Clays and Clay Minerals (2024), **72**, e20, 1–9
doi:10.1017/cmn.2024.16

Original Paper

Mobility of essential macro- and micro-elements in interaction between artificial sweat and potential peloids of some saline lakes in Mongolia

Javzmaa Batzul[1], Badnainyambuu Zandraa[1], Tserenkhand Baasankhuu[1], Batzul Tumur[2], Bolormaa Ouyntsetseg[3], Batsuren Dorjsuren[4,5] and Erdenechimeg Gongor[6]

[1]Department of Chemical and Biological Engineering, School of Engineering and Technology, National University of Mongolia, Ulaanbaatar 210646, Mongolia; [2]Department of Mathematics, School of Applied Sciences, Mongolian University of Science and Technology, Ulaanbaatar 14191, Mongolia; [3]Department of Chemistry, School of Arts and Sciences, National University of Mongolia, Ulaanbaatar 210646, Mongolia; [4]Department of Environment and Forest Engineering, School of Engineering and Technology, National University of Mongolia, Ulaanbaatar 210646, Mongolia; [5]Department of Hydrology, National Research Tomsk State University, Tomsk 634050, Russia and [6]Department of Medical Chemistry, School of Bio-Medicine, Mongolian National University of Medical Sciences, Ulaanbaatar 14210, Mongolia

Abstract

Individuals may experience health issues attributable to environmental pollution, sedentary lifestyles, and unhealthy dietary habits. In response, numerous non-pharmaceutical treatments and techniques have emerged, with therapy mud being one such approach. The primary aim of this research was to analyze the chemical and mineralogical compositions of peloids obtained from six salt lakes: Taigan (LI), Duruu (LII), Khadaasan (LIII), Ikhes (LIV), Tonkhil (LV), and Khulmaa (LVI) in the Gobi-Altai province of Mongolia. Sample analyses involved X-ray diffraction for mineralogical assessment and inductively coupled plasma-mass spectrometry (Agilent Technologies 7800 series in Canada) for determining the chemical composition of the solid phase. Among essential macro- and microelements, Mg, Ca, Na, K, Sr, Ga, Mo, and Se had been leached from peloid to artificial sweat. Sn (0.01 μg g^{-1}) at LIV and LVI lakes and Cu (0.01 μg g^{-1}) at LV lake transferred from peloids to sweat, but no mobility of these elements in other peloids was detected. Li (0.02–0.04 μg g^{-1}) was adsorbed from the sweat to potential peloids in LV, LIV, LIII, and LI lakes, while As (0.04–0.09 μg g^{-1}) leached from peloids to sweat in all lakes except for LII. Zn (0.01 μg g^{-1}) and Cr (0.04 μg g^{-1}) transferred from the sweat to peloids in all lakes. Macroelements (Na, K, Ca, and Mg) and microelements (Mo, Se), which are essential for the human body, leached from the peloid to sweat. However, the mobility of toxic elements was minimal. Among micro-elements, the transition of Sr occurred the most, which can be explained by the Sr content in the peloid.

Keywords: natural peloid; macro-elements; micro-elements; peloid chemical composition; peloid mineral composition

(Received: 03 February 2024; revised: 28 March 2024; accepted: 10 April 2024)

Introduction

Mud is a blend of organic and inorganic substances dissolved in water that has experienced different geological and biological processes in a natural (or artificial) physiochemical environment (Metshein et al., 2023). Most peloids contain organic and inorganic matter, micro- and ultra-micro-elements that originated from first and second sediments and sea, lake, and spring waters due to large surface area, ion exchange, and adsorption capacity (Carretero, 2002; Çelik Karakaya et al., 2010; Rebelo et al., 2011; Komar et al., 2015; Bastos et al., 2022). The sorption and ion exchange capacity of peloids relate to their mineralogical composition.

Clay minerals are generally hydrated alumino silicates containing alkaline and alkaline earth metals (Kim et al., 2016). Phyllosilicates (Kabata-Pendias, 2000; Eby, 2004; Carretero et al., 2010) with 1:1 and 2:1 layer-type structures have large ion exchange capacities (CEC). The CEC values vary with the type of clay: montmorillonite, vermiculite > illite, chlorite > kaolinite > halloysite (Kabata-Pendias, 2000; Eby, 2004. Peloid feldspar minerals are also capable of ion exchange and absorption of cations. The chemical nature of transition metals adsorbed on clay minerals has recently been the subject of great interest. Clays containing exchangeable transition metal cations (mainly Cu, Fe, and Co) are known to act as electron or proton acceptors; thus they can be activators in transformations, decomposition, and polymerization of the adsorbed organic species (Eby, 2004).

Corresponding authors: Batsuren Dorjsuren and Erdenechimeg Gongor; Emails: batsuren@num.edu.mn; erdenechimeg.g@mnums.edu.mn

Cite this article: Batzul J., Zandraa B., Baasankhuu T., Tumur B., Ouyntsetseg B., Dorjsuren B., & Gongor E. (2024). Mobility of essential macro- and micro-elements in interaction between artificial sweat and potential peloids of some saline lakes in Mongolia. *Clays and Clay Minerals* **72**, e20, 1–9. https://doi.org/10.1017/cmn.2024.16

The French chemist Desser first defined therapy mud composition in 1807 (Ivanov and Malakhov, 1963; Janchiv, 1979). Since then, many scientists have studied peloids, conducting numerous studies on the properties, ingredients, and processing of artificial peloids and their effects (Williams et al., 2008; Bokuchava, 2009; Tateo et al., 2009; Carretero et al. 2010; Çelik Karakaya et al., 2010; Quintela et al., 2010; Tateo et al., 2010; Rebelo et al., 2011; Kalkan et al., 2012; Fernández-González et al., 2013). Mongolia has many salt lakes and various types of scientific study such as geochemistry, hydrochemistry, hydrology, geology and zoology have been conducted on those lakes. Ariyadagwa, Dorjsuren and Janchiv started the study of Mongolian therapy mud (Dorjsuren et al., 1979; Janchiv, 1979) and Dolmaa performed a detailed study of the chemical composition of therapy mud from the lakes located in central area of Mongolia.

Work was done by Tserenpil on the organic structure of some mud (Tserenpil, 2005; Tserenpil et al., 2010) and Tserenkhand and her students examined peloids from western Mongolia (Tserensodnom, 2000; Badnainyambuu et al., 2015; Tserenkhand and Badnainyambuu, 2016; Badnainyambuu et al., 2018). Hot mud packs applied to affected body parts in combination with electrophoresis are used widely as a treatment. One method of pelotherapy is mud pack compress application – an option for treating localized areas of the body to increase skin permeability and microcirculation or reducing pain in the case of knee osteoarthritis (Metshein et al., 2023). During the treatments, the body emits sweat and sweat helps elements to be transitioned between the skin and the mud. Cation exchange processes between skin and mud play an important role in a mud treatment (Quintela et al., 2010). This mobility of elements between skin and peloid is related to element mobility between sweat and the peloid. To study the interaction between sweat and the peloid, the choice of method of peloid treatment, defining, controlling and adjusting the mechanism, is essential. This interaction study was performed and published by Carretero et al. (2010) and by Tateo et al. (2009). As shown in their studies, element mobility between peloid and sweat depends on the peloid's chemical composition and mineral structure, and chemical composition of water. The main objective of the present research was to determine the chemical and mineralogical compositions of peloids from six salt lakes: Taigan, Duruu, Khadaasan, Ikhes, Tonkhil and Khulmaa in Gobi-Altai province of Mongolia, and to assess essential and toxic element mobility in the interaction between the artificial sweat and the peloids.

Materials and methods

The peloids were collected from the following lakes: Khadaasan, Ikhes, Duruu, Taigan, Tonkhil and Khulmaa of Gobi-Altai province in July of 2017 and the locations are shown in Fig. 1.

LI, a tectonic lake at 1780 m above sea level, is 4.1 km^2 in area and contains black mud with a hydrogen sulfide odor. LII, located in Jargalant, Govi-Altai, is a salt lake with a 14 km coastline, situated at 1420 m above sea level, and also features black mud with a hydrogen sulfide odor. LIII, a non-outflow lake in Delger soum, Govi-Altai, at 1481 m above sea level, hosts black mud with a hydrogen sulfide odor. LIV, a tectonic lake near Darvi territory center, Govi-Altai, at 1640 m above sea level, covers an area of 19.3 km^2, and contains black mud with a hydrogen sulfide odor (Tserensodnom, 2000). LV, located 12 km from Tonkhil soum's center, exhibits an unstable water level, tectonic origin, 2062 m elevation, and a 6.2 km^2 area, featuring black mud with a hydrogen sulfide odor. Finally, LVI, positioned at the Khovd-Govi-Altai border, is a tectonic lake at 2234 m above sea level, covering 8.5 km^2, and containing black silt mud with a hydrogen sulfide odor (Tserensodnom, 2000).

Artificial sweat

An artificial sweat was prepared according to the EN 1811:1998 +A1:2008 standard. The sweat contains 0.5% sodium chloride, 0.1% lactic acid, 0.1% carbamide, and 1% sodium hydroxide, in a solution with pH 6.5±1. The composition of the sweat used in this study is shown in Table 1.

Methods

Some physicochemical parameters of the water such as pH, electrical conductivity (EC), oxidation reduction potential (ORP), dissolved oxygen (DO), total dissolved solids (TDS) and salinity were measured *in situ* using a multi-parameter HannaHI9828 instrument. Major ions of water were analyzed by titration methods and micro-elements of water were determined using inductively coupled plasma atomic emission spectroscopy.

The peloid samples underwent mineralogical analysis using the MAXima XRD-7000 X-ray diffractometer (Shimadzu, Japan) employing a scanning speed of 2.00°2θ min^{-1} with CuKα radiation from 5° to 60°2θ at room temperature. Quantitative mineralogical analysis of the solid phase was conducted using the Rietveld method. The chemical composition of the solid phase was determined using the X-ray fluorescence AXIOS mAX instrument with 4 kW intensity Kα and Lα lines. For the analysis, 50 mL of sweat was mixed with 5 g of peloid, dried at room temperature, and ground to a size of 0.074 mm. The resulting slurry was stirred at 60 rotations min^{-1} at 45°C for 1 h, followed by centrifugation at 4000 rotations min^{-1} for 20 min. The sweat compositions were measured using an inductively coupled plasma-mass spectrometer (ICP-MS; Agilent Technologies 7800 series, Canada) and the transfer of elements between sweat and peloid was quantified as micrograms of transferred element per 1 g of mud using Eqn (1):

$$a = \frac{(C_1 - C_0) \cdot v}{m}, \qquad (1)$$

where a is the amount of element transferred (in μg g^{-1}); c_0 is the initial concentration of sweat (in μg L^{-1}); c_1 is the final concentration of sweat after reaction with clay (in μg L^{-1}); v is the volume of sweat (in L) and m is the weight of peloid (in g).

Results and Discussion

Mineralogical composition solid phase of the peloids

Physico-chemical parameters, the main ions and the elemental compositions of lake water were determined. According to previous research (Cara et al., 2000; Williams et al., 2008; Çelik Karakaya et al., 2010; Fernández-González et al., 2013; Tserenkhand and Badnainyambuu, 2016), the mineralogical composition of peloids depends on their origin and geological locations. The mineralogical compositions of the peloids are shown in Fig. 2a–f, and the mineralogical contents and classification (Berry et al., 1987; William, 2000) of the peloids is shown in Table 2.

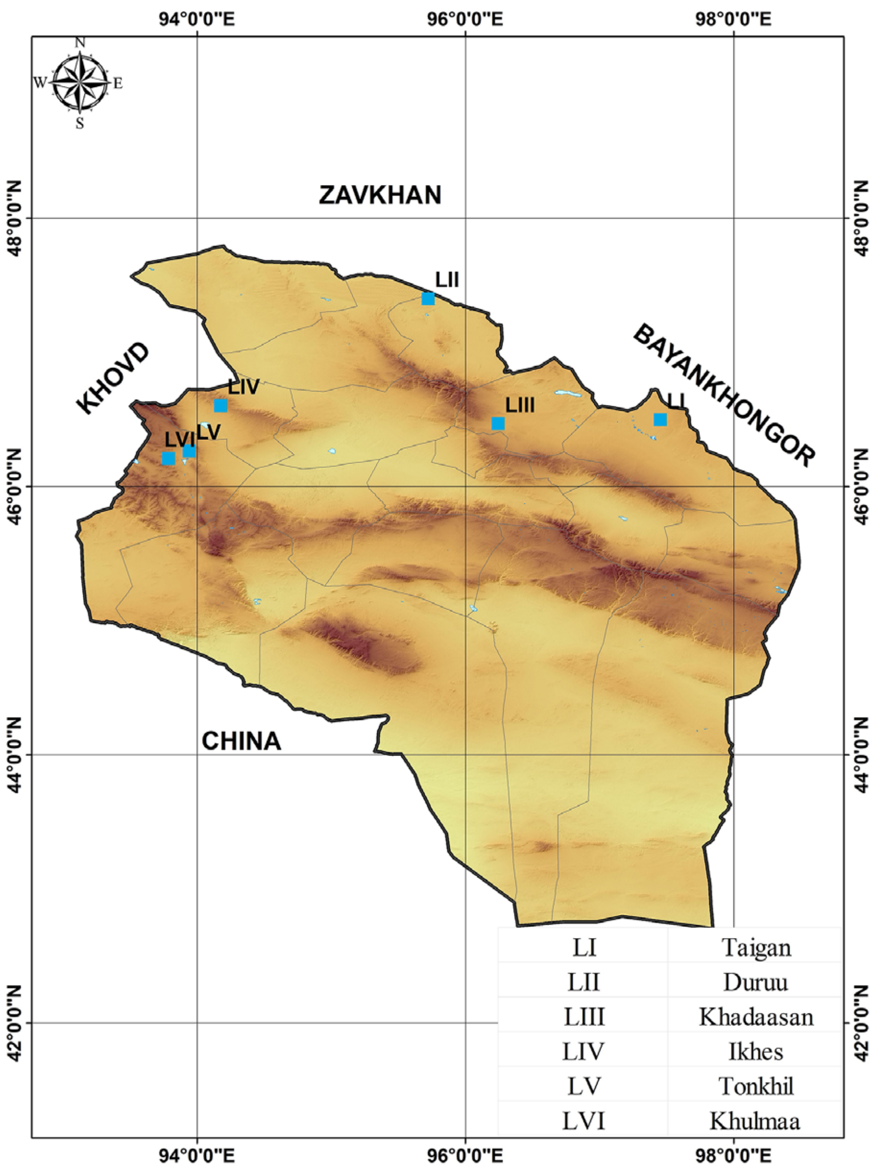

Figure 1. Locations of the six lakes, sources of samples used in the present study.

Table 1. Artificial sweat composition

Element	Content (μg L^{-1})	Element	Content (μg L^{-1})
Na	1887894.00	Li	4.48
Mg	11.89	Zn	0.91
Ca	1349.24	Mn	0.04
K	5115.98	Cr	3.73
Sr	0.25	Ce	0.00
Ga	0.60	Sn	0.17
As	10.95	W	0.01
Se	0.00	Fe	0.00
Mo	0.08	Co	0.00
Ba	3.07	Ni	0.08
U	0.00	Cu	0.00
V	0.00		

The X-ray diffraction patterns of the peloid minerals are shown in Fig. 2, in which the abbreviations for mineral names of Whitney and Evans (2010).

Chemical composition of the solid phases of the peloids

The solid phases of the peloids were found to contain 11 major elements and 32 minor elements. The results were compared with those of the peloids from reference data (i.e. so-called 'Clarke' values: Rudnick and Gao, 2003; Chertko and Chertko, 2008). All values considered are listed in Tables 3 and 4. The SiO_2 content of the peloid is smaller than that of Clarke (Rudnick and Gao, 2003) but the CaO and MgO contents are greater than those of Clarke (Rudnick and Gao, 2003) especially 20.25% CaO and 8.68% MgO in the peloid from Duruu lake. The Na_2O contents of the peloids from the Khadaasan, Duruu, and Tonkhil lakes are greater than those of Clarke, i.e. 6.11, 7.91, and 3.79%, respectively; the Fe_2O_3 and Al_2O_3 contents in peloids of Ikhes lake are greater than those of Clarke (Rudnick and Gao, 2003; Bastos et al., 2023).

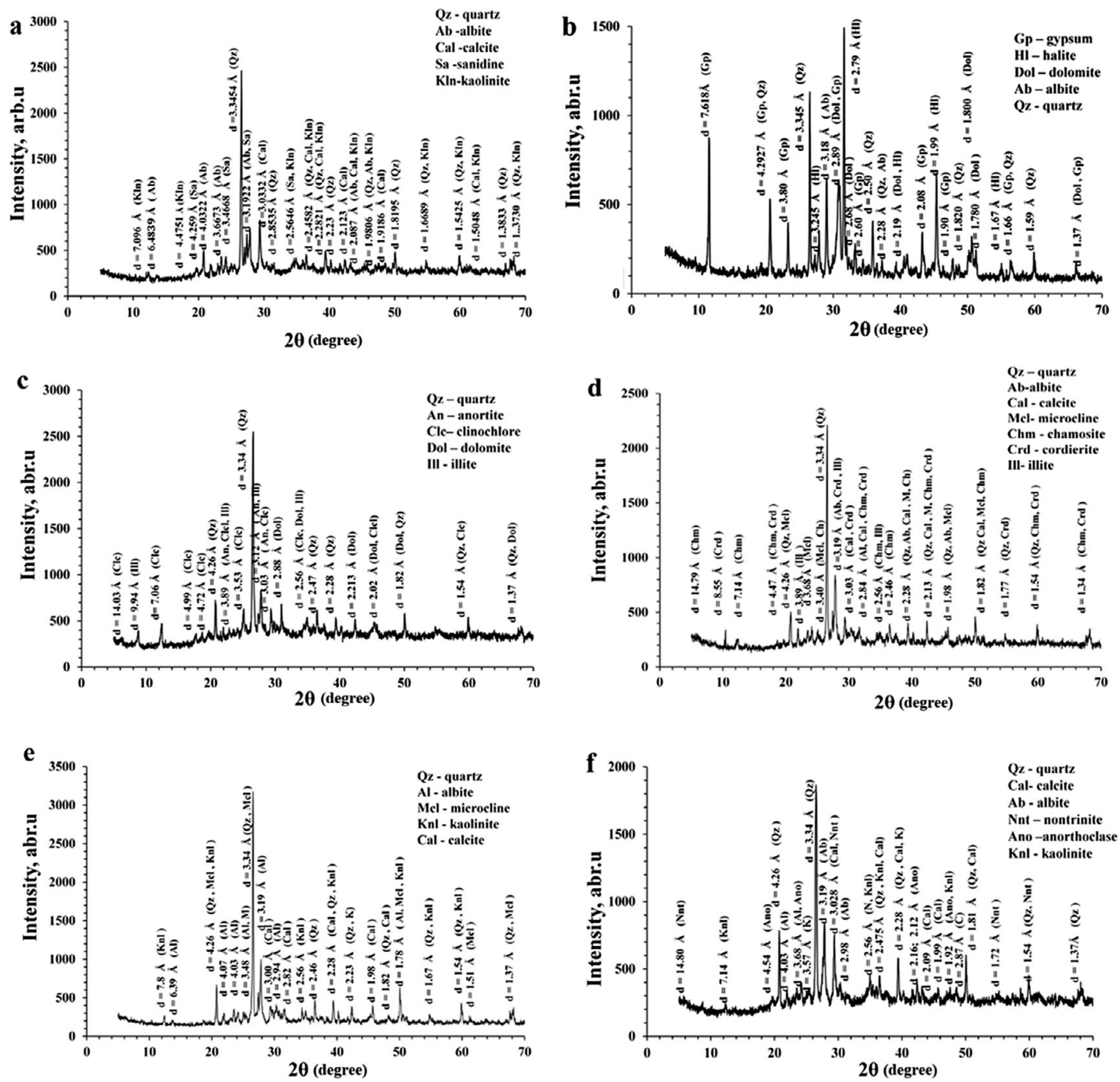

Figure 2. XRD patterns of peloids from: (a) Taigan Lake; (b) Duruu Lake; (c) Khadaasan Lake; (d) Ikhes Lake; (e) Tonkhil Lake; and (f) Khulmaa Lake.

The peloid from Duruu lake contains greater amounts of dolomite, gypsum, and halite in agreement with the MgO, CaO, and Na_2O contents, while peloids from other lakes contain alumino silicates consistent with their SiO_2 and Al_2O_3 compositions. The Na_2O/CaO of all peloids were smaller, 1.0. A high Na_2O/CaO ratio indicates the presence of swelling clay minerals ($1<Na_2O/CaO>3$), while a small ratio ($Na_2O/CaO<1$) is typical of non-swelling clay minerals (Ravaglioli *et al*., 1989; Cara et al., 2000).

The Sr content in peloids was elevated in all lakes and greater than the Clarke values for elements in continental crust or deep-water clay (Rudnick and Gao 2003; Chertko and Chertko, 2008) (Table 4). The Zr contents of all peloids was greater than the Clarke value for elements in the continental crust (Rudnick and Gao, 2003) or deep-water clay (Chertko and Chertko, 2008) in peloids of Taigan, Ikhes, and Khulmaa lakes. The Cr contents of peloids from the Taigan, Khadaasan, and Ikhes lakes were also greater than Clarke (Rudnick and Gao 2003; Chertko and Chertko, 2008) as the chromium content increases in the accumulation of soil washout and fine-grained sediments (Gonchigsumlaa, 2008). The amounts of Cu and Ni in all peloids were smaller than Clarke (Chertko and Chertko, 2008), except for Cu in the Khulmaa peloid. The Ni content in peloids from the Taigan and Ikhes lakes was greater than Clarke elements of the continental crust (Rudnick and Gao, 2003).

The Cr, Ni, and Cu contents are elevated as these elements can precipitate from carbonate-rich waters (Chertko and Chertko, 2008). The carbonate-bound fraction is the major solid-phase component for many trace elements (Cd, Pb, Zn, Ni, and Cu) in arid and semi-arid soils. Carbonate removal decreases the adsorption capacity of calcareous soils for trace elements such

Table 2. Mineralogical composition of the solid phase of the peloid (wt.%)

Mineral class	Mineral name		Mineral formula	Mineral content (%)						
				LI	LII	LIII	LIV	LV	LVI	LVII
Silicate	T[a]	Albite	$Na[AlSi_4O_8]$	13	12		9	28		
			$(Na)[(Si,Al)_4O_8]$						25	
		Anorthite	$(Ca)[(Si,Al)_4O_8]$			32				
		Microcline	$K[AlSi_4O_8]$				13	12		
		Anorthoclase (Sanidine)	$(Na,K)[(Si_3Al)O_8]$	27					6	
		Quartz	SiO_2	41	20	44	46	52	42	9
	P[b]	Kaolinite	$Al_2Si_2O_5(OH)_4$	7				5	6	4
		Illite	$(K\ H_3O)Al_2Si_3AlO_{10}(OH)_2$			11	15			35
		Clinochlore	$Al_2Mg_5Si_3O_{10}(OH)_8$			10				2
		Smectite	$Na_{0.3}Fe_2Si_4O_{10}(OH)_2{\cdot}4H_2O$						9	
		Chamosite	$(Mg_{5.036}Fe_{4.964})Al_{2.724}(Si_{5.70}Al_{2.30}O_{20})(OH)_{16}$				7			
	R[c]	Cordierite	$Mg_2[Al_4Si_5O_{18}]$				1			
Carbonate		Dolomite	$CaMg(CO_3)_2$		11	4				
		Calcite	$CaCO_3$	14			7	3	12	40
Sulfate		Gypsum	$CaSO_4{\cdot}2H_2O$		33					4
Halide		Halite	NaCl		24					6

LVII = Lo Pagon; [a]tectosilicate, [b]phyllosilicate, [c]ring silicate. LII peloid is a poly-mineral peloid containing carbonate, sulfate, and halite whereas the rest contain mostly phyllo- and tecto silicates of mineralogical compositions. The various mineralogical contents of the studied peloids express the physicochemical conditions for the occurrence of peloids, the peculiarities of the chemical elements, as well as the variety of geological conditions which have arisen.

as Zn (Han, 2007). The Y and La contents in all the peloids is smaller than Clarke for elements in deep-water clay (Chertko and Chertko, 2008). In contrast, the Y content of all peloids except Duruu, the La content of peloids from the Taigan, Ikhes, and Khulmaa lakes, the U content in peloids of Taigan, Duruu, Khulmaa, and Tonkhil, and the As contents of all peloids except from Duruu were greater than Clarke elements in the continental crust (Rudnick and Gao, 2003). The amount of La is greater in peloids where alkalinity is minimal due to its geochemical barrier at acid pH (Chertko and Chertko, 2008). At the same time, the increase in U and Y contents in peloids is due to isomorphic substitution with rare earth elements (especially La) in endogenous conditions (Chertko and Chertko, 2008), mostly occurring as a xenotime (YPO_4) with the Zr concentration increasing with increasing xenotime (Chertko and Chertko, 2008). These peloids have a large arsenic content because the lake water contains a significant amount of H_2S, which increases the solubility and mobility of arsenic, changing it to form the precipitate. The released arsenic then reacts with sulfide ions to form arsenic sulfide compounds, precipitating from the water column and accumulating in the sediments (Chertko and Chertko, 2008).

Table 3. Major elements (as oxides) and fluorine solid phase of the peloids (wt.%)

	LI	LII	LIII	LIV	LV	LVI	Clarke*
SiO_2	47.55	20.25	40.64	52.47	43.27	46.38	60.60
Al_2O_3	12.38	3.58	10.51	16.28	9.39	10.96	15.90
Fe_2O_3	5.87	1.03	4.81	6.74	3.61	4.16	6.71
CaO	9.80	14.78	6.85	4.10	9.67	8.80	6.41
MgO	4.91	8.68	5.34	3.05	5.84	6.07	4.66
Na_2O	1.76	7.91	6.11	1.71	3.79	3.10	3.07
K_2O	2.05	1.03	1.50	2.82	1.30	1.36	1.81
TiO_2	0.69	0.16	0.59	0.78	0.58	0.58	0.72
MnO	0.12	0.03	0.11	0.12	0.09	0.09	0.10
P_2O_5	0.22	0.05	0.18	0.22	0.13	0.14	0.13
F	<LD	0.27	<LD	<LD	<LD	<LD	
LoI	13.29	22.49	16.71	11.07	19.06	16.30	

*Average Clarke composition of the Earth's continental crust (Rudnick and Gao, 2003; Karakaya and Karakaya, 2018) LD = determination limit; LoI = loss on ignition.

Element mobility between peloid and artificial sweat

The final compositions of the artificial sweat were determined using ICP-MS and concentrations of elements leached from the peloids into sweat calculated as micrograms per 1 g of peloids.

When the results shown in Table 5 are compared with the elements of interaction between peloids and sweat from Spanish' researchers (Carretero et al. 2010), most elemental mobility was the same as that for the Lo Pagan mud. Deficiency in these elements can cause health problems (Bastos et al., 2022; Rudnick and Gao, 2003). Sodium and potassium are essential electrolytes that help regulate various physiological functions, including fluid balance, nerve function, and muscle contractions. High sodium intake can lead

https://doi.org/10.1017/cmn.2024.16 Published online by Cambridge University Press

Table 4. Minor elements in peloids (µg g^{-1})

Minor element	Lake						Clarke contents of elements	
	LI	LII	LIII	LIV	LV	LVI	Clarke*	Clarke**
Bi	<LD	<LD	<LD	<LD	<LD	<LD	0.18	—
Co	13	<LD	17	17	<LD	12	26.6	74
Cr	**209**	34	**140**	**207**	90	85	135	90
Cs	<LD	<LD	<LD	<LD	<LD	<LD	2.0	6.0
Cu	**113**	**30**	**106**	**97**	**42**	25	27	250
Ga	15	<LD	13	**21**	10	13	16	—
Ge	<LD	<LD	<LD	<LD	<LD	<LD	1.3	—
Hf	<LD	<LD	<LD	<LD	<LD	<LD	3.7	4.1
Mo	<LD	**39**	<LD	<LD	<LD	<LD	0.8	27
Nb	7	<3	11	12	5	1	8.0	14
Ni	**89**	16	54	**85**	39	35	59	225
Rb	**75**	27	**77**	**113**	**55**	48	49	110
Zn	92	20	52	**116**	59	47	72	—
Sr	**421**	**4307**	**403**	**245**	**732**	**529**	**320**	**180**
Ta	<LD	<LD	<LD	<LD	<LD	<LD	0.7	0.05
Th	<LD	<LD	<LD	9	<LD	8	5.6	7.0
V	115	32	99	118	78	89	138	120
W	<LD	<LD	<LD	<LD	<LD	<LD	1.0	—
Y	**26**	9	**20**	**26**	**23**	**28**	19	90
La	**41**	<LD	<LD	**37**	<LD	**36**	20	120
Zr	**184**	<LD	**135**	**167**	**138**	**178**	132	**150**
Sc	18	<LD	20	16	17	15	21.9	19
Sm	<LD	<LD	<LD	<LD	<LD	<LD	3.9	38
Pr	<LD	<LD	<LD	<LD	<LD	<LD	4.9	33
Ce	67	<30	33	70	54	53	43	350
Nd	<LD	<LD	<LD	<LD	<LD	<LD	20	140
U	**10**	**23**	<5	<5	**14**	**31**	1.3	80
Ba	407	184	373	525	333	352	456	2300
As	**13**	<LD	**12**	**21**	**11**	**21**	2.5	—
Pb	19	<LD	<LD	22	<LD	<LD	11	80
Sb	<LD	<LD	<LD	<LD	<LD	<LD	0.2	1.0
Sn	<LD	<LD	<LD	<LD	<LD	<LD	1.7	1.5

LD = determination limit; *average content of the relevant element in the Earth's crust (Rudnick and Gao, 2003), **average Clarke content of deep-water mud (Chertko and Chertko, 2008). Entries in bold denote elements present in greater amounts than in Clarke.

to water retention and higher blood pressure. Potassium helps counteract these effects by promoting sodium excretion and improving blood vessel function (William 2000). Mg is a basic activator of enzyme processes (Rudnick and Gao, 2003). Magnesium absorption is supported by proteins (especially casein), vitamin D and is decreased by fatty acids and phosphate. The ratio of Ca:Mg in the bones is normally 1:55. Calcium is a vital element in bone composition (Williams et al., 2008).

The world health organization considers essential elements for the human body to be Fe, Zn, Cu, Cr, I, Co, Mo, and Se (Gomes and Silva, 2007; Bhattacharya et al., 2016; Haftek et al., 2022). Mo and Se are transferred from peloid to sweat. Mo contributes to normal growth and development of organisms (Coughlan, 1983; Gomes and Silva, 2007; Bhattacharya et al., 2016), participates in protein anabolism (Bhattacharya et al., 2016), protects the liver and plays an important role in the human bone ratio of Ca:P=2:1 (Purev and Tsevegsuren, 2006; Enebish, 2015). By supporting the activity of these enzymes, molybdenum aids in detoxifying potentially harmful substances. This includes processing sulfur-containing compounds and breaking down purines to prevent the accumulation of waste products (Rose, 1983). This element is essential for human health (Rose 1983). Se can be a powerful

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Table 5. Concentration of elements leached from the peloids into sweat (μg g^{-1})

	a (μg g^{-1})						
	LI	LII	LIII	LIV	LV	LVI	LVII
Na	1210.41	24441.88	686.11	11600.82	4575.52	15532.11	28400
Mg	329.47	6300.43	0.13	1573.29	1297.78	4472.62	540.00
K	1646.12	14881.87	2007.10	2991.93	2726.98	9271.76	2390.00
Ca	686.50	6904.89	310.96	271.75	220.18	331.97	8430.00
V	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Sr	**0.65**	**31.14**	**0.65**	**0.59**	**0.65**	**1.15**	197.50
Ga	0.02	0.09	0.02	0.07	0.06	0.10	0.00
Mo	**0.06**	**0.71**	**0.01**	**0.01**	**0.03**	**0.10**	1.60
Ba	0.09	–0.01	–0.01	0.05	0.03	0.04	0.36
Se	**0.03**	**0.00**	**0.01**	**0.02**	**0.02**	**0.06**	0.05
U	0.01	0.08	0.00	0.00	0.01	0.00	0.07
Li	–0.03	0.13	–0.04	–0.03	–0.02	0.18	0.61
As	–0.09	0.01	–0.09	–0.08	–0.07	–0.04	0.04
Zn	0.00	–0.01	–0.01	–0.01	–0.01	0.00	0.05
Cr	–0.04	–0.04	–0.04	–0.04	–0.04	–0.04	0.01
Sn	0.00	0.00	0.00	0.01	0.00	0.01	—
Ni	0.02	0.00	0.00	0.00	0.00	0.00	0.15
Cu	0.00	0.00	0.00	0.00	0.01	0.00	–0.01
Fe	0.00	0.00	0.00	0.00	0.00	0.00	1.50
Bi	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Al	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Nb	0.00	0.00	0.00	0.00	0.00	0.00	0.44
Ce	0.00	0.00	0.00	0.00	0.00	0.00	—
W	0.00	0.00	0.00	0.00	0.00	0.00	—

Table 6. Correlation (R^2) of elements transferred between sweat and peloid

	Na	Mg	Ca	Sr	K	Mo
Na	1.000					
Mg	0.932	1.000				
Ca	0.576	0.583	1.000			
Sr	0.613	0.617	0.995	1.00		
K	0.879	0.966	0.708	0.728	1.00	
Mo	0.65	0.681	0.987	0.989	0.796	1.000

antioxidant (Bhattacharya et al. 2016; Gomes and Silva 2007; Wada 2004). These antioxidants help protect cells from oxidative damage by neutralizing free radicals, reducing the risk of chronic disease, and promoting cellular health. Also, it supports immunity by improving the function of immune cells (Iwegbue et al., 2016). Thus, as a part of the enzyme, glutathione peroxidase, along with vitamin E (Contempre et al., 1991; Arthur et al., 1993; Enebish, 2015), catalase, and superoxide dismutase, selenium forms a component of one of the important antioxidant defense systems of the body. This is directly related to the amount of Sr in the peloid. Sr is present in the bone structure and stabilizes calcium phosphate in bone. U and As are transferred to sweat at a minimal level and even transferred from sweat to peloid in some cases. Very little Ba is transferred to sweat or from sweat (0.01–0.09 μg g^{-1}) to peloids and cannot influence the biological role of elements.

Chromium (Cr^{3+}) plays a crucial role despite the small amount of it present in the human body. For instance, it regulates the amount of sugar in blood (Wada, 2004; Carretero et al. 2010; Bhattacharya et al., 2016) by acting with insulin on the first step in the metabolism of sugar entry into the cell, and facilitates the interaction of insulin with its receptor on the cell surface (Krejpcio, 2001). Hexavalent chromium is a toxic industrial pollutant and has been classified as a carcinogen possessing mutagenic and teratogenic properties (Bhattacharya et al., 2016). International

https://doi.org/10.1017/cmn.2024.16 Published online by Cambridge University Press

classification considers the Cr content to be <25 mg kg^{-1}. Cr mobility was studied by interaction between artificial sweat and Spanish mud (Carretero et al., 2010) with little Cr (< 0.05 μg kg^{-1}) transferred from sweat to peloid. According to our study, Cr has been transferred from sweat to peloid at a minimal level (0.04 μg kg^{-1}). Correlation between the highest mobility occurring among elements is shown in Table 6.

The present authors compared their results with those of Spanish researchers who claimed that Na transfer is related to the smectite content in peloid (Carretero et al., 2010). In the present study, although Na transfer depends directly on the Na^+ concentration in lake peloid mineral content, it has leached from peloid to sweat at a level of 24441.88 μg g^{-1} at most. Ca leaching from the peloid is generally related to the Ca content in peloid and has a strong positive relation in sweat. In other words, leaching of Sr is related to the Sr content in peloid, and Ca leaching is related to mineral concentrations such as calcite, gypsum, and dolomite in the peloids. Spanish researchers claimed that Na transfer relates to the smectite content in peloid (Carretero et al., 2010). In our study, although Na transfer depends directly on Na^+ concentration of lake water (R^2=0.8554) (Fig. 2a), it has leached from peloid to sweat at a level of 24441.88 μg g^{-1} at most. Ca leaching from the peloid is inversely related (R^2=–0.155) to Ca content in water and has a strong positive relation (R^2=0.9958) in sweat. In other words, leaching of Sr is related to Sr content in peloid and Ca leaching is related to the concentrations of minerals such as calcite, gypsum, and dolomite in peloids.

Conclusions

The use of natural mud in treatment is essential for the human body. In the present study it was crucial to determine whether the clay from the lakes studied in Mongolia contain macro- and micro-elements that are important for the human body, and to assess the possibility of using the clay for treatment. Peloids of the Taigan, Ikhes, Tonhil, Hadaasan, and Khulmaa Lakes of Gobi-Altai province are primary sediments with poly-mineral composition including silicate minerals. The peloid of the Duruu Lake includes calcite and halite and has $Na_2O/CaO<1$. The elevated concentrations of macro-elements (CaO, MgO, and Na_2O) and microelements (Sr, Mo) in the peloid of Duruu Lake are related to the amounts present of minerals such as dolomite, calcite, halite, and gypsum. Macro-elements (Na, K, Ca, and Mg) and micro-elements (Mo, Se) which are essential for the human body leached from the peloid to sweat. However, toxic element mobility was minimal. Macro-element (Na, Mg, and K) transfer between the peloid and sweat has a direct relationship with their lake water concentration; transfer of Ca has an inverse relationship with the calcium content in the water. Among micro-elements, the transition of Sr occurred the most, which can be explained by the Sr content in the peloid. Therefore, it is possible to use mud from these lakes for treatment in the future.

Data availability statement. All data generated or analysed during this study are included in this published article [and its supplementary information files].

Acknowledgements. Special thanks to reviewers and editors who reviewed and provided valuable feedback on the quality of the article's final version.

Author contribution. Conceptualization: E.G., T.B. and B.Z.; methodology: E.G. and J.B.; software: B.D.; formal analysis: B.T.; resources: E.G. and J.B.; writing - original draft preparation: T.B.; writing - review and editing: E.G., B.O. and J.B.

Financial support. This research was funded by the thematic projects (no. 11 and no. P2017-2399) of high-level research for the 2017–2019 academic years of the National University of Mongolia.

Competing interest. The authors declare that they have no competing interests.

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