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Geochemical Characterization and Balneological Potential of Peloid Muds from Salt Lakes in Northern Kazakhstan: A Case Study of the Zhylykol and Saryoba Deposits

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Abstract: ***The therapeutic mud (peloid) resources of Northern Kazakhstan remain largely unexplored despite the region's abundance of salt lakes. This study provides the first comprehensive geochemical characterization of peloids from two salt lakes of Northern Kazakhstan – Zhylykol lake in the Kostanay Region and Saryoba lake in the Akmola Region and evaluates their balneological potential. Elemental composition of mud samples was determined using X-ray fluorescence spectrometry (BRA-18 "Burevestnik"). The results reveal two distinct peloid types: Zhylykol mud is enriched in silicon (up to 45.56 %), potassium (up to 1.36 %), and sodium (up to 1.69 %), indicating high clay content and pronounced anti-inflammatory and detoxifying properties; Saryoba mud exhibits anomalously high concentrations of calcium (up to 6.27 %), magnesium (up to 5.18 %), iron (up to 3.84 %), phosphorus (up to 0.48 %), manganese (up to 0.11 %), and notably strontium (up to 0.22 %), suggesting pronounced osteotropic potential. Heavy metal concentrations (Pb, Cd, Hg) remain at trace levels, confirming the ecological purity of both deposits. Comparative analysis with world-renowned peloids (Saki Lake, Crimea; Dead Sea) indicates that the studied muds are comparable to established balneological standards. The findings suggest that Zhylykol mud represents a universal therapeutic agent, while Saryoba mud offers specialized osteotropic applications. These results provide a scientific basis for the potential use of Northern Kazakhstan's peloids in spa therapy and health tourism and underscore the need for further organic matter characterization.***

Keywords: Balneology, Therapeutic Mud, Peloids, Salt Lakes, Northern Kazakhstan, Geochemistry, X-Ray Fluorescence Spectrometry

1. Introduction

In recent years, interest in natural therapeutic mud (peloids) has been growing worldwide, driven by their positive therapeutic effects on the skin and fewer side effects compared to synthetic pharmaceutical products.[1, 2] Peloids are natural products consisting of a mixture of salt lake or mineral water (liquid phase) with organic and inorganic components (solid phase), formed through biological and geological processes . The therapeutic efficacy of peloids is determined by three principal factors: thermal, mechanical, and, most significantly, chemical. Chemical components penetrate the skin and exert reflex-humoral effects, triggering anti-inflammatory, analgesic, trophic, and metabolic processes. Key elements contributing to therapeutic action include silicon (stimulates tissue regeneration, improves skin elasticity), magnesium (anti-inflammatory, metabolic regulation), sulfur and sulfides (anti-inflammatory and resolutive effects), iron (hematopoiesis, tissue oxygenation), and a range of microelements (Zn, Cu, Mn, Co, Ni, V, Cr) that function as enzyme cofactors in metabolism and immune responses.

Kazakhstan possesses more than 40,000 salt lakes, the majority of which contain natural mud deposits whose potential remains underexplored.[3] Available data indicate a point-based and partial nature of peloid research in the country: the inorganic composition of natural muds from Western and Southern Kazakhstan is relatively well described in the literature, while there is a notable lack of systematic data from Northern and Eastern Kazakhstan. This gap is particularly significant given the increasing public demand for natural mud therapy and the growing number of visitors to natural sources who use peloids without official medical prescription or scientific understanding of their physiological effects.[4] Moreover, a major gap exists in the analysis of organic matter of muds from Kazakh lakes, which represents a potential source of biologically active compounds of natural origin.

The scientific communities studying Kazakhstan's peloids have primarily focused on lakes of specific regions – Zhalanashkol, Roy, and the "Kossor" deposit on the southern shore of Alakol Lake in South Kazakhstan, Inder, Aralsor, Alzhansor, Khakisor, Bolshoy Sor, and Sorkol from Western Kazakhstan, Lake Krivoe, Lake Stanovoe, Lake Minkeser, and Lake Safonkovo of Northern Kazakhstan.[5-10] More recently, studies have characterized the peloid of Lake Moiyldy (Pavlodar Region).[11]

Northern Kazakhstan is characterized by a diverse lake system, including both freshwater and saline lakes, with salt lakes such as Kulykol (bitter-saline, area 33 km²) and numerous smaller water bodies. Several salt lakes in the region – Boreyky, Sorkol, Aksuatsor, and Ashykolh – have been identified as potentially containing therapeutic mud deposits, yet detailed geochemical characterization of these peloids is virtually absent from the literature.[12] However, systematic studies linking the chemical composition of peloids from this region to their balneological potential have not been conducted. This is particularly important given that

organic compounds in peloids – humic acids, lipids, vitamins, and enzymes – are key determinants of unique therapeutic properties.

The goal of this study is to provide the first comprehensive geochemical characterization of therapeutic mud from salt lakes in Northern Kazakhstan- specifically, the Zhylykol and Saryoba deposits – and to evaluate their balneological potential through comparative analysis with world-renowned peloid deposits (Saki Lake, Crimea; Dead Sea). Our research employs X-ray fluorescence spectrometry to determine elemental composition of both mud and water samples, and assesses therapeutic potential based on concentrations of key bioactive elements (Si, Fe, Mg, Ca, K, Sr, Mn, Zn, and others).

2. Methods

Research objects

The study was based on bottom sediment (therapeutic mud) samples collected from the Kostanay and Akmola Regions of the Republic of Kazakhstan. The sampling sites included two saline lakes, Zhylykol (geographical coordinates: 51.175147° N, 72.079742° E) and Saryoba (geographical coordinates: 51.175583° N, 72.080305° E), both of which are endorheic lakes of continental origin. These lakes were selected because of their potential balneological value and the lack of comprehensive geochemical investigations of their peloid resources.

Sampling was performed in accordance with the recommendations of ISO 18400-102:2017 (Soil quality- Sampling- Part 102: Selection and application of sampling techniques) and ISO 18400-104:2018 (Soil quality – Sampling – Part 104: Strategies).[13, 14] At each sampling site, five point samples were collected from the upper 0–20 cm sediment layer and combined into a representative composite sample weighing at least 1 kg. Point samples were collected from the surface layer of bottom sediments (0–20 cm) at locations with the greatest accumulation of silty deposits.

The samples were placed in sealed polyethylene containers to prevent contamination and moisture loss and transported to the Testing Laboratory of the Scientific Center for Biocenology and Environmental Research, Margulan Pavlodar Pedagogical University, where they underwent subsequent sample preparation prior to geochemical analysis.

Sample preparation and analytical methods

Sample preparation involved drying the bottom sediment samples at room temperature to an air-dry state, grinding them in an agate mortar to a homogeneous powder, and sieving through a 1 mm mesh sieve to ensure uniformity.[15]

The elemental composition of the mud samples was determined using a BRA-18 "Burevestnik" X-ray fluorescence spectrometer (Russia). This instrument enables qualitative and quantitative analysis of chemical elements in the range from Na to U without the need for preliminary chemical digestion of the sample, thereby ensuring high accuracy and reproducibility of the results.

To ensure the reliability of the experiment, each sample was analyzed in triplicate. The analytical procedure comprised the following stages:

1) Selection of the optimal measurement parameters (X-ray tube voltage, anode current, and signal accumulation time) for each sample type;
2) Registration of fluorescence spectra for each sample within a specified energy range;
3) Qualitative analysis- identification of elemental lines based on their energy positions;
4) Quantitative analysis- calculation of the mass fraction (%) of each element based on the intensity of characteristic lines using calibration curves.

The concentrations of the following macro- and microelements were determined: Na, Mg, Si, P, S, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Pb, Sr, Cd, and Hg. The measurement uncertainty was calculated as the standard deviation of replicate determinations.

Samples of mud sediments from Lake Moiyldy (Pavlodar Region), previously studied using the same methodology, were used as reference control materials.[11] Comparative analysis with data from known therapeutic mud deposits (Saki Lake, Crimea; Dead Sea, Israel/Jordan) was conducted based on literature data.

3. Results and Discussion

Comparative analysis of the chemical composition of mud from lakes in Northern Kazakhstan

Using the spectral analysis data, we performed a detailed comparative analysis of the chemical composition of muds from lakes Zhylykol and Saryoba (Table 1).

Table 1: Comparative chemical composition of peloids from salt lakes, Northern Kazakhstan (mean values, %)

Chemical element	Zhylykol (Kostanay Region)	Saryoba (Akmola Region)
Si	4,45,950	3,94,433
Fe	28,850	27,733
Mg	39,450	42,600
Ca	0,7250	43,367
K	12,750	0,8200
Na	11,000	0,2900
S	0,0750	0,0750
P	0,0900	0,3500
Ti	0,6100	0,3833
Mn	0,0600	0,0800
Sr	0,1000	0,1967
Zn	0,0100	0,0100
Cr	0,0135	0,0157
Cu	0,0860	0,0853
Pb	0,0045	0,0046
Cd	0,0002	0,0002
Hg	0,0003	0,0003
As	0,0045	0,0056
Co	0,0030	0,0030
Ni	0,0045	0,0047
V	0,0077	0,0048
Sc	0,0008	0,0015

Comparative analysis of the elemental composition of mud sediments from lakes Zhylykol and Saryoba revealed two fundamentally different geochemical types of peloids.

The muds of Lake Zhylykol are characterized by maximum concentrations of silicon (Si – 44,59 %), potassium (K– 1,27 %), and sodium (Na – 1,10 %). The high silicon content indicates a significant proportion of fine-grained clay fraction, providing high sorption capacity and ion-exchange properties. Elevated potassium and sodium suggest a chloride-sodium-magnesium type of brine mineralization. This type of mud exhibits pronounced anti-inflammatory, detoxifying, and regenerating effects, making it a universal broad-spectrum therapeutic agent.

The muds of Lake Saryoba demonstrate a fundamentally different chemical profile. They are characterized by anomalously high concentrations of calcium (Ca– 4,34 %), magnesium (Mg – 4,26 %), iron (Fe – 2,77 %), phosphorus (P – 0,35 %), and manganese (Mn – 0,08 %). Additionally, Saryoba samples exhibit an extremely high strontium content (Sr – 0,20 %), which is 20–80 times higher than in the muds of Lake Moiyldy (Pavlodar Region). This elemental composition indicates carbonate genesis of the sediments and a significant biogenic component (phosphorus, manganese). Such mud exhibits a pronounced osteotropic effect, driven by the synergism of calcium, phosphorus, and strontium, and is recommended primarily for diseases of the musculoskeletal system.

The concentrations of heavy metals (lead, cadmium, mercury) in all studied mud samples are at trace levels (hundredths and thousandths of a percent), confirming the absence of technogenic contamination and indicating the ecological purity of the studied deposits.

Evaluation of mud samples for their therapeutic potential

Based on their therapeutic potential, the studied samples were divided into two groups:

Group 1 (Zhylykol)- the most balanced peloid, with exceptionally high silicon, potassium, and sodium. These elements promote tissue regeneration, improve skin elasticity, enhance microcirculation, and normalize water-salt metabolism. Iron (≈2.9 %) and magnesium (≈4.0 %) further contribute to anti-inflammatory and regenerating effects. This makes Zhylykol mud a universal therapeutic agent for skin diseases and musculoskeletal disorders.

Group 2 (Saryoba)- characterized by the strontium anomaly (≈0,20 %), 100 times higher than in Moiyldy mud. Strontium is an osteotropic element that selectively accumulates in bone tissue, potentially providing specific therapeutic effects in skeletal diseases. However, strontium is not among the recognized balneologically active components, and its high concentrations may require additional toxicological studies. The contents of silicon, iron, and calcium in these samples are lower than in Zhylykol mud.

Thus, the most pronounced therapeutic potential is demonstrated by sample Zhylykol as a universal anti-inflammatory and regenerating peloid, and sample Saryoba as a specialized osteotropic and regenerating agent. The choice of mud type should be determined by the nosological form of the disease and the required therapeutic effect.

Muds of the Kostanay and Akmola regions in the context of peloids of Kazakhstan

Based on available data, the mud samples from the Kostanay and Akmola Regions examined in this study are most closely related, in terms of type and composition, to the highly mineralized sulfide silt muds common in the lakes of Western Kazakhstan (Inder, Alzhansor).[16] They also show similarities to the chloride-sodium-magnesium type muds from the lakes of Northern Kazakhstan.[7]

Based on the available data, we suggest that the closest analogue to investigated muds outside Kazakhstan is the sulfide silt mud from the famous Saki resort in Crimea.[17] However, we also find grounds to suggest similarities with some Dead Sea muds, though their composition differs in type. Notably, the Saki mud contains significantly higher levels of certain bioactive substances, such as vitamins and lipids, than even the Dead Sea muds. This makes it a very valuable reference for comparison, as our samples also showed elevated concentrations of iron, magnesium, and other elements.

Dead Sea Mud: An Analogue with a Different Type of Mineralization

Dead Sea muds are also a well-known global analogue, yet they differ in one important aspect: their mineral-salt composition is predominantly chloride-carbonate and chlorine-calcium, while the muds from Crimean lakes – and, we assume, the samples in this study – are sulfate. This difference is caused by the influence of distinct regional geological conditions.[18]

Nonetheless, both mud types are employed in balneology and pursue similar therapeutic goals, particularly in treating diseases of the musculoskeletal system and skin. The Dead Sea is also well known for its high salt and trace element content, including bromine, magnesium, and potassium.[19]

We have not found any direct analogues in the available literature that replicate the anomalously high strontium levels unique to the Akmola Region. However, in terms of general type and key elemental composition – characterized by high Fe, Mg, Ca, K, and trace element contents – these muds fall within the class of highly mineralized sulfide silt muds, for which the Saki Lake mud in Crimea serves as the global standard.

4. Conclusion

This study provides the first comprehensive geochemical characterization of peloid muds from the Zhylykol and Saryoba salt lakes of Northern Kazakhstan. The results demonstrate distinct geochemical compositions with promising balneological potential and indicate that these deposits represent valuable natural therapeutic resources. The findings establish a scientific foundation for future clinical, mineralogical, and organic matter investigatios and

support the sustainable development of regional spa therapy and health tourism.

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