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Formation Dynamics and Ore-Generating Potential of Mineralized Lakes in Transbaikalia and Northeastern Mongolia

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Abstract

Small lakes of Transbaikalia and Northeastern Mongolia united in five systems – Barguzin, Eravnoye-Gusinoozersk, Ingoda, Onon-Borzya and Eastern Mongolian – are characterized. Within the boundaries of the systems, the lakes are assorted in compact groups characterized by common chemical composition and type of geochemical evolution. Ground and surface waters feeding the lakes are characterized. On the basis of the examination of the microelement composition of lake sources (about 200 lakes) and ground waters (more than 100 sources, wells and holes), the elements concentrating during evaporation of lake waters were distinguished. The outlooks of the use of small lakes as a kind of liquid ore for the industrial extraction of some metals (Li, U, REE *etc.*) are considered.

Key words: mineralized lakes, microelement composition, Transbaikalia, Northeast Mongolia

INTRODUCTION

Mineralized lakes are widespread within Transbaikalia and adjacent territories of Northeastern Mongolia (Fig. 1). With substantial size variations (water-surface area 0.01 n–10 n km^2) and salt content (0.1n–100n g/L) they have a number of common characteristics: small depth (usually not more than several metres), extremely limited catchment area, confinement to the zones of semiarid climate, absence of surface runoff. The lakes are grouped in systems that can be divided into two types as the first approximation. The first type includes the lake systems of linear intermountain troughs (Barguzin, Eravnoye-Gusinoozersk, Ingoda). The second type is represented by the lakes of areal extension over vast territories of eastern Transbaikalia and Northeast Mongolia with weakly rugged relief (Onon-Borzinsk and eastern Mongolian systems). Practical interest to some lakes was limited by do-it-yourself or semi-industrial soda mining in the first half of the past century [1] and fishery; however, taking into account the global trends, we may expect a substantial increase of attention to the lakes in the nearest future.

Mineralized lakes of Eastern Siberia were characterized in detail in the monographic report at the beginning of the second half of the past century [2, 3] which is generalization of the results obtained by many hydrogeological parties. However, the analytical possibilities of those years allowed one to determine only the concentrations of major components of lake waters; the geochemical specific features of lake water remained outside the framework of investigations. The lakes of Eastern Mongolia are poorly studied. In scarce publications concerning the lakes of Mongolia [4, 5], only the largest lakes situated mainly in the western part of Mongolia are considered. No

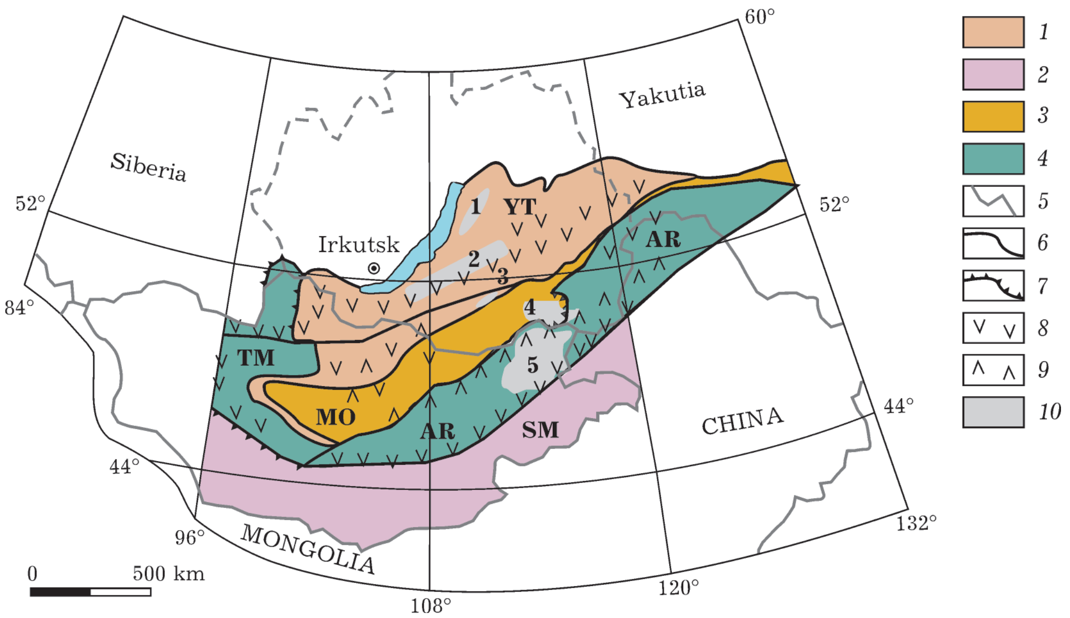

Fig. 1. Location of the system of small lakes of Transbaikalia and Northeast Mongolia on the geodynamical scheme of Northeast Asia (according to [Nokleberg, 2010]): *1–3* – terrains of the Central Asian folding (*1* – Yenisei-Transbaikalian (YT) (V-O_1); *2* – Southern Mongolian–Khingan (SM) (O-C); *3* – Mongol-Okhotsk (MO) (D-K_3)); *4* – superterrains (PR_3-Cm): Argun-Idermet (AR) and Tuva-Mongolian (TM); *5* – state boundaries; *6* – geological boundaries and faults; *7* – overlap faults; *8* – overlapping formations of the continental margin; *9* – overlapping formations of the transform continental margin; *10* – systems of small lakes: 1 – Barguzin; 2 – Yeravnoye-Gusinoozersk; 3 – Ingoda; 4 – Onon-Borzya; 5 – Northern Mongolian.

detailed geochemical studies were carried out even at these relatively large lakes. In this work we present a brief characterization of lake systems with special attention to their geochemical specificity. We studied more than 200 lakes and about 150 sources, wells, boreholes as a total.

GEOCHEMICAL SPECIFIC FEATURES OF LAKES AND UNDERGROUND WATER

Barguzin System

This system includes more than 1100 small lakes [6, 7]; their exact number, as well as the size and configurations, can vary every year. The absolute majority of the lakes are situated in the flood-plain of the Barguzin River; their water is fresh and close in composition to river water. Among mineralised lakes, three groups are distinguished: Garga-Argoda (Kharamodun), Ust-Argoda and Alga.

The lakes of the Garga-Argoda group have mainly thermokarst origin. Fresh-water and brackish alkaline (pH 8.7–9.7) with total dissolved solids (TDS) within the range 0.1–2 g/L are among the lakes of this group. Fresh-water thermokarst lakes are magnesium hydrocarbonate in the chemical composition, while the brackish ones are sodium hydrocarbonate (Table 1).

The Ust-Argoda group consists of four lakes: Sagan-Nur and three closely located lakes with common name Nukhe-Nur. Water in the lakes is characterized by high alkalinity (pH 9.7–10.6), high mineralization (14–16 g/L) and has the soda geochemical specificity.

The Alga group of lakes is the only group in the Barguzin trough that possesses sulphate specificity. Salinity varies within the range 6–70 g/L in the lakes of this group; pH 8.8–9.6.

Ground waters feeding the lakes relate to calcium hydrocarbonate or calcium-magnesium hydrocarbonate types. Only some of them are characterized by the increased fraction of sulphate ion and sodium. Mineralization of ground water is 0.08–0.3 g/L, pH values are close to neutral (pH 7.4–7.9). Sulphate ion dominates in the anion composition of thermal water, while sodium dominates in the cation composition. Mineralization of thermal water is much higher (0.28–1.1 g/L) in comparison with cool springs; pH is 8.5–9.9 (Table 2).

TABLE 1

Hydrochemical characteristics of lake water in the region under consideration

Characteristics	Lake systems				
	Barguzin	Yeravnoye-Gusinoozersk	Ingoda	Onon-Borzya	Eastern Mongolian
TDS, g/L	0.1–71	0.1–17	0.1–104	0.3–380	0.5–280
pH	8–10.5	7.6–10	8.4–10.1	8–10.14	7.2–10.1
Anions	SO_4, HCO_3	HCO_3, SO_4	HCO_3	HCO_3, Cl, SO_4	Cl, SO_4, HCO_3
Cations	Na, Mg, Ca	Na, Mg, Ca	Na, Mg, Ca	Na	Ca, Na, Mg
Concentration, μg/L:					
Li	1.1–2300	2.3–1000	1–1000	9–442	4–48 000
B	3.5–6600	3.3–1100	Background	52–65 000	42–92 000
V	Background	Background	0.3–176	1–500	1–646
Ge	Background	Background	0.02–25	0.01–40	0.8–6
As	0.1–140	Background	Background	0.5–14 000	19–7200
Se	Background	Background	Background	0.05–56 000	0.5–44
Br	5–14 600	9–23 800	n/d	n/d	29–777 000
Sr	75–6000	92–5600	44–1500	96–13 100	91–23 800
Zr	Background	0.01–375	Background	0.1–1650	0.03–790
Mo	0.5–45	0.3–472	Background	1–670	9–1420
Sb	Background	Background	Background	0.2–100	0.6–86
Cs	Background	Background	Background	Background	0.005–26
REE	Background	Background	Background	0.05–170	0.1–119
W	1–550	Background	Background	0.04–407	0.2–522
U	Background	0.1–154	Background	3.1–2200	6.8–4800

Note. n/d – not determined.

Yeravnoye-Gusinoozersk system

This system of small lakes extends for more than 500 km from the Vitim River in the northeast to the Dzhida River in the southwest and includes more than 100 lakes. Within the system under consideration, four groups of lakes are distinguished: Yeravnoye, Khorinsk-Uda, Gusinoozersk and Beloozersk.

Yeravnoye group. The major part of the lakes belonging to this group are concentrated within the Yeravnoye trough. These are mainly freshwater, alkaline lakes with mineralization 0.1–1 g/L, only two of them are brackish (TDS = 2.4 and 4.5 g/L). The most widespread water type is calcium-sodium or sodium-calcium hydrocarbonate; average pH is equal to 9.1 (see Table 1).

The lakes of **Khorinsk-Uda group** are close in chemical composition to the lakes of Yeravnoye group but differ by lower alkalinity (pH 8.3–9.1) and higher mineralization. Brackish lakes with total concentration of dissolved salts up to 7.3 g/L dominate in this group; sulphates account for a substantial fraction in the anion composition.

Gusinoozersk group unites ultrafresh (Gusinoye lake), fresh, brackish and salt lakes situated mainly within the limits of the homonymous trough. Salt content varies within the range 0.2–15 g/L with pH 8.1–9.6. Hydrocarbonate or hydrocarbonate-sulphate water is prevailing; the composition of water in the most heavily mineralised lake is sulphate-chloride. The cation composition of lake water relates to Ca–Mg, Mg–Na, Mg–Ca–Na and Na types.

Beloozersk group of lakes is also characterized by a broad range of water salinity (TDS = 0.1–17 g/L) and pH value (8.0–9.8). While salinity increases, the hydrochemical type of water changes from calcium-magnesium hydrocarbonate to sodium sulphate-hydrocarbonate.

The level of mineralization of the feeding ground water is 0.1–0.6 g/L with pH 7.0–8.8 (see Table 2).

TABLE 2

Hydrochemical characteristics of the sources in the region under consideration

Characteristics	Lake systems					
	Barguzin		Yeravnoye-Gusinoozersk	Ingoda	Onon-Borzya	Eastern Mongolian
	Thermal water	Cool water				
TDS, g/L	0.3–1.1	0.1–0.4	0.1–0.7	0.05–1.2	0.2–1.0	0.8–1.6
pH	8.0–10	6.7–8.3	7.1–9.1	6.5–8.5	6.5–8	7.1–8.3
Anions	SO_4, HCO_3	HCO_3, SO_4	HCO_3, SO_4	HCO_3	HCO_3, Cl, SO_4	HCO_3, Cl, SO_4
Cations	Na	Ca, Mg, Na	Ca, Mg, Na	Mg, Ca, Na	Ca, Mg, Na	Ca, Na, Mg
Concentration, mg/L:						
Li	43–1330	Background	Background	Background	5–164	5–530
B	44–220	Background	Background	Background	13–470	9–650
V	Background	Background	Background	Background	0–26	0.7–52
Ge	2–11.3	Background	Background	0.02–25	Background	Background
As	Background	Background	Background	Background	0.5–25	0.9–73
Se	Background	Background	Background	Background	0.1–4.3	0.1–7
Br	19–108	Background	15–460	n/d	n/d	12–1300
Rb	5–108	Background	Background	Background	Background	Background
Sr	110–3000	Background	30–2300	44–1500	80–1600	Background
Mo	0.5–45	Background	1.1–51	Background	0.5–25	1.3–20
Sb	Background	Background	Background	Background	0.1–28	Background
Cs	0.6–38	Background	Background	Background	Background	Background
REE	Background	Background	Background	Background	Background	0.01–11
W	7.2–82	Background	Background	Background	Background	Background
U	Background	Background	0–27	Background	0–22	1–176

Note. n/d – not determined.

Ingoda system

There are more than 20 lakes within the boundaries of the Ingoda system localized in the homonymous trough. Lakes with ultrasmall size and unstable hydrological conditions dominate among them. The lakes occupy flat, shallow depressions having round or oval shape in insignificant depressions of the relief.

A broad range of salt content variations is characteristic of the lakes of this system: from fresh with total amount of dissolved water 0.1–0.5 g/L to brackish and salt lakes with mineralization within the range 1.0–104 g/L. The lakes of the trough belong to the alkaline type; pH varies within the range 9.40–10.12 (see Table 1).

Hydrocarbonate ions dominate in the ion composition of lake-feeding ground and surface water in the Ingoda through; the cation composition is broadly varying from essentially calcium, calcium-magnesium-sodium to sodium. The total amount of dissolved salts also varies within a broad range from ultrafresh water (TDS = 0.05 g/L) to brackish alkaline (TDS = 1.19 g/L).

Onon-Borzya system

Ehis system includes several hundred lakes localized within the limits of Tsasuchey trough and its flanks, as well as at the adjacent territories to the south and to the east. The area of the largest lakes Zun-Torey and Barun-Torey is 300 and 580 km^2, respectively; while generally dominate the lakes of very small size with unstable hydrological conditions. Within this system, Northern Tsasuchey, Southern Tsasuchey, Torey and Borzya groups of lakes are distinguished.

Northern Tsasuchey group is characterized by the largest variations of salt content and the component composition of lake water. The TDS value varies within the range 1.0–120 g/L, pH of water is 8.0–9.9. The anion composition of lake water varies depending on salt content from hydrocarbonate (through hydrocarbonate-sulphate) to essentially chloride. The cation composition of water varies not so substantially changing from magnesium-sodium to sodium (see Table 1).

The lakes of the **Southern Tsasuchey group** are less diverse in composition. The salt content varies within 0.3–15 g/L with pH 9–10. The anion composition of water varies from hydrocarbonate through hydrocarbonate-chloride to chloride-hydrocarbonate, while the cation composition changes from sodium-magnesium to sodium.

Lake water of **Torey group** is characterized by insignificant variations of TDS value (0.4–16 g/L) and pH 9.4?9.8 but substantial diversity of component composition. While the salt content increases, the geochemical type of lake water changes from sodium hydrocarbonate-sulphate through sodium hydrocarbonate-chloride-sulphate to sodium hydrocarbonate-chloride.

Borzya group includes the lakes with the largest variations of salt content (from 0.4 to 310 g/L). The value of pH also varies within a broad range (pH 8.1–10). The hydrogeochemical type of lake water changes with increasing salt content from calcium hydrocarbonate to sodium chloride.

Underground water is characterized by TDS within the range 0.2–1 g/L, pH 6.5–8.4 and belongs to the hydrocarbonate type with the high fraction of chloride ions in some sources. The cation composition of water is more diverse and varies from calcium and calcium-magnesium to sodium (see Table 2).

Eastern Mongolian system of small lakes

There are about 5000 lakes in Eastern Mongolia [4, 5]. The major part of them is related by us to the Eastern Mongolian system of small lakes situated in the northeastern part of Mongolia. This lake system is the largest among lake systems under consideration. Within this system, there are Southern Torey, Central, Galutin and Kerulen groups. Southern Torey group includes the lakes situated to the south from Torey lakes; Kerulen group includes a chain of lakes extended along the Kerulen River. Central and Galutin groups together also form an extended band but substantial differences in the chemical composition of lake water did not allow us to unite them.

The lakes of **Southern Torey group** are typically alkaline brackish or salt (there are no fresh lakes) with salt content varying from 2 to 140 g/L. Sodium dominates in the cation composition. As salts accumulate, the geochemical type changes from sodium hydrocarbonate to sodium chloride-sulphate (see Table 1).

The lakes of the **Central group** are characterized by substantial variations of pH (7.2–9.9), water is mainly brackish, only in two lakes the salt content exceeds 10 g/L (up to 21 g/L). Fresh lakes are characterized by sodium-calcium hydrocarbonate water composition, while brackish lakes are of sodium hydrocarbonate type; salt lakes – of sodium chloride-hydrocarbonate.

The lakes of **Galutin group** are characterized by broad variations of salt content (1–144 g/L) and rather narrow pH range (8.2–9.2). As salts accumulate, the hydrochemical type of lake water changes from sodium hydrocarbonate through sodium chloride-hydrocarbonate to sodium chloride-sulphate.

Mainly salt lakes (5–99 g/L) comprise **Kerulen group**. For the major part of these lakes, TDS value exceeds 20 g/L, while pH varies insignificantly (pH 8.1–9.1). Sodium dominates in the cation composition, while either chloride or sulphates dominate in the cation composition.

Underground water feeding the lakes is characterized by increased mineralization (0.9–1.4 g/L) except for the sources of the Central groups where the total amount of dissolved salts is 0.3–0.5 g/L. Hydrocarbonate ions dominate in the anion composition of ground water, sometimes with substantial fraction of chloride ions (Southern Torey and Galutin groups) or sulphate ions (Kerulen group). The cation composition is extremely diverse (see Table 2).

Considering the metallogenic specificity of water systems in the region, we are to stress that the supply of “useful components” into lake water is performed mainly by the feeding ground water (more rarely surface water), while further concentrating occurs through evaporation processes. Thus, evaluating the ore-generating potential, it is necessary to consider not only the lakes but also ground water feeding them.

Underground water

The total content of dissolved salts in underground water rarely exceeds 1 g/L. The most strongly mineralized waters are thermal water of Barguzin trough and cool springs of the Eastern Mongolian system (see Table 2). The concentrations of the majority of analysed elements in the sources of all the systems do not exceed several micrograms per litre. Increased microelement content is characteristic of thermal water, but its localization in the boundary parts of Barguzin trough excludes the formation of lakes necessary for further concentrating valuable components. Thermal water may be considered as the potential independent liquid ore. As far as cool springs are concerned, the highest concentrations of many useful components are characteristic of the Eastern Mongolian system. Lithium and uranium concentrations reach several hundred micrograms per litre; rare earths and molybdenum reach several ten micrograms per litre.

Mineralized lakes

Substantial variations of mineralization and geochemical specificity of lake water are observed, not only for the lakes of different systems but also within the boundaries of each system (see Table 1). The majority of studied lakes are alkaline, fresh or brackish. The lakes of the Ingoda trough clearly belong to the soda evolution type. Within the Barguzin and Yeravnoye-Gusinoozersk lake systems the fraction of sulphate ions in lake water increases (to dominance). The lakes of the Eastern Mongolian system and especially Onon-Borzya system are very non-uniform in the geochemical water type.

Increased concentrations of some elements in feeding ground water provided salt accumulation in the lakes of Eastern Mongolia and to a smaller extent in the lakes of the Onon-Borzya system for which the highest level of concentrations of the majority of elements is characteristic. Lithium content reaches the condition level [8] accounting for about 80 mg/L. High concentrations of uranium (up to 5 mg/L), molybdenum (up to 1.4 mg/L), W (up to 0.5 mg/L), rare earths (up to 0.1 g/L) and some other elements are detected in some lakes.

CONCLUSIONS

The results of our investigations showed that the probability of detecting the objects like American salars or Tibetan metal-bearing lakes is very low; the concentrations of useful components are here substantially lower than the economically rational level or water volume in lakes is extremely insignificant. The practical interest to small lakes in future may be defined by three factors: 1) reduction of the level of revenue-producing concentration of useful components in water with the improvement of technologies; 2) correction of the strategy of mining operations with the transfer of emphasis to integrated processing of small deposits using mobile installations; 3) strengthening of ecological requirements to the development of mineral mining. Ecologically safe extraction of minerals implies not only the absence of avulsed wounds on the surface and in the Earth's interior in the form of open pit mines, pits, waste piles, but also the minimal action on the natural complex of the region. The latter is possible for developing only shallow drying lakes.

The historical excursus showed that the periods of substantial decline of water level occurred under the action of unfavourable climatic factors in many small water reservoirs of Southern Siberia and Mongolia, grouped into lake systems. The result of the influence of these factors was salt concentrating in the lakes, drying till long-term dry periods followed by periods of filling with water etc. In other words, with minimal economically rational concentrations of minerals, each lake of this type can be considered as a source of renewable ore, which removes or substantially weakens the problem of the amount of resources.

Practical development of small lakes may be substantially accelerated by the development of the mobile installations for selective extraction of useful components from lake water on the basis of rough-terrain performance vehicles. For lakes, unlike for ground brines of the Siberian Platform, the problem of utilization of highly aggressive water after metal extraction will not be so acute. Technological operations in winter or in early spring have additional advantages.

1. The access to the lakes with the sides that are often boggy in summer is thus simplified substantially.

2. The depth of the majority of lakes is 1.5–3 m, so 30–90 % of water volume gets frozen in winter. Thus additional concentrating of salts in lake water occurs, including useful components. Special studies for mineralised lakes of western Pribaikalia showed that the salt content of water in winter increases by a factor of 2–7.

3. The necessity to construct special setting tanks or reservoirs for used water is absent.

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