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Thermodynamic Evaluation of Mineral Balance in Water Thickness of the Soda Lake Doroninskoe (Eastern Transbaikalia, Russia)

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In recent years, lakes, including salted, attract the attention of researchers, also when reconstructing last climate changes using the bottom sediments (Solotchina et al., 2008, et al.). In this case the different geochemical characteristics are applied, which depend on the conditions of sedimentation, especially on the characteristics of the water thickness. In this regard the lake Doroninskoe is studied, the largest soda reservoir in Eastern Siberia (Zamana, Borzenko, 2010). Depositional feature of salted lakes is the ability of water thicknesses to form halogen minerals and halopelites, which presents not only in the level of long-term cycles, but in the seasonal dynamics due to variations in salinity and water temperature during the year. The difference in seasonal rhythm of soda lakes is the possibility of new sediment of soda in the winter and dissolving it in the summer that was observed in the lake Doroninskoe in the first half of the last century [Dzens-Litovskiy, 1968]. In recent decades, there was a noticeable desalination of this lake that had an impact on the modern mineral formation in it.

From June to April the salinity increase is clearly observed (from 10 to 36 g/l) in the surface layer in the seasonal dynamics of hydrochemical regime of the lake. Minimum salinity, observed in the summer, is the result of desalination by melted mass of ice, atmospheric precipitation and less mineralized groundwaters discharged subaqueous into the lake. In the near-bottom layer the seasonal salinity variations are not significant and, as a rule, occur synchronously with the upper zone (Fig. 1).

To assess the mineral formation we used a software complex computer simulation HG32 [Bukaty, 2002] which allows us to simulate processes occurring in the system water-rock. The estimation of mineral balances showed that currently the lake water was saturated with some carbonate and phosphorus-containing minerals such

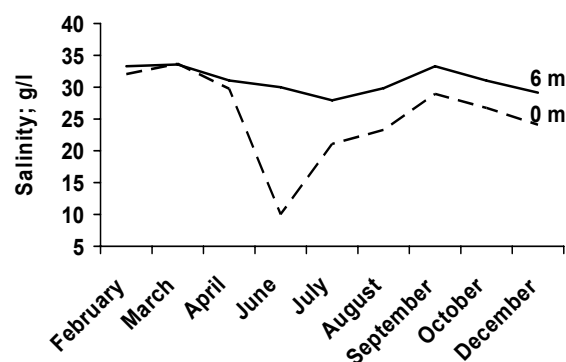


Fig. 1. Change the salinity of the surface (0 m) and bottom (6 m) layers in the annual cycle.

as calcite, dolomite, magnesite, chlorapatite, fluorapatite, and others. The balance is observed for some aluminum silicates: low-temperature analcime and albite and a number of montmorillonites and illites. In addition to these new formations the sulphuretted water of the lake Doroninskoe is saturated by troilite (Table 1). The analysis of bottom sediments showed that they have smectite-kaolinite-hydromica composition with admixture of carbonates dolomite-ankerite and soda groups and contain up to 2 % of iron sulfides (Yurgenson et al., 2011.). At the same time the cyclic recurrence is observed in mass of some secondary minerals, appeared due to changes in temperature and salinity of water.

Change in temperature and concentration gradients in the water affects the gaylussite solubility, whose formation is possible with salinity above 21 g/L and at positive water temperatures (Borzenko, 2013). According to the calculations and observations, the maximum supersaturation by gaylussite is noted in the autumn. In summer the balance is achieved only in the near-bottom water, as the surface layer is most desalinated at this time of year. In the summer the albite and quartz are not formed

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in the surface layer that is mainly due to relatively low activity of silicon, which is part of these minerals. The reliability of the obtained calculations is confirmed by X-ray diffraction analysis of hydrogenous sediment collected in sediment trap in the ice period (from January 24 to March 27, 2013) in the cryopeg areas (water, which has a negative temperature). Among founded of minerals were calcite (61.7%), monohydrocalcite (16.5%), thermonatrite (9.8%), albite (6.3%), and quartz (5.7%). Our calculations according to analyses of the composition of lake water for the last ten years have shown that the product of the activities of sodium ions and carbonate not exceed $10^{-2.30}$. The results of calculations are indicative that the saturation of lake water for soda in the summer is not achieved, because the solubility product which is the inverse value of the equilibrium constant of the reaction $2\text{Na}^+ + \text{CO}_3^{2-} + 10\text{H}_2\text{O} = \text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, for standard conditions ($t=25^\circ\text{C}$ and $P=1$ atm.) well $10^{-1.55}$. Unsaturated hydrogeochemical system remains in winter, when the water temperature drops to minus 1.1–1.5°C. At the point eutectic at $t=-2.1^\circ\text{C}$ concentration of sodium carbonate 5.75% (Kirgintsev et al., 1972), while the total salinity of the water in the lake is not more than 3.7%. It is not in balance with carbonate minerals such as nahcolite and throne. Obviously, in the seasonal dynamics of mineral equilibria the variations are characteristic of the upper hydrogeochemical zone, to a greater extent, in which variations in composition and water salinity take place, especially due to the formation and melting of ice cover. In the near-bottom layer such changes are primarily related to sulfide minerals as and the seasonal and interannual cut the hydrogen sulfide contents vary depending on the severity of winter, the thickness of the snow cover, and other climatic characteristics that

affect the intensity of microbiological processes, producing sulfide sulfur.

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Table 1 The equilibrium mineral water of the lake Doroninskoe

Mineral	Formula of mineral	The mass of the equilibrium of minerals; mg/l			
		The period of ice		The period of open water	
		0 m	6 m	0 m	6 m
Siderite	(Fe ²⁺)CO ₃	1.2	1.6	4.2E-01	–
Troilite	(Fe ²⁺)S (H ₂ O) ₂	1.4E-02	3.4E-01	1.0E-02	2.0E-01
Montmorillonite	Al ₂ Si ₄ O ₁₀ (OH) ₂ M	2.6E-02	2.7E-02	2.2E-02	2.0E-01
Chlorite	Al ₄ Si ₄ O ₁₀ (OH) ₈	7.0E-03	1.1E-02	6.0E-03	5.7E-02
Montmorillonite	Ca _{1.5} Al _{1.9} Si ₄ O ₁₀ (OH) ₂	3.7E-02	4.5E-02	3.7E-02	2.6E-01
Chlorapatite	Ca ₅ (PO ₄) ₃ Cl	2.7	2.1	5.9E-01	8.5E-01
Fluor apatite	Ca ₅ (PO ₄) ₃ F	13	9.4	2.7	3.7
Calcite	CaCO ₃ κ	6.0E-06	5.0E-06	2.0E-06	2.0E-06
Dolomite	CaMg(CO ₃) ₂	5.3	9.6	3.5	5.1
Montmorillonite	K ₃ Al _{1.9} Si ₄ O ₁₀ (OH) ₂	4.6E-02	4.5E-02	4.7E-02	3.5E-01
Muscovite	K(Fe ²⁺)AlSi ₄ O ₁₀ (OH) ₂	2.2E-01	2.0E-01	2.2E-01	3.1E-02
Illite	K ₅₀ Na _{0.4} Mg _{2.8} Al _{2.68} Si _{2.72} O ₁₀ (OH) ₂	1.1E-02	2.1E-02	1.6E-02	3.0E-03
Illite	Mg _{2.75} Al _{1.5} Si ₃ O ₁₀ (OH) ₂	1.0E-03	1.0E-03	2.0E-03	9.0E-03
Montmorillonite	MgAl ₂ Si ₄ O ₁₁ (OH) ₂	6.0E-02	7.6E-02	7.5E-02	5.2E-01
Chlorite	Mg _{2.25} Al _{1.5} Si _{1.25} O ₅ (OH) ₄	3.1E-02	2.3E-02	2.6E-02	1.8E-01
Magnesite	MgCO ₃	54	51	99	100
Lansfordite	MgCO ₃ (H ₂ O) ₅	1.0E-03	1.0E-03	1.0E-03	1.0E-03
Quartz	SiO ₂	1.7E-01	6.2E-01	–	3.2E-01
Analcime	NaAlSi ₂ O ₅ (OH) ₂	4.0E-03	4.0E-03	1.0E-03	3.0E-03
Albite	NaAlSi ₃ O ₈	1E-9	1E-9	–	1E-10
Strontianite	SrCO ₃	1.0	1.2	7.9E-01	5.1E-01
Gaylussite	CaNa ₂ (CO ₃) ₂ (H ₂ O) ₅	–	1.6E-09	–	2.3E-10

Note. E – degrees, – not an equilibrium.