UDC 553.04+553.777

Lithium-Bearing Underground Waters of the Irkutsk Region and Western Yakutia

S. V. ALEKSEEV[1], L. P. ALEKSEEVA[2], A. G. VAKHROMEEV[2], A. G. VLADIMIROV[3,4,5] and N. I. VOLKOVA[3]

[1]*Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, Ul. Lermontova 128, Irkutsk 664033 (Russia)*

E-mail: salex@crust.irk.ru

[2]*Rosneft-Bureniye Ltd., Irkutsk Division, Ul. Lermontova 128, Irkutsk 664033 (Russia)*

[3]*Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences, Pr. Akademika Koptyuga 3, Novosibirsk 630090 (Russia)*

[4]*Novosibirsk State University, Ul. Pirogova 2, Novosibirsk 630090 (Russia)*

[5]*Tomsk State University, Pr. Lenina 36, Tomsk 634050 (Russia)*

Abstract

New data on the spreading and geochemical features of lithium-bearing underground waters in the Irkutsk Region and Western Yakutia are presented. A taxonomic partitioning of the hydrogeological section of the Siberian Platform was carried out, and promising salt-bearing zones were allocated.

Key words: lithium-bearing salt waters and brines, hydrogeological formations and water-bearing complexes, geochemistry of underground water, Siberian Platform, Eastern Siberia

INTRODUCTION

The prospects of using underground salt waters and brines of Eastern Siberia as hydromineral raw materials were recognized for a long time with no doubt. The probable geological and operating reserves of hydromineral raw materials were vindicated by the authors of [1–11]. The Siberian Platform is characterized by unique resources with respect to highly mineralized underground water (Fig. 1). The hurricane concentrations of many valuable components (Ca, Mg, K, Cl, Br, Li, Sr, *etc.*), many times exceeding conditional requirements for commercial underground water development, determine the economic feasibility of the integrated processing of Siberian salines.

This paper is devoted to the systematization of new data concerning the geochemistry of underground salt water and brines, as well as performing a taxonomic division of the hydrogeological section of the southern and the northeastern part of the Siberian Platform. Basing on this there were particular promising areas chosen and estimates performed for the reserves hydromineral raw materials providing a long term profitable manufacture of lithium products in Russia.

SIBERIAN PLATFORM

The industrial brines of the Siberian Platform were studied in the course of oil explora-

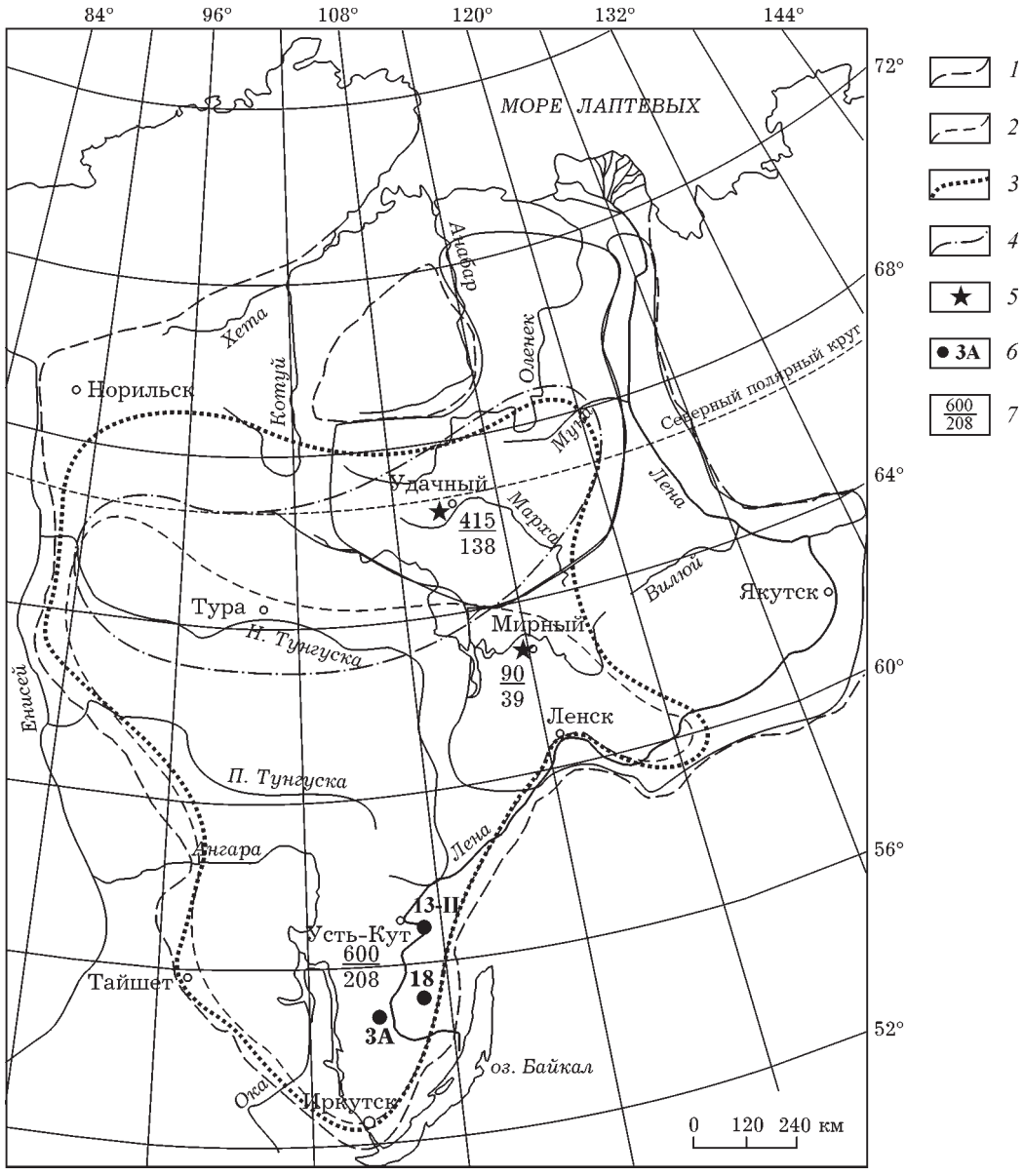

Fig. 1. Distribution of salt-bearing deposits and lithium-bearingy brines in the Siberian Platform: *1* – the boundary of the Siberian Platform, *2* – the distribution boundary of the Lower Cambrian salt-bearing deposits, *3* – the boundary of continuous distribution of lithium-bearing brines, *4* – the zone of complete saturation of sedimentary mantle metamorphized by lithium-bearing brines, *5* – diamond mining quarry, *6* – oil exploration boreholes (the Omoloy borehole No. 13-II, the Kovykta borehole No. 18, the Znamenskaya borehole No. 3A), *7* – data concerning the lithium content in the underground water, mg/L (the numerator is the maximum value, the denominator is the average value).

tion, as well as in the course of works related to searching for diamonds and other minerals. To date, within the oil and gas exploration areas, there were hundreds of deep boreholes drilled. In the Krasnoyarsk Territory and the Irkutsk Region there were revealed high-pressure zone of concentrated brines with the debit ranging within 3000–7000 m^3/day and the wellhead pressure up to 185 atm. In the territory of Yakutia, the lithium-bearing commercially significant brines were disclosed in the course of developing the kimberlitic pipes. In a number of quarries their affluence ranges within 125–210 m^3/h, or 3000–5000 m^3/day.

Below there is a brief description hydrogeochemical characteristics presented for lithium-bearing underground salt waters and brines of the Irkutsk Region and Western Yakutia.

TABLE 1

Main components of underground water within the Irkutsk Region and the Western Yakutia

Formations	Mg/Li	Content,									
		g/L							mg/L		
		M*	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cl^-	Br^-	Li^+	Rb^+	Sr^{2+}
Irkutsk Region											
Salt-bearing formation (C_1)											
Maximum	70.3	631.1	26.2	119.4	42.2	166.5	405.66	12.6	600	25.5	8070
Minimum	16.9	270	0.29	0.07	0.14	1.36	163.62	0.08	8.3	0.2	17
Average	63.5	454	12.3	36.2	13.2	96.2	268.8	5.2	208.4	10.1	2391
Подсолевая формация (V-C_1)											
Maximum	51.9	422.8	16.9	121.0	18.1	105.7	267.5	7.2	349	62	5480
Minimum	164.7	195.2	1	8.1	2.8	10.4	121.7	0.05	17	1.2	22
Average	148.3	340.1	6.3	52.5	10.1	56.5	212.1	4.0	68.1	11.2	2437
Western Yakutia											
Malaya Botuobiya area											
Subsalt formation (C_1)											
Maximum	276.2	444.6	9.7	42.2	25.0	120.7	290.8	6.8	90.5	4.5	2549
Minimum	1172.4	170	3.4	7.92	6.8	38.9	107.7	2.0	5.8	1.1	362
Average	437.3	404	8.1	13.4	17.1	101.7	257.2	5.9	39.1	3.6	1959
Subsalt formation (V-C_1)											
Maximum	716.7	433.9	42.0	92.1	64.5	141.5	280.1	6.7	90	14.0	3400
Minimum	2255.5	170	1.0	4.0	2.03	4.9	107.0	0.9	0.9	0.1	1300
Average	479.8	356.3	2.7	42.4	10.7	73.1	226.4	3.1	22.3	4.5	2200
Daldyn-Alakit area											
Aquifer systems (C_3)											
Maximum	180.5	252.2	5	29.2	21.8	46.7	162.8	2.6	120.8	7.7	866
Minimum	483.9	31.1	0.03	3.1	1.5	3.96	18.6	0.06	3.1	0.1	58
Average	225.2	92	1.7	8.3	7.5	13.8	58.6	1.0	33.3	1.21	311
Aquifer systems (V-C_2)											
Maximum	67.4	404.3	23.1	48.2	28.0	97.5	253.7	6.5	415.3	25.9	2138
Minimum	52.8	198	2.4	8.4	1.8	34.1	99.1	1.8	34.1	1.6	223
Average	92.5	310.6	11.3	24.8	12.8	62.2	194.9	3.9	138.4	10.1	1032
Drainage water from the quarry of the Udachnaya kimberlitic pipe											
Maximum	58.7	396.7	17.7	28.6	17.6	88.9	247.2	5.2	300	32.5	1578
Minimum	244.6	96.8	4.2	7.6	3.4	6.1	57.7	0.6	13.9	1.9	154
Average	79.2	272.3	10.9	20.6	11.7	52.8	170.1	3.0	147.7	16.6	894

*The mineralization level of underground water.

Lithium-bearing brines of the platform part of the Irkutsk Region

Lithium-bearing brines of the platform part of the Irkutsk Region are attached to the sedimentary strata of the Late Cambrian age. Terrigene carbonate sediments of the mantle contain a variety of underground waters different in composition and mineralization, from fresh waters to salines with different concentration, including extremely saturated ones, with the mineralization level of more than 600 g/L. Distribution of salines is caused by the presence of rock salt in the open-pit mine. In relation to the layers of rock salt, in the region there are subsalt (terrigene), salt-bearing (halogen) and

the supra-salt (carbonate) hydrogeological formation. From the standpoint of developing of industrial underground waters, subsalt and salt-bearing hydrogeological formations are considered the most promising (Table 1).

Subsalt (terrigenous) hydrogeological formation (V-$Є_1$) lies on the foundation of the Siberian platform and consists of the deposits of the Ushakov and the Moty series of the Lower Cambrian formations, as well as of the Riphean formations. The thickness of the formation ranges from 500–1000 to 2000–2500 m. The aquifer rocks are presented by sandstone, dolomite and dolomite-anhydrite species.

The formation distinctly exhibits a hydrogeochemical inversion inherent in the Angara-Lena artesian basin. This is expressed in the fact that within the subsalt horizons, the mineralization level of brines is lower than that inherent in the brines of the overlying salt-bearing stratum [2] ranging within 360–420 g/L. At the top part of the Upper Moty subseries there were disclosed extremely saturated brines with a mineralization level amounting to 518 g/L (the Kiya area). The composition of brines in the subsalt hydrogeological formation is presented predominantly by magnesium-calcium chloride type and less often by calcium-sodium type (see Table 1).

The salt-bearing (halogenous) hydrogeological formation ($Є_1$) covers the deposits of the Usolye, Belaya, Bulay and Angara series of the Early Cambrian. To the share of rock salt layers there falls more than a half of their total thickness. The occurrence depth of the salt-bearing formation ranges within 600–2500 m. The water-enclosing deposits exhibit a significant thickness (1500–2000 m); they are presented by fractured and cavernous dolomite and limestone species. The development of saturated, very saturated and extremely saturated salines is inherent therein. According to the chemical composition they belong to magnesium-calcium chloride types, less often to calcium chloride ones. The mineralization level of the brines mainly ranges within 270–500 g/L (see Table 1). The maximum values of mineralization level were registered for the Omoloy No. 13-II and the Znamenskaya boreholes No. 3A (631 and 621 g/L, respectively).

Lithium-bearing brines Malaya Botuobya district of Western Yakutia

These brines have been characterized for the subsalt (terrigenous) and salt-bearing hydrogeological formations.

The subsalt hydrogeological formation (V-$Є_1$) is attached mainly to the terrigenous differences of rocks, less often to carbonate rocks occurring at a depth of more than 1.5 km. Aquifer horizons are presented by thin (10–50 m) rock bursts vertically confined and mature with respect to spread. The mineralization level of salines occurring in the subsalt sedimentary strata ranges within 170–434 g/L (see Table 1). According to the chemical composition the brines are of sodium-calcium chloride type.

The salt-bearing hydrogeological formation ($Є_1$) is composed of low permeable Lower Cambrian carbonate rocks forming thin collector strata. The collector strata are presented by fractured, cavernous dolomite and anhydrite species with low filtration parameters. The inflows of brines were obtained from the depth ranging within 600–800 m. The composition of the underground water of the salt-bearing hydrogeological formation is presented predominantly by a magnesium-calcium chloride type (see Table 1). The mineralization level of brines ranges from 170 to 445 g/L.

Lithium-bearing brines of the Daldyn-Alakit district of Western Yakutia

The characteristic feature of the geological structure of the area consists in the absence of thick matured strata of rock salt. Here the sedimentary strata of the mantle of the Siberian Platform are predominantly terrigenous, carbonate and terrigenous carbonate rocks of the lower Paleozoic and Precambrian, those are intruded by numerous kimberlitic bodies and trappian intrusions. The lithium-bearing salines are disclosed within the depth range amounting to 0.1–2.5 km. The absence of any impermeable strata of rock salt and the intense tectonic fragmentation of the rocks determine the existence of an integrally single system with hydrogeodynamic system with aquifer systems bedded floor by floor.

The Upper Proterozoic, Lower Cambrian and Medium Cambrian aquifer systems (V-Є$_2$) are attached to clay-carbonate and carbonate rocks such as limestones and dolomites. The depth of the disclosing the underground water ranges from 500 to 2500 m. The collector strata are of porous, fractured-porous, fractured-cavernous, cavernous-porous type. The underground waters are presented by concentrated and very concentrated brines of calcium chloride type composition. Their mineralization level ranges from 198 to 404 g/L.

The Upper Cambrian aquifer system (Є$_3$) was disclosed in the carbonate sediment differences of the Morkoka and Markha series. Among the dense impermeable layers with the thickness of 30–200 m there are collector strata of fractured porous type distinguished, whose distribution in plain and in section is extremely uneven. The depth of disclosing the underground waters varies within the range from 90 (in river valleys) to 700 m (at watersheds). In the sole of the complex there lie almost impermeable sedimentary rocks. The underground water of the Upper Cambrian complex are presented by magnesium-calcium chloride and calcium-magnesium salt waters and brines. The mineralization level varies within a wide range from 31 to 252 g/L with the average value amounting to 92 g/L (see Table 1).

Lithium-bearing brines associated with diamondiferous kimberlitic pipes exhibit a close hydraulic connection with the water-bearing complexes of the enclosing terrigene sedimentary strata. The underground waters disclosed in kimberlitic bodies and in the enclosing rocks are characterized by the same magnitude of pressures being are identical in composition and mineralization level (see Table 1).

LITHIUM IN UNDERGROUND WATER

The lithium content within the Lower Cambrian halogen hydrogeological formation of the Irkutsk Region is quite heterogeneous. Concentrated lithium brines containing 30—560 mg/L were disclosed in the northern and central parts of the region. Less concentrated brines gravitating to the marginal parts of the Siberian Platform exhibit the lithium content equal to 1–125 mg/L. Weak brines of the edge portions contain $n \cdot 10^{-1}$–$n \cdot 10$ mg/L of lithium. The uneven concentration of lithium salines, could be, to all appearance, related to the composition of water-bearing rocks, the level of the metamorphization of salines and the intensity of sorption processes. Its major manifestations could be connected with bishofit and interbedded clay species. The lithium content in the rock salt is not higher than $5 \cdot 10^{-4}$% [1].

In general, the average content of lithium in the halogen formation amounts to 208 mg/L. The maximum (600 mg/L) concentrations were registered in the balykhtinskiy aquifer horizon at a depth of 2076 m (the Kovyka borehole No. 18).

For the Malaya Botuobiya district, the lithium content in the salt-bearing and subsalt concentrated brines ranges from 0.9 to 90.5 mg/L to increase markedly with increasing the mineralization level of underground water, which is inherent in concentrated brines in all the areas under consideration. Increasing the lithium content with increasing the mineralization level and decreasing the sodium-chloride coefficient confirms the assumption that one of the ways to accumulate the mentioned element consists in the process of underground water metamorphization under the conditions of hydrogeological isolation.

The lithium content in the salt waters and brines of the Upper Cambrian aquifer system of the Daldyn-Alakit district varies within the range from 3 to 120.8 mg/L (the average being of 33 mg/L). For the brines deep-seated (V-Є$_2$) aquifer systems and the water-bearing zones of kimberlitic pipes and trap intrusions, the average lithium content is higher amounting to 138 mg/L (ranging within 34–415 mg/L).

For the drainage waters from the quarry of the Udachnaya kimberlitic pipe, the average lithium content amounts up to 148 mg/L (the maximum inscribed value being equal to 300 mg/L), even though the minimum content of lithium (14 mg/L) could be considered of industrial significance.

RESULTS AND DISCUSSION

The hydrogeochemical data presented indicate a high ore potential of underground salt waters and brines of the Siberian Platform. A

TABLE 2

Data concerning the relative concentrations of lithium and Mg/Li ratio in the salt lakes of the largest deposits in the world [14, 15]

Countries	Deposit	Lithium content, mg/L		Mg/Li
		Range	Average	
Argentina	Rincon	200–2400	330	8.6
	Hombre Muerto	190–900	520–620	1.37
Bolivia	Uyuni	80–1150	320–532	18.6
China	Sitai	203–638	300	67.7
	Dongtai	161–591	300	40.3
	Zabue	896–1527	680–700	0.08
	Dansyuntso		430	0.22
Chile	Atacama	1000–7000	1400–1500	6.4
The USA	Silver Peak	100–300	200	

comparative analysis performed concerning the industrial deposits of lithium, those are presented by salt lakes allows one to draw the following conclusions: the underground brines of the Irkutsk Region and the Western Yakutia, though being more poor than South American Salar in the lithium concentration are quite comparable concerning this parameter with the deposits Tsaidam Basin in China (salt lakes Sitai and Dongtai) and Silver Peak in the USA (Table 2).

Unfortunately, the underground waters under consideration are characterized by a very high Mg/Li ratio, which makes it difficult to extract lithium, promotes the rise in the cost price of the production process and, to all appearance, would require for developing novel technologies. The economic feasibility of using the underground water as a hydromineral raw material should be determined for each deposit basing on geological and economic evaluation, taking into account the industrial concentration not only for lithium, but also for other components, as well as all the geological and hydrogeological, economic, technological and technical factors.

CONCLUSION

1. The Irkutsk Region and Western Yakutia possess the richest geological reserves of lithium-bearing industrial underground waters, being comparable with the salt lakes of South America and China in this parameter.

2. In the long term, the use of integrated innovative scheme for processing the hydromineral raw materials of the Siberian Platform should allow providing for the production of lithium compounds at a low cost price to help out the Russian lithium industry from stagnation. In order to direct the investment into the industrial development of the "liquid" ore reserves it is required to include the lithium-bearing brines Irkutsk Region and Western Yakutia in the state balance. Otherwise, this kind of minerals, as before, would remain promising for decades, but with no demand from the lithium industry of Russia.

3. In the short term, special attention should be paid to lithium-bearing brines from the Udachnaya kimberlitic pipe in Western Yakutia, which brines are sufficient to provide spare supplying the raw materials for the Russian lithium industry to examine on an industrial scale the novel methods for processing lithium-bearing brines.

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