

Article

Influence of Western Keivy Massif Rocks on the Chemical Composition of Natural Waters (Kola Peninsula, Russia)

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Abstract

The presented work is a logical continuation of the study of the chemical composition of the Lovozero district waters (the Kola Peninsula, Russia), an area inhabited by indigenous populations. The problem was posed due to the discovery of rare earth elements in drinking water in the Lovozero district (the Krasnoshchelye village). For monitoring, inductively coupled plasma was used, and the “water–rock” interaction was studied using “Selector” software. The results showed the Western Keivy Massif influence on the chemical composition of natural waters, which are used for drinking purposes for humans and animals. The interaction of water with magmatic rocks such as gabbro and subalkaline granites also leads to the formation of some major cations, anions, and heavy metals. Li, Sr, Y, La, and Ce concentrations are higher than in the Central’niy water intake located within the Khibiny Massif. The results of the modeling demonstrate the high migration capabilities of rare earth elements. The presence of rare elements and REEs in drinking surface and groundwaters, if consumed on a regular basis, can cause diseases of the nervous system and other organs.

Keywords: geochemistry; water–rock interaction; modeling; macroelements; rare earth elements; ICP-MS



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1. Introduction

Freshwater available for public use contains numerous dissolved constituents. These components, forming a contact medium, can pose risks to human health and the environment. Therefore, assessing the suitability of this water for drinking, domestic use, fishing, and other purposes is essential, as confirmed by analysis of its chemical composition. This work is a logical continuation of the study of the chemical composition of waters in the Lovozero District of the Kola Peninsula (Russia), an area inhabited by indigenous populations [1]. Among the cities and districts in the region, this area is identified as a high-risk zone, where a significantly higher incidence of urolithiasis, cardiovascular diseases, malignant neoplasms, and gastrointestinal diseases (such as stomach and duodenal ulcers, gastritis, and duodenitis) has been recorded compared to the average Russian rates [2]. Chemical analyses of drinking water in the Lovozero region (the Krasnoshchelye village) showed the presence of rare and rare earth elements (REEs), nitrates, and high lithium and

iron contents [3]. This raised the question of the need to study the “water–rock” interaction and evaluate the influence of the chemical composition of the rocks of the Western Keivy Massif on the chemical composition of natural waters.

Geological Structure of the River Ponoy Basin

Figure 1 shows the object of study, the western part of the Keivy Terrane and the Ponoy River basin. Lakes Yelskoe and Verkhneyelskoe and the Ponoy River tributary, the River Yelyok, are located in close proximity to one of the sampling sites for alkaline granites with a high concentration of rare earth elements. The Yelskoe Lake is located 15 km to the northeast of the Krasnoschelye village, and its waters, like those of the River Yelyok, flow into the Ponoy River upstream from the Krasnoschelye village.

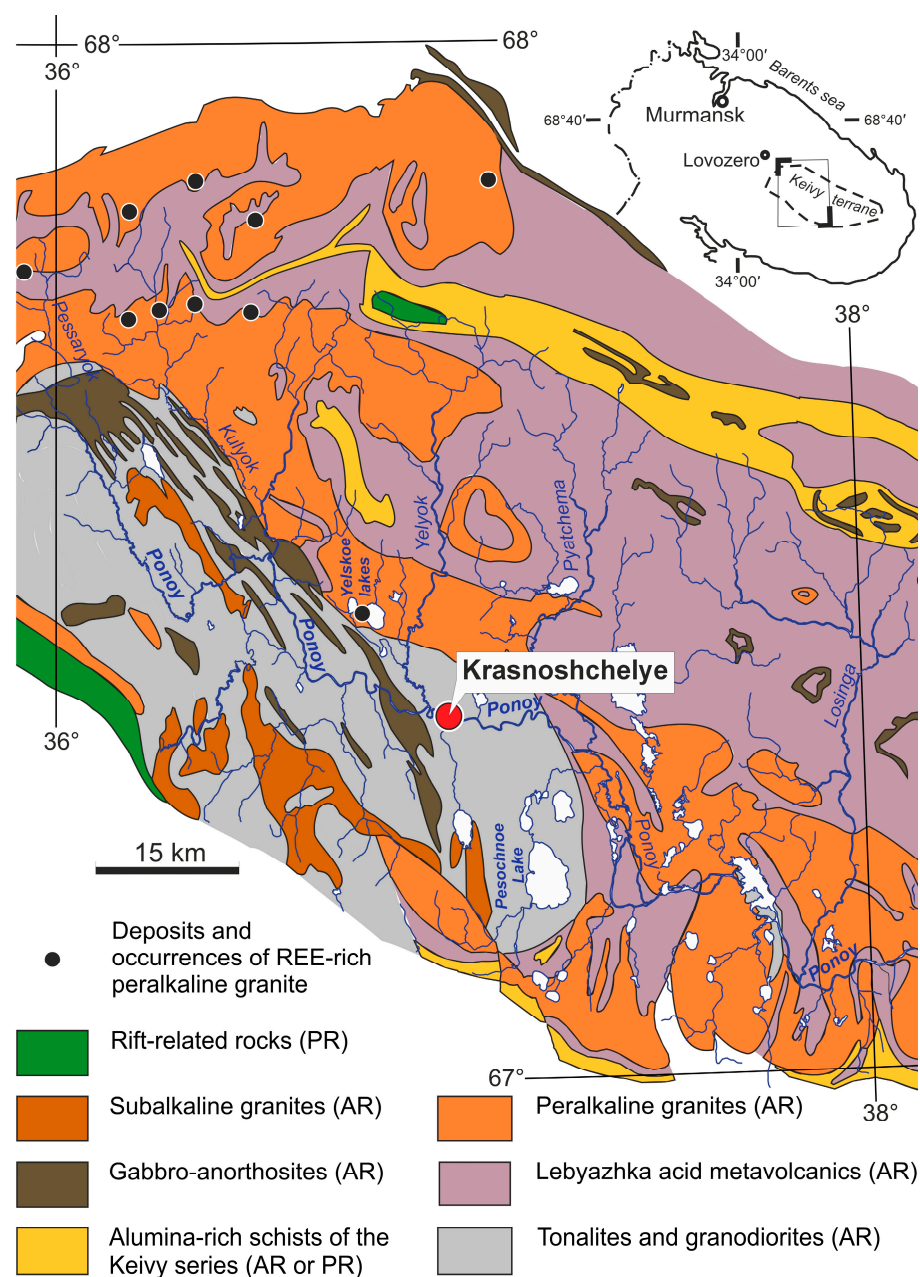


Figure 1. Geological map of the western part of the Keivy Terrane and the Ponoy River basin. The points of deposits and ore occurrences of alkaline granites rich in REEs are given according to the study [4]. The red dot is the location of water sampling.

The Keivy Terrane, which includes most of the Ponoy River basin, occupies the central part of the Kola Peninsula. And its geological structure is very different from the adjacent tectonic structures. A distinctive feature of the Keivy Terrane is the high-alumina, often giant-grained kyanite, garnet, and staurolite parashists, which are exposed in a continuous strip (the Keivy Parashist Belt) of west–northwest strike in the northeastern marginal part of the Keivy Terrane [5]. The age of the original rocks of these redeposited sediments remains controversial and is accepted as either Archean [5–7] or Paleoproterozoic [8,9]. The Keivy parashale belt and the Keivy ridge composed of these rocks are the watershed for the Kola Peninsula, a remnant of Paleoproterozoic (Yatulian) supracrustal riftogenic rocks [10,11] that lies in the area of the Serpovidny Ridge, on the parashists in the western part of the parashist belt. Another distinctive feature of the terrane is the widespread development (about 40% of the area) of acidic metavolcanics [12]. They are grouped together in the Lebyazhinskaya suite [10,13]. The age of these rocks is 2678 ± 7 million years [13], and was previously estimated at 2871 ± 15 million years [14]. The acid metavolcanics of the Lebyazhinskaya suite, together with the basement granitoids, are host rocks for the paragenetic association of alkali granites with aegirine and arfvedsonite and REE mineralization [15] and gabbro-anorthosites [16] with an age of 2.66–2.67 billion years [14,17–19]. The latter occupy 24% and 4% of the terrane area, respectively. The indicated rocks are either absent or developed in limited quantities in all other structures of the Baltic Shield.

Alkaline granites are the main concentrator of REE minerals within the Keivy Terrane [4,10]. The rock is medium- to fine-grained, and the main rock-forming minerals are quartz, albite, microcline, pyroxenes (aegirine, aegirine-augite), amphiboles, and aenigmatite [4].

Accessory minerals are ilmenite, magnetite, titanite, pyrrhotite, zircon, fluorapatite and monazite-(Ce). REE mineralization in alkaline granites is localized; therefore, the granites themselves are divided into two types: ordinary granites and REE-rich granites. Both types of granites are petrographically identical and differ only in the content of REE minerals such as chevkinite-(Ce) and its decay products, bastnesite-(Ce), allanite-(Ce), fergusonite-(Y), monazite-(Ce), britholite-(Y) and its decay products, thorite, apatite, titanite, pyrochlore group minerals, and xenotime-(Y) [4]. The localization of the latter within the alkali granite massifs has been established in a number of deposits and ore occurrences in the peripheral parts of the massifs (Figure 1). The closest occurrence of REE-rich granites within the Ponoy River basin to the village of Krasnoshchelye is Yelskoye Lake. Table 1 shows the chemical compositions of alkaline granites.

Table 1. Chemical composition of rocks of the Western Keivy Massif.

Element	Biotite Gneisses [10]	Acidic Metavolcanites [13]	Alkaline Granites [4]		Gabbro, Gabbro- Labradorites [16]	Subalkaline Granites [20]
			Ordinary Variety	REE-Rich Variety		
	Aver., n = 5	Aver., n = 72	Aver., n = 70	Aver., n = 19	Aver.	Aver., n = 6
	Mass fraction, %					
SiO ₂	69.32	71.03	73.23	73.42	46.31	70.99
TiO ₂	0.31	0.47	0.37	0.48	1.46	0.34
ZrO ₂			0.09	0.92		
Al ₂ O ₃	14.50	12.52	11.09	7.87	20.04	13.16
FeO	3.25	5.95	4.50	8.37	12.27	4.50
MnO	0.07	0.10	0.07	0.11	0.13	0.06
MgO	1.30	0.41	0.04	0.05	3.89	0.30
CaO	2.82	1.51	0.41	0.29	10.34	1.34

Table 1. Cont.

Element	Biotite Gneisses [10]	Acidic Metavolcanites [13]	Alkaline Granites [4]		Gabbro, Gabbro- Labradorites [16]	Subalkaline Granites [20]
			Ordinary Variety	REE-Rich Variety		
			Aver., n = 70	Aver., n = 19		
	Aver., n = 5	Aver., n = 72	Aver., n = 70	Aver., n = 19	Aver.	Aver., n = 6
Mass fraction, %						
SrO		0.008	0.028	0.027		0.010
Zn			0.02	0.07		
Li ₂ O			0.01	0.01		
Na ₂ O	3.99	3.56	4.16	2.81	3.19	3.57
K ₂ O	3.47	3.62	4.71	3.76	0.55	4.49
P ₂ O ₅		0.10	0.03	0.02	0.09	0.08
H ₂ O [−]		0.13	0.14	0.18	0.10	0.18
l.o.i.		0.58	0.51	0.48	0.46	
F [−]			0.05	0.04		
Cl [−]			0.01	0.01		
CO ₂		0.20	0.10	0.12		0.05
S _{total}		0.04	0.06	0.05		
Mass fraction, ppm						
Y		63	42	586		47
Zr		553	900			386
Nb		27				20
Ba		611				608
La		76	38	644		107
Ce		133	98	1423		197
Pr		19	10	155		25
Nd		64	40	556		86
Sm		12	8	119		15
Th		22	0			17
U		5				

l.o.i.—loss on ignition.

The goal of this work is to evaluate the influence of the chemical composition of the rocks of the Western Keivy on the chemical composition of natural waters using physicochemical modeling (SP “Selektor”).

2. Materials and Methods

Samples of natural surface and groundwater (from wells, hand-dug wells, and river) were collected in the area of the Krasnoshchelye village [3]. The quality of water in the studied area was assessed through analysis, primarily of inorganic components. In the present study, the analysis of water samples included determination of pH, Eh, alkalinity, anionic composition (Cl^- , SO_4^{2-} , NO_3^- , HCO_3^- , PO_4^{3-}), and NH_4^+ using titrimetry and potentiometry methods, using the liquid analyzer Ekspert-001 (Econix-Expert, Moscow, Russia). Elemental analysis was performed using inductively coupled plasma mass spectrometry with an ELAN 9000 DRC-e instrument (Perkin Elmer, Waltham, MA, USA) and Plasma Quant MS Elite (Analytik Jena GmbH, Jena, Germany) in Tananaev Institute of Chemistry. All measurements were carried out in accordance with the state standard GOST R 56219-2014 (ISO 17294-2:2003) [21], the official methodology CV 3.18.05-2005 [22], and the methods developed and used at the Institute of Chemistry. Method quantification limit (MQL) for REEs was 0.1 µg/L for La-Lu and 0.2 µg/L for Yb. The validity and reproducibility of the analysis were controlled using standard samples, STOK-16,

STOK-10 (Inorganic Ventures, Christiansburg, VA, USA), CRM-SOIL-A, and CWW-TM-A (High-Purity Standards, Charleston, SC, USA).

The main research method is the method of physical and chemical (thermodynamic) modeling (“Selektor” software package (SP), version 3.1) developed at the Institute of Geochemistry (Irkutsk, Russia) [23]. The “Selektor” implements the method of minimizing Gibbs energy based on a convex programming approach. The “Selektor” SP is equipped with a system of built-in thermodynamic data bases and has a module for creating models of varying complexity. The algorithm used allows for the calculation of complex chemical equilibria under isobaric–isothermal, isochemical, and adiabatic conditions in multisystems. The system can simultaneously contain an aqueous solution of an electrolyte, a gas mixture, liquid and solid hydrocarbons, minerals in the form of solid solutions and single-component phases, melts, and plasma. With the help of a computer, one can study both multi-component heterogeneous systems and megasystems consisting of interacting systems (reservoirs) connected to each other and the environment by flows of matter and energy. The physicochemical model includes 47 independent components (Al, B, Br, Ar, He, Ne, C, Ca, Cl, F, Fe, K, Mg, Mn, N, Na, P, S, Si, Sr, Cu, Zn, Ni, Pb, V, Ba, U, Ag, Au, Co, Cr, Hg, As, Cd, Mo, Se, La, Ce, Zr, H, O, $\bar{e}$), where $\bar{e}$ is an electron, and 1174 dependent components—546 of them are in aqueous solution, 76 are in the gas phase, 111 are in liquid hydrocarbons, and 440 are in solid phases, organic, and mineral substances. In this work, the “Selektor” SP is used for modeling in the “water–rock” system [21]. The model used is presented in [2,3]. The boundary conditions of the model are the amount of water (1000 kg), 100 kg of atmosphere, temperature of 5 °C, and 100 g of geological rock. In other words, the weathering process is studied as the interaction of “water–rock,” where water is rainwater. The chemical composition of the rocks is shown in Table 1.

3. Results and Discussion

The Selector SP has been used in the Institute of North Industrial Ecology Problems for over 30 years. It is a universally licensed program and is widely used in the study of natural and anthropogenic systems. According to the concepts outlined in [23], the weathering process is determined by the physicochemical state of water (temperature, pH, Eh, composition of dissolved gases) on the one hand, and the composition of rocks on the other. At the same time, the irreversible evolution of the multisystem (the computer analog of the real system), its characteristics (pH, Eh), and the composition of newly formed phases will be entirely controlled by independent thermodynamic state factors: temperature, total pressure, and the magnitude of the vector of the molar quantities of independent components (the chemical composition of the system), which, in turn, are a function of the independent coordinate of the entire nonequilibrium process—the parameter ν . The number of moles of the solid phase ν participating in the interaction, or the degree of interaction, i.e., the amount of rock that has reacted, mimics the rate of chemical processes. The number of moles varied from 1 to 0. The dependency tables are presented on a logarithmic scale, $\nu = 10 - \xi$ or $-\lg \nu = \xi$, which corresponds to a change in the content of the rock in the system from 0.1 to 100 g.

Pollutants enter into the water reservoirs from natural and anthropogenic sources. Atmospheric precipitation, water–soil, and water–rock interactions are the main natural sources of water pollution [24,25]. The geological and geochemical characteristics of the aquifer regulate the occurrence of pollutants in the water environment [25,26]. This work examines in detail the sources of major cations, anions, and heavy metals in water bodies and their impact on human health. The main sources of pollutants are sedimentary rocks, but the interaction of water with magmatic rocks such as granite, gabbro, nepheline syenite,

basalt, andesite, and ultramafic rocks also leads to the formation of some major cations, anions, and heavy metals [25].

The analysis of rocks in the studied area (Figure 1) indicates that the formation of the chemical composition of the Ponoy River and its tributaries is influenced by rocks such as biotite gneisses, alkaline granites, acid metavolcanites, gabbros, and sub-alkaline granites. Table 1 shows the chemical compositions of these rocks. Note that all rocks contain high concentrations of iron. The formation of the macrocomponent composition of the River Ponoy and its tributaries will clearly be influenced by biotite gneisses and gabbro (by Ca); alkaline granites are responsible for the appearance of Li, Sr, Zr, Y, La, Ce, Pr, and Nd. In this work, the interaction “water–rock–atmosphere” was investigated, where “rock” is the rocks presented in Table 1.

The chemical composition of the waters of the River Ponoy is an integral indicator of the influence of the chemical composition of the rocks of the Western Keivy Massif on the chemical composition of the waters in the area of the Krasnoshchelye village.

Table 2 shows the results of modeling the water–rock interaction and the forms of macroelement migration depending on the degree of interaction (ξ). This corresponds to a change in the rock content in the system from 10 to 100 g (using gabbro, gabbro-labradorite, and subalkaline granite as examples).

We have completed calculations for all rock types. Gabbro and gabbro-labradorites are presented as the most representative in terms of Al_2O_3 , FeO, MnO, MgO, and CaO content. Subalkaline granites contain higher concentrations of Na and K (Table 1). Leaching of these rocks will affect the chemical composition of the Ponoy river (comparison with monitoring) (Table 2).

Table 2. Results of modeling the forms of migration of macrocomponents during the “water–rock” interaction (“rock”—gabbro and subalkaline granites), mg/L.

Degree of Interaction, ξ	<i>Gabbro</i>					Monitoring Results
	Ca^{2+}	CaOH^+	CaCO_3	$\text{Ca}(\text{HCO}_3)^+$	CaHSiO_3^+	Ca^{2+}
1	0.738	1.90×10^{-7}	5.52×10^{-5}	1.40×10^{-3}	1.13×10^{-6}	2.98–2.43
0.8	1.17	4.72×10^{-7}	2.09×10^{-4}	3.37×10^{-3}	2.86×10^{-6}	
0.6	1.85	1.26×10^{-6}	8.79×10^{-4}	8.44×10^{-3}	1.19×10^{-5}	
0.4	2.91	3.46×10^{-6}	3.82×10^{-3}	2.09×10^{-2}	5.07×10^{-5}	
0.2	4.58	1.05×10^{-5}	1.81×10^{-2}	5.19×10^{-2}	1.60×10^{-4}	
0	7.21	3.83×10^{-5}	1.03×10^{-1}	1.27×10^{-1}	5.82×10^{-4}	
ξ	Mg^{2+}	MgOH^+	MgCO_3	$\text{Mg}(\text{HCO}_3)^+$	MgHSiO_3^+	Mg^{2+}
1	0.234	1.61×10^{-6}	1.33×10^{-5}	5.96×10^{-4}	1.03×10^{-6}	0.67
0.8	0.371	4.00×10^{-6}	5.02×10^{-5}	1.43×10^{-3}	2.62×10^{-6}	
0.6	0.588	1.07×10^{-5}	2.12×10^{-4}	3.59×10^{-3}	1.09×10^{-5}	
0.4	0.931	2.96×10^{-5}	9.28×10^{-4}	8.95×10^{-3}	4.68×10^{-5}	
0.2	1.47	8.96×10^{-5}	4.42×10^{-3}	2.23×10^{-2}	1.48×10^{-4}	
0	2.32	3.29×10^{-4}	2.52×10^{-2}	5.46×10^{-2}	5.42×10^{-4}	
ξ	Na^+	NaOH	NaAlO_2	NaHSiO_3	K^+	1.07
1	0.170	4.13×10^{-9}	5.37×10^{-11}	4.99×10^{-6}	3.51×10^{-2}	
0.8	0.189	7.17×10^{-9}	8.37×10^{-11}	8.83×10^{-6}	2.90×10^{-2}	
0.6	0.296	1.90×10^{-8}	9.55×10^{-11}	3.65×10^{-5}	5.62×10^{-2}	
0.4	0.465	5.23×10^{-8}	1.15×10^{-10}	1.56×10^{-4}	1.05×10^{-1}	
0.2	0.755	1.62×10^{-7}	2.83×10^{-10}	5.05×10^{-4}	9.66×10^{-2}	
0	1.22	6.10×10^{-7}	8.92×10^{-10}	1.89×10^{-3}	7.16×10^{-2}	

Table 2. Cont.

Degree of Interaction, ξ	Gabbro					Monitoring Results
	Ca^{2+}	CaOH^+	CaCO_3	$\text{Ca}(\text{HCO}_3)^+$	CaHSiO_3^+	Ca^{2+}
<i>Subalkaline granites</i>						
ξ	Ca^{2+}	CaOH^+	CaCO_3	$\text{Ca}(\text{HCO}_3)^+$	CaHSiO_3^+	
1	0.0956	8.62×10^{-9}	9.20×10^{-7}	6.64×10^{-5}	1.32×10^{-7}	
0.8	0.152	2.00×10^{-8}	3.11×10^{-6}	1.53×10^{-4}	3.07×10^{-7}	
0.6	0.240	4.82×10^{-8}	1.11×10^{-5}	3.61×10^{-4}	7.38×10^{-7}	
0.4	0.380	1.19×10^{-7}	4.16×10^{-5}	8.68×10^{-4}	1.82×10^{-6}	
0.2	0.603	3.03×10^{-7}	1.63×10^{-4}	2.11×10^{-3}	4.64×10^{-6}	
0	0.954	8.10×10^{-7}	6.82×10^{-4}	5.24×10^{-3}	1.24×10^{-5}	
ξ	Mg^{2+}	MgOH^+	MgCO_3	$\text{Mg}(\text{HCO}_3)^+$	MgHSiO_3^+	
1	0.0182	4.38×10^{-8}	1.33×10^{-7}	1.69×10^{-5}	7.26×10^{-8}	
0.8	0.0288	1.02×10^{-7}	4.49×10^{-7}	3.89×10^{-5}	1.69×10^{-7}	
0.6	0.0457	2.45×10^{-7}	1.61×10^{-6}	9.20×10^{-5}	4.06×10^{-7}	
0.4	0.0724	6.04×10^{-7}	6.01×10^{-6}	2.21×10^{-4}	1.00×10^{-6}	
0.2	0.115	1.54×10^{-6}	2.36×10^{-5}	5.38×10^{-4}	2.55×10^{-6}	
0	0.182	4.11×10^{-6}	9.85×10^{-5}	1.33×10^{-3}	6.82×10^{-6}	
ξ	Na^+	NaOH	NaAlO_2	NaHSiO_3	K^+	Na^+
1	0.191	1.62×10^{-9}	5.55×10^{-12}	5.03×10^{-6}	0.346	
0.8	0.351	4.37×10^{-9}	1.31×10^{-11}	1.36×10^{-5}	0.357	
0.6	0.608	1.15×10^{-8}	2.91×10^{-11}	3.59×10^{-5}	0.358	
0.4	1.02	3.01×10^{-8}	6.66×10^{-11}	9.37×10^{-5}	0.343	
0.2	1.67	7.92×10^{-8}	1.53×10^{-10}	2.47×10^{-4}	0.321	
0	2.68	2.15×10^{-7}	3.34×10^{-10}	6.70×10^{-4}	0.365	2.42–2.57

If we compare the modeling results with the monitoring data, we can draw a conclusion about the influence of each rock on the chemical composition of the Ponoy River waters. The results are as follows: gabbro affects the concentrations of Ca and Mg, subalkaline granites affect the concentration of Na, alkaline granites affect K. The appearance of REEs in the waters of the Ponoy River is determined by alkaline granites enriched with REEs (Table 3). The last column of Table 2 contains the analyses of the Ponoy River. Three analyses are presented for the specified elements. The data for Na 2.42, 2.52, and 2.57 mg/L are presented as 2.42–2.57. For calcium, three values are presented: 2.43, 2.98, and 4.23 mg/L.

Table 3 shows the results of modeling the water–rock interaction (rocks are alkaline granites enriched in REE) and the forms of migration of some elements depending on the degree of interaction (ξ). This corresponds to a change in the rock content in the system from 0.1 to 100 g. The highest content of iron and rare earth elements is found in REE-enriched granites. Table 3 presents the forms of REE migration and newly formed phases that demonstrate a high percentage of iron content at certain ξ .

The concentrations of elements presented in Table 3 are comparable with the monitoring results (the Ponoy River, samples were taken in the area of the Krasnoshchelye village), mg/L: Li—0.0032, Sr—0.017, Zr—0.00018, La—0.00031, Ce—0.00042, Y—0.00037, Nd—0.00033, and Pr—0.00006 [3]. Concentrations of rare elements and REEs are higher than the concentrations of the same elements in the wells of the Central'niy water intake located within the Khibiny Massif (the Kola Peninsula) [27].

Table 3. Results of modeling the forms of migration of elements (T 5 °C, P 1 bar).

ξ	Concentration, mg/L						
	La^{3+}	LaCO_3^+	LaF^{2+}	LaHCO_3^{2+}	LaOH^{2+}	LaSO_4^+	
3.0	1.61×10^{-6}	1.56×10^{-9}	1.26×10^{-11}	5.22×10^{-10}	1.51×10^{-10}	1.20×10^{-11}	
2.0	6.60×10^{-6}	1.21×10^{-8}	5.11×10^{-10}	2.95×10^{-9}	8.55×10^{-10}	4.87×10^{-10}	
1.0	6.21×10^{-5}	2.94×10^{-6}	4.77×10^{-8}	1.40×10^{-7}	4.11×10^{-8}	4.48×10^{-8}	
0.6	1.35×10^{-4}	3.73×10^{-5}	2.57×10^{-7}	7.22×10^{-7}	2.18×10^{-7}	2.39×10^{-7}	
0.2	1.80×10^{-4}	3.19×10^{-4}	8.49×10^{-7}	2.35×10^{-6}	7.58×10^{-7}	7.77×10^{-7}	
0	1.51×10^{-4}	6.99×10^{-4}	1.09×10^{-6}	3.08×10^{-6}	1.06×10^{-6}	1.01×10^{-6}	
ξ	Ce^{3+}	CeCO_3^+	CeF^{2+}	CeHCO_3^{2+}	CeOH^{2+}	CeSO_4^+	
3.0	2.31×10^{-6}	4.56×10^{-9}	4.69×10^{-11}	6.05×10^{-10}	3.65×10^{-10}	1.71×10^{-11}	
2.0	1.43×10^{-5}	5.37×10^{-8}	2.87×10^{-9}	5.16×10^{-9}	3.12×10^{-9}	1.05×10^{-9}	
1.0	1.33×10^{-4}	1.28×10^{-5}	2.63×10^{-7}	2.40×10^{-7}	1.47×10^{-7}	9.51×10^{-8}	
0.6	2.54×10^{-4}	1.44×10^{-4}	1.26×10^{-6}	1.10×10^{-6}	6.89×10^{-7}	4.49×10^{-7}	
0.2	2.52×10^{-4}	9.13×10^{-4}	3.08×10^{-6}	2.66×10^{-6}	1.78×10^{-6}	1.08×10^{-6}	
0	1.86×10^{-4}	1.76×10^{-3}	3.48×10^{-6}	3.06×10^{-6}	2.19×10^{-6}	1.24×10^{-6}	
ξ	Nd^{3+}	NdCO_3^+	NdF^{2+}	NdHCO_3^{2+}	NdOH^{2+}	NdSO_4^+	
3.0	1.62×10^{-6}	6.47×10^{-9}	4.57×10^{-11}	3.46×10^{-10}	5.25×10^{-10}	1.13×10^{-11}	
2.0	5.71×10^{-6}	4.34×10^{-8}	1.59×10^{-9}	1.68×10^{-9}	2.55×10^{-9}	3.98×10^{-10}	
1.0	4.86×10^{-5}	9.51×10^{-6}	1.34×10^{-7}	7.18×10^{-8}	1.11×10^{-7}	3.30×10^{-8}	
0.6	7.66×10^{-5}	8.77×10^{-5}	5.26×10^{-7}	2.70×10^{-7}	4.26×10^{-7}	1.28×10^{-7}	
0.2	5.64×10^{-5}	4.14×10^{-4}	9.60×10^{-7}	4.86×10^{-7}	8.19×10^{-7}	2.30×10^{-7}	
0	3.81×10^{-5}	7.30×10^{-4}	9.93×10^{-7}	5.12×10^{-7}	9.24×10^{-7}	2.41×10^{-7}	
ξ	Pr^{3+}	PrCO_3^+	PrF^{2+}	PrHCO_3^{2+}	Li^+	Sr^{2+}	
3.0	1.52×10^{-6}	4.28×10^{-9}	3.01×10^{-11}	7.45×10^{-10}	3.12×10^{-6}	2.31×10^{-5}	
2.0	1.79×10^{-6}	9.55×10^{-9}	3.48×10^{-10}	1.20×10^{-9}	3.11×10^{-5}	2.28×10^{-4}	
1.0	1.41×10^{-5}	1.94×10^{-6}	2.71×10^{-8}	4.76×10^{-8}	3.11×10^{-4}	2.28×10^{-3}	
0.6	2.47×10^{-5}	1.99×10^{-5}	1.18×10^{-7}	1.99×10^{-7}	7.82×10^{-4}	5.73×10^{-3}	
0.2	2.10×10^{-5}	1.08×10^{-4}	2.50×10^{-7}	4.15×10^{-7}	1.96×10^{-3}	1.44×10^{-2}	
0	1.47×10^{-5}	1.99×10^{-4}	2.69×10^{-7}	4.54×10^{-7}	3.11×10^{-3}	2.28×10^{-2}	
ξ	HZrO_3^-	ZrO^{2+}	ZrO_2	Y^{3+}	YOH^{2+}	pH	
3.0	8.96×10^{-5}	1.02×10^{-6}	8.40×10^{-4}	7.88×10^{-7}	8.92×10^{-10}	5.635	
2.0	1.20×10^{-3}	5.19×10^{-6}	8.14×10^{-3}	5.88×10^{-6}	9.18×10^{-9}	5.776	
1.0	4.20×10^{-2}	1.33×10^{-6}	5.51×10^{-2}	5.82×10^{-5}	4.63×10^{-7}	6.488	
0.6	1.64×10^{-1}	3.48×10^{-7}	8.71×10^{-2}	1.45×10^{-4}	2.82×10^{-6}	6.880	
0.2	5.38×10^{-1}	6.24×10^{-8}	1.08×10^{-1}	3.54×10^{-4}	1.80×10^{-5}	7.302	
0	9.22×10^{-1}	2.25×10^{-8}	1.10×10^{-1}	5.46×10^{-4}	4.63×10^{-5}	7.529	
Composition of newly formed phases, %							
ξ	MnO_2	Al(OH)_3	FeO(OH)	Msc	Apt	Mnt	SiO_2
3	1.27	0.01	98.72				
2	1.17	9.11	89.72				
1	0.3		22.76	0	0	5.17	71.77
0,6	0.19		14.85	3.42	0	0	81.54
0,4	0.18		13.71	3.16	0	0	82.95
0	0.17		12.71	2.93	0.03	0	84.17

Note: Msc— $\text{KAl}_3\text{Si}_3\text{O}_{10}\text{O}_2\text{H}_2(\text{H}_2\text{O})_{4.5}$; Apt— $\text{Ca}_5(\text{PO}_4)_3\text{F}$; Mnt— $\text{Na}_{0.33}\text{Al}_{2.33}\text{Si}_{3.67}\text{O}_{10}(\text{OH})_2$.

Changes in the composition of newly formed phases according to Table 3: the concentration of FeO(OH) varies within the range from 98.72 to 89.72% (at $3 < \xi < 2$) and FeO(OH) from 22.76 to 12.71% (at $1 < \xi < 0$); SiO₂ from 71.77 to 84.17% ($1 < \xi < 0$); aluminosilicates from 5.17 to 2.93% ($1 < \xi < 0$); and MnO₂ from 1.27 to 0.17 ($3 < \xi < 0$). Similar elements in comparable concentrations were found in water samples from the Samarkin stream of the Sikhote-Alin Nature Reserve with the same list of newly formed phases assessed as a result of modeling the water–rock system [28]. The results of the modeling demonstrate the high migration capabilities of rare earth elements (lanthanides). This leads to the possibility of overcoming the natural biological barriers of the body, in particular, the blood–brain barrier. This is evidenced by the results of a study of the distribution of chemical elements in the composition of organs and tissues of living organisms in the Sikhote-Alin territory (Russia) [28].

4. Conclusions

The results of the study helped to evaluate the influence of the chemical composition of the rocks of the Western Keivy Massif with an increased content of REEs on the chemical composition of natural waters that are used for drinking purposes by people and animals. The chemical composition of the River Ponoy is an integral indicator of the influence of rocks in the area of the village of Krasnoshchelye.

The presence of rare earth elements in drinking surface and well water, if consumed on a regular basis, can cause diseases of the nervous system and other organs. The presence of REEs in surface natural and drinking waters has been established in other settlements of the Lovozero region [29]. The research results can be used in the fields of geochemistry, hydrology, ecology, and medicine.

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