan M.Diarov (Diarov, 2019; Diarov et al, 2016).

The actual chemical salt compositions of the Chelkarsky, Satimolinsky, and Inder structures were analyzed. Since the ore strata have now undergone significant changes in lithological and chemical compositions and it is impossible to draw generalizing conclusions from them, it was necessary to find the gross (based on mass analyses) chemical salt compositions of boron-potash salts of Chelkarsky, Satimolinsky and Inder deposits of the boric province, and first of all, the dependence of individual salt components based on the average composition was clarified. boron-bearing rocks and are shown in Tables 1-3.

Table 1. Average gross chemical composition of boron-bearing horizons of salt massifs (for rocks containing more than 0.5% boron oxide).

Deposits	Samples	Average chemical composition of the components, %											
		B_2O_3	K	Mg	Ca	Na	Cl	SO_4	CO_3	Br	н.о.	H_2O	The sum of the salts
Chelkar	222	4,34	3,0	2,93	2,69	22.54	40,19	9,37	-	0,102	4,45	10,44	100
Satimola	388	5,13	4,13	3,47	3,14	20,69	35,85	14,03	2,68	0,022	5,17	5,7	100
Inder	999	3,47	5,63	3,40	2.18	23,48	41,83	12,18	0,54	0,039	1,07	6,72	100

Table 2. Salt composition of borosolic ores of boron deposits.

No, p/p	Deposits	Salt compositions (in weight %)							
		B_2O_3	$MgCl_2$	$MgSO_4$	KCl	$CaSO_4$	NaC1	н.о.	$MgCO_3$
1	Chelkar	4,34	3,53	3,66	5,72	9,14	57,43	4,45	-
2	Satimola	5,13	0,27	8,15	7,87	10,67	52,6	5,17	3,77
3	Inder	3,47	0,7	4,82	10,73	7,4	59,69	1,07	0,78

Table 3. The actual ratio of gross salt components (in weight. %) boron-potash salts.

Deposits	$\frac{CaSO_4}{B_2O_3}$	$\frac{(MgSO_4 + MgCl_2)}{B_2O_3}$	$\frac{CaSO_4}{MgSO_4 + MgCl_2}$
Chelkar	2,11	1,63	1,27
Satimola	2,08	1,64	1,27
Inder	2,14	1,60	1,34

Despite the complex, diverse lithological, mineralogical and chemical composition of the rocks and the significant remoteness of individual parts of the Central potassium-boron Province, the concentration of boron oxide is strictly related to magnesium and calcium salts. Specifically, the limit of the dependence of boron oxide and magnesium and calcium salts is theoretically determined by the ratio of molecular weights, which was established by academician M. Diarov, based on numerous studies. This approach has received the status of a scientific discovery and is one of the important search features (Tukhfatov et al, 2025; Trapeznikov, 2021). The multicomponent ores of the Caspian lowland require a special approach and a comprehensive study of mineral raw materials, taking into account mining, geological, mining, hydrogeological, geotechnical conditions and gas dynamic phenomena (Asylkhankyzy et al, 2024). These factors are discussed in the monograph "Mining and chemical raw materials for the production of potash and potassium-containing fertilizers" (Zhanbatyrov et al, 2024; Diarov, 2019). Let us briefly consider each factor separately using the example of the structure of Satimol.

Geological conditions. All structures of this type are classified as deposits with difficult mining and geological conditions. The Satimol structure is located in the Central part of the Caspian syneclise. Tectonically, the Caspian syneclise is characterized by the presence of three structural floors: subsalt, saline and suprasalt (Kasenov et al, 2023). A joint analysis of the relief, the thickness of the sulfate rocks and the morphology and lithology of the salt rocks themselves allowed us to identify four anticlinal structures within the arched part of the Satimola salt massif: the Central, Southeastern, Western, and Kaldybai (Fig. 2). The axes of the anticlinal folds are elongated parallel to the axes of the dome and undulate along the strike.

The central anticlinal structure. The Central anticlinal structure is the most promising for the discovery of new deposits of boron-potassium salts. The most powerful complex of potash and boron-potassium salts is found here. The structure is stretched from northwest to southeast for a distance of 10 km with a width of 2-3 km. The ratio of the long and short axes is 1:3.5. The fold is tilted to the northeast. Along the stretch, the structure sinks to a depth, the capacity of boron-potassium salts is abnormally high. This may be due to the partial preservation of the hinge part of the fold. The potash deposit of the central site was explored in 1967-1973 together with boron-potash salts and eluvial borates. Potash salts are characterized by unstressed morphology and variable mineralogical and chemical composition. The length of the strata is up to 6000m. The capacity ranges from 2m to 35m, with even more in some parts of the field.

The strata of potash and boron-potash salts of the productive zone do not have a rectilinear direction in occurrence, but are complicated by isoclinal folds of various orders, with almost directed axial planes, with hinges sinking in the direction of the general fall of the anticlinal structure. In accordance with this, the outcrops of the layers of the productive zone onto the salt mirror have a complex pattern reflecting the internal tectonics of the salt stratum.

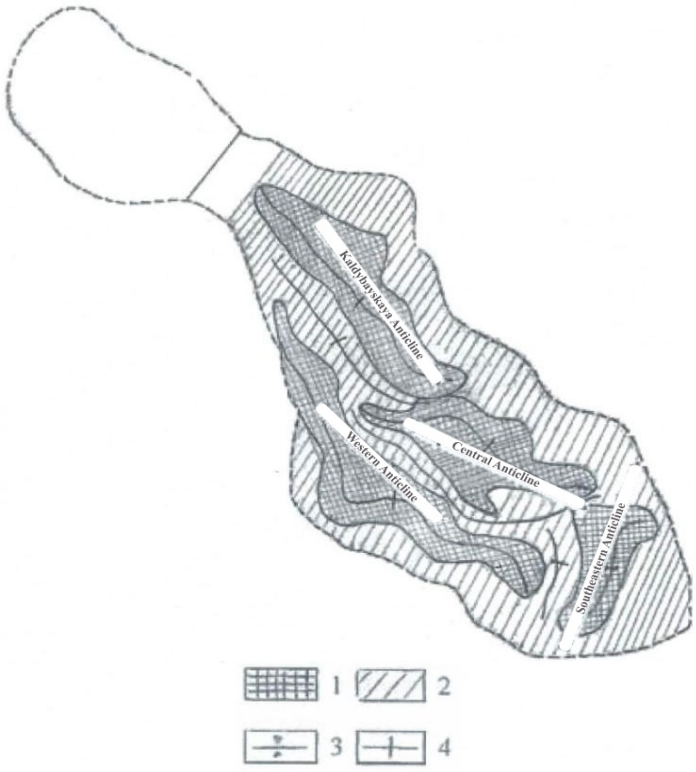

Figure 2. Diagram of the tectonic structure of the dome of the salt dome of Satimola.
Scale 1:50000.
1-anticlinal structures; 2-areas of predominantly monoclinic occurrence of salt rocks.

Southeastern anticlinal structure It stretches from northeast to southwest. The length is up to 6 km. The ratio of the long and short axes is 1:3. Adjacent synclinal structures, elongated in a northwesterly direction, are located everywhere on the dome next to the identified anticlinal structures. Their core consists of younger age salt deposits. Judging by the geological situation of the dome and the data of oriented samples taken from exploratory wells, the angles of rock fall are mostly steep, reaching 50-60 °. However, there are areas where potash and boron salts lie in a relatively flat (no steeper than at an angle of 30-45°) monocline.

Kaldybai anticlinal structure. It is strongly elongated in a northeasterly direction. The ratio of the axes is at least 1:7. Boron-potash and potash salts of the southwest wing were discovered by wells №№2, 34, 20, 29, 23 and 380. The fold is isoclinal in nature with steep angles of incidence of the wings. According to the data of the oriented sample of well No. 34, the angle of incidence of the southwest wing of the fold is 75°. The northeastern wing of the Kaldybai structure is also composed of potash and boron-potash salts discovered by wells No.93, 10, 4, 22 and 382. In the section of well No. 4 (range 606-610 m), the boron-bearing pack is

represented by brownish-red rock salt, boracite-anhydrite rocks. The upper boron-bearing pack in well No. 23 is based on silvinites, and the lower part is weakly boron-bearing. The boron horizon was uncovered by well No. 23 at a depth of 593-599 m and is lithologically represented by boracite-carnallite-halite-kieserite rock with a weighted average content of B203 - 3.60% and K20 - 1.99%. Well No. 34 uncovered the upper boron bearing pack at a depth of 384-397 m under the silvinite formation. It consists of two boron-bearing formations bearing boracite mineralization, separated by a layer of rock salt. The upper stratum is composed of rock salt with a weighted average content of B203 - 0.78%, the lower one is composed of halite-kieserite rock with a content of B203 - 4.35%.

Western anticlinal structure. The structure is elongated from northwest to southeast. Judging by the data of structural prospecting wells and kernoscopy, the outcrops to the salt mirror of the rocks of the productive zone in the southwestern wing repeat the character of the outer wing of this site in their configurations. Apparently, the tectonic forces that displaced the dome wing simultaneously affected the nature of the occurrence of boron salts in the Western anticline. The length of the structure is 17 km. A peculiar complex of boron-potassium, potash, and potassium-magnesium salts of various compositions has been discovered in the salt column, confined to certain horizons in the middle part of the stratigraphic salt section.

The studied potash deposits are a series of irregular morphologically stratified and lenticular bodies. They have been opened by many wells. The potassium occurrences are cut by single wells.

The outlet of the layers of the potassium-bearing zone to the salt mirror has a complex configuration due to the peculiarities of the internal tectonics of the salt massif and is shown in Fig.3.

Thus, the mineralization of the Central potash-boron province of the Caspian Basin has no analogues in the world practice in terms of quality, quantity and variety of boron raw materials. Boron-potassium salts containing boron, potassium and magnesium are easily enriched complex mineral raw materials. In addition, the presence of rare earth metals significantly increases the potential value of the mineral resources of the Caspian Basin. (Freyman, 2020; Asylkhankyzy et al., 2020)

The presence of lithium, rubidium, and caesium was found in all lithological varieties of salt rocks in the dome. The upper horizons of the salt domes of the Caspian basin have been washed away by groundwater, and huge amounts of salts have been removed from them. When salts are removed, insoluble minerals accumulate above the salt mirror in the form of a kind of tire, called a "plaster hat" or cap. The main part of precious metals and REM are concentrated in insoluble salt sediment and represent practically natural storages. The content of lithium, rubidium and caesium in boron concentrates of four technological samples of salts of the Satimola dome is shown in Table 4.

Table 4. The content of lithium, rubidium and caesium in boron concentrates of four technological samples of salts of the Satimola dome.

No. p/p	Samples	Mineral composition	The content of rare and scattered elements, in %		
			Li	Rb	Cs
1	Technological sample No. 1. Boron salts (sle.No.512, int.803-818m)	Halite, polyhalite, caliborite, clay	0,0066	0,0030	0,0002
2	Technological sample concentrate No. 1	Caliborite, polyhalite, clay	0,0140	0,005	0,0006
3	Technological test No. 17. Boron salts. (square No.513, int.452,5-456m)	Halite, sylvin, polyhalite, caliborite, anhydrite	0,0072	H.o.	0,0002
4	Technological sample concentrate No. 17	Preobrazhenskite, polyhalite,, anhydrite, clay	0,0225	H.o.	H.o.
5	Technological test No. 18. Boron salts	Halite, sylvin, polyhalite, caliborite, anhydrite	0,0066	0,0020	H.o.
6	Technological sample concentrate No. 18	Preobrazhenskite, polygalite, caliborite, clay	0,01	0,0030	H.o.
7	Technological test No. 19. Boron ores. (square No. 514, int.1080-1086m).	Halite, polyhalite, caliborite, clay	H.o.	H.o.	0,0001
8	Technological sample concentrate No. 19.	Caliborite, polyhalite, clay	H.o.	H.o.	0,0001

Mining conditions. The mining conditions of the Satimol structure are considered in detail in the Mining Plan. (Plan gornykh rabot, 2023) Taking into account the morphology of the productive layers of the Satimola deposit, the following development systems are planned:

• ore mining using combine harvesters (flat and inclined formations);

• drilling and blasting method of ore extraction (inclined and steeply falling formations);

The discovery of reserves of potash and boron salts of the Satimola deposit is carried out in stages.

– the first stage is the construction of mine shafts No. 1 and No. 2, which open the Central section of the deposit.

– the second stage is the opening of the South flank of the deposit with shafts No. 4 and No.5.

– the third stage is the construction of ventilation shaft No. 3 with a diameter of 8 m on the North-West flank of the deposit, which provides the necessary amount of fresh air to ventilate the mine workings with a maximum production of 25.0 million tons of potash ore per year.

Hydrogeological conditions. The central potassium-boron province is located within the North Caspian groundwater basin. During the exploration of the Satimola deposit in 1979-1985 and with additional research at the mine shaft site in 2008, 61 hydrogeological wells were drilled and pilot filtration work was carried out.

The groundwater of the Satimol structure is connected to the suprasalt hydrogeological floor, the average capacity of which reaches 360 m. Table 5 shows the rocks composing the hydrogeological section.

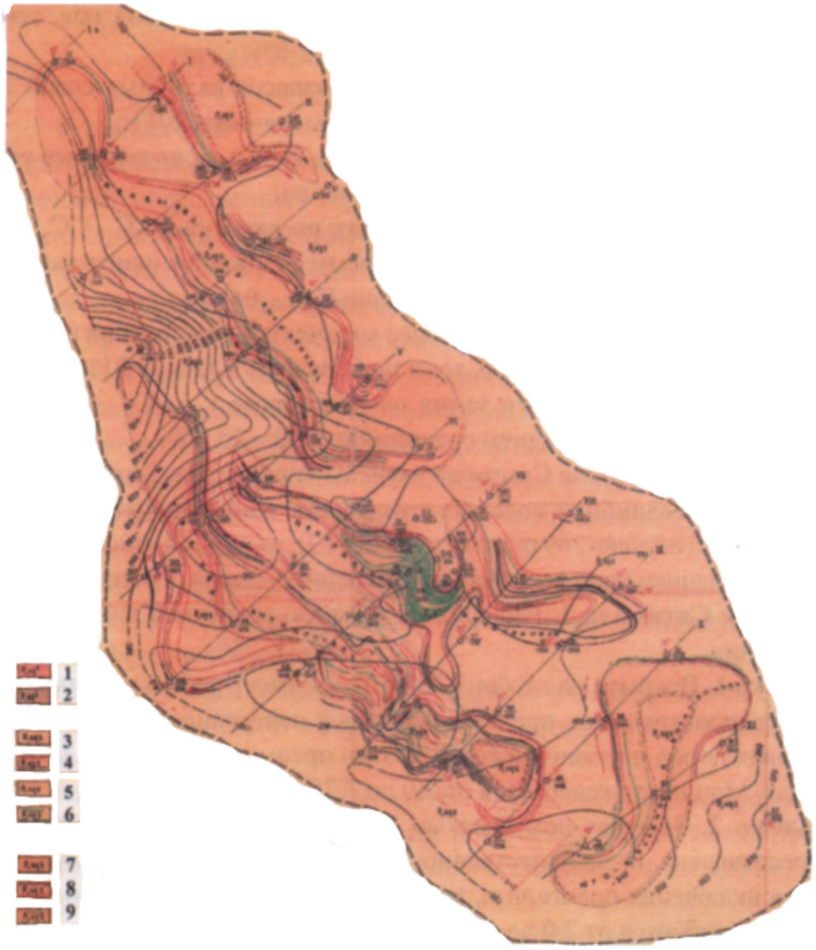

Figure 3. Geological and lithological map of the salt mirror of the salt dome structure of Satimol. Compiled by K.Kamashev, 1979.
1-sulfate stratum (gypsum and anhydrites); 2-eluvial borates (hydroboracite, ulexite), upper halite zone; 3-rock salt; 4-potassium salts (sylvinites, carnallites, polyhalites); 5-anhydrites; 6-rock salt with borate inclusions (caliborite, asharite, hydroboracite) productive boron bearing zone; 7-rock salt; 8-potash salts (sylvinites, carnallites, polyhalites, kainites); 9-boron-bearing rocks (boracite, preobrazhenskite, caliborite, asharite, hydroboracite.

Table 5. Rocks forming the hydrogeological section.

Age (index)	Breeds	Depth, m	Filtration coefficient, m/day
Qmhv	Lenses of sand in clays	10	0,07
Qb-Qnhz	Lenses of sand in clays	10-60	2,52
N_2^3ap - N_2^3ak	Lenses of sand in clays	60-90	10^{-6}
N_2^3ap - N_2^3ak	Lenses of sand in clays	90-130	2,26
N_2^3ap - N_2^3ak	Lenses of sand in clays	130-190	10^{-7}
K_2	Clays, chalk, marl, seashell	190-210	1,0
K_1	Clay	210-230	10^{-6}
J_{1-2}	Clay	230-280	10^{-6}
T	Clay	230-360	10^{-6}
P_1k^p	Gypsum, clay, borate ores	230-360	0,0077

The generalization of all hydrogeological materials on the Satimola deposit allows us to draw the following conclusions on the assessment of water flows into the mine workings during the development of potash salts.

1) The expected inflow of groundwater into the mine shafts during their sinking will not exceed 35 dm3/s (126m3/h) – from the flooded stratum of the Upper Pliocene Akchagyl horizon (N23ak). The sinking of mine shafts should provide for reliable isolation of aquifers, followed by their overlap with structural elements of the mine shaft.

2) The only probable external source of groundwater inflows into the mining operations carried out for the development of salts may be exploration geological wells cut by mining operations. These wells will work as through filters. In reality, flows from them are possible only from the weakly water-bearing Lower Permian Kungur sulfate zone (P1kp), composed of relatively stable rocks capable of ensuring the safety of that part of the exploration wells that uncovered these rocks. Due to the low filtration parameters of these rocks, inflows from such wells will not exceed 1-2 liters/s for any period of rock salt development. However, in order to avoid cutting exploration geological wells by mining operations and ensure the safety of mining operations, it is recommended to leave well sights near.

3) The salt column is practically anhydrous. The source of water supply to the mine workings (subject to the safety of the ceiling, borehole pillars and the tightness of the mine shafts) may be rare intra-formation leaching cavities with a volume not exceeding 20-30 m3, with a maximum daily inflow of up to 20 m3. In this regard, given the insignificance of brine occurrence, there is no need for special measures, since it is possible to limit the special equipment available in the underground mine, only providing for the availability of storage tanks, followed by the involvement of brines in the drilling process.

Geotechnical conditions. Engineering and geological studies on the structure of Satimol were carried out at all stages of geological exploration, as a result of which

representative data for the deposit were obtained. In addition, to substantiate the design decisions, the experience of work at the Inderskaya exploration mine was used, based on the general genesis of salt rocks, their almost similar composition (the Caspian salt basin) and the uniformity of structures (salt domes). (Kasenov et al, 2024; Kasenov et al, 2024). Research at the Satimola deposit was carried out by VNIIG (1967) and GIGHS (1979 - 1985). From the entire complex of engineering and geological studies, the following initial data were selected: for the suprasalt stratum - the results of the GIGHS, for the salt stratum - the work of 2008-2010, as the most representative for the deposit in terms of area, depth, and number of tests.

The GIGHS examined samples taken from nine wells, which fairly fully represent both the Central Site (eluvial borates) and the deposit as a whole. A total of about 300 rock samples were taken.

According to the conclusion of GIGHS, the cover layer of the Satimola deposit is generally characterized as relatively homogeneous in terms of strength.

The sulfate stratum containing boron mineralization is characterized by stable strength parameters, with the exception of massive gypsum anhydrite layers, which are characterized by average values of compressive strength of 496 kg/cm2 and tensile strength of 55 kg/cm2.

The corresponding figures for gypsum are 237 and 27.3 kg/cm2. Gypsum-clay rocks lying directly above the mineral strata are noticeably weaker than the main massif: the compressive strength is 95.4 kg/cm2, and the tensile strength is 26.3 kg/cm2. For salt rocks, the compressive strength ranges from 233 to 519 kg/cm2, and tensile strength ranges from 17 to 21 kg/s.

Based on the results of engineering and geological studies, the GIGHS concluded that there are no large zones (sites) with weakened rock stability, weathering zones, and tectonic fragmentation within the Central Area, which could be identified and shown in the scale of the geological map of the field being presented. Such areas are small and local. Given the fact that the Central Site is the most structurally complex element of the Satimol structure, this conclusion can be confidently extrapolated to the entire deposit.

Gas dynamic phenomena (gas content). The main feature of the mining conditions during the operation of the Satimola deposit is the presence of gas content here. The first signs of the presence of gas phenomena on the structure of Satimol were noted in 1964 during prospecting for boron-potassium salts. From 1965 to 1968, special gas drilling studies were carried out at the structure in 28 structural exploration wells relatively evenly spaced over the area.

Analysis of gas logging materials showed that all recorded gas occurrences are confined to the salt column of the structure and, as a rule, are located at depths exceeding 500 m in 25 wells out of 28; only in three wells weak gas occurrences are recorded at depths of 300-400 m. Moreover, in two of them, these manifestations are confined to the upper horizons of the salt stratum, and in one – to the bottoms of the gypsum-anhydrite stratum and the tops of the salt. Thus, a conclusion was made about the gas content of the salt stratum.

In 1983-84, at the stage of detailed exploration of the Central section of the field (eluvial borates), gas logging was carried out by the LGKS-4AP serial station in 16 wells during drilling and component-by-component analysis of drilling fluid samples for marginal hydrocarbon gases using a gas-capping thermograph of the XG-1G type, which allows determining the content of the air mixture in gases of the maximum hydrocarbons from CH4 to C6H14. As a result, a conclusion was made about the gas permeability of kaprock and its low gas content.

1. Only folded dislocations are developed at deposit No. 99, and there are no disjunctive tectonic disturbances. There is one extended intraformational zone associated with the movement of salt masses inside the core of the structure, a fracture zone, a parallel crumpling zone in the host salts, and several size-limited fractured zones. These tectonic elements have no outlet to the salt mirror and are associated with breccia and conglomerate-like textures, especially of carnallite rocks, with somewhat weakened physical and mechanical properties (Tukhfatov et al, 2024).

2. All workings were completed without fastening, isolated collapses were observed in breccated carnallite rock.

3. Strength coefficient of potash salts according to Protodyakonov 1-2, boron salts 3-5. The stability assessment was carried out by measuring the workings with a section of 7.5 square meters. m. The sides of the workings approached each other by 8 mm in 110 days, and the roof by up to 3mm. Thus, it was concluded that the rocks are stable.

4. The only source of brine occurrences are the deaf cavernous cavities of leaching filled with extremely saturated uterine brines.

5. The recommended capacity of the ceiling water-proof rear sight is 100 m.

6. The gas content of the deposit is related to both the host rocks and ore layers. The gas is in a free, bound and micro-connected state. The distribution of free gas is extremely uneven and ranges from 0 to 11.5 m3/m3. The average free gas content in rocks is rock salt, non-explosive - from 0 to 2, with an average of 0.39 m3/m3; explosive - 5.3 m3/ m3, carnallite-kieserite-polyhalite - 0.29 m3/m3. Free gases consist of methane (70-99%), heavy hydrocarbons and nitrogen are present in small amounts (0.6-2.2%).

The distribution of bound gases is uneven from 0.005 to 2.83 m3/t.

Explosive rocks have the highest gas content, which is on average 4 times higher than non-explosive rocks. Composition nitrogen (41-88%), methane (5.7-40.2%), hydrogen (4.08-7.55%), carbon dioxide (0.12-2.67%). In the total gas content (0.48 m3/m3) of bound gases, 1-10%, the rest are free. The gas permeability of salts is very low and does not exceed 9.5x10-2 m. darcy.

By the nature of the manifestation, they are divided into:

– Usual gas emissions from the surface of mine workings (pressure less than 10 kPa) for rocks with carnallite up to 100x10-4m3/m2/min, on average 52-574m3/m2/min; silvinites – 51x10-4m3/m2/min and 32 x10-4m3/m2/min; rock salt -17 x10-4m3/m3/min and 14 x10-4m3/m2/min, respectively.

– Souffle gas emissions occur from boreholes and wells or cracks that have exposed accumulations of free gas. Of the 164 wells analyzed, souffle gas emissions were recorded in 55, and in some souffles were observed 10-16 times, while there was an outflow or discharge of drilling fluid, and at high pressure, drilling tools. The maximum measured pressure was 4 MPa, the highest calculated pressure determined by the fracture factor of the drilling tool was 38 MPa. At a pressure of more than 10 kPa, a rock pin is ejected into the hole, and at a higher pressure, a hand-held drilling tool can be ejected. The density of souffles is 1.3 for every 100 p.m of drilling.

There are two types of sudden emissions: actual sudden emissions and sudden rashes. The latter occur after blasting operations and in all cases are associated with some kind of geological complications, where the rocks are weakened and have little strength. Sudden emissions of rock and gas form spherical and elliptical shapes with an average volume of 16.9 m3.

According to the intensity of emissions from blasting operations, they are divided into five types: microbursts of up to 3 tons/discharge (11.2% of all emissions), low-strength - 3-20 tons/discharge (29.9%), medium-strength - 20-150 tons/discharge (41.1%), high-strength - 150-600 tons/discharge (15.9%) and powerful - more than 600 tons/emission (1.9%). Most of the high-intensity and powerful emissions come from the host rock salt.

It should be noted that in the course of geological exploration in 2008-2010, 24 cases of gas release from wells were recorded at the Satimola field. For the most part, gas occurrences were noted in the form of foaming of drilling mud, and only in three cases was the release of the solution, while the maximum calculated gas pressure was about 9 MPa. The difference between these data and the experience of deposit No. 99 is explained by the depth of the salt relative to the wellhead - 350 m (Satimol) and 0 m (Inder) during underground drilling from the mine and the associated pressure of the column of flushing liquid. With a washing liquid density of about 1.3 g/cm3, the initial pressure at the entrance to the salt layer at a depth of 350 m will be about 4.5 MPa and increases by 1.27 MPa every 100 m. Such an excess of the solution pressure over the gas pressure does not allow the latter to enter the borehole, in addition, the process of colmatation of cracks and pores during drilling generally eliminates any manifestations (of course, at a lower gas pressure).

The methods of forecasting gas occurrences at field No. 99 developed during this period were:

– Core. When the core is divided into discs with a length less than its diameter, a sudden release will occur regardless of the method of penetration. The method is reliable for rocks with a strength of less than 140 kgf/cm2, but with higher strength it is not always reliable, since the division into discs does not always occur in this case.

Most of the emissions in boron salts are confined to areas with a maximum content of boron oxide.

– The acoustic forecasting method is based on measuring the noise level of salt when dissolved in water. It is applicable to carnallite rocks in the drilling and blasting method of sinking.

These methods are planned to be applied at the Satimola field during mining operations and, if necessary, supplemented to predict gas events.

Materials and methods. A comprehensive study of potash and boron-potassium salts was carried out using various methods:

• Continuous sampling (core) of boron-potash salts obtained as a result of drilling boreholes. • Detailed description of the rocks.

• Lithological, mineralogical and chemical study of potash and boron salts by determining mineralogical compositions under a microscope in immersion liquids; conducting complete chemical analyses with determination of B_2O_3, K, Mg, Ca, Na, Cl, SO_4, CO_3 and insoluble residue; recalculation by component compositions of rocks into salt compositions.

• Study of the physical and mechanical properties of the mountain range, taking into account the modeling of loads under different conditions and positions.

• Study of gas dynamic phenomena on special stands with core samples, taking into account different porosity, pressure and temperature changes.

Results and discussions. All conditions and phenomena that arise and affect technological processes during mining operations were studied.

1. The complex geological conditions of the structures of the Caspian Lowland and the multicomponence of ores should be noted. Ore bodies are represented by stratified, plate-lenticular and lenticular deposits, while they are often not consistent in terms of thickness and mineral composition. The presence of noble and rare earth metals increases the potential value of the object. The separate location of eluvial borates makes it possible to develop a separate project, regardless of the main part of potash and potash-containing ores.

When preparing deposits of potash and potash-containing ores by the underground method, it is proposed to explore the central part in detail by conducting a complex of exploration, and to explore the remaining areas by conducting advanced operational exploration. (Kasenov et al, 2024; Yue Hao et al, 2025).

The specified geological conditions must be taken into account when developing project documents for mining.

2. The hydrogeological conditions are simple, but given the high dependence of potash ores on the effects of water, it is necessary to plan water protection measures for the entire period of operation of the facility.

3. Mining conditions are also very difficult when developing a deposit underground. Given the high variability of geological conditions, mining of each ore deposit must be approached individually.

4. The geotechnical conditions have been studied, but it is necessary to obtain additional data immediately before developing a specific geological unit in real production conditions.

5. Gas dynamic phenomena, according to research, will occur during the development of horizons below 350 meters.

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Conclusions. All geological, mineralogical, and gas emission studies were conducted on extracted cores in laboratory conditions at research institutes in the Soviet Union and Kazakhstan, as well as during boron ore mining at the Inder uplift and underground exploration of deposit No. 99.

Pilot industrial development is required for underground mining of potash and potash-bearing ores to clarify technological parameters of the mining systems at this stage (Zhanbatyrov A.A., 2024). These provisions should be incorporated into the current Code of the Republic of Kazakhstan “On Subsoil and Subsoil Use,” similar to the approach used in uranium deposit development.

Based on the studies performed, the following conclusions can be drawn:

1. The Mining Plan for the extraction of ores from the Satimola deposit takes into account all the features of mining, geological, mining, hydrogeological, geotechnical conditions and gas dynamic phenomena.

2. The following underground mining systems have been adopted:

– ore mining using combine harvesters (flat and inclined formations);

– drilling and blasting method of ore extraction (inclined and steeply falling strata).

3. Local development planning has been adopted in certain areas with difficult mining and geological conditions.

4. It provides for the use of precious and rare earth metals, i.e. complex processing of mineral raw materials.

5. Provide for the training of mining engineers and technicians for the underground mining of potash deposits at Atyrau University of Oil and Gas.

6. To organize scientific research laboratories for the study of the mineral resources of the Caspian Lowland.

7. To ensure the development of regulatory documents on industrial safety in the underground mining of potash and potash-containing ores.

8. To amend the current Code of the Republic of Kazakhstan "On Subsoil and Subsoil Use", which provides for pilot production to adjust the technological parameters of underground mining systems in order to efficiently and safely develop potash and potash-containing ores.

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