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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
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CONTENTS

Geology

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HYDROGEOCHEMICAL FEATURES OF THE NORTH-WESTERN REGIONS OF THE TORGAY DEPRESSION IN RESPECT OF THE SEARCH FOR DEPOSITS OF STRATEGIC METALS

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Abstract. Prospecting works are among the most important stages of geological exploration campaigns. Hydrogeochemical features of 10 prospecting sites in the north-western regions of the Torgay depression are considered in the present work. Results. The groundwaters of the region under investigation are diverse, both in their salinity and in chemical composition. The occurrences of salt waters (TDS more than 10 g/dm^3) originate from continental salination, as the region under study has arid climate. In general, the dominating chemical composition of the waters is HCO_3-Cl Ca-Mg-Na, SO_4-HCO_3-Cl Na-Ca-Mg and SO_4-Cl-HCO_3 Ca-Mg-Na. The elements most frequently occurring in the waters are Cu, Zn, Bi, Sn, Cr and Pb, the presence of Be, As, V, Co, Mo. Scientific novelty. — for the first time, the characteristics of zonal and local hydrogeochemical were established. — the greatest concentration of Bi, As, Mo, Cu and Zn was detected in the waters, the most contrasting hydrogeochemical anomalies were recorded for Cu, Zn, Sn and Bi; — for the first time, the parameters of the concentration coefficient (CF) of Be, Pb, Sn, Bi, Mo, V, Cu, Zn, Co, Cr and the standardized contrast coefficient (SCF) of Be, Pb, Sn, Mo, V, Cu, Zn, Ag, Co, Cr in the groundwater of the exploration areas were calculated. Practical value. The results provide a significant contribution into advancement of the fundamentals of hydrogeochemical methods for the search of strategic metals in Kazakhstan.

Keywords: hydrogeochemical prospecting, background, anomaly, standardized contrast factor, the Torgay depression

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ТОРҒАЙ ОЙЫСЫНЫҢ СОЛТҮСТІК-БАТЫС АЙМАҚТАРЫНЫҢ МЫСАЛЫНДА СТРАТЕГИЯЛЫҚ МЕТАЛДАР КЕНОРЫНДАРЫН ІЗДЕУДІҢ ГИДРОГЕОХИМИЯЛЫҚ ЕРЕКШЕЛІКТЕРІ

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Аннотация. Іздеу жұмыстары – геологиялық барлау жұмыстарының ең маңызды кезеңдерінің бірі. Бұл кезеңде барынша шынайы ақпарат алу кейінгі жұмыстардың табысты әрі тиімді болуына ықпал етеді. Жұмыста Торғай ойысының солтүстік-батыс аудандарында орналасқан 10 іздеу учаскесінің гидрогеохимиялық ерекшеліктері қарастырылған. Нәтижелер. Зерттеліп отырған өңірдің жерасты сулары жалпы минералдану дәрежесі мен химиялық құрамы жағынан алғанда едәуір әртүрлілікпен сипатталады. Ең алдымен, зерттеліп отырған өңір аридті климаттық жағдайда орналасқаны себепті тұзды сулардың (10 г/дм^3-ден жоғары) пайда болуы континенттік тұздану үдерістерімен тығыз байланысты. Жалпы алғанда, құрамдық жағынан HCO_3–Cl Ca–Mg–Na, SO_4–HCO_3–Cl Na–Ca–Mg және SO_4–Cl–HCO_3 Ca–Mg–Na типіндегі сулар басымдыққа ие. Зерттелген жерасты суларының құрамында жиі кездесетін элементтерге Cu, Zn, Bi, Sn, Cr және Pb жатады. Сонымен қатар, Be, As, V, Ag, Co, Mo элементтерінің де бар екендігі анықталды. Ғылыми жаңалық: — бірінші рет аймақтық және жергілікті гидрогеохимиялық фонның сипаттамалары белгіленді; — суларда Bi, As, Mo, Cu және Zn ең көп концентрациясы анықталды, Cu, Zn, Sn және Bi үшін ең қарама-қарсы гидрогеохимиялық аномалиялар тіркелді; — алғаш рет Be, Pb, Sn, Bi, Mo, V, Cu, Zn, Ag, Co, Cr концентрация коэффициентінің (КК) және Be, Pb, Sn, Bi, және тб., жер асты суларының стандартталған контраст коэффициенті (СКК) параметрлері анықталды. — барлау алаңдары есептелді. Практикалық құндылық. Іздеу гидрохимиялық элементтерінің ассоциациясын сипаттайтын аномалиялардың 3 түрі анықталды. Алынған нәтижелер Қазақстан Республикасында стратегиялық металдар іздеу саласында гидрогеохимиялық әдістерді дамытудың негізін қалауда маңызды үлес қосады.

Түйін сөздер: гидрогеохимиялық іздеулер, фон, аномалия, стандартталған контрасттық коэффициент, Торғай ойысы

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ГИДРОГЕОХИМИЧЕСКИЕ ОСОБЕННОСТИ СЕВЕРО-ЗАПАДНЫХ РАЙОНОВ ТОРГАЙСКОГО ПРОГИБА В СВЯЗИ С ПОИСКАМИ МЕСТОРОЖДЕНИЙ СТРАТЕГИЧЕСКИХ МЕТАЛЛОВ

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Аннотация. Поисковые работы – это одна из важнейших стадий геологоразведочных работ, на которой получение максимально достоверной информации может определить успех и эффективность всех последующих работ. В работе рассмотрены гидрогеохимические особенности 10 поисковых участков в северо-западных районах Торгайского прогиба. Результаты. Подземные воды изучаемого региона весьма разнообразны, как по величине общей минерализации, так и по их химическому составу. В первую очередь проявления соленых вод (более 10 г/дм^3) обязаны своим происхождением процессам континентального засоления, учитывая нахождение исследуемого района в аридном климате. В целом, доминируют воды HCO_3-Cl Ca-Mg-Na,

SO_4-HCO_3-Cl Na-Ca-Mg, SO_4-HCO_3-Cl Mg-Ca-Na и SO_4-Cl-HCO_3 Ca-Mg-Na состава. Наиболее часто встречаются в изученных водах Cu, Zn, Bi, Sn, Cr и Pb, установлены Be, As, V, Ag, Co, Mo. Научная новизна. — впервые установлены характеристики зонального и локального гидрогеохимического фона; — в наибольшей степени в водах выявлено концентрирование Bi, As, Mo, Cu и Zn, наиболее контрастные гидрогеохимические аномалии фиксируются по Cu, Zn, Sn и Bi; — впервые рассчитаны параметры коэффициента концентрирования (КК) Be, Pb, Sn, Bi, Mo, V, Cu, Zn, Ag, Co, Cr и стандартизированного коэффициента контрастности (СКК) Be, Pb, Sn, Bi, Mo, V, Cu, Zn, Ag, Co, Cr в подземных водах поисковых участков. Практическая ценность. Определены 3 типа аномалии характеризующие ассоциации поисковых гидрохимических элементов. Полученные результаты, несомненно, вносят значимый вклад в развитие фундаментального направления гидрогеохимических методов поисков стратегических металлов в Республике Казахстан.

Ключевые слова: гидрогеохимическая разведка, фон, аномалия, стандартизированный коэффициент контрастности, Торгайский прогиб

Introduction. Geochemical survey over the object of investigation, in particular rocks, soils, natural waters, plants, atmosphere, biosphere (the area in which living organisms are developing, includes the lower layers of the atmosphere, a part of the lithosphere, and the hydrosphere), is split into lithochemical search over the primary and secondary dispersion halos, lithochemical search over dispersion fluxes, hydrogeochemical search, biogeochemical and atmochemical search. Unfortunately, there is currently a distinct separation in Earth science: mineralogists and geochemists are engaged in developing the theoretical foundations and substantiating lithochemical search, hydrogeochemical search is carried out by the specialists in hydrogeochemistry, while experts in botany perform biogeochemical search. The integrated geochemical studies in which these directions would proceed on a united methodological basis are almost completely absent. In the present paper, the first attempt is made to summarize all hydrogeochemical data over the north-western regions of the Torgay depression (Fig. 1), where more than 20 deposits of iron, bauxites, gold and polymetals have been discovered by present, which will undeniably make a substantial contribution into the progress of fundamental direction related to the hydrogeochemical methods for the search of strategic metals in the Republic of Kazakhstan.

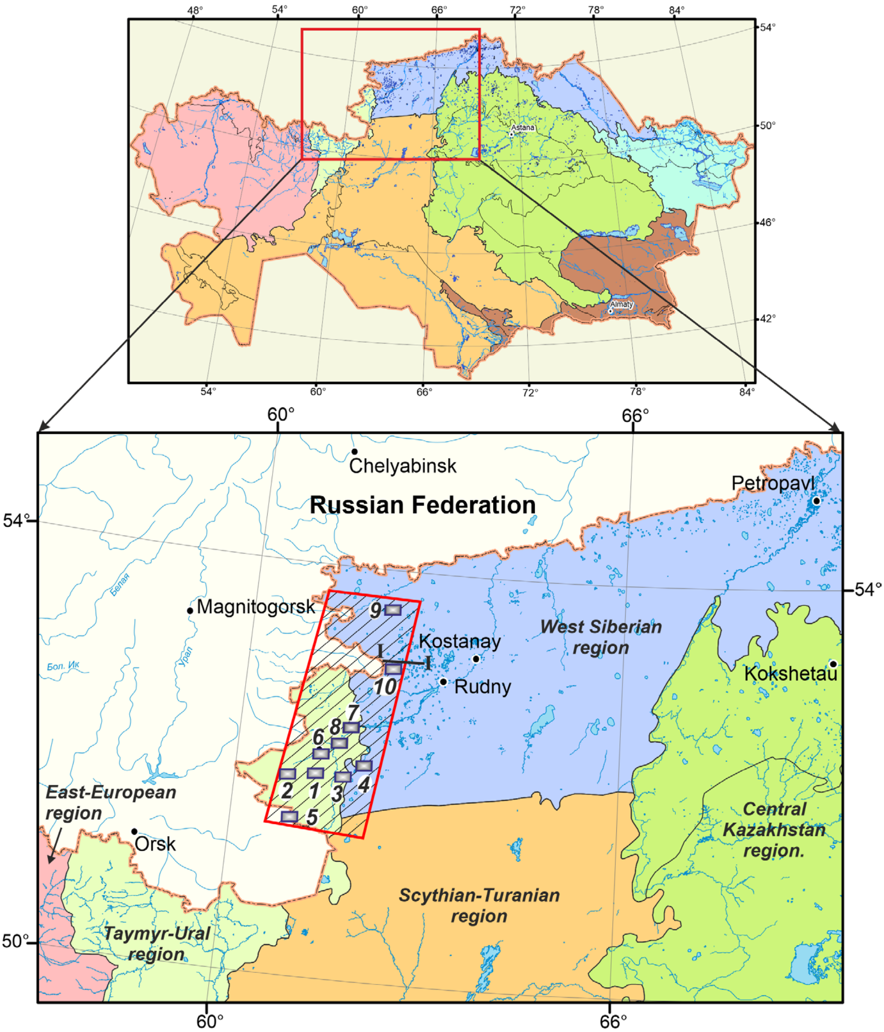

Fig. 1. Location of the region under investigation (a) and prospecting sites (b) within the boundaries of the north-western regions of the Torgay depression.
Boundaries: 1 – state, 2 – of hydrogeological regions; 3 – the area under investigation; 4 – prospecting sites: 1 – Milyutinsky, 2 – Shevchenkovsky, 3 – Kamyshinsky, 4 – Krasnooktyabrsky, 5 – Akkarginsky, 6 – Zhetigarinsky, 7 – Denisovsky, 8 – Shekubaevsky, 9 – Smirnovsky, 10 – Varvarinsky; 5 – hydrogeological section along the I – I line.

Materials and methods. The first generalization of listed data on the groundwaters of the north-western regions of the Torgay depression was carried out. The chemical types of water are indicated according to the formula proposed by M.G. Kurlov, following the sequence from smaller to larger values. For the graphical visualization of groundwater chemical composition, Piper diagram is used. Statistical treatment of hydrogeochemical data was performed according to the instructions on geochemical search methods (Ovchinnikov, 1983), as well as other methodological recommendations (Beus, et al., 1975; Kopylova, et al., 2013). A hydrogeochemical field is understood as a kind of geological fields where the parameters of ion-salt, trace component, gas and organic composition of groundwaters of the object under investigation are considered as indices. The hydrogeochemical background is understood as the average (over most frequently occurring ones) concentration of a groundwater component, while a hydrogeochemical anomaly is a concentration substantially exceeding the background level and characterized by the halo-type behavior. The hydrogeochemical background and anomalies are also dependent on survey scale and are divided into regional, zonal, and local.

The ability of certain elements to be accumulated in groundwaters can be assessed using concentration factor (CF), which is the ratio of element concentration in water to its average concentration in the Earth's crust, according to V.I. Vernadsky and A.I. Fersman (Rudnick, et al., 2003): the higher is excess of element concentration in groundwater over its average concentration in the Earth's crust, the higher is hydrophilic ability of the element.

The contrast factor of the concentrations of chemical elements was determined using the standardized contrast factor (SCF), which is the above-background value normalized to the mean square deviation (for the normal distribution law) or a standard multiplier factor (for the lognormal distribution law). SCF is analogous to the contrast value used to characterize weak anomalies (Shvartsev, 1998):

$$SCF = (Ci – Cb)/\sigma,$$

where Ci is element content in the sample, Cb is the background value, σ (ε) is the square mean deviation (standard multiplier factor). The SCF value can be below zero, which means that element content is below the average value. SCF equal to 1 is accepted as the upper boundary of the background. The contrast degree is determined from SCF values as follows: less than 1 – below the background and background level, from 1 to 2 – a minimal anomalous value, from 2 to 3 – moderately anomalous value, more than 3 – sharply anomalous value. The use of SCF allows tracing the additive and multiplicative complex anomalies.

Results. The region under study (see Fig. 1b) is situated within two hydrogeological regions of Kazakhstan embracing the northern part of the Taymyr-Ural region and the western areas of the West Siberian region (Atlas…, 2022). The former region relates to the Hercynian folding areas, subjected to relatively weak uplifts during the contemporary time, and composed mainly of substantially metamorphosed Paleozoic rocks, among which a significant part is played by intrusions. The underground and surface water runoffs are directed into the adjacent reservoir water basins. At the territory of Kazakhstan, the region is represented by the Bolsheuralsky basin of nonartesian and artesian groundwaters, related to the Ural uplift (Smolyar, et al., 2002). Groundwater composition is broadly affected by evaporative concentrating processes. The fresh waters, with their composition formed due to the rock weathering processes, occur mainly in the western part of the West Siberian region (Medeshova, et al., 2024) (Fig. 2).

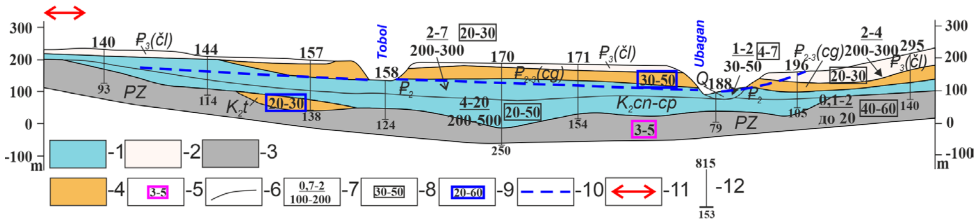

Fig. 2. Hydrogeological cross section along the I – I line.
Hydrogeological units – Aquifers and aquifer systems with groundwater salinity, g/dm^3: 1 – up to 1-3; 2 – up to 3-10; 3 – water-bearing zones with fracturing and tectonic faults in the crystal rocks of different ages, with different groundwater salinities; 4 – regional and local water-impermeable layers, composed mainly of clay-mudstone-marl; 5 – prevailing salinity of the groundwaters of local aquifers and groundwaters of fractured water-bearing zones in crystal rocks; 6 – the stratigraphic boundaries of hydrogeological units; *Hydrogeological parameters:* 7 – numbers: numerator – prevailing well yields, L/s; denominator – prevailing water-transmitting capability of water-bearing rocks, m^2/day; 8 – prevailing effective thickness of water-bearing rocks, m; 9 – prevailing thickness of regional and local water-proof layers, m; 10 – piezometric level, m (in most cases, piezometric level coincides with the level of groundwaters with free surface); 11 – the object of investigation; 12 – hydrogeological well, numbers: upper – well No., lower – well depth, m.

Groundwaters of the region under study are quite diverse, both in total salinity and in chemical composition. First of all, the occurrences of salty waters (with TDS more than 10 g/dm^3) are due to the continental salination processes, since the region under investigation has arid climate. In general, the dominating water composition is HCO_3-Cl Ca-Mg-Na, SO_4-HCO_3-Cl Na-Ca-Mg, SO_4-HCO_3-Cl Mg-Ca-Na and SO_4-Cl-HCO_3 Ca-Mg-Na (Fig. 3a, Table 1). The waters are characterized by pH from weakly acidic (5,2) to weakly alkaline (8,2). The geochemical array under consideration includes the waters from ultrafresh (84 mg/dm^3) to saline (28,4 g/dm^3). The chemical composition of waters changes in the same direction from hydrocarbonate calcium to chloride sodium, often with increased sulfate ion content, which is evidence of continental salination processes.

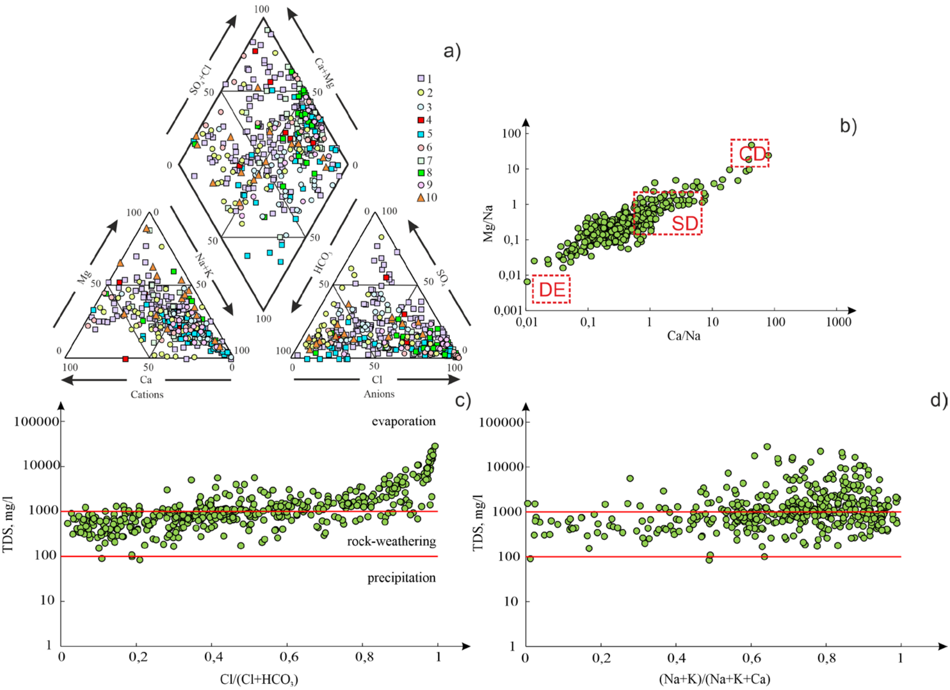

Fig. 3. Piper diagram of the chemical composition of groundwaters at the prospecting sites in the north-western regions of the Torgay depression (a), dependence of Mg/Na on Ca/Na (b), mechanisms of the formation of natural water chemical composition (according to Gibbs, 1970) (c-d). Prospecting sites: 1 – Smirnovsky; 2 – Varvarinsky; 3 – Denisovsky; 4 – Shekubaevsky; 5 – Krasnooktyabrsky; 6 – Kamyshinsky; 7 – Milyutinsky; 8 – Shevchenkovsky; 9 – Akkarginsky; 10 – Zhetigarinsky. The processing forming the chemical composition of groundwaters: DE – dissolution of evaporites; SD – silicate dissolution; CD – carbonate dissolution.

A two-dimensional plot shown in Fig. 3b depicts the ratios of Mg/Na to Ca/Na, which are used to analyze the changes in ion concentrations during such processes as the dissolution of carbonates, silicates, and evaporates (Gaillardet, et al., 1999; Mukherjee, et al., 2012). A positive correlation between the indicated ratios is observed, which may be evidence that the major cations enter the solution during silicate rock weathering. Gibbs diagrams (Gibbs, 1970) allowed us to reveal a contribution from atmospheric precipitation into the chemical composition of groundwaters, the transition of elements from water-bearing rocks during weathering, and the effect of evaporative concentrating on water composition. The representative points fall within the fields of rock weathering and evaporative concentrating, which suggests a substantial contribution from both the water-bearing rocks and evaporative concentrating processes into the chemical composition of fresh HCO_3 Ca waters during the formation of saline groundwaters of Cl Na and Cl-SO_4 Na composition (see Fig. 3. c, d).

Table 1 – Parameters of local, zonal hydrogeochemical background and the contrast of anomalies within the prospecting sites in the north-western regions of the Torgay depression

Value	TDS, g/dm³	pH	Chemical compounds and elements, mg/dm³												number of samples
			Be	As	Pb	Sn	Bi	V	Ag	Co	Cr	Cu	Zn	Mo	
Akkarginsky site															
C_{min}-C_{max} $C_b(C_{an})$	469-10797 3430(4900)	7-7,7 7,4(7,5)	0,02-0,04 0,03(0,04)	–	–	0,1	0,05-0,03 0,16(0,21)	–	–	0,0-0,5 0,25(0,38)	0,25-2,0 1,1(1,5)	0,10-2,72 0,79(1,25)	0,3-25,0 5,1(9,6)	0,15-0,25 0,20(2,24)	15
SCF_{max}	–	–	0,74	–	–	–	1,89	–	–	1	1,07	4,6	1,11	–	
Varvarinsky site															
C_{min}-C_{max} $C_b(C_{an})$	168-2792 749(1024)	5,4-7,3 6,9(7,1)	0,01-0,05 0,03(0,04)	0,15-0,15 0,15(0,15)	0,1-1 0,46(0,67)	0,05-0,2 0,09(0,11)	0,02-0,5 0,21(0,28)	0,25-3,5 1,49(2,12)	0,01-0,1 0,05(0,08)	–	0,25-4 0,99(1,48)	0,1-6 0,96(1,67)	0,5-13,5 1,66(2,87)	0,01-0,1 0,06(0,09)	34
SCF_{max}	–	–	1,08	–	1,27	2,04	2,04	1,59	4,04	–	3,1	9,96	9,66	0,73	
Denisovsky site															
C_{min}-C_{max} $C_b(C_{an})$	303-2007 866(1060)	7,1-8,2 7,6(7,7)	–	–	–	–	–	–	–	–	–	0,75-22,5 5,84(9,05)	0,25-21 5,14(7,97)	0,05-0,15 0,12(0,14)	30
SCF_{max}	–	–	–	–	–	–	–	–	–	–	–	2,6	2,81	0,68	
Zhetigarinsky site															
C_{min}-C_{max} $C_b(C_{an})$	303-1375 1007(1256)	7,1-7,7 7,6(7,7)	0,01-0,04 0,02(0,02)	0,01-0,35 0,15(0,18)	0,01-0,15 0,08(0,1)	–	0,01-0,35 0,14(0,17)	–	–	0,01-0,25 0,12(0,15)	0,01-1 0,55(0,68)	0,01-5 2,6(3,22)	0,01-25 6(7,44)	0,01-0,4 0,16(0,19)	15
SCF_{max}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Kamyshinsky site															
C_{min}-C_{max} $C_b(C_{an})$	262-28375 5192(9312)	7-8,1 7,4(7,6)	–	–	–	–	0,05-0,15 0,11(0,13)	0,6-0,6 0,6(0,6)	–	1,5	0,25-1,25 0,72(0,95)	0,1-0,75 0,32(0,43)	0,5-6 1,59(2,27)	0,1-0,15 0,12(0,13)	16
SCF_{max}	–	–	–	–	–	–	1,02	–	–	–	1,15	20,13	9,85	1,19	
Krasnooktyabrsky site															

C_{min}-C_{max} $C_b(C_{an})$	84-21075 1484(3305)	6,8-8 7,6(7,7)	0,02	0,1	0,05-0,15 0,1(0,13)	0,05-0,75 0,22(0,31)	0-0,4 0,19(0,25)	–	–	0,25	0,4	0,1-2 0,52(0,77)	0,25-2,1 0,75(1)	0,05-0,4 0,18(0,23)	34
SCF_{max}	–	–	–	–	1	2,78	1,81	–	–	–	–	13,81	48,71	2,42	
Milyutinsky site															
C_{min}-C_{max} $C_b(C_{an})$	341-22427 3536(5857)	6,5-8 7,4(7,5)	0,03-0,75 0,19(0,34)	–	0,05-0,25 0,15(0,19)	0,05-0,15 0,06(0,08)	0-0,2 0,11(0,13)	0-2,5 0,77(1,23)	0-0,1 0,03(0,05)	0-0,25 0,13(0,21)	0-2,5 0,94(1,25)	0,1-12,5 1,49(2,55)	0-21 2,81(5,23)	0,1-0,25 0,15(0,17)	52
SCF_{max}	–	–	1,95	–	1,16	2,28	1,97	1,89	–	0,71	2,58	4,01	1,49	2,58	
Smirnovsky site															
C_{min}-C_{max} $C_b(C_{an})$	153-12918 1699(2800)	5,2-8,2 7,2(7,4)	0,02-0,04 0,03(0,04)	–	0,05-0,35 0,13(0,19)	0,05-0,75 0,16(0,25)	0-1,25 0,18(0,26)	0,25-2 1(1,28)	0,01-0,15 0,07(0,09)	0,15-0,75 0,45(0,66)	0,15-5 0,87(1,29)	0-6 0,62(1,03)	0,4-25 5,4(9,12)	0,1-1 0,23(0,33)	146
SCF_{max}	–	–	–	–	1,75	3,38	6,66	1,81	1,62	0,71	4,97	17,33	2,64	3,62	
Shevchenkovsky site															
C_{min}-C_{max} $C_b(C_{an})$	264-14582 3032(5078)	6,2-8,1 7,5(7,7)	0,1	–	0,05	0,05-0,15 0,1(0,13)	0-0,4 0,19(0,25)	–	–	0,15-0,5 0,33(0,45)	0,75-5 2,07(2,87)	0-5 0,97(1,63)	0,6-2,4 1,15(1,4)	264-14582 3032(5078)	20
SCF_{max}	–	–	–	–	–	1	1,81	–	–	–	1,83	4,91	4,75	–	
Shekubaevsky site															
C_{min}-C_{max} $C_b(C_{an})$	366-1629 1033(1288)	6,5-7,6 7(7,2)	–	–	–	–	0,05-0,15 0,11(0,13)	–	–	–	0,4	0-20 4,84(9,16)	0,75-10 3,92(6,55)	0,1	6
SCF_{max}	–	–	–	–	–	–	0,77	–	–	–	–	–	2,06	–	
Zonal hydrogeochemical background															
C_{min}-C_{max} $C_b(C_{an})$	84-28375 1838(2083)	5,2-8,2 7,3(7,3)	0,01-0,75 0,08(0,09)	0,1-0,15 0,11(0,12)	0,05-1 0,18(0,2)	0,05-0,75 0,13(0,14)	0-1,25 0,17(0,18)	0-3,5 1,09(1,15)	0-0,15 0,05(0,05)	0-1,5 0,33(0,39)	0-5 0,96(0,99)	0-22,5 3,47(1,43)	0-25 4,8(3,65)	0,01-1 0,18(0,17)	368
SCF_{max}	3803	7,5	0,18	0,13	0,33	0,21	0,24	1,65	0,08	0,61	1,43	2,96	6,59	0,24	

Note: C=content; b=background, an=anomaly «–» – no data.

Discussion. The elements possessing the highest ability to accumulate in groundwaters are the elements forming cations (Li, Na, K, Rb, Cs, Mg, Ca, etc.) and anions (B, F, Cl, Br, Ge, As, Mo, etc.). As far as the complex-forming elements are concerned (Be, Fe, Zn, Cu, La, Sn, Ta, etc.), their ability to get accumulated in groundwaters is minimal. These elements only slightly accumulate in groundwaters, the concentration factors of most of them are less than unity for groundwaters. Only in some geochemical types of groundwaters some of these elements can undergo concentrating. The aqueous dispersion halos of ore deposits may be classified as the objects of this type.

At present, most of the published works deal with the studies of geological, hydrogeological, and geochemical factors affecting the distribution of radioactive and ore-forming elements in the waters of different isotope-geochemical types (Ford, et al., 2010; Muhammad, et al., 2012; Degueldre, et al., 2014; Ogawa, et al., 2019; El-Mezayen, et al., 2020; Novikov, et al., 2021; Novikov, et al., 2023; Zhang, et al., 2024; Aleku, et al., 2024).

The data on the distribution of some metals in the groundwaters of prospecting sites in the north-western regions of the Torgay depression are presented in Table 1. The elements occurring most frequently in the waters under study are Cu, Zn, Bi, Sn, Cr and Pb. In addition, Be, As, V, Ag, Co and Mo were also detected. The background (zonal) trace component composition of the groundwaters in the region under investigation can be arranged in the following sequence from larger to smaller concentrations (mg/dm^3):

$Zn_{3,,65}>Cu_{1,43}>V_{1,15}>Cr_{0,99}>Co_{0,39}>Pb_{0,20}>Bi_{0,18}>Mo_{0,17}>Sn_{0,14}>As_{0,12}>Be_{0,09>}Ag_{0,05}$. The characteristics of the local hydrogeochemical background are also presented in Table 1. Summarizing the available factual information over all prospecting sites, we were able to calculate the concentration factor (CF) and standardized contrast ratio (SCF) (see Table 1, Fig. 4). It has been determined that the elements concentrating to a higher extent in the groundwaters of the region under investigation are bismuth, silver, molybdenum, copper, and zinc (Fig. 4a, 5). Among them, the elements exhibiting the highest contrast of anomalies are copper, zinc, chromium, molybdenum, tin, and bismuth (Fig. 4b). The distribution of trace components in the groundwaters of prospecting sites changes substantially depending on the mineralogical composition of ore deposits. Below some hydrogeochemical anomalies over the main prospecting sites will be described in brief.

From the hydrochemical point of view, the groundwaters of the *Akkarginsky site* are characterized by the broad occurrence of Cl Na waters, with their total salinity varying within a broad range from 0,8 to 10 and more g/dm^3. The formation of chloride waters takes place under the conditions of continental salination, with insufficient wetting and hindered water exchange. At the sites where Aral clay is absent, fresh Cl-HCO_3 Na-Mg waters appear. The presence of Cu, Zn, Cr, V, Bi, Be, Mo and As was revealed in groundwaters. The maximal concentrations of Cu (5,0 mg/dm^3) were detecte4d in well No. 2030, drilled through the granitoids of the Barambay massif. Other elements detected in these waters were (mg/dm^3): Be up to 0,02; Ga up to 0,05; Bi up to 0,35; Cr up to 0,75; Zn up to 0,5. The waters from wells Nos. 2032, 2033 and 47, drilled through ancient shale rocks, were also determined to contain (mg/dm^3): Cu up to 5; Zn up to 15; Cr up to 2; Bi up to 0,4; Be up to 0,05, and Mo up to 0,05. So, all the features characteristic of polymetallic ore mineralization have been established in the groundwaters.

The groundwaters of the *Varvarinsky site* are distinguished by diverse chemical composition. The prevailing waters are low-mineralized, with HCO_3 Na-Ca composition and total salinity ranging from 0,15 to 0,85 g/dm^3 and neutral pH = 7,0-7,1. In addition to widely occurring hydrocarbonate and chloride waters, there are also local zones containing SO_4-HCO_3 Na waters with acidic pH ranging between 5,4 and 6,6. The salinity of these waters is not high, as a rule, not higher than 1 g/dm^3. The sulfate-hydrocarbonate waters are associated with bauxite and chamoisite-hydrogoethite ores. The acidity and increased sulfate content of these waters are likely explained by the oxidation of disseminated sulfides occurring in bauxite ores.

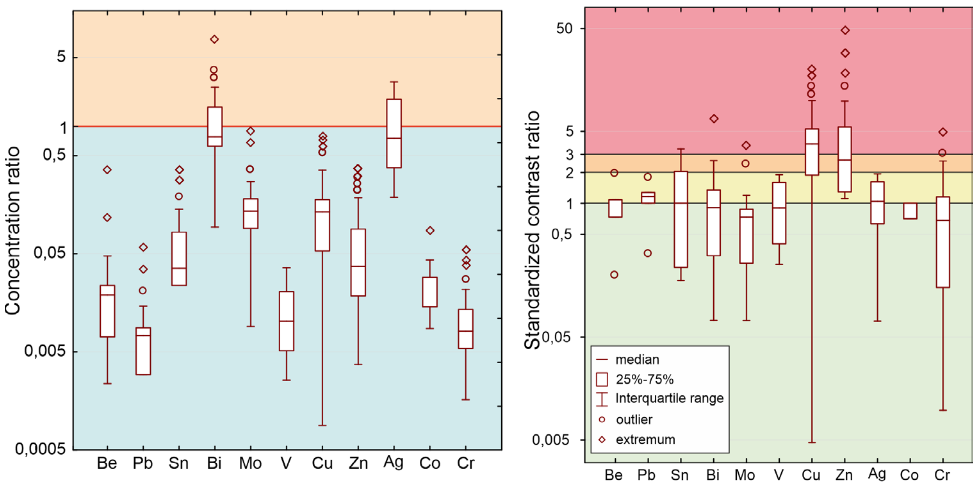

Fig. 4. The variation ranges of concentration factor (CF) values (a) and the diagram of variation ranges for the standardized contrast ratio (SCF) (b) in the groundwaters of prospecting sites in the north-western regions of the Torgay depression.

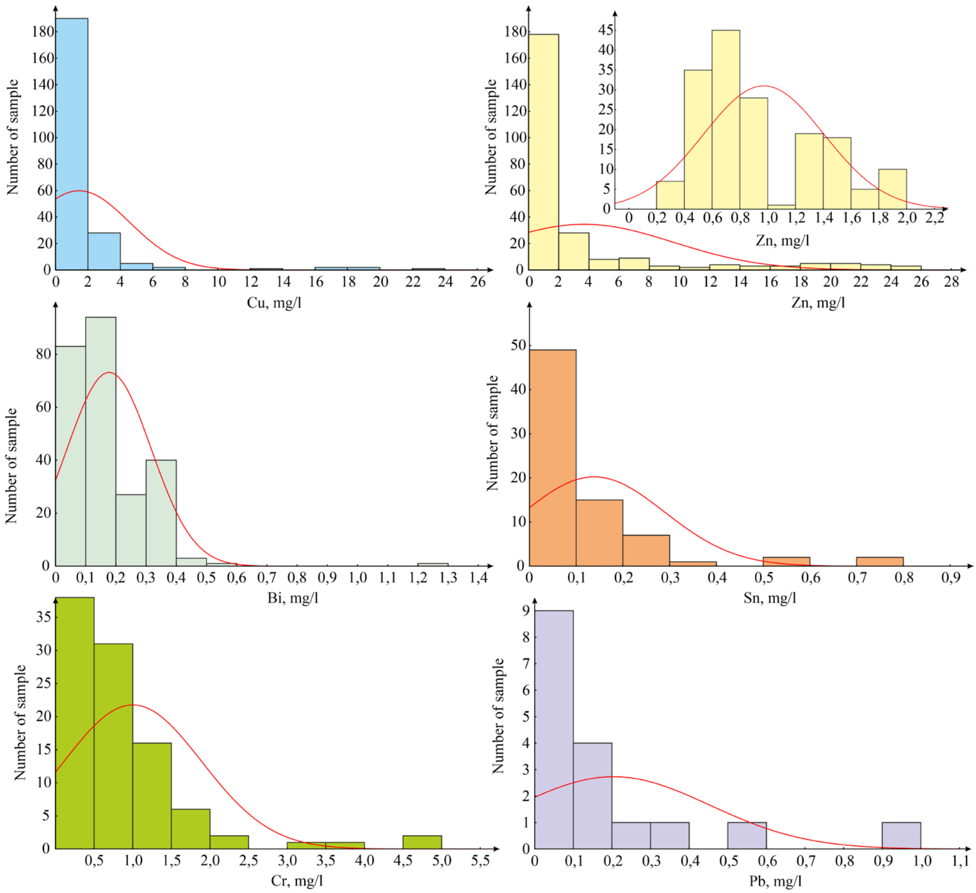

Fig. 5. Distribution of microelements in the groundwaters of the prospecting sites of the north-western regions of the Torgay depression.

In addition to usual salt-forming components, some trace components were detected in the waters associated with bauxite deposits; the maximal concentrations of these components are (mg/dm^3): Cu up to 15; Zn>25; Pb up to 1; Bi up to 0,5; Sn up to 0,02; Cr up to 4. in addition, the presence of molybdenum, arsenic, beryllium, silver, and gallium was detected. The distances from ore deposits at which the complex hydrogeochemical anomalies are detected, for copper (up to 4 km), zinc (up to 4 km), bismuth (up to 4-5 km) and tin (up to 2,5 km) at the Varvarinsky site are among the longest ones (Fig. 6).

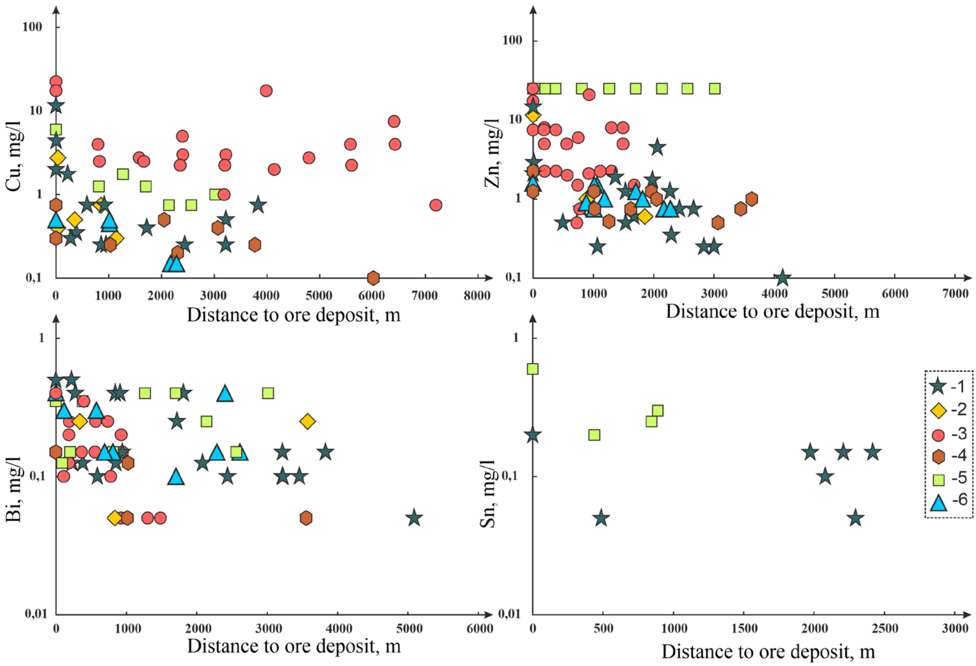

Fig. 6. Aqueous dispersion halos (Cu, Zn, Bi, Sn) of ore deposits at the prospecting sites of the north-western regions of the Torgay depression. Prospecting sites: 1 – Varvarinsky; 2 – Akkarginsky; 3 – Denisovsky; 4 – Kamyshinsky; 5 – Smirnovsky; 6 – Shevchenkovsky.

In the hydrochemical respect, the *Denisovsky site* is characterized by the occurrence of mixed HCO_3-Cl Na-Mg and Cl-HCO_3 Na-Mg waters. Total salinity varies from 0,3 to 1,3 g/dm^3, the average value being 0,7-0,8 g/dm^3. The waters are neutral or alkaline. In addition to widely occurring mixed waters, waters with SO_4-Cl Na and Cl-SO_4- Na composition associated with greenstone and tuff were revealed. The increased sulfate content in waters is due to sulfide mineralization, detected in the core of wells (123,126) drilled through greenstone. Analysis of copper distribution in the groundwaters allowed us to map five anomalous zones. In the geological respect, the anomaly of the first type is associated with greenstone and tuff in the greenstone rock mass of the Silurian age. The Silurian sediments host small gabbro and diorite blocks. Densely disseminated pyrite in association with chalcopyrite was detected in wells 123 and 126, located in the zone of the anomaly. Copper content in some depth intervals reaches 1 %. There is a relatively small gabbro massif in the central part of the anomalous zone, associated with the zone of igneous rock contact with serpentinite. Taking into account the favorable geological structure and positive data obtained in hydrogeochemical studies providing the evidence of the possibility to detect the industrial-scale mineralization, it is recommended to organize geological exploration work over the detected anomalous zones.

With respect to the anion composition, the waters from the *Zhetikarinskoye* *deposit* are mainly HCO_3 Mg, with total salinity not higher than 0,7 g/dm^3 and weakly alkaline reaction (pH = 7.1-7,6). The composition of these waters is formed under the effect of leaching of the ultrabasic rocks under the conditions of active water exchange. The content of Cu in the waters varies from 0,75 to 5 mg/dm^3, Zn from 0,15 to 12,5 mg/dm^3. Bismuth is detected almost in all samples, Cr is often present, Mo occurs rather frequently, while he was detected only in one sample. The high concentrations of Cu and Zn in waters, as well as the presence of such elements as Bi, Cr, Mo and Be, provide evidence of the broad occurrence of ore mineralization in the Zhetikarinsky ultrabasic and Milyutinsky granitoid massifs.

Hydrochemical studies over the wells of the *Kamyshinsky site* have shown that highly mineralized Cl Na waters are prevailing. Water salinity varies within a broad range from 2 to 30 g/dm^3, pH=7-8. The maximal concentrations of copper and zinc were detected in water from well No. 49: Cu 0,75 mg/dm^3, Zn 1,25 mg/dm^3. The groundwaters from wells No. 49 and 51 depict the halo indices of ore mineralization, associated with the Upper Paleozoic granites.

The *Krasnooktyabrsky site* is only poorly studied in the hydrochemical respect. The waters in tested wells have mainly Cl Na composition. Increased concentrations of Zn, Pb, Mo, Sn, Bi, V, Co were detected in the waters from the tested wells at this site. These elements, detected in the waters associated with bauxite deposit, are of interest in the hydrogeochemical respect because their aqueous dispersion halos contain trace elements characteristic of polymetallic ores.

At the *Milyutinsky site,* prevailing waters have Cl Na composition with total salinity 2 to 10 g/dm^3 and pH = 7-7,8. In most of the tested wells, the concentrations of Cu, Zn and other elements do not exceed the background levels, only at the contacts of granitoids with ancient metamorphic shale rocks and limestone copper content increases to 4 mg/dm^3, Zn to 15 mg/dm^3, molybdenum to 0,1 mg/dm^3. The most interesting case is well No. 481, a water sample from which was determined to contain, mg/dm^3: Be 0,75; Mo up to 0,1; Cu 4; Zn 7. The high concentrations of beryllium and molybdenum are a direct sign of the presence of rare metal ores, so it is necessary to drill several boreholes 100-150 m deep in the near-contact zone of wells No. 481 and 483, and to test the core thoroughly for the rare metal mineralization.

Three hydrogeochemical anomalies were revealed at the *Smirnovsky site.* The hydrogeochemical anomaly at the Northern site includes the aqueous halos of Bi, Mo, Cu and Zn. Mineralization is observed mainly in the zone of exo-contact with the Late Hercynian intrusion of leucocratic granites. The host effusive rocks, represented by porphyrites of basic composition with subordinate quartz porphyrites, are intensively metamorphised and in some sites transformed into hornfelsed shale. The quartz and quartz-feldspar veinlets form a dense network in these rocks, thus forming an ore stockwork. The aqueous halo of Bi, associated with greisenized granites, is characterized by Bi content up to 0,13 mg/dm^3 in groundwaters (well No. 231). Bi content in the groundwaters directly associated with the ore zone reaches 0,35 mg/dm^3 (well No. 516). At the region of halo waters occurring beside the ore zone in the direction of groundwater runoff, Bi content is 0,2 mg/dm^3 and lower (wells No. 551, 552, etc.). The aqueous halo of Mo coincides with that of Bi, but is smaller in size. The halo waters with anomalous Cu content widely occur within the ore rare metal zone and in the effusive metamorphised rock mass. The hydrogeochemical anomaly includes halo waters with Cu content up to 2 mg/dm^3.

Judging from the results of tests over the wells at the *Shevchenkovsky* prospecting site, waters mainly have Cl Na composition. Anomalous Mo, Bi, V concentrations are associated with crystalline shale and the zones of contact with the serpentinite massif. As suggested by the concentrations of Mo (up to 0,75 mg/dm^3), Bi (up to 1,25 mg/dm^3) and V (more than 5 mg/dm^3), it may be concluded that rare metal mineralization occurs at this site because vanadium and bismuth in association with molybdenum are the direct hydrochemical prospecting signs of the indicated type of mineralization. To reveal the industrial-scale rare metal mineralization, it is necessary to arrange prospecting works in the area where the wells No. 17, 229, 16 and 317 are located, and to drill boreholes to a depth of 100 m.

Conclusion. Summing up all the aforesaid, the following conclusions can be drawn:

1) The groundwaters of the region under investigation are diverse, either in total salinity or in chemical composition. In general, prevailing waters have HCO_3-Cl Ca-Mg-Na, SO_4-HCO_3-Cl Na-Ca-Mg, SO_4-HCO_3-Cl Mg-Ca-Na and SO_4-Cl-HCO_3 Ca-Mg-Na composition. These waters are characterized by pH from weakly acidic (5,2) to weakly alkaline (8,2). The geochemical system under consideration contains the waters ranging from ultrafresh (84 mg/dm^3) to saline (28,4 g/dm^3). A regular change of the chemical composition of groundwaters occurs in the same direction from HCO_3 Ca to Cl Na, often with increased SO_4 content, which is evidence of continental salination processes.

2) The elements most frequently occurring in the studied waters are Cu, Zn, Bi, Sn, Cr and Pb. In addition, the presence of Be, As, V, Ag, Co and Mo was determined. The background (zonal) trace component composition of the groundwaters in the region under investigation can be represented as a sequence from higher to lower content (mg/dm^3): $Zn_{3,65}>Cu_{1,43}>V_{1,15}>Cr_{0,99}>Co_{0,39}>Pb_{0,20}>Bi_{0,18}>$ $Mo_{0,17}>Sn_{0,14}>As_{0,12}>Be_{0,09>}Ag_{0,05}$. It has been determined that bismuth, silver, molybdenum, copper and zinc concentrate to a higher extent in the groundwaters of the region under investigation. The highest contrast of anomalies is characteristic of copper, zinc, chromium, molybdenum, tin, and bismuth.

3) The first type of anomalies is characterized by the copper pyrite association of the prospecting indicating hydrochemical elements: the increased concentrations of Cu, Zn, Co, the presence of As and Sn. The second type of anomalies is characterized by the polymetal group of hydrochemical prospecting indicators: along with increased Cu, Zn content, also Bi, Pb, Ga, As, Ag, Cr and V are detected. The anomaly of the third type manifests itself in the increased Cu content, the presence of Mo, Be and Bi, which are the elements characteristic of rare metal mineralization.

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