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SHORT COMMUNICATIONS

Rare-Earth Elements and the Genesis of Ore Mineralization at the Kalgutinskoe Tungsten Ore Field, Gornyi Altai

G. F. Ivanova, G. M. Kolesov, V. S. Karpukhina, and E. V. Cherkasova

Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, ul. Kosygina 19, Moscow, 119991 Russia

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Rare-earth elements (REE) are widely used as indicators of the conditions under which rocks and minerals were produced [1, 2]. This paper reports the results of our study of REE in granites and minerals from quartz zones with ore mineralization and the principal parameters under which these minerals were formed at the Kalgutinskoe ore field, which is located in the southeastern part of the Gornyi Altai Range, within the Charysh–Terekta tectono–stratigraphic zone.

The ore field is spatially restricted to the Kalgutinskii granite massif, which is hosted by a volcanic trough filled with Middle Devonian acid volcanics [3] (Fig. 1). The massif consists of two intrusive com-

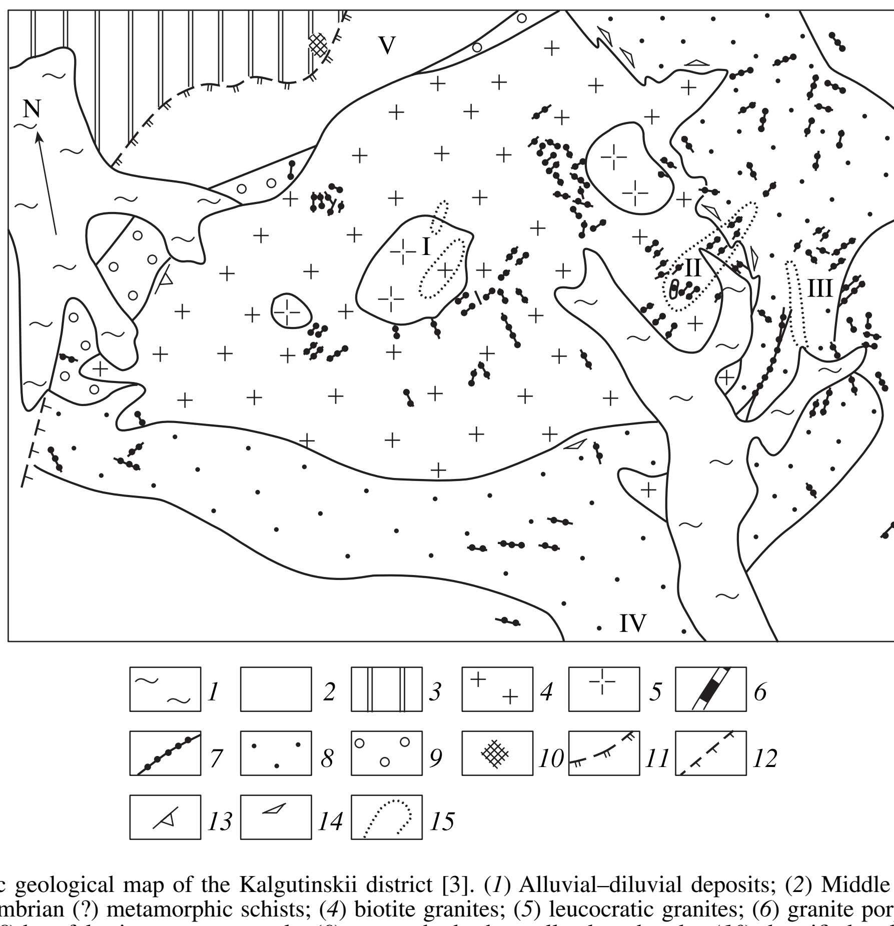

Fig. 1. Schematic geological map of the Kalgutinskii district [3]. (*1*) Alluvial–diluvial deposits; (*2*) Middle Devonian volcanic sequence; (*3*) Cambrian (?) metamorphic schists; (*4*) biotite granites; (*5*) leucocratic granites; (*6*) granite porphyries; (*7*) granite porphyry dikes; (*8*) hornfelsation contact aureole; (*9*) contact hydrothermally altered rocks; (*10*) skarnified rocks; (*11*) overthrusts; (*12*) normal faults; strike and dip symbols at contacts: (*13*) steep, (*14*) low-angle (20°–40°); (*15*) zones with mineralized veins. Structurally distinct zones of ore mineralization: (I) intrusive; (II) inner contact; (III) outer contact above the intrusion; (IV) inner contact away from the intrusion; (V) outer volcanic.

plexes. The earlier one comprises biotite granites of the main phase, which account for 90% of the massif by volume, the leucogranites of satellite intrusions, and aplite and aplite-pegmatite veins of the final phase. The younger complex consists of a dike belt of granite porphyries with elevated contents of rare metals and apatite-bearing elvanes and ongonites. The granites–leucogranites were dated at 215–210 Ma, and the rocks of the dike complex have ages of 205–190 Ma [4]. Data on the melt inclusions in quartz from some intrusive and dike rocks of the Kalgutinskii granite massif [5] indicate that the initial crystallization temperatures of the successively emplaced magmas systematically decreased (from 730–710°C for the main-phase granites to 690–670°C for the intrusive leucogranites). The microgranite and felsite porphyries of the dike complex show a temperature scatter from 700–670°C to 650–630°C. The complex also includes higher temperature dikes (up to 800°C) of fluorite-bearing felsite porphyries.

The tungsten ore mineralization is contained in quartz–wolframite veins. Mineralized rocks are known in various parts of the massif [3]: in the central part of the intrusion (Dzhumalinskoe ore occurrence, Fig. 1, I), in the inner contact zone (Kalgutinskoe ore deposit, Fig. 1, II), and in the outer-contact zone above the intrusion (Southern Kalgutinskaya mineralized zone, Fig. 1, III). The remote outer-contact zone (Fig. 1, IV) contains only geochemical dispersion aureoles of W, and the outer-contact volcanic zone (Fig. 1, V) bears quartz veinlets with pyrite, chalcopyrite, and bismuthite.

The wolframite–quartz vein system of the Dzhumalinskoe ore occurrence is spatially restricted to the biotite and leucocratic granites of the central part of the Kalgutinskii Massif. The ore mineralization is contained in relatively thin veins and veinlets. The determined vertical amplitude of the ore mineralization is approximately 100 m.

The southeastern contact zone of the massif hosts the Kalgutinskoe Mo–W deposit, which consists of a suite of quartz–wolframite veins that swarm within a northeast-trending stripe about 2 km long and 0.5 km wide. The lengths of the veins range from a few meters to 330 m, and their thicknesses rarely exceed 1 m. The vertical amplitude of the ore mineralization is >500 m. The mineralized veins are hosted in porphyritic biotite granites that are extensively greisenized. In addition, greisens occur as isolated patches with extensive stringer and disseminated Mo mineralization (Molibdenovyi Shtok Prospect). The wolframite mineralization consists of wolframite and huebnerite [6, 7]. All the researchers who have studied this deposit [3, 6, 8] pointed out that mineralizing processes occurred in several stages. According to [6], the zoning of mineralized veins at the Kalgutinskoe deposit is as follows (from the outer contact inward the massif): W $\longrightarrow$ W, Mo $\longrightarrow$ complex rare-metal mineralization $\longrightarrow$ W, and Mo $\longrightarrow$ W (Mo). Most resources of the deposit are related to the quartz–beryl–wolframite stage of the ore-forming processes [7].

In the outer-contact zone above the intrusion, altered intrusive rocks host the Southern Kalgutinskaya Zone of quartz veins. The zone trends for approximately 1 km and was traced downward to depths of 300–350 m. The quartz–wolframite veins and wall-rock silification halos reach a few meters in thickness. The W mineralization consists of ferberite with minor amounts of molybdenite and beryl. The mineralized quartz veins contain more fluorite and siderite than the analogous veins at the Kalgutinskoe deposit [7].

The mineralogical zoning of the Kalgutinskoe field of W ore mineralization is, according to [3, 6–8], pronounced in a decrease in the amount of quartz veins with molybdenite and beryl in the direction from the core of the massif toward its remote outer contact and a simultaneous increase in the contents of the molybdenite–wolframite and wolframite–fluorite ore mineralization. From the inner- to the outer-contact zones above the intrusion, the processes of greisenization become systematically less intense, and the mineralized quartz veins contain systematically more fluorite, barite, and siderite. The composition of the tungsten mineralization also systematically varies: it is wolframite and huebnerite at the Kalgutinskoe deposit and ferberite at the Southern Kalgutinskoe ore occurrence. Chemical analyses of wolframite from the mineralized zones confirm that it is richer in Mn (up to 71% $MnWO_4$) in the quartz–wolframite veins at the Kalgutinskoe deposit and is practically pure ferberite (2–3% $MnWO_4$) in association with siderite and fluorite at the Southern Kalgutinskoe ore occurrence [7].

RARE-EARTH ELEMENTS IN GRANITES AND MINERALS

The distribution of REE was determined in the granites of the Kalgutinskii Massif, the micas from these granites, felsite porphyry from a dike, and in the most ubiquitous "telescoped" minerals from mineralized zones and altered granites that host these zones: muscovite and fluorite from the Kalgutinskoe deposit and the Southern Kalgutinskoe ore occurrence. Rocks and minerals were analyzed for REE at the Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences by neutron activation [9], which made it possible to accurately determine the concentrations of REE and to evaluate the concentrations of other elements (Ta, Rb, Cs, and Sr).

The Rb/Sr ratio (1.98) of the biotite granite of the Kalgutinskii Massif (at its Dzhumalinskii Prospect) is typical of rare-metal granites (>0.3) [10]. The Rb concentrations systematically increase in the sequence coarse-grained biotite granite (387 ppm) $\longrightarrow$ biotite (1270 ppm) $\longrightarrow$ muscovite from the same granite (1518 ppm) $\longrightarrow$ muscovite from muscovite granite

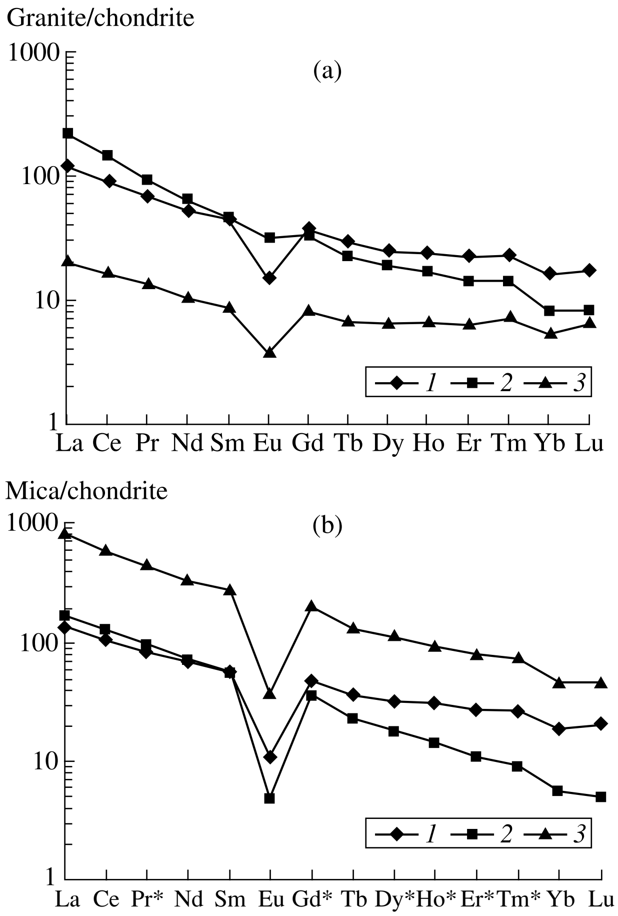

Fig. 2. Chondrite-normalized REE patterns of (a) rocks and (b) micas from the Kaltuginskoe ore field. (a) (*1*) Kg-23; (*2*) Kg-27; (*3*) Kg-29. (b) (*1*) Kg-23m; (*2*) Kg-65; (*3*) Kg-23b. See Table 1 for the characteristics of the samples.

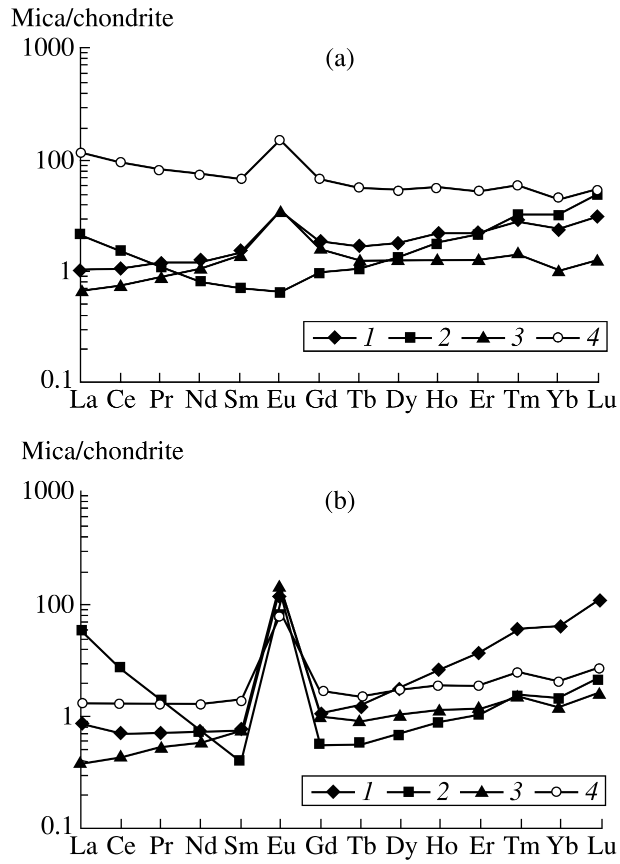

Fig. 3. Chondrite-normalized REE patterns of muscovite from mineralized veins and greisens at the Kalgutinskoe deposit. (a) (*1*) Kg-50; (*2*) Kg-52; (*3*) Kg-61(m); (*4*) Kg-56. (b) (*1*) Kg-57; (*2*) Kg-64; (*3*) Kg-31(m); (*4*) Kg-70(m). See Table 1 for the characteristics of the samples.

(2262 ppm) ⟶ muscovite from the beryl–molybdenite–wolframite association of mineralized veins (2472–2685 ppm). The Cs concentrations show an analogous increase in the same petrographic succession from 28.3 to 700 ppm. The concentrations of Ta in the micas (3.2–60 ppm) are lower than in the granites (178 ppm), and the maximum Ta concentration (1120 ppm) was detected in felsite porphyry.

The REE concentrations in the granites, felsite porphyry, micas from the granites, and muscovite from mineralized veins of various compositions at the Kalgutinskoe deposit are presented in Table 1, and the corresponding chondrite-normalized patterns are displayed in Figs. 2 and 3.

According to our data, the coarse-grained porphyritic biotite granites and altered granites of the Kalgutinskii Massif have negative Eu anomalies (Eu/Eu* = 0.36–0.78), a feature typical of rare-metal granites [10] (Fig. 2a). The relatively high REE concentrations of the rocks and the predominance of LREE over HREE (La_N/Yb_N = 7.3–25.9; La_N/Sm_N = 2.7–4.7) suggest that the parental melt of the granites was strongly differentiated. The felsite porphyries are noted for much lower REE concentrations than those of the granites. The REE patterns of the biotite and muscovite are analogous to those of the granites (Table 1, Fig. 2b). They have deeper Eu minima (Eu/Eu* = 0.15–0.19), fairly high REE concentrations (as in the granites), and a predominance of LREE over HREE [La_N/Yb_N = 7.5–3.1]. The REE concentrations in the biotite are much higher (by a factor of six and more) than in the muscovite and granite (sample Kg-23b).

The REE concentrations and chondrite-normalized patterns of muscovite from the Kalgutinskoe deposit (Table 1, Figs. 3a, 3b) notably differ from those of micas and granites (see above). The REE concentrations in them are one to two orders of magnitude lower, and Eu minima give way to Eu maxima. Only muscovite from the greisenization zone (sample Kg-52) has Eu/Eu* = 0.89. The "ore" muscovites are differentiated according to their REE patterns (Figs. 2a, 2b). The muscovite of the quartz–molybdenite veins has Eu/Eu* = 2.1–2.3 (Fig. 3a). Eu anomalies are pronounced more clearly (Eu/Eu* = 5.1–22.7) in musco-

Table 1. REE concentrations (ppm) in granites from the Kalgutinskii Massif, micas from the granites, and mineralized veins at the Kalgutinskoe deposit

Sample	Sample characterization	La	Ce	Pr+	Nd	Sm	Eu	Gd+	Tb	Dy+	Ho+	Er+	Tm+	Yb	Lu	ΣREE	La_N/Yb_N	La_N/Sm_N	Eu/Eu*
Kg-23	Biotite granite, Dzhumalinskii Prospect	28.2	56.00	6.35	24.7	6.34	0.81	7.3	1.19	6.1	1.31	3.65	0.51	2.72	0.43	145.6	7.29	2.68	0.36
Kg-27	K-feldspathized and sericitized granite	51.2	89.60	8.44	29.9	6.54	1.69	6.58	0.89	4.62	0.92	2.25	0.31	1.39	0.2	204.5	25.92	4.71	0.78
Kg-29	Felsite porphyry	4.91	10.10	1.23	4.85	1.24	0.2	1.62	0.26	1.58	0.36	1.03	0.16	0.9	0.16	28.6	3.84	2.38	0.43
Kg-23b	Biotite from biotite granite, Dzhumalinskii Prospect	198.9	373.0	41.0	156	39.8	1.98	39.8	5.2	27.4	5.08	12.7	1.62	7.71	1.1	911.3	18.15	3.01	0.15
Kg-23m	Muscovite from biotite granite	33.0	66.00	7.78	32.0	8.22	0.57	9.65	1.4	7.83	1.67	4.38	0.59	3.1	0.48	176.7	7.49	2.41	0.19
Kg-65	Muscovite from granite with disseminated fluorite	40.3	81.20	8.76	33.4	8.12	0.26	7.1	0.89	4.3	0.76	1.71	0.2	0.9	0.12	188.0	31.05	2.99	0.10
Kg-52	Muscovite from greisen with molybdenite and fluorite	0.5	0.94	0.1	0.37	0.1	0.04	0.19	0.041	0.33	0.098	0.35	0.07	0.54	0.12	3.785	0.65	3.03	0.89
Kg-50	Muscovite from a quartz–molybdenite vein	0.25	0.67	0.11	0.57	0.21	0.19	0.37	0.066	0.45	0.12	0.36	0.06	0.41	0.076	3.91	0.43	0.72	2.1
Kg-61(m)	Muscovite from a quartz–wolframite vein	0.16	0.47	0.081	0.5	0.2	0.19	0.32	0.049	0.31	0.07	0.21	0.03	0.17	0.031	2.79	0.67	0.48	2.3
Kg-56	Muscovite from a quartz–molybdenite vein	2.77	6.01	0.75	3.46	0.98	0.82	1.34	0.22	1.31	0.31	0.85	0.13	0.74	0.13	19.82	2.63	1.17	2.21
Kg-57	Muscovite from a quartz–pyrite–molybdenite vein	0.2	0.45	0.066	0.34	0.11	0.73	0.21	0.048	0.43	0.14	0.58	0.13	1.06	0.26	4.75	0.13	1.10	14.7
Kg-31(m)	Muscovite from a quartz–wolframite–molybdenite vein	0.095	0.28	0.049	0.28	0.11	0.76	0.2	0.036	0.25	0.061	0.19	0.03	0.2	0.039	2.58	0.33	0.52	15.6
Kg-64	Muscovite from a quartz–wolframite–molybdenite vein	1.38	1.70	0.13	0.33	0.06	0.6	0.11	0.022	0.17	0.047	0.17	0.03	0.24	0.052	5.04	4.06	14.62	22.7
Kg-70(m)	Muscovite from a quartz–wolframite vein	0.31	0.80	0.12	0.6	0.2	0.43	0.34	0.058	0.41	0.1	0.3	0.05	0.34	0.063	4.12	0.64	0.93	5.1

Note: (+) calculated values.

Table 2. REE concentrations (ppm) in fluorite from granites of the Kalgutinskoe deposit and mineralized veins at the Southern Kalgutinskoe ore occurrence

Sample	Sample characterization	La	Ce	Pr+	Nd	Sm	Eu	Gd+	Tb	Dy+	Ho+	Er+	Tm+	Yb	Lu	ΣREE	La_N/Yb_N	La_N/Sm_N	Eu/Eu*
Kalgutinskoe deposit																			
Kg-53	Cavity with quartz and fluorite crystals in biotite granite	4.17	11.00	1.7	8.69	2.99	0.65	5.0	0.86	5.51	1.39	4.32	0.68	4.32	0.77	52.05	0.68	0.36	0.54
Kg-54	Quartz vein with fluorite and pyrite in altered granite	0.58	1.73	0.31	1.89	0.74	0.07	1.3	0.22	1.38	0.34	1.03	0.17	1.03	0.18	10.97	0.4	0.47	0.22
Kg-55	Disseminated fluorite in altered granite	7.17	14.90	1.71	7.0	1.93	0.22	2.72	0.45	2.84	0.68	2.08	0.34	1.82	0.36	44.22	2.77	2.23	0.30
Kg-65	The same	10.6	24.00	3.27	14.5	4.43	0.58	5.45	0.77	4.33	0.88	2.28	0.32	1.62	0.25	73.28	4.6	1.44	0.36
Southern Kalgutinskoe ore occurrence																			
Kg-21	Quartz–wolframite vein with fluorite	3.05	9.00	1.46	7.91	2.95	1.1	4.54	0.66	3.9	0.81	2.23	0.32	1.65	0.26	39.84	1.30	0.62	0.93
$Kg\text{-}78(m)_1$	The same	8.16	20.00	2.9	14.2	4.58	1.25	5.99	0.83	4.5	0.92	2.31	0.32	1.59	0.23	67.78	3.61	1.07	0.73
$Kg\text{-}78(m)_2$	The same	3.8	9.53	1.33	6.47	2.02	0.61	2.59	0.36	1.96	0.41	1.07	0.15	0.76	0.12	31.18	3.51	1.13	0.82
Kg-80(m)	The same	5.88	17.10	3.07	19.0	7.47	2.59	10.1	1.42	7.68	1.58	4.03	0.54	2.74	0.42	83.62	1.51	0.47	0.92
Kg-83(m)	The same	9.58	24.90	3.7	19.4	6.51	1.81	8.72	1.19	6.13	1.23	3.02	0.41	1.79	0.28	88.67	3.76	0.88	0.75

Note: (+) calculated values.

vite from veins of quartz–wolframite–molybdenite and quartz–wolframite composition and a quartz–pyrite–molybdenite veinlet (Fig. 3b). In the "ore" muscovite, HREE prevail over LREE [La_N/Yb_N = 0.13–0.64]. The only exceptions are samples Kg-56 and 64.

The REE concentrations in fluorite from the granites of the Kalgutinskoe deposit that bear no wolframite mineralization and from quartz–wolframite–fluorite veins of the Southern Kalgutinskoe occurrence are listed in Table 2, and the corresponding chondrite-normalized REE patterns are presented in Fig. 4. Fluorite form the granites, and mineralized veins shows contrastingly different REE patterns, whose variations are close to those determined in the micas. Fluorite from the granites has a deep negative Eu anomaly (Eu/Eu* = 0.22–0.54) (Fig. 4a), which gives way to weak anomalies (Eu/Eu* = 0.75–0.93) in this mineral from the mineralized veins (Fig. 4b). Fluorite disseminated in the granites is characterized by the predominance of LREE over HREE [La_N/Yb_N = 2.7–4.6], similarly to micas from the granites. In contrast to them, fluorite from a quartz–wolframite vein and a cavity with crystals in the granite (samples Kg-53, 54) is characterized by the predominance of HREE over LREE [La_N/Yb_N = 0.36–0.47]. Fluorite from mineralized veins at the Southern Kalgutionskoe ore occurrence contains predominantly LREE [La_N/Yb_N = 1.3–3.76].

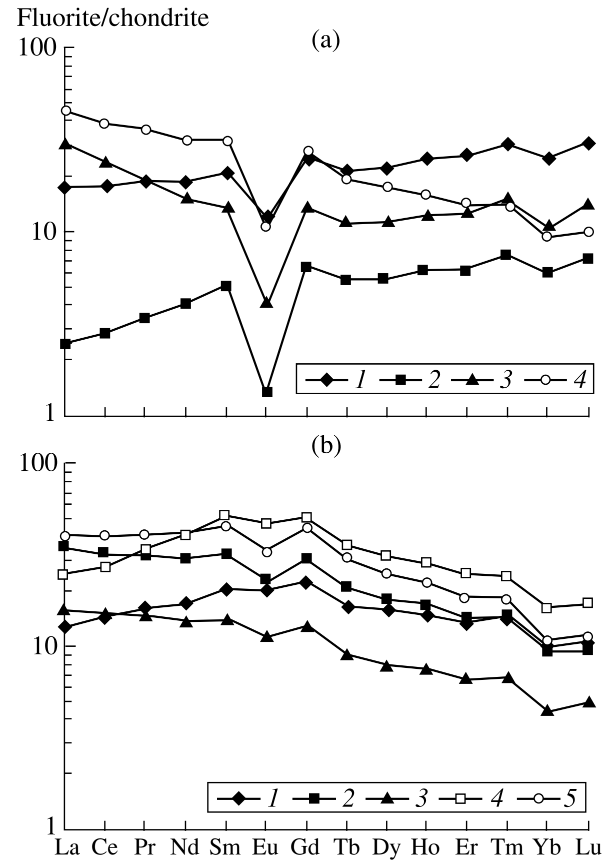

Fig. 4. Chondrite-normalized REE patterns of fluorite from (a) granites of the Kalgutinskoe deposit and (b) veins at the Southern Kalgutinskoe ore occurrence. (a) (*1*) Kg-53; (*2*) Kg-54; (*3*) Kg-55; (*4*) Kg-65. (b) (*1*) Kg-21; (*2*) Kg-78(m)$_1$; (*3*) Kg-78(m)$_2$; (*4*) Kg-80(m); (*5*) Kg-83(m). See Table 2 for the characteristics of the samples.

FLUID INCLUSIONS

In order to constrain the physicochemical conditions under which the ore mineralization was produced, we examined fluid inclusions (FI) in quartz and fluorite from the mineralized veins and their host granites at the Kalgutinskoe deposit and Southern Kalgutinskoe ore occurrence. Inclusions were examined in the same mineral assemblages, micas, and fluorites in which REE were determined. The fluid inclusions are mostly two-phase gas–liquid. They have irregular or equant shapes, range from 10 to 90 μm across, and contain up to 40% of the gas phase. Occasional inclusions (which were found in quartz from the ores of the Kalgutinskoe deposit) are three-phase CO_2–H_2O, with up to a 70 vol % gas. The fluid inclusions were examined by means of homogenization (>200 FI) and cryometry (>150 FI). Our results are summarized in Table 3 and Fig. 5.

Fluorite and quartz in granites from the Kaltuginskoe deposit (samples Kg-53, 54, 55) bear inclusions with homogenization temperatures (T_h) equal to 225–160°C. The solutions have a chloride-sodic composition (T_{em} from –23.6 to –21°C) and salinity of 17.8–7.2 wt % equiv. NaCl. Higher temperatures were determined for quartz from mineralized veins. The T_h are equal to 280–165°C for quartz–muscovite greisen and quartz–molybdenite veins, 240–170°C for the quartz–wolframite veins, 330–180°C for the quartz–wolframite–molybdenite veins, and 375–230°C for a quartz–wolframite–beryl–molybdenite vein (Table 3).

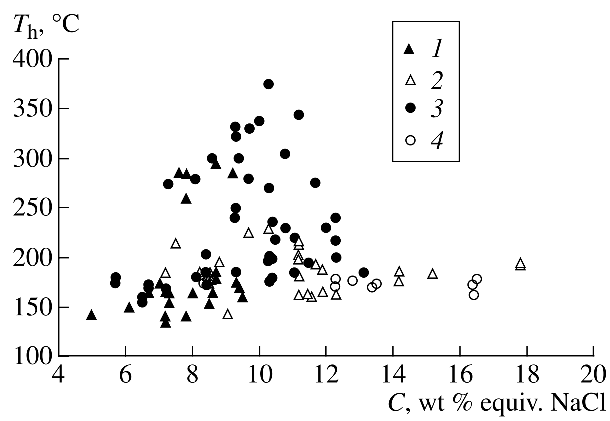

Fig. 5. Homogenization temperatures and salinity of solutions in fluid inclusions in minerals. Mineralized veins: (*1*) fluorite from the Southern Kalgutinskoe ore occurrence; (*3*) quartz from the Kalgutinskoe deposit. Granites of the Kalgutinskoe deposit: (*2*) fluorite; (*3*) quartz.

Table 3. Homogenization temperatures and salinity of solutions in fluid inclusions in quartz from the Kalgutinskoe deposit and fluorite from the Southern Kalgutinskoe ore occurrence

Sample	Sample characterization	Mineral	T_h, °C	Salinity of solutions, °C, wt % equiv NaCl	T_{em}, °C
			Kalgutinskoe deposit		
Kg-53	Cavity with quartz and fluorite crystals in biotite granite	Fluorite	225–180	11.9–8.4	
Kg-54	Quartz vein with fluorite and pyrite in altered granite	Fluorite	216–168	17.8–11.2	
		Quartz	184–162	16.4–8.3	
Kg-55	Disseminated fluorite in altered granite	Fluorite	216–160	12.0–7.2	–23.6 … –21
Kg-52	Muscovite greisen with molybdenite and fluorite	Quartz	260–175	11.0–10.3	
Kg-50	Quartz–molybdenite vein with muscovite	Quartz	280–170	12.3–6.7	
Kg-56	The same	Quartz	230–160	9.3–6.5	–15.7
Kg-57	Quartz–pyrite–molybdenite veinlet with muscovite	Quartz	180–170	6.7–5.7	
Kg-31(m)	Quartz–wolframite–molybdenite vein	Quartz	240–170	10.4–5.7	–15.8 … –15
Kg-64	Quartz–wolframite–molybdenite vein	Quartz	220–165	13.0–11.0	–17.3
Kg-60	Quartz–wolframite–beryl–molybdenite vein	Quartz	375–230*	11.2–9.3	
Kg-73	Quartz–wolframite–molybdenite vein	Quartz	330–210*	11.0–8.0	
Kg-75	The same	Quartz	280–180*	12.3–7.3	
			Southern Kalgutinskoe ore occurrence		
Kg-21	Quartz–wolframite vein with fluorite	Fluorite	300–260	9.2–7.6	
			178–150	8.6–6.0	–19 … –17
$Kg-78(m)_1$	Quartz–wolframite–fluorite vein	Fluorite	185–142	9.3–5.0	
$Kg-78(m)_2$		Fluorite	325–280	Ì.Ó.	
Kg-80	Quartz–wolframite veinlet with fluorite	Fluorite	170–140	9.4–6.7	

* Carbon dioxide–water inclusions were found.

The concentrations of salts in the fluid inclusions are 13–6.5 wt % equiv. NaCl. No clear correlations were detected for the T_h and salinities of solutions in the fluid inclusions (Fig. 5). For all ore types, the eutectic melting temperatures (T_{em}) in the inclusions are similar, from –15 to –17.30°C, which testifies to chloride potassic–sodic compositions of the solutions. The salt concentrations calculated from the melting temperatures of gas hydrates for the inclusions with CO_2 (Kg-60, 73, and 75) were 7.3–5 wt % equiv. NaCl, their CO_2 concentrations reached 40 wt %, and the fluid pressures were as high as 1.2 kbar.

Quartz–wolframite–fluorite veins of the Southern Kalgutinskoe ore occurrence were formed at temperatures of 325–140°C, and the solutions had chloride potassic–sodic compositions (T_{em} from –17 to –19°C) and salt concentrations of 9.4–5 wt % equiv. NaCl (Table 3). A comparison of the REE concentrations with the crystallization temperatures of fluorite from mineralized veins at the Southern Kalgutinskoe ore occurrence revealed their negative correlation (Tables 2, 3).

Our research conducted at the Kolgutinskoe mining district revealed systematic variations in the REE concentrations and their proportions in the succession granites, greisenization zones, associations of mineralized quartz veins in the inner and outer contact zones of the massif. Negative Eu anomalies, the predominance of LREE over HREE in the granites, and micas from them at the Dzhumalinskii Prospect give way to weak negative Eu anomalies in muscovite from the greisenization zone and to positive Eu anomalies in mineralized veins at the Kalgutinskoe deposit. The REE concentrations in muscovite from this deposit are significantly (up to two orders of magnitude) lower than in micas from the granites, and HREE dominate in them, over LREE.

The REE patterns of fluorite are analogous to those determined for the micas. Fluorite disseminated in the granites and occurring in quartz–fluorite veinlets in the granites without wolframite mineralization of the Kalgutinskoe deposit is characterized by deep negative Eu anomalies, whereas fluorite from quartz–fluorite–wolframite veins at the Southern Kalgutinskoe ore occurrence has weak Eu anomalies and is much richer in MREE. The homogenization temperatures of inclusions in the ore fluorite are much higher than the analogous values for fluorite from the granites, and the salt concentrations in the former are lower than in the latter.

In contrast to the Southern Kalgutinskoe ore occurrence, the ore mineralization at the Kalgutinskoe deposit was produced at the heterogenization of the fluids at higher temperatures and concentrations of salts in the solutions.

CONCLUSIONS

(1) Systematic variations in the composition and REE concentrations were identified in the micas and fluorite in the sequence from granites to veins in the inner and outer contact zones. These variations are correlated with the physicochemical parameters of the origin of ore mineralization and mineralogical zoning of the ore field. This enabled us to regard REE as geochemical indicators of the zoning of wolframite ore mineralization at the Kalgutinskoe ore field.

(2) Ore mineralization was produced at the weakly pronounced heterogenization of the fluids, at temperatures of 375–140°C, pressures of up to 1.2 kbar, from chloride potassic–sodic solutions with salinities of 13–5.7 wt % equiv. NaCl, and from CO_2–H_2O solutions with salinities of 7.3–5 wt % equiv. NaCl. The CO_2 concentration in the solutions reached 40 wt %.

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