

The Main Features of the Formation and Chemical Composition of the Lakes of Eastern Transbaikalia (Russia)

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Abstract: The concentrations of bicarbonate, carbonate, sulphate and chloride ions grow irregularly in the conditions of an arid climate due to the evaporation of lake water. Basically, in the lake waters, the concentrations of carbonate complexes ($\text{HCO}_3^- + \text{CO}_3^{2-}$) and chloride ions (Cl^-) increase. The accumulation of sulphate (SO_4^{2-}) does not happen, mainly as a result of bacterial reduction. The rapid growth of $\text{HCO}_3^- + \text{CO}_3^{2-}$ is also associated with this process. The chloride ion content increases with increasing salinity, as well as because no geochemical barriers exist to hinder its accumulation. As a result, soda or chloride-soda lakes are generally formed in the considered territory. Sulphate lakes are extremely rare.

1 INTRODUCTION

This article presents the results of hydro-chemical investigations, made in August 2019, of the chemical composition of some lakes in Eastern Transbaikalia. All of the considered lakes are located in the Chita-Ingoda depression. This depression is one of the largest Mesozoic basins in Transbaikalia; it is up to 260 km long, with an average width of 17 km and a total area of about 4400 km² (Florensov, 1960). There are about 20 lakes in the depression. The largest of the lakes is Lake Doroninskoe, a soda lake. Its area is 5 km², and it has a maximum depth of 6,5 m. It is a meromictic lake with a pronounced layered stratification of the salinity of the water in its physical and chemical characteristics. The salinity, depending on the season, ranges from 10 to 35 g/L in the top layer of the oxygen-encompassing depth of 3–5 m; in the hydrogen sulphide layer, the salinity is in a narrower range – 28–36 g/L.

The main feature of the lakes in the considered territory is the considerable variability of their salinity and chemical composition. Extreme continental climate and interannual variations in the total moisture of the territory lead to significant changes in the hydrological regime of the lakes and lake water transitions from one hydro-chemical type to another. Directed transformations of the chemical

composition, with the change from carbonate to sulphate and then to chloride, must occur in the course of this change according to previous works (Posokhov, 1981; Shvartsev, 1982; Drever, 1982).

Such a succession of the chemical composition occurs due to the precipitation of salts as the lake water is saturated; first, the least soluble minerals, calcite and dolomite, precipitate, and then gypsum, soda, etc. The actual distribution of chemicals in the waters of the studied lakes (table 1) differs from the above scheme of metamorphism.

Only in freshwater lakes with an anionic composition was carbonate actually the most abundant anion, and the second most abundant ion was chloride one in the salt lakes; in some cases, chloride held the lead position. Sulphates dominated only in one case; in the other cases, the sulphate concentration was below 20 % (eq.). The advanced growth of the chloride ion concentration compared to that of sulphate ions in the lake water does not correspond to the ratio of these anions in the groundwater, which provides the bulk of the salt supply for these lakes (table 2, figure 1). The equivalent concentration of chloride is on average lower than that of sulphate. Therefore, to saturate the water with sulphate minerals and precipitation, generally, chloride and sulphate ions must accumulate in equal proportions. Actually, in the studied lake waters, not only is the accumulation of sulphates proportional to that of chlorides, but it lags

behind the rate of accumulation and the contents of bicarbonate and carbonate, which, in comparison to sulphate and chloride, in most cases grow more

intense. Such a situation is not in line with the general ideas about these minerals and requires special consideration.

Table 1: Chemical composition of lakes water.

No	Lake	pH	DOC	HCO ₃ ⁻ + CO ₃ ²⁻	SO ₄ ²⁻	Cl ⁻	F ⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TDS
1	Doroninskoe	9,88	34,2	12952	133,4	4715	11,4	7,37	35,8	10209	127	28191
2	Chepchek-2	9,59	83,4	9308	1690	6326	29,4	10,2	27,5	8647	37,4	26076
3	Torm	8,96	18,8	2935	590	2090	12,8	4,81	347	2388	13,8	8381
4	Chepchek-3	9,25	24,1	3770	610	960	10,0	11,0	20,0	2610	20,1	8011
5	Balm	8,96	73,1	2600	89,6	540	4,10	9,50	19,8	1432	23,6	4719
6	Hunduyskoe	9,53	29,7	2096	70,0	536	4,50	2,00	93,6	1024	42,2	3868
7	Chepchek-1	9,05	36,7	1024	23,6	178	4,60	14,2	30,1	494	10,0	1778
8	Lebedinskoye	9,90	23,9	871	10,2	28,2	0,69	11,1	25,6	317	4,55	1268
9	Bolvanka	9,88	16,8	249	435	126	0,38	23,1	18,3	338	1,74	1191
10	Hund-1	8,50	28,1	667	10,7	4,00	0,95	25,3	52,0	129	3,05	891
11	Tanga	9,07	14,5	460	19,4	35,5	0,83	16,7	27,8	132	11,7	703
12	Gorekatsan	9,09	19,8	377	10,0	10,0	1,26	13,8	14,4	112	2,81	540
13	Hund-2	9,04	19,5	323	40,2	11,8	0,57	26,3	18,0	88,6	4,08	512
14	Great	9,05	2,60	295	33,6	8,91	0,95	13,2	23,8	74,8	2,38	451
15	Nikolaev	9,10	34,2	246	4,11	11,2	0,42	19,4	15,3	52,0	1,87	349

Table 2: Groundwater chemical composition of district Chita-Ingoda depression on dedicated types.

No	pH	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TDS
1	7,07–7,72	69,6–497,1	1,5–43,5	1,4–12,2	12,1–65,9	6,42–49,1	2,43–46,1	0,03–3,17	109–686
	7,56	241,8	18,5	6,33	38,6	19,7	22,2	1,09	348
2	7,58–8,1	378,7–778	32,7–443	3,6–29,1	80,1–115	34,7–55,8	94,6–189	0,05–8,24	855–1365
	7,83	575	143	14,5	72,0	43,6	127,9	3,0	980

Note. $\frac{\text{Min-Max}}{\text{Avg}}$

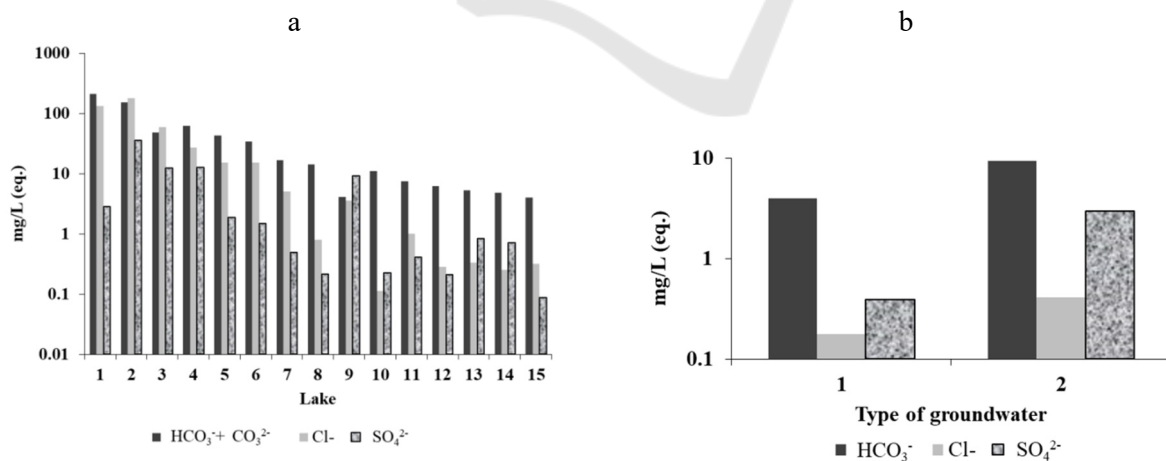


Figure 1: Distribution of major anions in the lake water (a) and groundwater (b). (Numeration of lakes and groundwater types according to the tables 1 and 2, respectively).

2 RESULTS AND DISCUSSION

The calculation of the change of the composition of water due to its evaporation was executed according to the thermodynamic modelling program HG32 (Bukaty, 2002). The soda lake Doroninskoe (Q1) was chosen as a model. The calculations used the water chemical composition feeding the Doroninskoye lake (Q2) (table 3). The chloride, as the most conservative component, was used as an indicator of the degree of evaporation; it does not enter into reactions concerning the formation of hydro-minerals in the studied range of TDS.

The residual solution composition (Q3) was estimated using the concentration of water up to the level of chloride in the lake water over the ions,

resulting in the percent equivalent of the presented relations: $\text{CO}_3^{2-} + \text{HCO}_3^- - 45$; $\text{Cl}^- - 27$; $\text{SO}_4^{2-} - 26$; $\text{Na}^+ - 97$ %. The model solution were supersaturated by calcite, dolomite, fluorapatite and gypsum were the main components of the equilibrium phases (table 4). The result of the thermodynamic calculation corresponds to a scheme in which metamorphic water evaporated, but it differs significantly from the data on the lake. In this case, the estimated sulphate content (5945 mg/L) was higher, and the estimated bicarbonate and carbonate content (9056 mg/L) is lower than in the lake water.

The causes of various theoretical and actual concentrations of anions can be explained as follows.

Table 3: Components and physico-chemical parameters of model solutions.

Solution	pH	$\text{CO}_3^{2-} + \text{HCO}_3^-$	SO_4^{2-}	Cl^-	F^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	TDS
		mg/L								
Q ₁	9,98	12952	133,4	4715	11,4	7,37	35,8	10209	127	28190
Q ₂	7,55	19,6	1,55	0,81	0,02	3,15	1,67	1,83	0,25	28,9
Q ₃	9,45	9056	5945	4715	0,73	$1 \cdot 10^{-6}$	0,60	10628	511	30856

Table 4: Saturation of model solutions with minerals (per liter).

No	Mineral name	Formula	Mineral mass, mg
1	Calcite	CaCO_3	3836
2	Dolomite	$\text{CaMg}(\text{CO}_3)_2$	133
3	Magnesite	MgCO_3	-
4	Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	1627
5	Chlorite	$\text{Mg}_{2,25}\text{Al}_{1,5}\text{Si}_{11,25}\text{O}_5(\text{OH})_4$	0,57
6	Montmorillonite	$\text{MgAl}_2\text{Si}_4\text{O}_{11}(\text{OH})_2$	0,49
7	Montmorillonite	$\text{Ca}_{0,15}\text{Al}_{1,9}\text{Si}_4\text{O}_{10}(\text{OH})_2$	1,36
8	Montmorillonite	$\text{K}_{0,33}\text{Al}_{1,9}\text{Si}_4\text{O}_{10}(\text{OH})_2$	9,33
9	Montmorillonite	$\text{Na}_{0,33}\text{Al}_{2,33}\text{Si}_{3,67}\text{O}_{10}(\text{OH})_2$	0,02
10	Montmorillonite	$\text{KMgAlSi}_4\text{O}_{10}(\text{OH})_2$	0,70
11	Natron	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	-
12	Analcime	$\text{NaAlSi}_2\text{O}_5(\text{OH})_2$	-
13	K-Illite (total)		2,05
14	Illite	$\text{Mg}_{2,75}\text{Al}_{1,5}\text{Si}_5\text{O}_{10}(\text{OH})_2$	0,04
15	Fluorapatite	$\text{Ca}_5(\text{PO}_4)_3\text{F}$	125
16	Chlorapatite	$\text{Ca}_5(\text{PO}_4)_3\text{Cl}$	1,23
17	Troilite	$(\text{Fe}^{2+})\text{S}$	0,37

Note. Dash – water is not saturated.

In lakes, the balance of inorganic carbon is formed due to the intake of bicarbonate ion with underground and surface runoff and mineralization of dissolved organic matter (DOC). The values of DOC indicate their high concentration in the lake waters (table 1). Detritus is one of the sources of DOC, which comes from the watershed and is formed as a result of the mineralization of algae. Although it is believed that most of the detritus is

allochthonous (Hutchinson, 1957), when it is introduced to the watershed, in many cases the bulk of it is likely to accumulate in the reservoirs themselves with withering algae. The extensive development of the coastal strip is observed in most lakes. Perhaps photosynthesis in the water column is the main process of organic carbon formation. In the surface layers of the salt lakes, the total production of DOC bacteria and algae in the summer period is

estimated to be $60 \text{ mg C}/(\text{m}^2 \cdot \text{d})$ (Namsaraev and Namsaraev, 2007).

The lag in the accumulation in the lake waters, and often the sulphate ion output, occur due to the associated microbiological processes as well. This happens only because of the processes of sulphate reduction. The intensity of the sulphate reduction in lakes in the Transbaikal region in the summer is estimated to be $30 \text{ mg S}/\text{dm}^3$ per day on average (Gorlenko et al., 2010). More than 100 mg/L of hydrogen sulfide was recorded in the bottom layers of Doroninskoye soda lake, tested at different times (Borzenko and Zamana, 2011).

However, the role of sulphate reduction is not limited to the transformation of forms of sulphur, since electron transport is provided by the oxidation of carbon, which is part of the dissolved organic matter in the water column. It is known that sulphate-reducing bacteria (SRB) include agents containing the light isotope ^{12}C in their metabolism (Galimov, 1968). The mirror-symmetrical distribution curves of the concentrations of S^{2-} and $\delta^{13}\text{C}$ in the water column demonstrate the relationship of the sulphate reduction process with the carbon isotopic composition clearly (figure 2). The most carbon was present ($\delta^{13}\text{C} = -0.17 \text{ ‰}$) in the chemocline zone, where the concentration of hydrogen sulphide in the period under review was the greatest. The oxygen isotopic composition of the carbonates involved in the oxidation of biogenic carbon also points to oxygen's entry into carbonate

ions from sulphates. The parallel curves of isotope distribution and the concentrations of sulphate are proof.

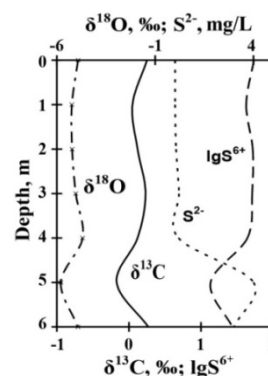


Figure 2: Distribution of dissolved S^{6+} , S^{2-} , $\delta^{13}\text{S}$ and $\delta^{18}\text{O}$ in the Doroninskoe lake water.

The sediment associated with the saturation of water in certain hydrogenic minerals is no less of an important factor in the formation of the hydrochemistry of lakes. According to thermodynamic calculations (table 5), for lakes, typically the carbonate type of sedimentation in the hydrogenic deposition may contain in small amounts calcium and magnesium carbonates, clay minerals (montmorillonite, illite), zeolites (chlorite), metal sulphides, etc.

Table 5: Saturation of water with minerals in lakes considered (mg/L). (Numeration of minerals according to the table 4).

Lake	Mineral							
	1	2	3	5	8	14	15	17
Doroninskoe	$6 \cdot 10^{-6}$	5,32	54,9	$5 \cdot 10^{-2}$	0,046	$2,9 \cdot 10^{-3}$	13,3	0,37
Chepchek-1	$2 \cdot 10^{-6}$	0,48	$2 \cdot 10^{-4}$	$1 \cdot 10^{-3}$	$5 \cdot 10^{-5}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-4}$	-
Chepchek-2	$2 \cdot 10^{-7}$	17,4	3,21	$2 \cdot 10^{-6}$	$4 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	1,94	-
Chepchek-3	$1 \cdot 10^{-7}$	5,23	$1 \cdot 10^{-4}$	$4 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$3 \cdot 10^{-8}$	0,14	-
Torm	$2 \cdot 10^{-7}$	32,4	5,02	$6 \cdot 10^{-5}$	2,0	$1 \cdot 10^{-4}$	2,03	-
Balm	9,33	26,2	55,7	$1 \cdot 10^{-8}$	$1 \cdot 10^{-10}$	$9 \cdot 10^{-6}$	0,07	0,07
Hunduyskoe	$1 \cdot 10^{-6}$	8,47	28,6	$6 \cdot 10^{-7}$	0,04	$2 \cdot 10^{-6}$	0,09	-
Great	1,35	18,6	5,11	$1 \cdot 10^{-12}$	$2 \cdot 10^{-5}$	$9 \cdot 10^{-7}$	0,06	-
Nikolaev	$9 \cdot 10^{-7}$	43,0	$2 \cdot 10^{-4}$	$1 \cdot 10^{-12}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-6}$	0,09	$1 \cdot 10^{-4}$
Lebedinskoye	-	45,9	39,5	$3 \cdot 10^{-12}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	0,08	0,25
Hund-1	$9 \cdot 10^{-7}$	11,2	$1 \cdot 10^{-3}$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-5}$	0,07	-
Hund-2	2,2	6,11	$1 \cdot 10^{-3}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-5}$	0,07	-
Tanga	$9 \cdot 10^{-7}$	7,13	$5 \cdot 10^{-4}$	$5 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	0,09	-
Gorekatsan	8,6	4,80	$2 \cdot 10^{-4}$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-5}$	$9 \cdot 10^{-8}$	0,07	0,23
Bolvanka	$9 \cdot 10^{-7}$	4,41	$4 \cdot 10^{-9}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	0,05	0,02

Note. Dash – water is not saturated.

Gypsum formation does not occur, mainly due to the low content of sulfate ions in lake waters. The chloride ion has no restrictions in the form of hydrogenic minerals in this salinity range. Therefore, its content increases with increasing salinity of water.

3 CONCLUSIONS

Therefore, the formation and transformation of the chemical composition of the water of the saline lakes of East Transbaikalia is a multifactor process, which, along with evaporative concentration, involves hydrobiological processes and sedimentation inside the basin. The content in the salt lakes' waters of carbonate and sulphate components depends on the functioning of the microbial community in a particular basin (body of water). Evaporative sedimentation limits the accumulation in water of many components, but the bacterial production of carbonate complexes along with conjugate sulphate reduction allows them to concentrate in substantial amounts, up to the formation of soda or chloride-soda waters. The hydro-chemical variety of salt lakes is determined by the dominance of a particular process in the formation of the composition of the salt.

Obviously, differences in the composition of host rocks, the intensity of water exchange, the thermodynamic conditions and other factors determine the variety of water-rock interactions. The composition of secondary products can provide isotope fractionation during certain stages in a water-rock-gas system.

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REFERENCES

- Borzenko, S. V. and Zamana, L. V. (2011). Reduced forms of sulfur in the brine of saline-soda lake Doroninskoe, Eastern Transbaikal region. *Geochemistry International*, 49(3): 253–261.
- Bukaty, M. B. (2002). Software engineering for the solution of hydrogeological problems. *Bulletin of the Tomsk polytechnic university*, 305(6): 348–365
- Drever, J. I. (1982). *The geochemistry of natural waters*, Prentice-Hall. Englewood Cliffs.
- Florensov, N. A. (1960). *Mesozoic and Cenozoic depressions of the Baikal region*, Academy of Science USSR. Moscow–Leningrad.
- Galimov, E. M. (1968). *Geochemistry of stable carbon isotopes*, Nedra. Moscow.
- Gorlenko, V. M., Namsaraev, Z. B., Bryantseva, I. A., Boldareva, E. N., Sorokin, D. Y., Buryukhaev, S. P., Namsaraev, B. B., Matyugina, E. B. and Borzenko S. V. (2010). Microbial communities of the stratified soda lake Doroninskoe (Transbaikal region). *Microbiology*, 79(3): 390–401.
- Hutchinson, G. E. (1957). *A treatise on limnology*, Jonh Wiley. New York.
- Namsaraev, B. B. and Namsaraev, Z. B. (2007). Microbial processes of carbon cycling and habitat conditions in alkaline lakes of Transbaikalia and Mongolia. In T. N. Zhilina, L. M. Gerasimenko and G. A. Zavarzin, *Proceedings of the S.N. Vinogradsky Institute of Microbiology. Issue 14. Alkalophilic microbial communities*. (pp. 299–322). Moscow: Nauka.
- Posokhov, E. V. (1981). *Chemical evolution of the hydrosphere*, Gydrometeoizdat. Moscow–Leningrad.
- Shvartsev, S. L. (Ed.). (1982). *Fundamentals of hydrogeology. Hydrogeochemistry*, Nauka. Novosibirsk.