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Physico-chemical Characteristics of Natural Mud of Salt Lakes of North-East Kazakhstan

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Abstract

The article presents the results of a study of the physicochemical properties, mineral and elemental composition of the natural mud of Moiyldy, Tuzkala, Arasan, Shoshkaly, the eastern coast of Lake Alakol salt lakes of the North-Eastern region of Kazakhstan. Research on the composition of mud is one of the current trends carried out by scientists from different countries to identify compounds that cause their positive therapeutic effects. A review of the available data on the physical and chemical composition of natural muds in Kazakhstan showed the lack of systematic studies of the composition and structure of peloids in the North-Eastern part of the country, which are popular for their healing properties. The surface morphology, mineral composition, and physico-chemical parameters of natural mud were studied for the first time. The interpretation of the obtained data was carried out by taking into account previous studies of peloids from other regions of Kazakhstan, and a physico-chemical assessment of its therapeutic effect was given. According to the results obtained, the studied peloids are mostly salt-saturated muds with a pH range of 8.66 - 9.69. Peloids are characterized by a high content of sulfate ions and ammonium ions, which together have anti-inflammatory and wound-healing effects. The mineral composition is mainly represented by fine-grained quartz and albite. All samples are characterized by a high content of bismuth compared to its clarke in the Earth's Crust, which indicates the need for monitoring control of the composition and studying the possible effects of using these native muds.

Keywords: Natural mud; Peloid; Silt; North-Eastern Kazakhstan.
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1. Introduction

Natural mud of salt lakes is gaining popularity every year due to their natural healing properties, the effect of indirect influence through the skin. It is a natural product consisting of a mixture of salt lake or mineral water (brine) with organic and inorganic components (solid phase) obtained as a result of biological (humus) and geological influence (clay minerals).[1] The issue of studying the chemical composition of natural mud to identify the factors responsible for their positive therapeutic effect has been dealt with by researchers from different countries for many years. So, basically a complex physicochemical study of mud and, to a lesser extent, organic compounds were described in the works of Baricz *et al.* (Romania);[2] Potpara *et al.* (Montenegro);[3] Dolmaa *et al.* (Mongolia);[4] Martínez-Villegas *et al.*, Sua´rez *et al.* (Cuba);[5,6] Odabasy *et al.*; Çelik Karakaya *et al.* (Turkey).[7,8] Long-term monitoring studies of the physicochemical composition and ecological state of natural peloids were carried out by groups of scientists Muradov *et al.* (Russia),[9] Pavlovska *et al.* (Latvia),[10] Bergamaschi *et al.* (Italy).[11]

The conditions and time of the maturation process can change some characteristics of peloids, such as their plasticity, absorption capacity, biochemical composition.[12,13] Three factors influencing the formation of the chemical composition and genesis of silt mud: the salt composition of the brine of a reservoir, soil, and organic matter of plant and animal origin. At the same time, the degree of accumulation of mud is greatly influenced by the morphological features of water bodies, water salinity, the geological structure of the shores and the landscape features associated with it.[2,6]

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Information on the chemical composition of the peloids of the salt lakes of Kazakhstan is currently extremely scarce. The most studied physicochemical properties of peloids of the salt lakes of Western Kazakhstan - Khakisor, Aralsor, Inder, Alzhansor, Bolshoi Sor, Sorkol, carried out by Akhmedenov and Khalelova from 2017 to 2020;[14] as well as South Kazakhstan - the Kossor field, three kilometers from the southern coast of Lake Alakol, Lake Zhalanashkol and Lake Rey, located in the Balkhash basin of the Almaty region since 2012-2015, conducted by Tokpanov *et al*.[15-17]

A review of the available data shows the lack of systematic scientific research on the composition and properties of natural mud in the lakes of the North-Eastern region of Kazakhstan. However, the number of visitors to these natural sources, who use them without an official medical prescription on an intuitive basis and positive previous experience, is increasing every year. In this regard, the investigation of the composition and structure of these muds for the purpose of scientific understanding of their physiological effect on human skin is relevant. The purpose of this study was to give a chemical and mineralogical characterization of the natural peloids of the lakes of the North-Eastern region of Kazakhstan, as well as to interpret their positive therapeutic effect from a scientific point of view. The objects of study were the peloids from: the eastern coast of Lake Alakol (46°06'17.8"N 81°41'27.0"E); the Lake Arasan, located in the Zharma district of Kalbatau village (49°15'50.8"N 81°44'33.1"E); Lake Shoshkaly, located in the northwestern part of the Beskaragay district on the territory of the Republican State Institution "State Forest Natural Reserve "Semey Ormany" (Eastern region); Lake Moiyldy in the Pavlodar region, on the basis of which the recreation complex JSC "Sanatorium Moiyldy" operates; Lake Tuzkala, located in the Lebyazhinsky district (Northern region). Depending on the geographical location and climatic conditions, fluctuations in the composition and content of mineral and organic substances of peloids will vary over a fairly wide range, which indicates their specificity in each individual case. The results of the study will identify the features of the chemical and mineralogical composition of natural mud and assess the influence of climatic conditions on their formation. The interpretation of the results will make it possible to determine the possible positive and negative therapeutic effects of mud that are now actively used by tourists without medical supervision. We believe that this study will open up new research tasks for the determination of biologically active compounds in these natural objects and preparation of complex emulsions based on them.

2. Experimental section

2.1 Sampling samples

Table 1 presents the objects of study, their coding, and geodata of mud sampling. Samples were taken to a depth of up to 20 cm in one layer using the point method: the area was divided into 4 equal parts and samples were taken from the center of each square, weighing at least 200 g each according to Government Standard (GOST) 17.1.5.01-80. Approximately the distance between each sample was 4-5m. White natural mud of Lake Shoshkaly (4-ShWP) was sampled from a depth of 20-40 cm. The GPS location at the time of sampling was determined using the Google Maps mobile phone application. Sampling was carried out in the autumn period (September 2022). The averaged samples were stored in clean polyethylene containers with tightly closed lids at 40°C in a dark place.

Table 1. Objects of study and sampling sites.

Research object	Sample coding	Sampling geodata
Black mud of Alakol lake	1-AlBP	46° 03′ 36″N 82° 02′ 12″E
Black mud of Arasan lake	2-ArBP	49° 15′ 51″ N 81° 44′ 28″ E
Black mud of Shoshkaly lake	3-ShBP	51°16'57.9"N 78°41'58.7"E
White mud of Shoshkaly lake	4-ShWP	51°16'57.9"N 78°41'58.7"E
Black mud of Tuzkala lake	5-TKBP	51° 52′ 11″ N 77° 28′ 29″ E
Black mud of Moiyldy lake	6-MBP	52°23'48"N 77°04'03"E

2.2 Determination of the physico-chemical properties of the mud

Determination of the pH value of the peloid and the dense residue of the aqueous extract was determined according to GOST 26423-85. To do this, a peloid suspension was prepared by mixing 30 g of peloid with 150 cm^3 of distilled water (suspension 1:5), and after settling, the pH value of the supernatant was measured using an S47 Seven Multidual pH/conductivity meter (Russia) equipped with an InLabExpertPro pH electrode, module measurement has an accuracy of pH±0.001. Calibration of the pH module was carried out with a standard set of three buffer solutions with pH 4.01, 7.00, 9.21. To ensure the reliability of the obtained data, the electrode was thoroughly cleaned after each measurement. Then the suspension was filtered, the filtrate was used to determine the solid residue of the aqueous extract. The experiment was carried out with three repetitions. The maximum hygroscopic moisture of the peloid was determined according to GOST 28268-89. For this purpose, the analytical samples were placed in preliminarily numbered, dried, and weighed cups without lids so that the height of the sample layer does not exceed 4 mm. Then they were placed in a desiccator with a saturated solution of potassium sulfate to saturate the samples with water vapor and hermetically sealed. The first weighing of the cups was carried out 15 days after the start of saturation with an error of no more than 0.001 g. Repeated weightings were carried out every 5 days until a constant weight was obtained with a mass difference of no more than 0.005 g.

The content of mobile forms of nitrogen in the nitrate form was determined according to GOST 26951-86 by the potentiometric method. For the extraction of nitrates, a solution of potassium alum with a mass fraction of 1% was used at a ratio of sample mass and solution volume of 1:2.5. The samples with the extracting solution were stirred for 3 min, and the content of nitrates was determined using an ion-selective electrode. The mobile forms of phosphorus and potassium in the mud samples were determined according to the Machigin method (GOST 26205-91) by the photometric method. For this, ammonium carbonate with a concentration of 10 g/dm^3 with pH = 9 was used as an extracting solution at a soil-to-solution ratio of 1: 20. The samples were thoroughly mixed with the solution for 5 min and left for 20 h. Then the suspensions were filtered through paper filters and phosphorus was determined with the oxidation of organic matter in the form of a blue phosphorus-molybdenum complex on a photoelectrocolorimeter and potassium on a flame photometer. A 2 cm thick cuvette relative to the reference solution was used at a wavelength of 710 nm on a spectrophotometer to determine phosphorus and at a wavelength of 770 nm using a flame photometer to determine potassium. To determine mobile sulfur, 15 cm^3 of a precipitating solution of acidified barium chloride was added to the samples and thoroughly mixed and not earlier than 10 min later, the concentration in the form of barium sulfate was determined turbidimetrically by the optical density of the suspension in a cuvette with a thickness of 5 cm relative to the reference solution at a wavelength of 520 nm (GOST 26490-85). Soluble starch is used as a suspension stabilizer. Sodium, potassium, ammonium, calcium, magnesium cations were determined by capillary electrophoresis according to the regulatory document 16.1:2:2.2:2.3.74-2012 (KZ.07.00.03091-2015) and chloride ions, sulfate ions in the introductory exhaust according to regulatory document 16.1:2:2.3:2.2.69-10 (KZ.07.00.03091-2015). The method for measuring water-soluble forms of ions is based on the extraction of the components with distilled water. The background electrolyte was a mixture based on benzimidazole, tartaric acid, and 18-Crown-6. For data collection and processing, a system of capillary electrophoresis "KAPEL-104T" with indirect detection at a wavelength of 254 nm, on the software "Elforan" was used. The content of total organic carbon, humic acid carbon, and fulvic acid carbon in the aqueous extract was also determined by the pyrophosphate express method developed by N.N. Kononova and N.P. Belchikova. To do this, 100 cm^3 of a freshly prepared solution of 0.1 N sodium pyrophosphate and 0.1 N sodium hydroxide, having a pH of about 13, was added to samples weighing 5 g. After 18 h, the resulting extracts were filtered through filter paper (blue ribbon). To determine the total organic carbon content, the solution was further neutralized by the dropwise addition of a sulfuric acid solution until a slight turbidity appeared in the solution, after which the contents of the flask were evaporated to dryness on a water bath. Then, the content of organic carbon was determined by the Tyurin method, which included repeated extraction of humic substances with a 0.1N solution of sodium hydroxide. The titration was carried out with 0.1 N Mohr's salt solution in the same flask, diluting the contents with 10 cm^3 of distilled water, using phenylanthranilic acid as an indicator. To determine the amount of carbonic humic acids, a solution of sulfuric acid was added dropwise to 50 cm^3 of the initial extract until turbidity appeared, which is observed at pH 2.0-3.0. After thorough mixing, the contents of the beaker were heated at 80 °C on an electric stove for 30 minutes, then the cooled at room temperature for complete precipitation of the humic acid gel within 18 hours. Then, filtration was carried out through a dense filter (blue ribbon) wetted with 0.05 N sulfuric acid solution. The precipitate of humic acids was dissolved with hot 0.05 N sodium hydroxide solution. The resulting solution was brought to 100 cm^3 with distilled water. Next, 20 cm^3 of the resulting solution was taken and analyzed in the same way as in determining the total carbon content. The amount of carbon in fulvic acids is determined by the difference between the total content of organic carbon in the extract and its content in humic acids. The type of mud is determined by the hydrochemical classification and is represented by the Kurlov formula, showing the main macro-components with a concentration of 20% mmol, written in descending order (Table 2).

2.3 Determination of inorganic elemental composition

To determine the gross concentrations of elements a quadrupole mass spectrometer with inductively coupled plasma ICP-MS Agilent 7500cx manufactured by Agilent Technologies (USA) was used. The samples were pre-dried to a constant mass at 105 ^{0}C and worn to a size of 0.071 mm. The 0.1000 g weight sample was placed in a fluoroplastic glass. 10 cm^3 of hydrofluoric acid, 5 cm^3 of chloric acid, and 5 cm^3 of nitric acid were added to it and mixed, and evaporated to moist salts. Then 40 cm^3 of 5% nitric acid solution was added and heated until the salts dissolved. After that, it was cooled and quantitatively transferred to a 100 cm^3 volumetric flask to be brought to the mark with a 5% nitric acid solution and mixed. The device was pre-calibrated with certified mixtures, which were prepared by diluting a standard sample of ions of elements manufactured by “Inorganic Ventures” (USA). According to the calibration schedule, the analysis result was provided by the instrument software.

2.4 Determination of mineralogical and granulometric composition

The granulometric composition of the mud was determined according to GOST 12536-2014 by the pipette method. Volumetric mineralogy was determined by X-ray diffraction (XRD) using an X'Pert High Score modular X-ray diffractometer manufactured by PANalitical (Netherlands). To prepare for analysis, the samples were centrifuged at 5000 rpm for 45 min to separate the solid phase from the solution. After that, the solid phase was dried in air and homogenized in an agate mortar. The studies were carried out at a temperature of 23 °C and a humidity of 51%. The analyzes were carried out in the range of diffraction angles 2θ from -12º to +140º with a minimum scanning step of 0.001º. The diffraction pattern data were interpreted using the Crystallography Open Database (COD), Inorganic Crystal Structure Database (ICSD) file cabinet.

To study the surface microrelief and particle size distribution (PSD), scanning electron microscopy (SEM) was used using a JSM6390LV low-vacuum analytical scanning electron microscope manufactured by JEOL Ltd. (Japan) with an energy-dispersive microanalysis system INCA EnergyPenta FET X3 from OXFORD Instruments Analytical Limited (Great Britain). Particle size distribution was calculated using ImageJ software, particle size distribution was plotted in OriginPro 2018 software.

3. Results and discussion

The studied mud samples are a jelly-like plastic mass from light brown (sample 4-ShWP) to dark gray (samples 5-TKBP and 6-MBP) with the smell of hydrogen sulfide, which has an oily sheen (Fig. 1 and Table 2). Sample 2-ArBP contained large inclusions of organic residues; the rest of the samples had a homogeneous mass. All samples had a slightly alkaline

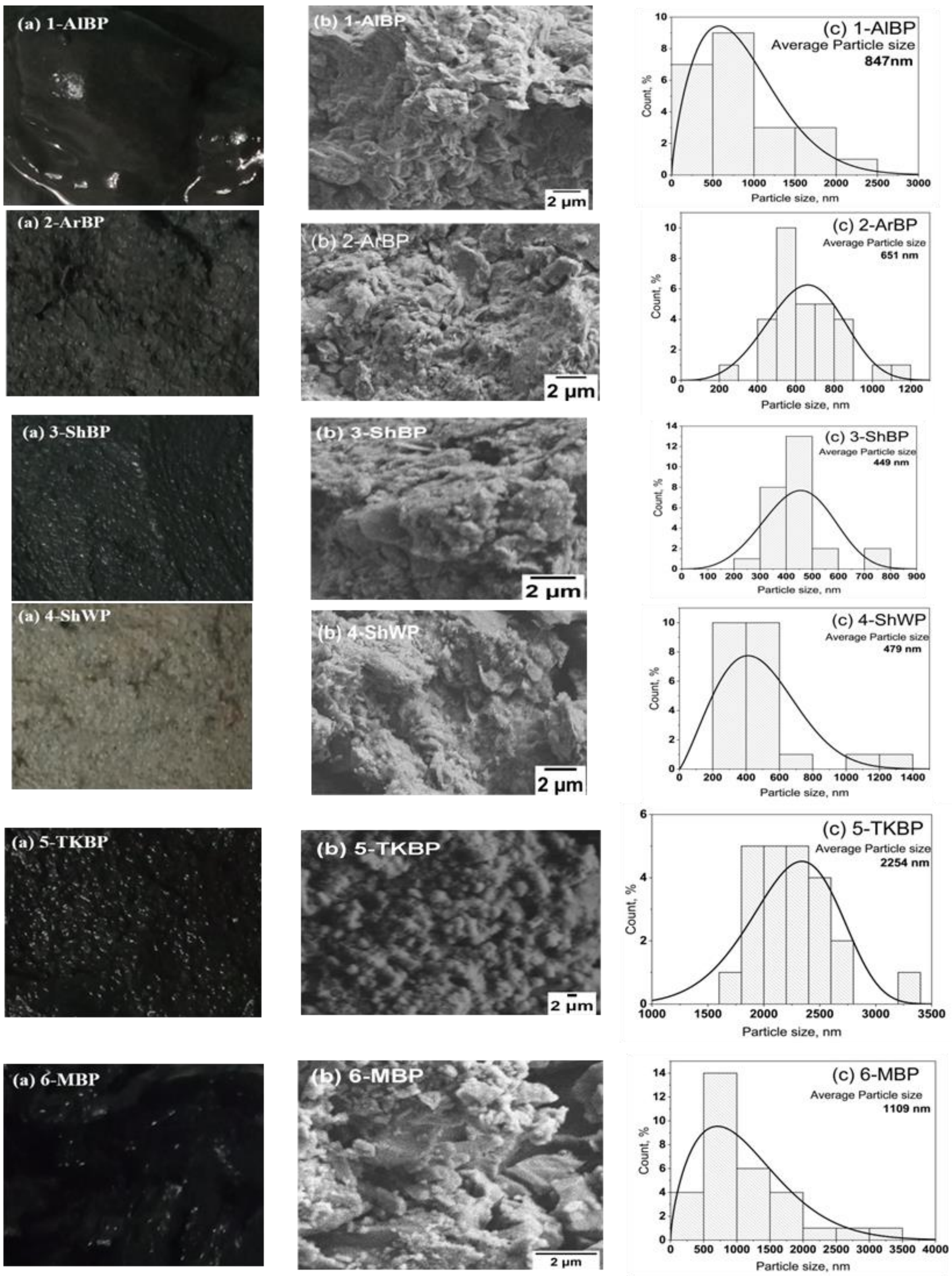

Fig. 1 Sample morphology: (a) general view of averaged samples; (b) SEM images of scale of 2μm; c) PSD.

Table 2. Organoleptic properties and typology of samples.

Sample	Hydrochemical classification and type	Main inorganic composition (Kurlov's equation)
1- AlBP	Highly mineralized, alkaline. Sodium-ammonium-sulfate.	$M40\frac{SO_4 56.15}{NH_4 666.78 Na 36.962 [Mg 2.5]}, \%mmol;$ pH9.25
2-ArBP	Highly mineralized, slightly alkaline. Ammonium-sulfate.	$M96\frac{SO_4 171.15}{NH_4 365.84 [Mg 3.25]}, \%mmol;$ pH8.87
3-ShBP	Salty, alkaline. Sodium-ammonium-chloride-sulfate.	$M155\frac{SO_4 121.77 Cl 50.61}{NH_4 386.45 Na 92.95}, \%mmol;$ pH9.67
4-ShWP	Salty, alkaline. Sodium-ammonium-chloride-sulfate.	$M216\frac{SO_4 51.72 Cl 26.96}{NH_4 296.04 Na 59.25}, \%mmol;$ pH9.69
5-TKBP	Salty, slightly alkaline. Sodium-ammonium-chloride-sulfate.	$M408\frac{SO_4 120.31 Cl 119.08}{NH_4 784.79 Na 81.30 [Mg 3.50]}, \%mmol;$ pH8.66
6-MBP	Salty, slightly alkaline. Sodium-ammonium-sulfate-chloride.	$M400\frac{SO_4 1307.29 Cl\ 84.41}{NH_4 1{,}410 Na 22.93 [Mg 8.25]}, \%mmol;$ pH8.97

environment with the highest pH value in samples of black and white mud of Shoshkaly Lake.

PSD according to the results obtained by SEM (Figs. 1b-c) shows that the average particle size is the smallest in samples 3 and 4, the largest in sample 5. Mud 1 and 2 can be classified as silty-sand according to Shepard,[18] sample 3, 4 and 5 - sand, sample 6 - sandy-silt (Fig. 2). These results may indicate the continental character of all muds with a low percentage of clay fraction.[5]

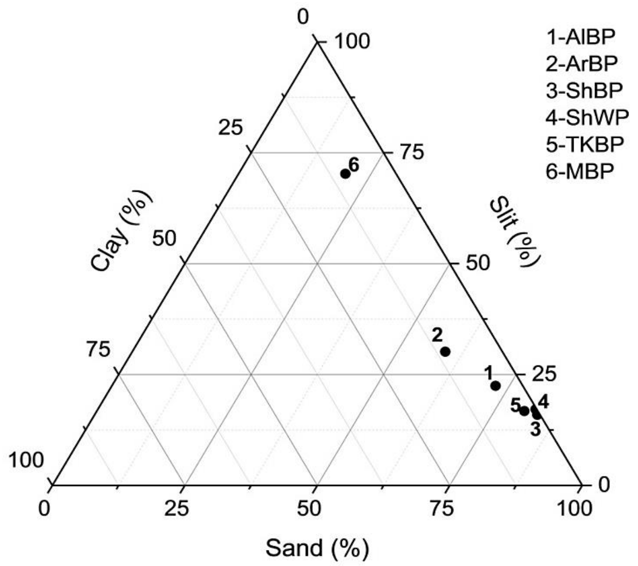

Fig. 2 Sediment granulometric composition.

The results of the granulometric and mineral composition (Table 3) show that samples 3-5 contain large fractions of mineral particles 1 - 0.25 mm in size, which is ten times higher than the accepted norm for use in peloid therapy.[19] This indicates the need to screen out this fraction with the potential use of these types of natural mud. Sample 6 differs from other samples in the highest content of the clay fraction, which is composed of quartz, halite, and calcite. According to Pozo *et al*. high concentrations of halite can cause an increase in the content of the clay fraction and affect the textural features of the peloid.[20] From the point of view of assessing the sensation when applied to the skin, the peloid can provide a soft tactile effect with a large specific surface area without mechanical irritation.[11] The presence of calcite in the sample may cause a therapeutic effect, since carbonates stimulate subcutaneous circulation and epidermal renewal.[21] According to the literature, particle size distribution plays an important role in the mobility of metal ions. Samples 1-5 mostly contain coarse-grained sandy fractions, mainly represented by quartz and albite.

The 2-ArBP sample differs from other samples in the largest amount of clay fraction and a significant content of clay fraction. According to the mineral composition, this peloid contains elevated amounts of magnetite. This is confirmed by the results of elemental analysis (Table 4), showing high concentrations in comparison with other peloids of iron, titanium, vanadium, aluminum, chromium, which are part of magnetite. Since magnetite has its own magnetic moment, this peloid opens up prospects for its complex use in peloid therapy and magnetotherapy. Samples 4 and 5 differ in the presence of zeolite X and zeolite Y, respectively, and in terms of elemental composition, the total concentrations of magnesium, beryllium, silver, cadmium, and antimony are increased compared to other samples. This may demonstrate the potential affinity of these minerals for these elements. Also, zeolites can enhance the absorption activity of these peloids in terms of active radicals, solar radiation, ecotoxicants, and pathogenic microbes.[22] However, due to the fact that these peloids have a small proportion of the clay fraction, this property can be enhanced by pre-screening to remove the coarse sand fraction. Peloids 1, 2, and 6 contain large amounts of the clay fraction and presumably can retain moisture best of all, have higher heat capacity and plasticity.[23,24] According to the obtained physicochemical parameters (Table 4), the maximum hygroscopic moisture was determined in the samples of 1-AlBP and 2-ArBP lakes located in the more eastern region, and the highest mineralization of the water extract in the samples of 5-TKBP and 6-MBP lakes in the northern part of the study region. Taking into account the norms of humidity adopted for the use of mud in balneorology

Table 3. Mineralogical and granulometric composition of peloid samples (%).

	1- AlBP	2-ArBP	3-ShBP	4-ShWP	5-TKBP	6-MBP
NON CLAYS						
Silicates						
Quartz low, SiO_2	44.1	41.2	57.2	25.8	37.8	45,3
Plagioclase-Albite, $Na[AlSi_3O_8]$	51.2	26.9	36.1	59.1	40.5	-
Zeolite X (Mn,Rb-exchanged, dehydrated), Si/Al<2	-	-	-	3.4	-	
Zeolite Y (purely siliceous), Si/Al>2 $(Na_2,Ca,Mg)_{3,5}[Al_7Si_{17}O_{48}]\cdot 32H_2O$	-	-	-	-	2.1	-
Carbonates						
Calcite, $CaCO_3$	2.2	14.4	2.6	6.3	2.3	23,5
Salts						
Halite, NaCl	0.3	1.3	2.3	5.4	15.2	29,3
Oxides						
Hematite, Fe_2O_3	-	-	-	-	-	1,9
Magnetite, $FeO\cdot Fe_2O_3$	2.1	16.2	1.8	-	2.1	-
Granulometric composition, %						
1-0.25mm	3.072	8.159	36.415	31.199	43.289	6.533
0.25-0.05mm	55.005	39.678	44.063	47.704	31.518	2.317
0.05-0.01mm	14.361	11.254	3.108	3.720	5.886	11.395
0.01-0.005mm	1.695	3.720	0.471	0.094	0.518	3.861
0.005-0.001mm	3.437	7.063	0.047	0.141	2.025	5.745
<0.001mm	22.429	30.127	15.896	17.142	16.765	70.150

25-75%, then all samples can be suitable for these purposes. When compared with the results of studies of peloids from other regions of Kazakhstan, it can be concluded that the studied samples of the eastern region (samples 1-4) are similar in mineralization to the studied muds of the lake Zhalanashkol of South Kazakhstan,[15] the studied lakes of Western Kazakhstan,[14] however, they differ in a lower content of calcium and magnesium ions and a higher content of sulfate ions. In all samples, the highest content of sulfate ions in the aqueous extract was revealed in comparison with the salt

Table 4. Physico-chemical parameters of mud samples.

Parameter	1- AlBP	2-ArBP	3-ShBP	4-ShWP	5-TKBP	6-MBP
pH	9.249±0.028	8.865±0.167	9.666±0.119	9.685±0.018	8.664±0.024	8.973 ± 0.088
Maximum hygroscopic moisture, %	61.44	57.29	26.54	23.38	29.60	27.82
Mineralization of mud solution, g/dm^3	40.00±1.35	96.00±2.34	154.67±3.11	216.00±2.34	408.00±2.34	400.00± 2.12
Group composition of humus, %						
C total	0.084	0.108	0.1716	0.1332	0.1212	0.039
C (humic acids)	0.0624	0.0888	0.0744	0.0648	0.0936	0.0012
C (fulvic acids)	0.0216	0.0192	0.0972	0.0684	0.0276	0.0378
Water aqueous forms of composition, $mg\ kg^{-1}$						
Cl^-	1,115±38	1,399±50	17,967±639	9,571±341	42,273±1,502	29,966±756
SO_4^{2-}	53,904±2,592	164,304±7891	116,899±5,616	49,651±2,381	115,498±5,549	125,500±6,024
Ca^{2+}	300±6	500±10	100±2	100±2	1,200±24	800±16
Mg^{2+}	600±7	780±10	120±1	120±1	840±10	1,980±24
Na^+	8,501±195	3,313±76	21,378±491	13,628±313	18,698±430	5,275±121
K^+	111.5±4.4	133.0±5.2	374.4±14.6	203.2±8.0	263.3±10.3	213.33±8,19
NH_4^+	120,020±7,957	65,851±4,610	69,561±4,149	53,107±3,399	141,262±8,193	253,849±19,750
Mobile forms of composition, $mg\ kg^{-1}$						

P – P_2O_5	10.07±0.13	6.23±0.09	55.98±0.45	20.75±0.31	27.60±0.36	33.11±0.31
K – K_2O	419.48±5.32	758.89±6.87	903.45±7.46	466.54±5.60	545.91±5.83	15,556±147
S – SO_4^{2-}	136.04±5.25	138.83±5.68	138.29±5.68	124.33±4.88	138.17±5.39	125.25±4.70
N-NO_3^-	14.10±0.46	19.10±0.68	52.50±1.37	27.50±0.93	81.30±2.11	>109
Total concentration of elements, mg kg^{-1}						
Li	27.58±0.23	54.32±0.62	32.44±0.36	35.68±0.38	30.79±0.31	37.44±0.38
Be	0.2086±0.0020	0.2247±0.0021	0.1819±0.0025	0.3905±0.0032	0.4332±0.0045	0.1819±0.0019
Na	19,530±190	14,730±140	19,930±180	19,300±180	29,350±270	47,500±530
Mg	13,910±140	21,620±210	17,830±170	21,920±210	20,650±200	19,570±190
Al	51,730±520	51,860±530	47,300±550	48,560±490	40,260±420	36,440±390
P	751.1±77	632.9±64	485.6±49	417.8±42	706.2±72	768.5±78
K	15,170±770	13,710±640	13,037±490	13,031±420	11,358±720	11,373±780
Sc	19.76±0.20	19.29±0.19	15.84±0.16	15.6±0.17	15.76±0.16	11.87±0.11
Ti	2,278±24	2,437±26	1,687±20	1,668±20	1,307±14	1,540±19
V	54.98±0.61	77.05±0.86	38.61±0.42	37.24±0.41	39.75±0.43	45.24±0.51
Cr	36.68±0.39	52.82±0.61	26.88±0.29	27.32±0.30	29.45±0.32	39.5±0.44
Mn	350.1±4.2	444.1±5.1	323.5±4.5	339.9±4.7	596±6.6	480.1±5.3
Fe	18,040±210	25,090±280	13,890±170	14,950±180	15,360±200	16,550±190
Co	7.94±0.09	12.42±0.14	4.96±0.07	5.55±0.07	6.31±0.07	7.41±0.08
Ni	29.05±0.34	28.28±0.32	15.66±0.18	16.82±0.19	15.91±0.17	18.02±0.21
Cu	16.3±0.1	27.1±0.4	47.1±0.6	25.1±0.4	26.2±0.4	18.8±0.2
Zn	27.9±0.4	40.6±0.5	50.4±0.7	39.1±0.5	34.92±0.4	25.7±0.3
Ga	13.00±0.14	13.88±0.15	9.15±0.12	8.99±0.10	8.13±0.09	9.66±0.11
Ge	1.089±0.011	1.323±0.011	0.678±0.010	0.737±0.010	0.790±0.010	0.899±0.010
As	4.40±0.06	14.38±0.16	2.78±0.03	3.47±0.04	3.75±0.05	2.89±0.03
Rb	59.75±0.69	53.27±0.67	52.11±0.66	51.5±0.65	44.85±0.53	51.37±0.65
Sr	279.7±3.1	284.5±3.2	265.8±3.5	303.0±3.8	280.7±3.1	781.4±8.5
Y	17.15±0.34	12.98±0.22	9.75±0.15	9.64±0.16	12.52±0.21	9.66±0.16
Zr	92.87±1.00	97.02±1.20	63.69±0.89	68.41±0.93	64.35±0.88	71.28±0.85
Nb	12.35±0.20	11.24±0.19	9.80±0.15	6.99±0.11	4.96±0.09	7.29±0.13
Mo	1.031±0.015	3.087±0.046	0.9831±0.012	2.059±0.032	4.123±0.055	1.992±0.032
Ag	0.3211±0.0050	0.2298±0.0030	0.1724±0.0020	0.3135±0.0040	0.2188±0.0030	0.2054±0.0030
Cd	0.876±0.012	0.6431±0.010	0.747±0.012	0.939±0.015	0.880±0.013	0.658±0.010
Sb	0.648±0.010	1.407±0.020	0.795±0.012	0.801±0.011	0.739±0.011	0.471±0.009
Cs	3.441±0.045	3.905±0.044	2.225±0.035	2.162±0.036	2.153±0.036	3.207±0.042
Ba	490.4±5.6	594.7±6.8	354.1±4.6	366.2±4.8	344.4±4.5	252.7±3.9
La	17.09±0.24	15.03±0.22	12.207±0.19	11.838±0.18	15.179±0.21	13.909±0.20
Ce	33.10±0.48	30.45±0.45	23.65±0.39	23.42±0.39	28.33±0.43	37.16±0.51
Pr	3.968±0.051	4.176±0.052	3.687±0.048	3.59±0.047	3.901±0.050	4.126±0.052
Nd	32.41±0.41	32.06±0.41	19.39±0.36	21.27±0.38	21.30±0.38	21.69±0.36
Sm	3.356±0.046	3.023±0.043	2.408±0.031	2.329±0.030	2.800±0.032	2.514±0.020
Eu	0.5421±0.0630	0.4852±0.0550	0.3361±0.0420	0.3493±0.0450	0.3654±0.0460	0.2975±0.0450
Gd	1.700±0.022	1.379±0.015	0.9293±0.010	0.930±0.011	1.262±0.014	1.107±0.015
Tb	0.2367±0.0045	0.1978±0.0040	0.1444±0.0020	0.1195±0.0020	0.1702±0.0040	0.1642±0.0025
Dy	3.120±0.040	2.530±0.040	2.070±0.030	2.132±0.010	2.475±0.040	2.099±0.032
Ho	0.5213±0.0080	0.3682±0.0060	0.2524±0.0040	0.2536±0.0040	0.3075±0.0050	0.2672±0.0040
Er	1.3510±0.0200	0.9954±0.0120	1.045±0.0150	0.6976±0.0100	0.8546±0.0110	0.7202±0.0100
Hf	2.208±0.030	2.13±0.030	1.498±0.020	1.447±0.020	1.649±0.023	1.746±0.028
Ta	0.9301±0.0150	2.589±0.0350	0.7867±0.0100	1.3300±0.0180	0.8102±0.0100	0.9499±0.0150
W	1.3550±0.0180	1.4110±0.0180	0.8337±0.0120	0.5889±0.0100	0.8277±0.0120	0.8416±0.0110
Tl	0.1630±0.0020	0.1544±0.0020	0.1142±0.0020	0.1142±0.0020	0.0811±0.0015	0.1242±0.0018
Pb	18.27±0.24	16.38±0.23	39.82±0.52	26.46±0.41	26.6±0.36	14.14±0.21
Bi	1.0760±0.0150	0.4607±0.0080	1.0740±0.0150	0.7878±0.0100	0.5744±0.0080	0.3521±0.0050
Th	2.204±0.030	2.183±0.030	1.622±0.020	1.781±0.020	1.772±0.022	1.633±0.021
U	1.599±0.018	1.932±0.022	0.7984±0.010	0.7558±0.010	1.391±0.016	2.39±0.032

extract. Sulfate ions, together with chloride ions and sodium ions, have an antioxidant and anti-inflammatory effect in the Magnesium ions play an important role in the migration and proliferation of endothelial cells and are essential for cell metabolism, has anti-inflammatory, regenerating and analgesic effect.[27] Ammonium salts have a keratolytic effect of an anti-allergic and anti-inflammatory nature, reducing flaking and facilitating the course of skin diseases such as psoriasis, dermatitis (eczema), *etc*.[28] The highest content of potassium and sodium ions was found in the 3-ShBP sample. It is known that sodium and potassium ions increase skin permeability, promote moisture retention, activate the ion transport system through the cell membrane, and participate in the elimination of toxins.[3] All samples have a low content of organic carbon relative to the accepted at least 5% norm for sulphide-silt mud. The highest content in comparison with all the studied samples is noted in the samples of black and white Shoshkaly mud, in which the maximum hygroscopic moisture, on the contrary, is lowered. This confirms the fact that moderate humidity and heat are favorable for humification, since otherwise the processes of biological oxidation proceed more intensively with the accumulation of the mineral component. The 5-TKBP and 2-ArBP samples are distinguished by the highest content of humic acids; 3-SHBP - fulvic acid. Humic acids, in comparison with fulvic acids, have a greater absorption capacity of elements, form structural mineral aggregates, improving thermal properties. The elemental composition of fulvic acids is characterized by a lower content of nitrogen and a higher content of oxygen, they are more hydrophilic. Comparison of the total content of phosphorus and potassium and their mobile forms shows that the main part of phosphorus and potassium is in a fixed form in all peloids, except for the 6-MBP sample. In the last case, the maximum potassium content is in the exchange form, which suggests its bioavailability. When analyzing the elemental composition, the data were compared with the accepted content in the continental crust (CC) according to Taylor and Vinogradov.[29,30] The content of lithium (1.5–2.7 times), arsenic (1.5–8.0), silver (2.3–4.3), antimony (2.4–7.0), cadmium (4.3–6.3), and bismuth (41–126) was increased in the composition of all studied samples. Sample 2 has the highest content of arsenic and antimony. This may correlate with the high content of iron in this sample, since these metals have a high affinity for iron-bearing minerals.[8,31] Since sample 2 differs in its textural features, including a fine clay fraction, this can also confirm its high adsorption properties.[32] Sample 4 in its composition contains the maximum excess of the concentration of cadmium. All samples are distinguished by a high content of bismuth, especially sample 1 and 3. Samples 3-5 in their composition show an excess of lead concentration by 1.9-2.8 times with a maximum value for sample 3. High content of bismuth can be explained by the fact that the content of bismuth in sulfide minerals varies by several orders of magnitude and tends to be concentrated to a greater extent together with galena. Especially these results correlate in the case of sample 3 with the highest content of lead and bismuth in comparison with other samples. In the 6-MBP sample, the content of sodium and strontium is increased approximately by 2.0; in samples 2, 4-6, an increase in the concentration of molybdenum in the range of 1.7 - 3.4 times is observed. However, if we take into account the norms for carbonate deep-sea sediments for strontium and molybdenum, then these values do not exceed them, which indicate the accumulation of these elements in sediments is a natural process. Elements that are in increased concentrations in the studied samples compared to the values in CC are included in the group of chalcophile metals according to Goldschmidt and have a specific affinity for sulfur. Most of the elements that exceed the concentrations in the studied samples can potentially exhibit limited mobility in a neutral and slightly alkaline environment with a low content of organic matter and, despite toxicity, may not adversely affect the quality of natural mud. However, other factors, such as temperature, the ratio of cations to anions, ionic strength, microbial metabolites, *etc*., can significantly change the mobility of elements.[32] The analysis of the elemental composition showed that there is no stable dependence of the concentration of elements on the geographical location, with the exception of sodium, the content of which is increased in the samples of the salt lakes of the northern part - Tuzkala and Moiyldy. Comparison with research data from other regions of Kazakhstan is not possible due to their absence.

4. Conclusions

In summary, physicochemical and mineralogical analysis of natural muds of the north-eastern region of Kazakhstan showed that the studied peloids are salt-saturated, with the exception of the mud of Alakol and Arasan lakes, with a pH of 8.66 - 9.69, sulfide muds with a low content of humus carbon. They have a mostly homogeneous colloidal mass of dark gray color for black mud and light gray color for white mud of Shoshkaly lake with a highly developed specific surface area. Mineralogical analysis showed that the peloids are mainly composed of fine-grained quartz and albite, which indicates its coastal continental origin. The peloids of lakes Moiyldy, Alakol, Arasan due to their fine texture can have a soft tactile effect on the skin and are quite reactive. All samples, except for Moiyldy lake, require preliminary screening of the sand fraction if they are potentially used in peloid therapy. The mud of Alakol and Arasan lakes can be attributed to the silty-sand type, the sample of Shoshkaly and Tuzkala lakes is sandy, and the Moiyldy lakes are sandy-silt. An analysis of the mineral composition showed that the natural mud of Arasan lake contains magnetite, which makes this peloid promising in complex therapy with a magnetic field. The Shoshokaly white mud and Tuzkala black mud contain the mineral zeolite in their composition, which increases they potential sorption capacity of ecotoxicants. However, the analysis of the gross content of elements in the mud showed an increased content to varying degrees in all samples of arsenic, silver, antimony, cadmium, bismuth in comparison with their weight clarkes. Most of these metals are chalcophiles and may have limited mobility in slightly alkaline media. However, most other factors can affect the mobility of ions, which indicates the need for constant monitoring and careful application of these muds in the absence of medical control. The study of the content of mobile forms of basic cations and anines of natural mud shows that the peloids of lakes located to the east differ from the composition of peloids of Western and Southern Kazakhstan by a lower content of calcium and magnesium cations and an increased content of sulfate ions. The peloids of the Tuzkala and Moyildy lakes, located in the northern part, had the highest mineralization, the content of sodium, ammonium, magnesium, sulfate ions, which in combination had a keratolytic effect in the treatment of skin diseases. A detailed study of the physicochemical composition of sapropels of salt lakes in North-Eastern Kazakhstan was carried out for the first time. Its rich mineral composition enables scientific substantiation of the conditions for its complex use in balneology, and also promotes new extensive research to explore all the potential benefits.

Conflict of Interest
There is no conflict of interest.

Supporting Information
Not applicable.

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