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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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ASSESSMENT OF THE RESERVOIRS IMPACT ON THE MAXIMUM RUNOFF OF THE SYRDARYA RIVER

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Abstract. This article considers the changing of maximum runoff in the Syrdarya River basin considering the influence of the large Shardara reservoir. Hydrological data were used for four gauging station, in the lower, middle and at the beginning part of Kazakhstan in the Syrdarya River. To analyze the hydrological characteristics of the studying basin data from published cadastral materials from the Hydrological Yearbooks were used. To calculate the parameters of the maximum runoff, total integral curves were constructed, and water discharges of rare frequency in different sections of the Syrdarya River were estimated. To construct the availability curves of water discharges the method of truncated distributions was mainly used. Recommendations are proposed for calculating the maximum runoff in different sections. After the creation of reservoir, only part of the multiyear series was used to calculate the maximum runoff in the Syrdarya River with the reservoir on multiyear runoff regulation. The change in the annual maximum runoff of the Syrdarya River in the gauging stations located downstream of the Shardara reservoir, Tomenaryk, Tasboget and Kazaly from 1967 to 2020 was estimated. The results of maximum runoff calculations before and after the construction of the Shardara reservoir are analyzed. The influence of reservoirs on the maximum flow is an urgent problem in the rational use and management of floods, therefore the probabilistic values of the maximum flow of rare occurrence have been clarified. Consequently, for each period, the probabilistic values of runoff characteristics of different availability were identified based on the construction of distribution curves. Changes in the maximum runoff averaged from 20 % (downstream of the Shardara reservoir) to 32 % (Kazaly village) in the direction of reduction. Results obtained are useful for planning and conducting project work and for the development of measures to protect areas from flooding.

Keywords: maximum runoff, statistical method, series heterogeneity, availability curve, reservoirs

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СЫРДАРИЯ ӨЗЕНІНІҢ ЕҢ ЖОҒАРЫ АҒЫНДЫСЫНА СУ ҚОЙМАЛАРДЫҢ ӘСЕРІН БАҒАЛАУ

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Аннотация. Бұл мақалада Шардара ірі су қоймасының әсерін ескере отырып, Сырдария алабы өзендерінің ең жоғары ағындысының өзгерісі қарастырылған. Сырдария өзенінің қазақстандық бөлігінің жоғарғы, орта және төменгі ағысындағы төрт тұстамалар бойынша гидрологиялық деректер пайдаланылды. Зерттеліп отырған алаптың гидрологиялық сипаттамаларын талдау үшін «Гидрологиялық жылнамаларда» жарияланған, кадастрлық материалдардан алынған мәліметтер пайдаланылды. Ең жоғары ағындының сипаттамаларын есептеу үшін жиынтық интеграл қисықтары тұрғызылып, Сырдария өзенінің әртүрлі тұстамаларында сирек қайталанатын су өтімдері бағаланды. Су өтімінің қамтамасыздық қисықтарын тұрғызу үшін басым бөлігінде қиылған әдіс қолданылды. Көп жылдық ағындыны реттейтін су қойма орналасқан Сырдария өзенінде ең жоғары ағындының көпжылдық

қатарының су қойма тұрғызылғаннан кейінгі бөлігі ғана пайдаланылды. Сырдария өзенінің Шардара су қоймасының төменгі бьефі, Төменарық, Тасбөгет және Қазалы тұстамаларының 1967–2020 жж. бойынша ең жоғары ағындысы бағаланды. Шардара су қоймасы салынғанға дейінгі және салынғаннан кейінгі ең жоғары ағындыны есептеу нәтижелері талданды. Себебі, су қойманың ең жоғары ағындыға әсері төменгі бьефтегі су деңгейін ұтымды пайдалану кезінде өзекті мәселе болып келеді. Сондай-ақ, су тасқыны мен су тасуды басқару кезінде сирек қайталанатын ең жоғарғы ықтимал су өтімдері нақтыланды. Сондықтан әр кезең үшін тұрғызылған қамтамасыздық қисықтары негізінде ағынды сипаттамаларының әр түрлі қамтамасыздықтағы ықтималдық мәндері анықталды. Ең жоғары ағындының өзгеруі орташа есеппен 20 % - дан (Шардара су қоймасының төменгі бьефі) 32 % - ға дейін (Қазалы ауылы) азаяды. Алынған мәліметтер нақты жобаларды әзірлеу мен жүзеге асыру кезінде, аумақтарды су тасудан қорғану шараларын әзірлеу кезінде пайдалануға арналған.

Түйін сөздер: ең жоғары ағынды, статистикалық әдіс, қатардың біртектілігі, қамтамасыздық қисығы, суқойма

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ОЦЕНКА ВЛИЯНИЯ ВОДОХРАНИЛИЩ НА МАКСИМАЛЬНЫЙ СТОК РЕКИ СЫРДАРИЯ

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Аннотация. В данной статье рассмотрены вопросы изменения максимального стока в бассейне реки Сырдария с учетом влияния крупного водохранилища Шардара. Использовались гидрологические данные по четырем створам в нижней, в средней и в начале казахстанской части реки Сырдария. Для анализа гидрологических характеристик изучаемого бассейна использовались данные из опубликованных кадастровых материалов, приведенных в «Гидрологических ежегодниках». При расчете параметров максимального стока построены суммарные интегральные кривые, оценены расходы воды редкой повторяемости в выбранных створах реки Сырдария. Для построения кривых обеспеченности расходов воды в основном использовался метод усеченных распределений. После создания водохранилища для расчета максимальных сток воды реки Сырдария с водохранилищем многолетнего регулирования стока использовалась лишь часть многолетнего ряда. Оценено изменение многолетнего максимального стока реки Сырдария в створах нижний бьеф Шардаринского водохранилища, Томен-арык, Тасбогет и Казалы с 1967 по 2020 гг. Проанализированы результаты расчета максимального стока до и после построения Шардаринского водохранилища. Так как влияние водохранилищ на максимальные расходы воды и обусловленные ими уровни в нижнем бьефе являются актуальной проблемой при рациональном использовании, а также при управлении паводков и половодий вероятностные значения максимальных расходов редкой повторемости были уточнены. Поэтому для каждого периода выявлены вероятностные значения характеристик стока различной обеспеченности на основе построения кривых распределений. Изменения максимального стока в среднем составляют от 20 % (нижний бьеф Шардаринского водохранилища) до 32 % (с.Казалы) в сторону уменьшения. Полученные данные предназначены для планирования и проведения проектных работ, для разработки мероприятий по защите территорий от затопления.

Ключевые слова: максимальный сток, статистический метод, неоднородность ряда, кривая обеспеченность, водохранилища

Introduction

The progressive development of civilization and climate change require an appropriate assessment of environmental water resources. Water deficiency and excess is clearly affect the quality of human life. Control and management of water resources are possible mainly through the implementing of hydraulic structures (Nowak, 2022).

The construction of reservoirs, especially for long-term water regulation, has a very significant impact on the runoff, including the maximum runoff, and reduce the risk of flooding of territories. As a result, long series of observations turn out to be inhomogeneous. The current situation and the degree of flood hazard are characterized by 2-end part of the series after the creation of a large reservoir or their entire cascade. In the following work the issues of reservoirs construction and their effect on the maximum runoff as well as on flooding of territories are considered. (Gapparov et al., 2022; Jichao et al., 2022; Duskayev et al., 2021; Arystambekova et al., 2017; Narbayev et al., 2017).

The impact of reservoirs on maximum runoff and changes in downstream water levels is enormous. The calculated maximum runoff in the downstream side of the dam is determined by the maximum runoff rate with a given probability. Therefore, the temporal distribution of the maximum runoff and the main distribution parameters have to be recalculated, which requires new calculations (Arystambekova et al., 2019).

Subsequent works (Galperin, 2006; Galperin, 2016) have analyzed the long-term course of maximum runoff in relation to ever-changing economic activities on water objects in southern and south-eastern Kazakhstan. In particular, it is necessary to select a representative period for estimating the distribution parameters of the maximum runoff characteristics. It depends on the steadily changing climate and the increasing anthropogenic pressure on water resources.

Therefore, for planning and implementing water management measures in the River basin of the Syrdarya the calculations and analyses of the maximum runoff are necessary to taking into account influence of the reservoirs. Results obtained can be used for the rational distribution of the river runoff of Syrdarya, as well as for forecasting dangerous hydrological phenomena in the study area basin.

Therefore, in this work we determinate to study and identify the current dynamics of changes in the main characteristics of the maximum runoff of the Syrdarya river basin for the rational use of water resources.

Materials and Methods

All questions regarding the physical-geographical position and socio-economic situation that are related to the environmental features of the Syrdarya River basin were described by Savoskul and Chevnina. (Savoskul, 2003).

The Syrdarya River is mostly formed on the territory of Uzbekistan. And according to the latest source it is estimated at 36.57 km^3/year. Significant water losses are observed in the desert section of the river, the withdrawal of most of the water by agriculture, similarly to the river Amudarya. In the driest years, the remaining runoff reaching the Aral Sea is less than 10 % (Frenken, 2013).

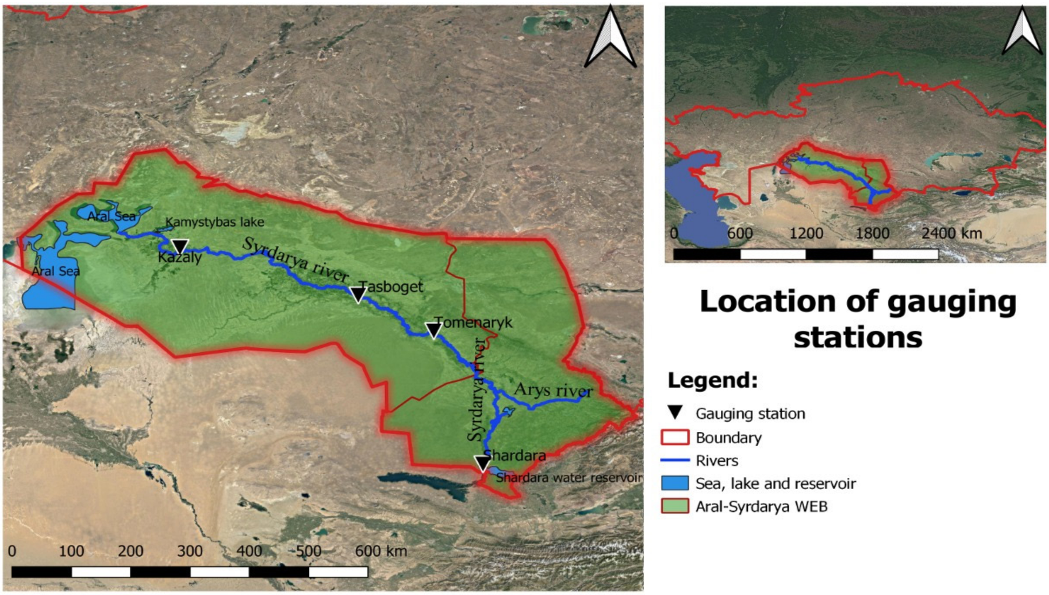

Fig 1. Physical -geographical position of the Syrdarya River

Calculation and analysis of long-term fluctuations in maximum runoff of the Syrdarya River basin was carried out according to observations at hydrological gauging stations located in the basin. Table 1 shows the information at the stations for which the analysis of the change in the maximum runoff was carried out.

Table 1 - Estimated characteristics of the maximum water runoff, m^3/s

River-section	F, km^2	H_{ave}, m	Period	Number of years of observations
Syrdarya - downstream of the Shardara reservoir	174 000	225,00	1924-1966	96
			1967-2020	
Syrdarya – Tomenaryk	219 000	154,00	1914-1966	106
			1967-2020	
Syrdarya – Tasbuget	-	122,0	1942-1966	78
			1967-2020	
Syrdarya - Kazaly	-	60,00	1930-1966	90
			1967-2020	

In this work, to calculate the maximum hydrological characteristics of the Syrdarya river runoff, the following data on the maximum average annual water discharges of the RSE Kazhydromet network for the observation period were used (Annual data, Kazhydromet).:

1. Syrdarya river - downstream of the Shardara reservoir (1924–2020)
2. Syrdarya river - Tomenaryk (1927–2020)
3. Syrdarya river - Tasbuget (1942–2020)
4. Syrdarya - Kazaly (1912–2020)

A static series of hydrological observations at a specific river gauging station is part of the calculation work. Consequently, it is needed to evaluate how the existing series or the period selected for calculation (calculation period) reproduces the typical pattern of runoff variation over time and how it is representative for calculation (Methodological recommendations, 2005; Methodological recommendations, 2009; Zvyagintseva et al., 2021).

The representativeness of a series of hydrological data is determined by the average quadratic error of the average series values, indicating as far as it differs from the runoff norm. Therefore, the representativeness depends on the duration of the observation series, on the coefficient of variability and series correlation (Methodological recommendations, 2005; Methodological recommendations, 2009; Building regulations, 2003; Daryl Lama, 2011).

Regulatory structures on rivers, on the one hand, can “cut off” the flood high peaks, reducing the danger, and on the other hand, they can also increase it - in the event of a breakthrough of the structures and in the event of a low-quality flood forecast, when the reservoir is already full, and the water inflow to it ever increasing, forcing emergency discharges.

The relevance of the issues of assessing possible maximum discharges and water levels as a hydrological component of risks is obvious. However, these estimates, due to the anthropogenic transformation of the conditions of accumulation and consumption of moisture in watersheds, are significantly complicated, especially in arid and semi-arid regions, where the distribution of these extreme characteristics along the length of watercourses is complex under natural conditions (Galperin, 2009; Galperin, 2016).

To provide water for irrigated agriculture in the river basin, several reservoirs have been created: Toktogul (19.5 km^3, Kyrgyzstan), Kairakkum (4.2 km^3, Tajikistan), Lake Aydarkul (41 km^3, Uzbekistan) and Shardara (5.7 km^3, Kazakhstan). In order to regulate spring floods and water discharges from the Toktogul hydroelectric power station, Kazakhstan built the Koksarai reservoir with a volume of a billion cubic meters in the South Kazakhstan region, which was first filled in the spring of 2010 (Shonbaeva, 2014).

It should be noted that these reservoirs are influenced by the maximum flow of the Syrdarya River, where the change in the maximum flow of the Syrdarya River occurs due to the intake of water into reservoirs located along the length of the river and the influence of the Shardara reservoir.

The article provides calculations of changes in the annual maximum flow of the Syrdarya River at gauging stations below the Shardara reservoir Tomenaryk, Tasboget and Kazaly, carried out from 1967 to 2020, taking into account the influence of the Shardara reservoir.

The influence of lakes and reservoirs on the annual runoff is taken into account by using the reduction factors calculated by the formula:

$$\delta = \frac{1 - W_d}{(y_h + W_d)}, \quad (1)$$

where:

δ - the coefficient of change (reduction) in annual runoff in fractions of a unit
y_h - household runoff, changed under the influence of economic activity
W_d - the volume of filling of lakes and reservoirs.

The volume of filling lakes and reservoirs, due to the lack of regime observations of the water level is determined approximately. For lakes and reservoirs on the river Syrdarya is taken equal to 0.90, for the Shardara reservoir - 0.80 - in accordance with the recommendations of regulatory documents (Guidelines, 1986).

The volume of filling lakes and reservoirs is determined by the drawdown coefficient:

$$W_k = K_{ave} W_n, \quad (2)$$

where:

K_{ave} – drawdown coefficient
Wn - the useful capacity of lakes or reservoirs, in million m^3.

Absolute changes (reductions) in runoff are determined by the formula:

$$\Delta y_{ave} = y_{ave}(1 - \delta), \quad (3)$$

Natural runoff is calculated by the expression:

$$y_{nat} = y_{ave} + \Delta y_{ave}, \quad (4)$$

For the Shardara reservoir - 0.80 in accordance with the recommendations of regulatory documents.

Results and discussions

According to the analysis of the constructed total integral curves of the maximum river runoff, the values of the maximum water discharges (Qmax) of rare frequency in various gauging stations on the Syrdarya River were revealed - a very difficult task that cannot be solved using standard methods (Table 2).

It is quite obvious that maximum water discharges decreased following the construction of the reservoirs. For instance, at the gauging station downstream of the Shardara reservoir, the discharge was 2490 m³/s in 1960 and 1170 m³/s in 1971. Similarly, at the Kazaly gauging station, the discharges were 1650 m³/s and 703 m³/s for the same years, respectively. After commissioning of a water reservoir the largest discharge were in the gauging station the downstream of the Shardara reservoir was 1590 m³/s (1998), and in the gauging station Kazaly was 899 m³/s (2005). Accordingly, gauging station Tomenaryk in the early years Q_{max} was 2080 m³/s (1960), in recent decades - almost half as much - 649 m³/s (1992). Quite small Q_{max} values appeared until 1966, Q_{max} was 890 m³/s (1947), and since 1967 it has reached 488 m³/s (1983) - 570 m³/s (2000).

In the same way, after the calculations were performed, a decrease in the discharges of the maximum runoff in the gauging station of the downstream of the Shardara reservoir was observed – 631 m³/s (2020), Tomenaryk - 569 m³/s (2020), Tasbuget - 401 m³/s (2020), in the gauging station Kazaly - 378 m³/s (2020).

Table 2 - Statistical characteristics of the Q_{max} before and after the creation of reservoirs

River - Gauging station	Full period			I period			II period			Changes, %	
	Years	Q_{max}, m³/s	σ	Years	Q_{max}, m³/s	σ	Years	Q_{max}, m³/s	σ	Q_{max}, m³/s	σ
Syrdarya river – downstream of the Shardara reservoir	1924-2020	1457	557	1924-1966	1880	512	1967-2020	1120	304	23,2	45,4
Syrdarya river – Tomenaryk	1927-2020	1224	553	1927-1966	1615	492	1967-2020	841	268	31,2	51,5
Syrdarya river – Tasbuget	1942-2020	835	446	1942-1966	1315	335	1967-2020	613	292	26,6	34,5
Syrdarya river – Kazaly	1912-2020	638	291	1912-1966	842	221	1967-2020	434	197	32,0	32,3

Obviously, the complete series of recorded Q_{max} over a long period no longer characterize the current conditions. The series are heterogeneous, and other factors may a significant role in the formation of the heterogeneity of the series: climate change and economic activity in the watershed.

Table 3 - Analysis of the homogeneity of hydrological series Q_{max}

River - Gauging station	Periods		Student Statistics		Fisher statistics		Inference about the homogeneity of the series	
				Student Statistics ta	Fisher statistics F			
	I	II	t			Fa		

Syrdarya river – downstream of the Shardara reservoir	1924-1966	1967-2020	8.98	1.98	2.86	1.77	heterogeneous	heterogeneous
Syrdarya river – Tomenaryk	1927-1966	1967-2020	9.36	1.98	3.37	1.76	heterogeneous	heterogeneous
Syrdarya river – Tasbuget	1942-1966	1967-2020	9.36	1.98	1.32	1.76	heterogeneous	homogeneou
Syrdarya river – Kazaly	1912-1966	1967-2020	9.94	1.98	1.26	1.76	heterogeneous	homogeneou

Table 2 compares the statistical characteristics of Q_{max} for two periods for the gauging stations of the Syrdarya river. The average of the maximum water discharges and their standard deviations from the late 60s - early 70s in connection with the creation of reservoirs decreased by about 1.5-2 times. To check the homogeneity of the series, an integral curve has been constructed (Fig. 2).

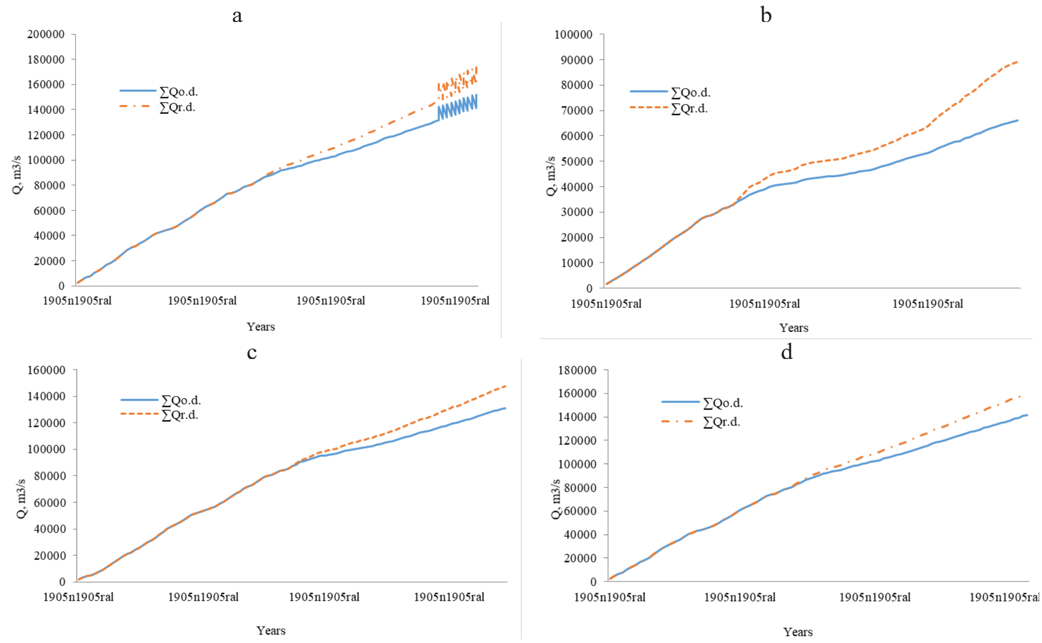

Figure 2. Integral curve of average maximum water discharges of the river Syrdaria in gauging stations: a – downstream of the Shardara reservoir, b – Tasboget, c – Tomenaryk, d - Kazaly

According to the series of Q_{max} observations, the curves of the maximum water discharges for the modern period for four sections were constructed. At statistically processing the series of maximum runoff, limiting the calculation period is inappropriate. Naturally, the exception is the series along the gauging stations, above which large reservoirs have been created. The year of the start of filling or commissioning of this hydraulic facility is the beginning of the modified statistical series. The results of Q_{max} calculations of different availability and distribution parameters are shown in table. 4.

At constructing the availability curves, the method of truncated distributions was mainly used in the version described by Galperin (2009).

Table 4 - Estimated characteristics of the maximum water discharges, m^3/s

River - Gauging station	F, km^2	Period	Method	Cs	Probability distribution, Q m^3/s			
					1	3	5	10
Syrdarya river – downstream of the Shardara reservoir	174 000	1924-1966	Full distribution	-0.28	2956	2770	2670	2513
		1967-2020	Truncated, 50 %	1.00	2240	1942	1800	1598
Syrdarya river – Tomenaryk	219 000	1914-1966	Full distribution	-0.14	2729	2525	2415	2249
		1967-2020	Truncated, 50 %	3.00	1971	1610	1430	1211
Syrdarya river – Tasbuget	-	1942-1966	Full distribution	-1.22	1787	1749	1720	1669
		1967-2020	Full distribution	0.48	1643	1414	1295	1123
Syrdarya river – Kazaly	-	1930-1966	Full distribution	0.94	1511	1341	1259	1140
		1967-2020	Truncated, 40 %	1.00	1032	882	810	705

Conclusion

Based on the calculations and analysis of the Syrdarya River's maximum runoff, it has been determined that the construction of the Shardara Reservoir has influenced the alteration of the maximum runoff regime. This is justified as the heterogeneity number of integral curves analyzed decrease in the maximum runoff, but considers this not only with the construction of hydraulic structures, but also with water management measures that use water not rationally.

The calculations results for four gauging station show a decreasing value of the maximum runoff varying from 20 % to 32 %. At the Shardara downstream gauging station reservoir in the early years, the maximum runoff was observed to be 1880 m3/s, but after the construction of the reservoir it increased to 1120 m3/s; at gauging station Tomenaryk - 1615 m3/s - after 841 m3/s, at gauging station Tasbuget 1315 m3/s - after 613 m3/s, at gauging station Kazaly - 842 m3/s - after 434 m3/s are respectively. In addition, the peaks became rare, as the average of the maximum water discharges decreased by 2-3 times. The variability of maximum water discharges has strongly decreased.

The results are intended for application in the design and execution of specific engineering projects, as well as in the creation of measures to protect areas from flooding.

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STRUCTURAL-TECHTONIC AND MINERALOGICAL STRUCTURE OF INDER LIFTING FIELD, MINING AND CHEMICAL RAW MATERIALS IN ATYRAU REGION

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Abstract. The paper presents studies on the facies complex of salt rocks of the boron-potassium deposit of the Inder uplift. Among them, the main widespread varieties of rocks are distinguished, namely, sylvine-polyhalite and carn. allite-kieserite. The chemical and mineralogical compositions of these rocks both along the strike of the layers and especially in the vertical section vary within wide limits, but at the same time there are certain patterns of relationships between the composition of minerals. The chemical and mineralogical characteristics of salt rocks are presented for wells where a change in the composition of salt rocks occurs with a transition to essentially carnallite rocks with bischofite. The internal salt tectonics of the deposit is distinguished by exceptional consistency of the general direction of the strike of both the entire structure as a whole, and the features that compose it. This is due to the proximity of the location of the monoclinal structure under consideration to the marginal part of the salt-dome uplift, as well as the basal anhydrite of the upper cycle of salt accumulation. The anhydrite horizons, which are found in the cores of all salt domes, are accepted as markers. The barium to strontium ratio was used to correlate the anhydrites. Based on the distribution of barium and strontium, the main anhydrite horizon was identified, which is of primary importance in establishing the identity of the sections of salt deposits in the domes. The total thickness of the entire salt rock complex exposed in the area is estimated at 750–800 m. The footwall of the boron-potassium deposit contains stratigraphic younger rocks, while the hanging wall contains older ones. The productive strata are characterized by a complex mineral composition and are composed of sylvinites, polyhalite, kieserite, carnallite, and bischofite rocks. In many cases, potassium salts have mixed compositions. The most common boron minerals are hydroboracite, caliborite, preobrazhenskite, boracite, etc.

Keywords: boron-potassium deposit, basal anhydrite, sylvine-polyhalite and carnallite-kieserite rocks, bischofite, salt tectonics, boron minerals – hydroboracite, caliborite, preobrazhenskite, boracite

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АТЫРАУ ОБЛЫСЫНЫҢ ИНДЕР КӨТЕРІЛІМІНІҢ СТРУКТУРАЛЫ-ТЕХТОНИКАЛЫҚ ЖӘНЕ МИНЕРАЛДЫҚ ҚҰРЫЛЫМЫ, ТАУ-КЕН ХИМИЯЛЫҚ ШИКІЗАТЫ

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Аннотация. Мақалада Индер көтерілиміндегі бор-калий кен орнының тұзды жыныстарының фациялық кешені берілген. Олардың ішінде тау жыныстарының негізгі кең таралған түрлері ерекшеленеді, атап айтқанда сильвин-полигалит және карналлит-кизерит. Бұл жыныстардың химиялық-минералогиялық құрамы қабаттардың соғуы бойынша да, әсіресе тік қимасында да кең ауқымда өзгереді, бірақ сонымен бірге минералдардың құрамы арасында белгілі бір байланыс заңдылықтары бар. Тұзды жыныстардың құрамының өзгеруі ұңғымаларда да кездеседі, онда бишофит бар негізінен карналлиттік жыныстарға ауысатын тұзды жыныстар. Кен орнының ішкі тұз тектоникасы тұтас құрылымның да, оның құраушы белгілерінің де соғуының жалпы бағыты бойынша ерекше консистенциясымен ерекшеленеді. Бұл қарастырылып отырған моноклинальды құрылымның орналасуының тұз күмбезінің көтерілуінің шеткі бөлігіне, сондай-ақ тұздың жиналуының жоғарғы циклінің базальды ангидритіне жақын болуына байланысты. Маркерлер ретінде барлық тұзды күмбездердің өзектерінде кездесетін ангидрит горизонттары алынады. Ангидриттерді корреляциялау үшін барий мен стронцийдің қатынасы пайдаланылды. Барий мен стронцийдің таралуы негізінде күмбездердің тұзды шөгінділерінің учаскелерінің сәйкестігін белгілеуде бірінші дәрежелі маңызы бар негізгі басты ангидриттік горизонт анықталды. Өнімділік қабаты күрделі минералды құраммен сипатталады және сильвиниттер, полигалит, кизерит, карналлит және бишофит жыныстарынан тұрады. Көптеген жағдайларда калий тұздары аралас композицияларға ие. Бордың ең көп таралған минералдары гидроборацит, калибрит, преображенскит, борацит, т.б.

Түйін сөздер: бор-калий кен орны, базальды ангидрит, сильвин-полигалит және карналлит-кизерит жыныстары, бишофит, тұз тектоникасы, бор минералдары – гидроборацит, калиборит, преображенскит, борацит

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СТРУКТУРНО-ТЕХТОНИЧЕСКОЕ И МИНЕРАЛОГИЧЕСКОЕ СТРОЕНИЕ МЕСТОРОЖДЕНИЙ ИНДЕРСКОГО ПОДНЯТИЯ, ГОРНО-ХИМИЧЕСКОЕ СЫРЬЁ В АТЫРАУСКОЙ ОБЛАСТИ

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Аннотация. В работе предствлены исследования по фациальному комплексу соляных пород борно-калийного месторождения Индерского поднятия. Среди них выделяются основные распространенные разновидности пород, а именно сильвин-полигалитовые и карналлит-кизеритовые. Химико-минералогические составы этих пород как по простиранию пластов, так и особенно в вертикальномс разрезе изменяются в широких пределах, но при этом имеют место определенные закономерности связей состава минералов. Представлена химико-минералогическая характеристика соляных пород по скважинам, где происходит изменение состава соляных пород с переходом к существенно карналлитовым породам с бишофитом. Внутренняя соляная тектоника месторождения отличается исключительной выдержанностью общего направления простирания как всей структуры в целом, так и слагающих им особенностям. Это связано с близостью расположения рассматриваемой моноклинальной структуры к краевой части солянокупольного поднятия, а также базального ангидрита верхнего цикла соленакопления. В качестве маркирующих приняты горизонты ангидритов, которые встречаются в ядрах всех соляных куполов. Для корреляции ангидритов было использовано отношение бария к стронцию. По характеру распределения бария и стронция был выделен главный ангидритовый горизонт, имеющий первостепенное значение при установлении идентичности разрезов соляных отложений куполов. Общая мощность всего вскрытого на участке комплекса соляных пород оценивается в 750-800 м. В лежачем боку борно-калийного месторождения находятся стратиграфически более молодые породы, а в висячем – более древние. Продуктивная толща характеризуется сложным минеральным составом и слагается сильвинитами, полигалитовыми, кизеритовыми, карналлитовыми и бишофитовыми породами. Во многих случаях калийные соли имеют смешанные составы. Наиболее распространенные борные минералы – гидроборацит, калиборит, преображенскит, борацит и др.

Ключевые слова: борно-калийное месторождение, базальный ангидрит, сильвин-полигалитовые и карналлит-кизеритовые породы, бишофит, соляная тектоника, борные минералы – гидроборацит, калиборит, преображенскит, борацит

Introduction

The significant resources of very scarce mining and chemical raw materials for the economy of Kazakhstan Republic are concentrated in the depths of the Caspian cavity, the Aktobe in the Urals and adjacent areas, including many types of boron-potassium, potassium-magnesium, magnesium chloride salts, boron ores, sodium sulfate, bromine and others. This raw material is still little used, but it is extremely necessary for many industries and the agricultural sector. All of them are associated with salt-bearing fields of the Lower Permian halogen formation of the Northern Caspian region, except sodium sulfate, and also called the East European salt-bearing basin.

According to the level of exploration, 95 structures are known to date in Kazakhstan part of the salt-bearing basin, bearing potassium mineralization to one degree or another, which 50 are perspective. In terms of the amount of potassium and magnesium salts resources, only four objects are classified in the fields of Zhilyanskoye, Inderskoye, Satimolinskoye and Chelkarskoye (Gorbov,1973: 70–104; Bocharov et al., 1981: 139–144; Aksenov et al., 2000: 5–6; Ivanov et al., 1972. 328; Korenevsky et al., 1966: 297; Tikhvinsky, 1976: 102–114; Tikhvinsky, 1985: 15–20; Filko, 1990: 6–12).

The Inder lifting field, which is associated with a peculiar complex of potassium-magnesium boron-bearing salt rocks of various compositions, is a salt-dome structure of an open, intruded type. The anticlinal part of this dome, cut off by the denudation surface over an area of about 250 km2, is covered only by a complex of residual gypsum cap rocks of relatively low thickness. In this regard, some structural elements of the salt strata are reflected directly in the relief structures of the gypsum cap and serve as an important factor in deciphering the tectonics of the salt strata of the lifting field.

Currently, the Inder lifting field is one of the most developed salt domes of the Caspian basin by drilling. More than seven thousand wells over 1–2 km have already been drilled on its area, deepening into the salt rocks. Wells are located very unevenly on the area of the uplift and, accordingly, its different sections have been studied with varying degrees of detail.

Most of the surface of the Inder lifting field is covered with a uniform network of boreholes with a density of 14 boreholes per 1–2 km; in some exploration areas (pic. 1) a net of boreholes 250x100 m reached a density of 40 boreholes per 1-2 km, and finally, in relatively small development areas side deposits in the gypsum cap and horizons of potassium boron-bearing salt rocks in the salt mass, drilling was carried out at an even greater density.

The boron-potassium deposit in question is located in the southeastern part of the Inder uplift and is located not far from the north-east shore of Lake Inder. It is intersected by twenty-three exploration profiles located on average every 100 m, which for more than 2 km trace the distribution of boron-bearing potassium and potassium-magnesium salt rocks and associated borate deposits in a gypsum cap. Thanks to additional drilling of deeper and inclined wells, the genetic connection of the borate deposits of the gypsum cap with the boron-bearing horizons of the salt strata, some features of the tectonics of salt rocks and changes in their chemical and mineralogical composition were clearly revealed.

Research materials and methods

To determine the mineral composition of the rocks by complete and abbreviated salt analyzes were carried out in laboratory conditions. A complete method includes immersion microscopic method for clarifying the density, cleavage and quantitative composition of minerals, abbreviated method includes determining specific gravity, dry and insoluble residue. When transporting and storing ore, the safety requirements of GOST 12.2.003, GOST 12.3.009 must be met. Sample preparation for chemical analysis was carried out according to GOST 21560.0 (Safety rules for mining and processing of solid minerals, 2013). Sample analyzes according to GOST 20651.3-93. The results of the study are reflected in the following tables.

To clarify the geological structure and tectonic structure of the salt mass in the area of the boron-potassium deposit, geological sections were compiled along all exploration profiles, and on their basis, a geological and lithological map of the surface of the salt mirror, which is presented in (Pic. 2). As can be seen from this map, a pack of salt rocks emerges on the surface of the salt mirror, having a fairly consistent north-west strike and a steep dip, at an angle of 70–800, to the northeast.

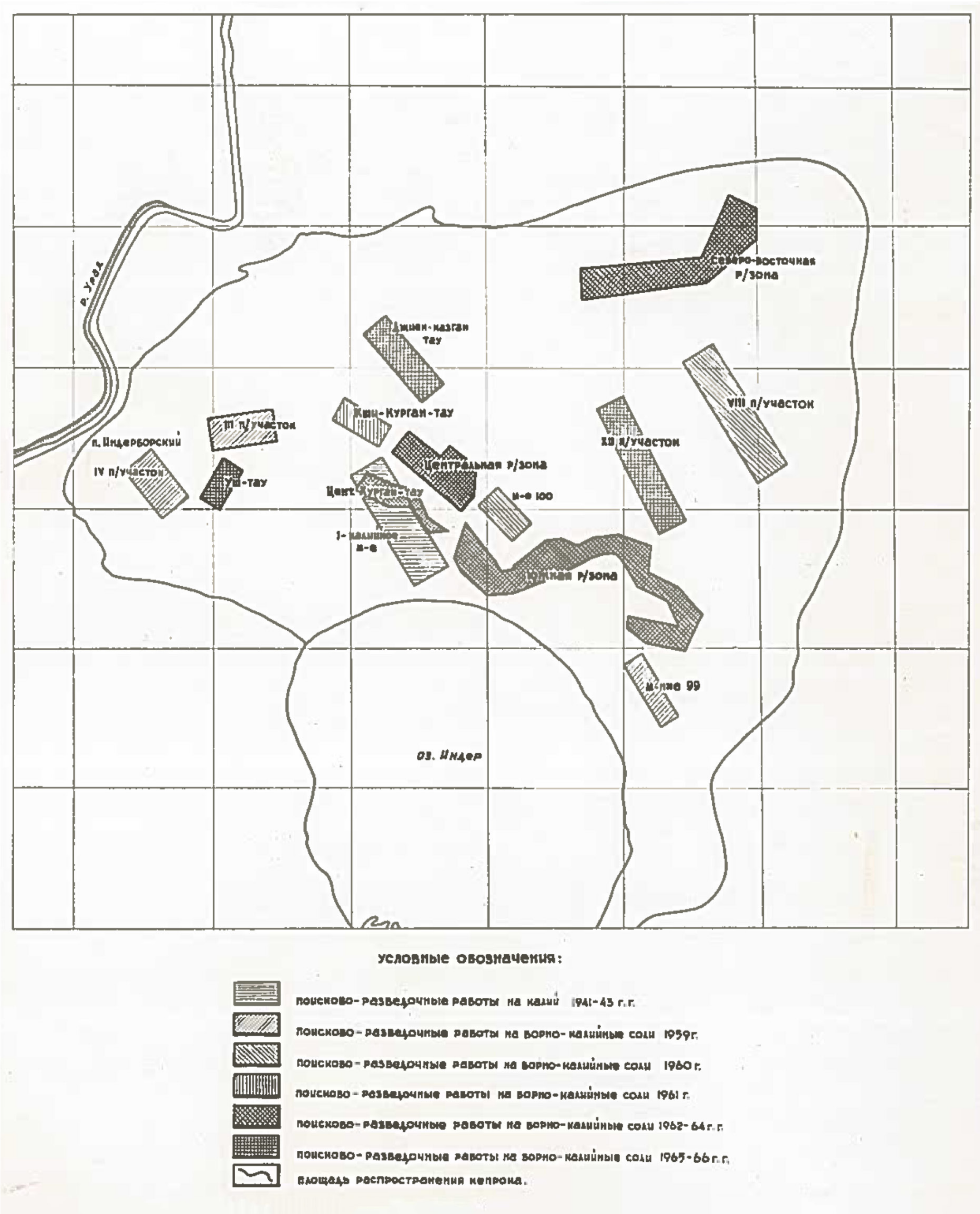

Figure 1 – Layout of prospecting and exploration areas for boron-potassium salts

Thus, in the area of the boron-potassium field, there is essentially a monoclinal structure, placed almost on its head, and in accordance with this, the salt mirror is an erosional section, on the surface of which layers of salt rocks are exposed. The pattern of exposure of these layers to the surface of the salt mirror obviously reflects the nature of tectonic disturbances in layering and, as can be seen on the geological and lithological map presented in (Pic. 2), in this area the salt rocks are characterized by relatively calm compression

Figure 2 – Schematic geological and lithological map of the salt mirror of the boron-potassium field

Both on the geological sections (Pic. 3) and on the geological-lithological map of the salt mirror and the stratigraphic section of the Lower Permian field, it is clearly visible that the salt layer, uncovered by wells in the boron-potassium deposit area, is represented in the main rock salt unit containing the formation and lenses of boron-bearing potassium and potassium-magnesium salt rocks, predominantly sulfate in composition.

Among them, there is a frequent alternation of two main varieties of rocks, often connected by mutual transitions, these are sylvite - polyhalite with calibrite and carnallite-kieserite with preobrazhenskite. The chemical-mineralogical composition of these rocks is very variable and along the strike of the same layer varies from essentially sylvinite to glaserite or kainite, on the one hand, and from essentially bischofite and carnallite to kieserite and less commonly kainite, on the other.

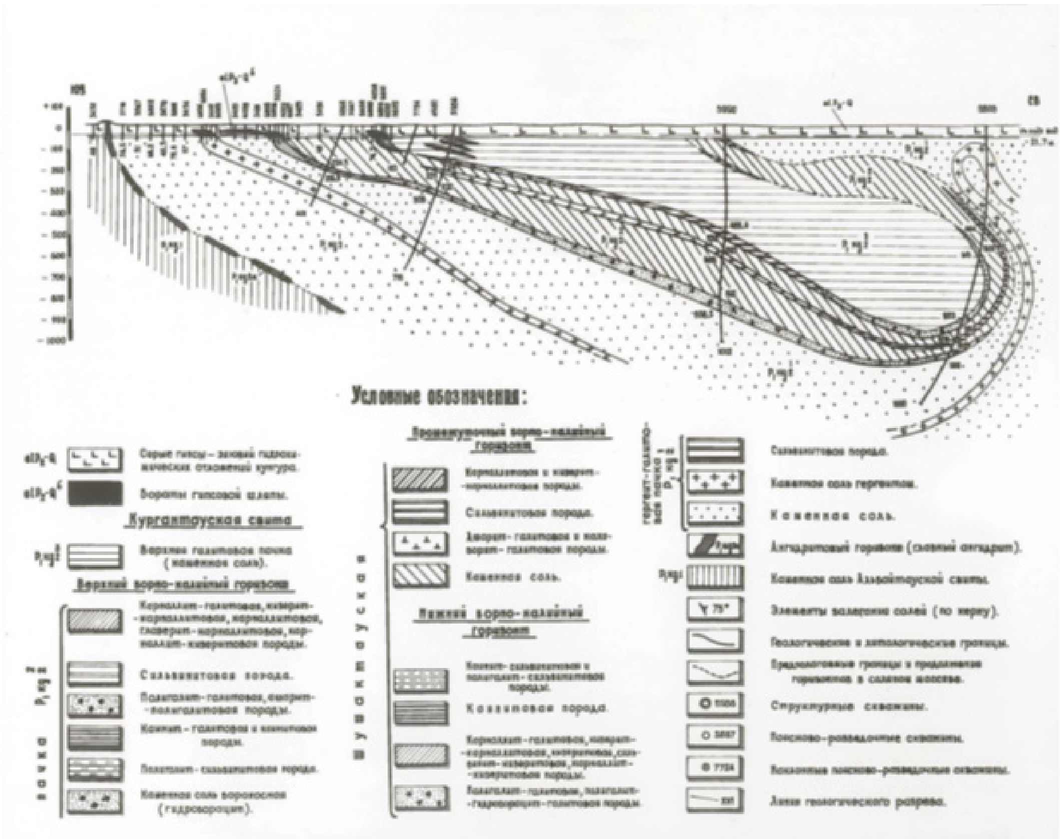

Figure 3– Geological section along lines XV–XV

Below we will give a brief chemical and mineralogical characteristics of the salt rocks of this area. The main rock that makes up the section of the salt strata in the area of the boron-potassium deposit, as noted, is rock salt. According to incomplete chemical analyses, the halite content in this rock varies widely, from 85.5 to 97 % NaCL; impurities are represented mainly by anhydrite and to a lesser extent by carbonates, borates, clayey matter and some other minerals.

Layers and lenses of sylvite-polyhalite-halite rocks have a fairly uniform mineralogical but highly variable chemical composition. In most cases, these rocks, according to available chemical analyzes and immersion viewing of samples, are characterized by the following weighted average composition:

Table 1
Weighted average sample composition

№ well / interval, m Minerals	Скв№6009 46,1–69,5	Скв№3612 48,2–66,2	Скв№6011 48–53,3	54,6–58
halite	78,6 %	66,2 %	80,9 %	72,8 %
polyhalite	13 %	21,2 %	8,6 %	14,9 %
Sylvina	7,2 %	10,7 %	7,2 %	7,5 %
caliborite	1 %	1,8 %	1,7 %	0,1 %
anhydrite	-	0,2 %	0,2 %	0,2 %

As you can see, it is mainly rock salt with a large admixture of sylvite and polyhalite. In some places among these rocks there is an interlayer containing up to 30 % clays, in some places they turn into sylvinites (well No. 3565, 6020, etc.), the composition of which can be characterized by the following limits of the content of the main components:

Table 2
Composition of samples from well No. 3565,6020

Minerals	Avarage content
Halita	38.4 - 52.8 %
Silvina	32 - 42.1 %
Polyhalite	10.2 - 16.3 %
Caliborite	0.8 - 2.2 %
Others	2.8 – 4 %

Among the latter are lenses of sylvite-caliborite rocks containing up to 45 % caliborite and more than 36 % sylvite (well No. 3565, depth 46.0–48.0 m). Peculiar polyhalite-ascharite-halite rocks were encountered in well No. 6051 (10.3–17.2 % asharite).

In some areas of these rocks along the strike of the same formation, instead of the usual polyhalite, kainite is present in significant quantities.

Indicative in this regard are the rocks discovered by well No. 4038 on the XV exploration profile. In the section of this well, six layers can be distinguished, the mineralogical composition of which, according to recalculation of chemical analyzes, is characterized by the following ratios of the main components

Table 3
Mineral analysis of samples from well No. 4038

interval, m Minerals	47,5–53,5	53,5–57,5	57,5–62,0	62,0–64,0	64,0–66,0	66,0–70,0
Halita	74,5 %	68,5 %	42,9 %	32,8 %	61,6 %	88,1 %
Cainita	14,0 %	23,8 %	48,5 %	27,8 %	4,5 %	0,3 %
Silvina	7,7 %	2,9 %	3,9 %	26,6 %	21,6 %	-
Polyhalite	-	-	-	-	-	-
Kaliborita	1,2 %	2,5 %	2,1 %	9,4 %	7,5 %	0,2 %
Anhydrite	3,0 %	2,9 %	2,2 %	2,9 %	3,7 %	-

Essentially Cainite rock was encountered on the 11th exploration profile by well No. 3583. This breed is characterized by the following composition:

Table 4
Data on well No. 3583

Minerals	Content
Cainita	56.6 %
Halita	27.2 %
Caliborita	11.9 %
Silvina	2.6 %
Anhydrite	1.5 %

In some cases, the appearance of essentially glaserite rocks is noted among the layers of the rocks under consideration. The mutual transition of the above is most clearly established in the section of well No. 6020 on the XVI exploration profile, which from 44.7 to 50.7 m, as noted above, passed through a fairly rich polyhalite-sylvite-halite rock, and lower to 58.7 m. intersected significantly glaserite rocks, content from 25.94 to 42.62 % glaserite. The weighted average composition of the rock in this interval (from 50.7 to 58.7 m) is expressed by the following contents of the main components:

Table 5
Weighted average rock composition in the interval (from 50.7 to 58.7 m)

Minerals	Contenr
Glaserite	35.0 %
Halita	33.0 %
Polyhalite	14.3 %
Silvina	10.6 %
Cainita	4.8 %
Kaliborita	1.2 %

Rocks of similar composition were also discovered by the neighboring well No. 6017, which passed through them from 58.6 % to 73.2 m and stopped in rock containing 42.64 % glaserite. Similar rocks with an admixture of glaserite were encountered on the Xth exploration profile by well No. 4527, on the XVIth exploration profile by well No. 4517 and in some other places in the area under consideration.

In the recumbent side of the sylvite-polyhalite rock formation, extending from the northeast

side of the site of boron-potassium deposit No. 99, a noticeable admixture of carnallite appears among the usual minerals composing it, this can be seen in the following data from the calculation of chemical analyzes for the mineralogical composition, according to immersion viewing of samples from well No. 6010 (XV profile):

Table 6
Conversion of chemical analysis data to mineralogical composition for well No. 6010

Interval, m Minerals	48,0–51,5	51,5–66,5	66,5–69,0
Halita	65,5 %	74,0 %	68,2 %

Polyhalite	18,8 %	5,7 %	20,3 %
Silvina	11,2 %	7,6 %	5,4 %
Carnallita	1,0 %	3,1 %	2,2 %
Kaliborita	3,3 %	2,6 %	1,6 %
Anhydrite	-	7,0 %	2,4 %

On the XIII exploration profile, three inclined wells No. 6054, 6053, 6057, as well as vertical wells 3584 and 3564, uncovered this entire formation, which in this place has a true thickness of 60 m. Wells No. 6054 and No. 6053 discovered ordinary low-grade sylvite-polyhalite-halite rocks, which are characterized by the following content limits of the main components:

Table 7
Contents of components for wells No. 6054 and No. 6053

Minerals	Content
Halite	55.8–79.0 %
Polyhalite	11.0–6.4 %
Silvina	3.4–23.0 %
Kaliborita	1.4–2.5 %

Inclined well No. 6057 in the upper part, from 48.5 to 52.5 m. intersected poor sylvite-polyhalite rocks, similar in composition to those reached at the bottom of well No. 6058. Below, from 52.5-halite (0.07–1.34 % K) and caliborite (0.69–1.07 % B2O2), and then the well entered the zone of kieserite-carnallite - halite rock, which, in the interval 75.0–76.0, ends with kieserite-carnallite rock, as can be seen from the following data from the recalculation of chemical analyzes to the mineralogical composition:

Table 8
Sample analysis data for well No. 6057

Interval, m Minerals	73,5–75,0	75,0–76,0
Carnallita	21,3 %	42,2 %
Kieserita	18,6 %	25,8 %
Halita	50,7 %	21,4 %
Silvina	3,4 %	5,6 %
Boratov	3,4 %	3,5 %
Anhydrite	2,6 %	1,3 %

In accordance with the change in the composition of the rock with depth, characteristic of sylvite - polyhalite-halite rocks, calibrite is replaced towards the bottom by preobrazhenskite and boracite, the main boron minerals of the kieserite-carnallite rock. In the footwall of this rock, from 76.0 to 88.0 m, the well entered rock salt with anhydrite containing 93.3 % halite and about 6 % anhydrite.

It should be noted that vertical well No. 3564, drilled slightly southwest of inclined well No. 6057, intersected the same layer of kieserite - carnallite rock at its very exit to the salt mirror. The mineralogical composition of the rock found here is as follows:

Table 9
Mineralogical composition of the rock from well No. 3564

Minerals	Content
Carnallite	33.4 %
Kieserita	26.1 %
Preobrazhenskite	17.6 %
Halita	14.4 %
Bishofita	5.4 %
Polyhalite	2.8 %

As can be seen from the given values, this rock is generally similar to the rocks encountered by well No. 6057 in the interval 75.0–76.0 m, but the appearance of bischofite here, as well as the increased boron content expressed by preobrazhenskite, attracts attention.

Results

Thus, the layers of the considered rocks, both in section and along strike, showed changes in composition from essentially kainite and glaserite, on the one hand, to essentially carnallite with bischofite, on the other.

In addition to the rocks considered, carnallite-kieserite rocks with compositional changes within a very wide range are also significantly developed in the area of deposit.

The main layer of these rocks extends across the central part of the site; a number of smaller lenses and interlayers were encountered in the very northwestern part of it.

The variability of the composition of carnallite-kieserite rocks is perfectly illustrated by the data of recalculation of chemical analyzes to mineralogical composition for the section of well No. 6059, which are given in Table No. 1. As can be seen from the data in this table, the considered formation in the section of well No. 6059 is represented mainly by carnallite-kieserite rocks with preobrazhenskite

Table 10. Results of recalculation of chemical analysis data for the section of well No. 6059 into mineralogical composition (wt.%)

Interval, m / Minerals	56-57	57-58	58-59	59-60	60-61	61-62	62-63	63-64	64-65	65-66	66-67	67-68	68-69
Halite	74,4%	75,5%	83,6%	61,8%	16,0%	12,6%	23,2%	55,7%	88,9%	77,4%	58,7%	64,0%	25,6%
Kieserit	3,1%	1,4%	1,8%	14,3%	44,5%	70,9%	45,3%	19,1%	0,8%	0,9%	3,5%	2,1%	33,5%

Carnallite	15,2%	13,4%	6,4%	13,4%	26,3%	13,0%	22,6%	12,5%	4,3%	12,3%	16,6%	24,5%	30,1%
Silvin	1,0%	0,1%	0,8%	--	2,5%	1,5%	1,9%	2,0%	0,5%	0,4%	1,9%	0,8%	2,8%
Anhydrite	3,7%	5,5%	5,1%	2,5%	0,8%	0,4%	1,7%	2,2%	3,8%	4,9%	3,5%	3,0%	3,1%
Preo-brazhenskit	2,7%	4,2%	2,8%	6,4%	8,9%	1,1%	4,3%	8,0%	0,6%	4,9%	16,4%	4,7%	6,9%
Undissolved residue	0,1%	0,1%	0,1%	0,1%	0,2%	0,1%	0,1%	0,3%	1,1%	1,1%	0,1%	0,1%	0,3%

Table 11. Results of recalculation of chemical analysis data along the well section into mineralogical composition (wt.%)

Wells	№6016	№6058		№6118	
Interval, m Minerals	48,6-68,2	83,0-93,1	47,8-48,7	48,7-56,7	48,6-68,2
Kieserita	31,2-40,7 %	19,5 %	16,4 %	Kieserita	31,2-40,7 %
Carnallita	15,9-30,9 %	19,6 %	--	Carnallita	15,9-30,9 %
Halita	11,7-22,2 %	40,8 %	36,3 %	Halita	11,7-22,2 %
Silvin	--	2,0 %	12,8 %	Silvin	--
Bishofita	--	--	10,8 %	Bishofita	--
Preobrazhenskite	9,4-40,2 %	17,2 %	--	Preobrazhenskite	9,4-40,2 %
Others	0,6-1,5 %	1,4 %	1,2 %	Others	0,6-1,5 %

It should be noted that in the roof of the main layer of carnallite-kieserite rocks on the IV and V exploration profiles, wells Nos. 3370 and 6113 uncovered rocks depleted in kieserite and carnallite, but enriched in sylvite and polyhalite. In composition, they are close to the previously considered sylvite-polyhalite-halite rocks, which can be seen from the following data from the conversion of chemical analyzes to mineralogical composition:

Table 12
Composition of samples for wells No. 3370 and 6113

Wells	№3370		№6113
Interval, m Minerals	43,2-57,0	43,4-64,5	64,5-69,7
Halita	74,9 %	69,6-76,1 %	72,2 %
Silvin	13,8 %	7,6-21,7 %	13,2 %
Polyhalite	5,6 %	3,0-5,1 %	7,3 %
Carnallita	2,4 %	--	--

Kieserita	--	0,9-2,3 %	--
Kaliborita	1,9 %	--	1,2 %
Preobrazhenskite	--	1,7-6,6 %	--
Impurities	1,2 %	0,2-0,25 %	0,2 %

In well No. 3470 on the XIV exploration profile, where the layer of carnallite-kieserite rocks experiences an inflection, along with the expected rocks, a polyhalite-sylvite-halite rock with a calibrite of the following composition were discovered:

Table 13
Composition for well No. 3470

Minerals	Content
Halita	52.1 %
Silvina	19.1 %
Polyhalite	15.8 %
Kaliborita	9.4 %
Impurities	3.3 %

Similar changes in the mineralogical composition of this formation are also established along strike in the very southeastern part of the boron-potassium deposit site (wells No. 4023, 4045).

On the III exploration profile, inclined wells No. 6058, 6059 and 6068 exposed the main layer of carnallite-kieserite rocks to the full thickness, which is 35 m here. The composition of the rocks have already been given above in wells No. 6058 and 6059.

In the downstream side of the formation, well No. 6068 discovered kieserite rocks with halite and carnallite, characterized by the following content limits of the main components:

Table 14
Data for wells No. 6068

Minerals	Avarage Content
Kieserita	52.0 --84.1 %
Halite	5.5 -- 23.2 %
Carnallite	3.4 – 20.5 %
Silvina	1.2 – 11.0 %
Preobrazhenskite	0.8 – 3.9 %

Vertical well No. 3617, drilled between inclined wells No. 6058 and 6068 in the upper part from 46.6 to 61.7 m, uncovered heavily boron-bearing rocks, containing up to 48 % preobrazhenskite, which in dip corresponds to the rich boron-bearing rocks discovered by well No. 6058 at in the interval 83.0-93.1 m, below, from 64.55 to 76.3 m (bottomhole), it entered kieserite rocks, corresponding in terms of formation uplift to the rocks penetrated by well No. 6068, and in the interval from 61.7 to 64.55 m encountered an interlayer of kieserite-carnallite rock with bischofite of the following composition:

Table 15
Data for well No. 6068

Minerals	Content
Carnallite	41.5 %
Kieserita	32.7 %
Bishofita	14.0 %
Halita	5.9 %
Preobrazhenskite	1.7 %
Anhydrite	1.7 %
Clay matter	2.5 %

In addition to the main layer of carnallite - kieserite rocks discussed above, an interlayer of carnallite rock with polyhalite was encountered by wells No. 6105, 6107 and 6106 in the southwestern part of the exploration profile and well No. 3296 on the VII exploration profile (see Fig. 2). Interlayers of carnallite rock were encountered, and on the northeastern side of the boron-potassium field site, wells No. 6070, 6224, 6213, 6204 and 6202 in the section of the last well, among the carnallite rock at an interval of 75.0–78.0 m, bischofite rock was encountered containing 84, 26 % bischofite, 6.44 % kieserite and 4.5 % halite and carnallite.

There are almost no burrs in these rocks, but the relatively high bromine content in bischofite rocks is noteworthy - 0.329–0.411 %.

Thus, in the area of the boron-potassium deposit, a unique facial complex of salt rocks is exposed. It is represented by a steeply descending rock salt unit containing layers, layers and lenses of boron-bearing potassium and potassium-magnesium salt rocks, predominantly sulfate in composition.

Among them, two main, most common varieties of rocks stand out, between which mutual transitions are outlined, namely syvin — halite polyhalite and carnallite - kieserite. The chemical and mineralogical composition of these rocks, both along the strike of the layers and especially in the vertical section, varies within wide limits, but a certain pattern is captured.

From the above chemical and mineralogical characteristics of salt rocks, as well as from the data of the geological section along the XV exploration profile (Fig. 3), it clearly emerges that both in the sylvite layers there are polyhalite-halite, and in the layers of carnallite-kiesert rocks with northeast to southwest, that is, towards the recumbent side, the composition of the salt rocks changes with their transition to essentially carnallite rocks with bischofite.

If this general direction of change in the composition of rocks in the vertical section of salts is a relic of the normal sequence of salt deposition in the salt basin, then in the area of the boron-potassium deposit we are essentially dealing with a structure overturned to the southwest. In other words, in this area, as one would expect (Khalturina et al., 1985: 215; Valyashko; Diarov et al., 1981: 101–109), in the north-eastern part of the deposit, that is, closer to the central part of the salt uplift, there are lower stratigraphic horizons, and in the direction towards its marginal parts, that is, towards roof in the south-west direction, increasingly upper stratigraphic horizons of the salt strata emerge on the surface of the salt mirror

Both on the northeastern and southwestern sides of the monoclinal structure of the boron-potassium deposit site, there are almost parallel ridges of gypsum-anhydrite rocks, indicating the presence of anhydrite horizons in the salt stratum. Unfortunately, the complete section between the anhydrite horizons in this area has not been established in detail by drilling.

The total thickness of the entire salt rock complex discovered on the site is estimated at 750–800 m.

In structural-tectonic terms, the boron-potassium deposit is located in the southern part of the Inder uplift and is located on the southwestern wing of the salt dome structure framing the depression basin of Lake Inder. This situation determines the main features and peculiarities of the tectonic structure of the salt block explored by surface and underground mine workings. In general terms, this block can be described as a monoclinal structure, extending along the side of the uplift from northwest to southeast with the strata dipping to the northeast at an angle of about 700.

Taking into account the fact that the roof of the salt strata of the uplift is located in its peripheral frame, the salt rocks of the monoclinal structure falling to the north-east actually have an overturned bedding to the southwest, reflecting the presence of a cornice in the side part of the salt-dome structure,

Thus, in the recumbent side of the boron-potassium deposit there are stratigraphically younger rocks, and in the hanging side there are more ancient ones. This general rule should be taken into account not only in general stratigraphic constructions, but also when comparing different horizons of salt rocks exposed in the field.

The features of internal salt tectonics are quite clearly revealed from the analysis of documentation materials from underground mine workings. As can be seen from the structural-lithological map compiled from this material, the block of salt strata discovered at a horizon 300 m below the surface, as in the salt mirror, has a fairly simple tectonic structure. When considering this map, attention is drawn, first of all, to the exceptional consistency of the general direction of strike of both the entire structure as a whole, as well as the features that make it up

Against the background of the consistency of the main liniments of the tectonics of the layered structure, only smooth bends of individual layers, layers and units of salt rocks are noted, which are a reflection of local manifestations of layer-by-layer plastic movements of salt. The latter are usually accompanied by noticeable changes in the thickness of the salt rocks that make up the layers, layers and units, without breaking their continuity. The only exceptions in this regard are the layers of anhydrite and polyhalite.

The noted consistency of the bedding strike is due to the proximity of the location of the monoclinal structure under consideration to the marginal part of the salt dome uplift, as well as the basal anhydrite of the upper cycle of salt accumulation. At the level of annual layers, manifestations of isoclinal folding of different orders are noted, but it does not violate the consistency of the main liniments of tectonics, since the axial densities of these folds are oriented parallel or almost parallel to the general strike of the monoclinal structure.

The main complicating element of the internal tectonics of the salt mass at the deposit is a large ring structure, opening in the south-eastern half of the ore field, between the main crosscut in the north-west and ort 16 in the south.

The productive stratum is characterized by a complex mineral composition and is composed of sylvinites, polyhalite, kieserite, carnallite and bischofite rocks. The potassium salts have mixed compositions in many cases.

The most common boron minerals are hydroboracite, calibrite, preobrazhenskite, boracite, etc. (Fig. 4). During the formation of the domes, the original sequence of occurrence of halogen deposits, including boron and potassium salts, was sharply disrupted. In this regard, linking the sections of the potassium-boron-bearing zone of the domes is very difficult. The absence of micro- and macrofauna and leading species of spores and pollen in salt deposits, the unreliability of linking salts according to their lithology required the development of correlation characteristics for halogen dome rocks

Anhydrite horizons, which are found in the cores of all salt domes, are taken as markers. The ratio of barium to strontium was used to correlate anhydrites. Based on the nature of the distribution of barium and strontium, the main anhydrite horizon was identified, which is of paramount importance in establishing the identity of the sections of the salt deposits of the domes (Diarov, 2003: 220).

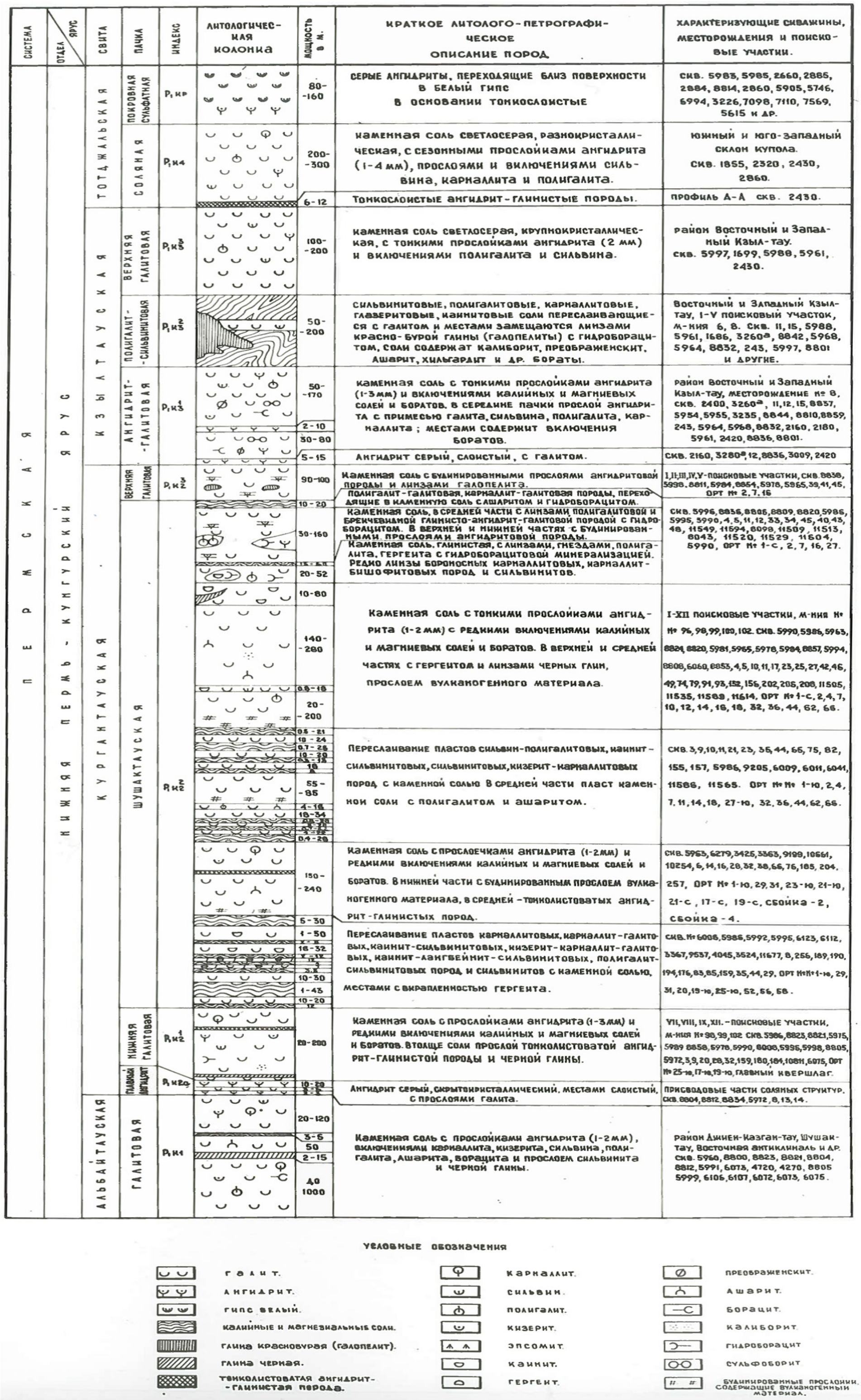

Fig.4. Summary stratigraphic section of the Lower Permian field

The deposit was explored underground using a system of mining workings at a horizon of -300m and wells to a depth of 900–950m. Mine shafts and workings can be used during operation. (Fig.5). The ore-bearing strata is rock salt. Within the explored area, 10 sheet-like deposits of boron-potassium salts and six potassium salts, isolated from each other, were identified and explored. Their length ranges from a few hundred meters to 1.5–2.0 km, thickness – 1–2 to tens of meters.

Figure 5 – Schematic geological plan of the 300m horizon of the boron-potassium deposit

The composition of potassium field is predominantly sylvinite. Approved reserves amount to 35 million tons of sylvinite (6.3 million tons of K2O). Another 4 million tons of K2O are contained in boron-potassium deposits. In terms of the number of explored reserves of potassium salts, the deposit is classified as small. However, it should be taken into account that, firstly, there are real opportunities for significant growth due to additional exploration and, secondly, the field has been opened by a mine and production can be carried out now

As you know, one of the types of potash fertilizers is raw ground sylvinite. Provided that there are 50% losses during production and the mine capacity is 500 thousand tons. of sylvinite per year (140 thousand tons of 100% KI), the enterprise can operate for 35 years, and taking into account the increase in reserves, even longer. In parallel with the processing of sylvinite deposits, it is possible to mine carnallite and bischofite-carnallite ores. The predicted K2O resources throughout the Indera dome are estimated at 9 million tons in categories (P1) and 192 million tons (P2). The resources of magnesium chloride (MgCl2) are 6 million tons (P1) and 120 million tons (P2).

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Conclusion

1. The facile complex of salt rocks is exposed in the area of the boron-potassium field of the Inder uplift. Among them, two main, most common varieties of rocks stand out, between which mutual transitions are outlined, namely syvin - halite polyhalite and carnallite – kieserite. The chemical and mineralogical composition of these rocks, both along the strike of the layers and especially in the vertical section, varies within wide limits, but at the same time there are certain patterns of relationships between the composition of minerals.

2. In this case, the chemical and mineralogical characteristics of salt rocks from wells are presented, and a change in the composition of salt rocks occurs with their transition to essentially carnallite rocks with bischofite.

3. The total thickness of the entire complex of salt rocks discovered in the area is estimated at 750 - 800 m. In the recumbent side of the boron-potassium field, there are stratigraphically younger rocks, and in the hanging side there are more ancient ones. This general rule must be taken into account not only in general stratigraphic constructions, but also when comparing different horizons of salt rocks exposed in the deposit.

4. Based on data from underground mine workings the internal salt tectonics of the field is distinguished by the exceptional consistency of the general direction of strike of both the entire structure as a whole, as well as the features that compose it. This is due to the proximity of the location of the monoclinal structure under consideration to the marginal part of the salt dome uplift, as well as the basal anhydrite of the upper cycle of salt accumulation.

5. The productive stratum is characterized by a complex mineral composition and is composed of sylvinites, polyhalite, kieserite, carnallite and bischofite rocks. In many cases, potassium salts have mixed compositions. The most common boron minerals are hydroboracite, calibrate, preobrazhenskite, boracite, etc. The composition of potassium deposits is predominantly sylvinite. There is a possibility of increasing the deposit's reserves through additional exploration.

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