
MINERALS
AND MINERAL PARAGENESES

Allanite-(Ce): a Typical Mineral of Metakimberlite from the Lake Kimozero Area, Karelia

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Received November 19, 2015

Abstract—Paleoproterozoic kimberlite from the Kimozero area in Karelia is the oldest rock of this type in Russia. It is strongly tectonized, metamorphosed, and it finally transformed into metakimberlite of the prehnite-pumpellyite facies with widespread lanthanide minerals: allanite-(Ce), bastnaesite-(Ce), bastnaesite-(La), parisite-(Ce), and monazite-(Ce). The contacts between their crystals and other metamorphic minerals, e.g., titanite, antigorite, and tremolite, are characterized by induction surfaces of concerted growth. Among lanthanide minerals, allanite-(Ce) is the most abundant. It occurs close to clinocllore pseudomorphs after phlogopite or as intergrowths with titanite in aggregates of tremolite–actinolite, calcite, and dolomite. Allanite crystals from the Kimozero area are not zonal, but vary in lanthanide contents and the Fe³⁺/Fe²⁺ ratio in grains no more than tens of microns from one another. Kimozero allanite mostly belongs to the allanite–ferriallanite series (up to 30% of ferriallanite endmember); the lesser amount corresponds to the allanite–Cr-bearing allanite series. At the late stage of metamorphism, allanite was partly replaced with parisite, bastnaesite, or monazite.

Keywords: allanite-(Ce), metakimberlite, prehnite-pumpellyite facies, Kimozero, Karelia

DOI: 10.1134/S1075701517080074

INTRODUCTION

Orthite got its name from J. Berzelius in 1818 owing to the straight outlines of crystals. Later, the mineral was called allanite. The structure of this mineral, which was resolved by Ueda (1955) and Rumanova and Nikolaeva (1959), is based on the clinzoisite structure CaCaAlAl₂[O/OH/SiO₄/Si₂O₇], where one Ca atom is replaced with lanthanides and one Al atom is replaced with Fe²⁺ and/or with Mg, Mn: Ca REE Fe²⁺ Al₂ [O/OH/SiO₄/Si₂O₇]. In addition, part of the Al can be replaced with Fe³⁺, Cr, V, and Mn³⁺, while part of Ca is replaced with Sr and Mn²⁺. Epidote and allanite, as well as clinzoisite and allanite, frequently make up zonal crystals whose cores are enriched in lanthanides (Khvostova, 1963, and others). At present, the following mineral species are distinguished: the most abundant allanite-(Ce) with predominance of cerium; much less abundant allanite-(La) or allanite-(Nd) and ferriallanite, where Fe³⁺ > Al (Khvostova, 1962; Yakubova, 1972; Pan and Feet, 1991; Ercit, 1992; Holtstam et al., 2003; Giere and Sorensen, 2004; Armbruster et al., 2006; Hanson, 2012; *Fleischer's ...*, 2014). Allanite-(Ce) is a widespread accessory mineral of granitoids and granitic pegmatites; syenite and syenitic pegmatites, monzon-

ite, and fenite; high- and medium-temperature metasomatic rocks: calc-silicate skarn, propylite; metamorphic rocks variable in facies (Labuntsov, 1939; Zhironov et al., 1961; Khvostova, 1962; Phillipots and Auge, 2009); and alpine-type metamorphic–hydrothermal veins (Grammacoli, 1978). In all these rocks allanite occurs as zonal or finely zoned crystals. The REE composition of allanite is sufficiently stable: Ce > La > Nd ≫ Pr > Sm > Gd; the concentrations of other REE, Y, and U are commonly negligible; the Th contents vary from traces to 1 wt % or sporadically higher (Murata et al., 1957; Khvostova, 1962; Yakubova, 1972; Giere and Sorensen, 2004). Allanites enriched in La or Nd, as well as in Th and quite often U, develop in differentiated granitic pegmatites. Cores of such crystals are commonly metamict. Ferriallanite is a characteristic mineral for alpine-type veins and high- and medium-temperature alkaline metasomatic rocks. Thus, allanite is a good indicator of conditions inherent to the formation of rocks and minerals.

MATERIALS AND METHODS

The collection of Kimozero kimberlites gathered by E.V. Putintseva from natural outcrops and boreholes has been studied. This collection, donated to the

Petrographic Museum of the Institute of Earth Sciences, St. Petersburg State University, comprises hand specimens, sawed samples, thin and polished sections, and results of chemical analyses.

Most photomicrographs and analyses of minerals were taken and performed by N.N. Korotaeva on a JEOL SM-6480 LV electron microscope equipped with microprobe at the Laboratory of Local Research Methods, Department of Petrology, Geological Faculty, Moscow State University, using standard techniques. Minerals containing lanthanides and actinides were analyzed by the technique elaborated by I.M. Kulikova (Kulikova and Nabelkin, 2014). A full X-ray spectroscopy technique to determine 14 lanthanides taking in account superposition of lines, effects of selective absorption, and excitation by other elements was elaborated by R.L. Barinsky in 1958 at the Institute of Mineralogy, Geochemistry, and Crystal Chemistry of Rare Elements (IMGRE), Moscow. I.M. Kulikova upgraded Barinsky's technique and applied it to modern instruments. The experimental conditions are as follows: WDS regime, accelerating voltage 20 kV, electron beam current 30 nA, current stabilization regime. Fourteen lanthanides are determined along with Y, Th, U, Ca, P, Si, Ti, Al, Fe, Mn, Mg, Sr, Na, Ba, and Ti. Standards are synthetic phosphates of individual lanthanides and yttrium; Th, U, Ti dioxides; barite and celestine; the exposure time is 10–60 s. Analytical lines are measured over two time periods: first, the relative intensities of even lanthanides, Si, Y, Th, P, Ca, and Sr are measured; then, according to the same scheme and at the same points, the relative intensities are measured for the rest of the elements. The detection limits (wt %) are 0.2 for Y, Pr, Sm, Gd, and Yb; 0.12 for Na; 0.08 for Cr, V, Mn, Mg; and 0.02 for Th and U. Concentrations of 30 or more chemical elements are calculated synchronously in program Calc-ZAF.exe, ZAF and PAP correction methods.

Kimberlites of the Kimozero Area

The Paleoproterozoic Kimozero occurrence of diamond-bearing kimberlites, one of the world's oldest, is located in the Onega Structural Unit of the Karelian Craton; its basement is represented by the Vodlozero Block of the Paleoproterozoic stabilization. The Kimozero occurrence is a flattened and elongated (~ 2 km) lode and a series of steeply dipping pipelike bodies composed of massive kimberlite, kimberlite breccia, and tufflike rocks of at least two intrusive phases (Ushkov, 2001; Ustinov et al., 2009; Putintseva et al., 2009). These are the oldest diamond-bearing kimberlitic rocks in Russia. Their isotopic age, estimated by diverse methods, varies from 1.99 to 1.74 Ga (Ustinov et al., 2009).

Kimberlite rocks of phase I make up the outer "units" of the Kimozero body. These units are enriched in laths of magmatic calcite. Olivine or oliv-

ine plus phlogopite with rims of tetraferriphlogopite are predominant among phenocrysts; magnesio- to aluminomagnesiochromite and ilmenite (up to picroilmenite) are frequent. The morphology of actinolite-tremolite pseudomorphs surrounding serpentinite pseudomorphs after olivine allows us to suggest that monticellite rims initially surrounded olivine. Kimberlite rocks of phase II, which form the inner units of the body and part of the steeply dipping pipelike bodies, are more magnetic. Frequently, they are massive with multitude of olivine and phlogopite phenocrysts with tetraferriphlogopite rims. Judging from abundant titanite among pseudomorphs of clinocllore after phlogopite, the latter is enriched in Ti.

The cementing groundmass of kimberlitic rocks of Kimozero contains abundant olivine, phlogopite, lath-shaped calcite, and frequent crystals of ilmenite, chromite, titanomagnetite, apatite, and perovskite (judging by the morphology of replacement products); baddeleyite and zircon are infrequent.

The contents and distribution of lanthanides in kimberlite of Kimozero are typical of kimberlitic rocks, LREE are abundant, and a negative Eu anomaly is evident (Fig. 1).

Metakimberlites

Kimozero kimberlitic rocks are, as a rule, multifold and intensely tectonized. Kink bands have developed widely in phlogopite crystals; phlogopite phenocrysts are frequently folded, torn, or twisted. Like host gabbrodolerite and Paleoproterozoic (Ludicovian) volcanic-sedimentary rocks, kimberlites underwent regional greenstone metamorphism under conditions of prehnite-pumpellyite facies, and as a result, were transformed into metakimberlites. The host metaigneous rocks contain syngenetic albite, minerals of chlorite and epidote groups, titanite, actinolite, quartz, prehnite, fine-grained pumpellyite, ferroaxinite, and native copper. This is a typical set of minerals in greenstone rocks of the prehnite-pumpellyite facies (Coombs, 1960; Seki, 1961; Liou et al., 1987; Spiridonov et al., 2000; Phillpots and Auge, 2009). Metakimberlites from the Kimozero area are commonly composed of serpentine, as a rule, alumina-free tremolite-actinolite ($f = 8-21$), calcite and other carbonates, chlorite, and titanite, the amount of which varies in a wide range. Olivine of kimberlitic rocks is completely replaced with minerals of the serpentine group, mainly antigorite and frequent relics of reticulate lizardite. Platelets of antigorite contain inclusions of powderlike magnetite. Antigorite-magnetite intergrowths with 0.5% Ni are typical. Occasionally olivine is replaced with ferric talc ($f = 5.6-11.2$). The composition of calcite in intergrowths with tremolite is $\text{Ca}_{0.97-0.99}\text{Mg}_{0-0.02}\text{Fe}_{0.01}\text{Mn}_{0-0.01}$. Phlogopite is replaced to a certain degree with clinocllore containing titanite inclusions. Primary Cr-spinel is partly replaced with Cr-magnetite free of Ti, Zn, and Mn, as well as with

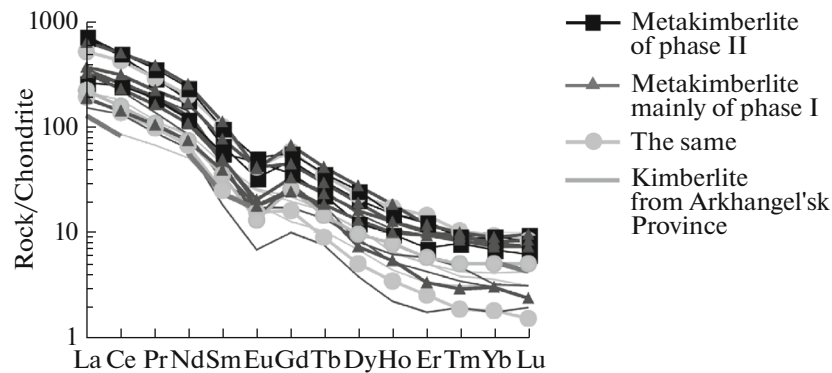


Fig. 1. Distribution of chondrite-normalized lanthanide contents in kimberlites from Kimozero area. Chondrite concentrations are taken from (McDonough and Sun, 1995). Chemical compositions of kimberlites from Arkhangel'sk Province are taken from (*Carbonatite and Kimberlite ...*, 2005). Data of (Ustinov et al., 2009) were used to compile graph.

Cr-bearing clinocllore. The primary Ti minerals—ilmenite, perovskite, and titanomagnetite—are almost completely replaced with earthy or fine-grained titanite and to a lesser degree with pseudobrookite, hematite, or rutile. The abundant actinolite—tremolite amphibole characteristic of Kimozero metakimberlite most likely formed due to reworking of primary olivine and calcite. Metakimberlite from the contact zone with shungite-bearing rocks is enriched in sulfides, mainly pyrite, as well as in goethite and jarosite as products of pyrite oxidation in weathering mantle.

Small segregations of metamorphic—hydrothermal minerals of lanthanides—allanite-(Ce), bastnaesite-(Ce), bastnaesite-(La), parisite-(Ce), and monazite-(Ce)—are relatively widespread in metakimberlite of the Kimozero area. Contacts between crystals of these minerals and titanite, antigorite, and tremolite are inductive surfaces of joint growth. This is a new genetic type of REE minerals. Naturally, we can suggest that LREE was initially contained in primary calcite and perovskite of kimberlite (Dawson, 1980). Metamorphic minerals of lanthanides inherit the Ce, Ce—La, Ce—La—Nd specificity of magmatic calcite and perovskite of kimberlite. Allanite-(Ce) is the most abundant of them.

Allanite-(Ce) from Metakimberlites of Kimozero Area

Allanite is occasionally observed as clusters of small prismatic and long-prismatic crystals among clinocllore platelets in pseudomorphs after deformed phlogopite phenocrysts (Fig. 2). The mineral more frequently forms clusters of prismatic crystals among tremolite—actinolite and calcite aggregates (Fig. 3), as well as irregularly shaped segregations commonly intergrown with titanite (Figs. 4, 5). The clusters of allanite crystals are up to 0.7×0.06 mm in size; individual crystals are no larger than 0.03 mm. Allanite occasionally contains inclusions of pentlandite.

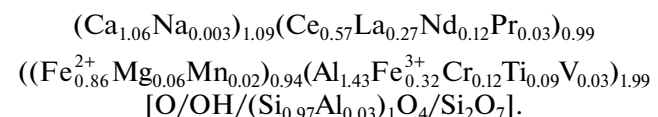
Allanite in clinocllore aggregates is depleted in Ti and contains traces of Cr and V (Table 1, analyses 1—

5). Allanite in intergrowths with titanite, which are observed in calcite and tremolite—actinolite aggregates, contains 1.5—2.0 wt % TiO_2 (Table 1, analyses 6—9). Allanite in intergrowths with titanite at the contacts with ferrichromite and tremolite—actinolite aggregates contains 1—2 wt % TiO_2 and up to 9 wt % Cr_2O_3 (Table 2, analyses 10—15). Variations of the Ce, La, Nd, and Pr contents in all three types of allanite are similar. Appreciable amounts of Sm, Gd, and Yb were detected only in allanite among pseudomorphs of clinocllore after phlogopite.

The specificity of Kimozero allanite comprises the following features: (1) its crystals are not zoned; (2) significant variability in lanthanide contents and $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratio is noted in the crystals, which are a few tens of microns apart from one another (Fig. 5); and (3) diversity of lanthanide compositions, when some crystals are selectively enriched in Ce, while others are abundant in La, and still others are characterized by $\text{Nd} > \text{La}$ (Fig. 6).

Most of the Kimozero allanite belongs to the allanite—ferriallanite series (up to 30% of ferriallanite endmember), and a smaller part, to the allanite—Cr-bearing allanite series (Fig. 7).

The mean chemical composition of allanite-(Ce) in metakimberlite from the Kimozero area ($n = 15$) is as follows (wt %): 30.05 SiO_2 , 1.24 TiO_2 , 1.50 Cr_2O_3 , 0.36 V_2O_5 , 12.50 Al_2O_3 , 4.27 Fe_2O_3 , 10.40 FeO , 0.22 MnO , 0.43 MgO , 9.98 CaO , 7.47 La_2O_3 , 15.61 Ce_2O_3 , 0.91 Pr_2O_3 , 3.29 Nd_2O_3 ; total is 98.40. This corresponds to the formula



At the late stage of metamorphism, allanite is partly replaced with parasite and bastnaesite or monazite.

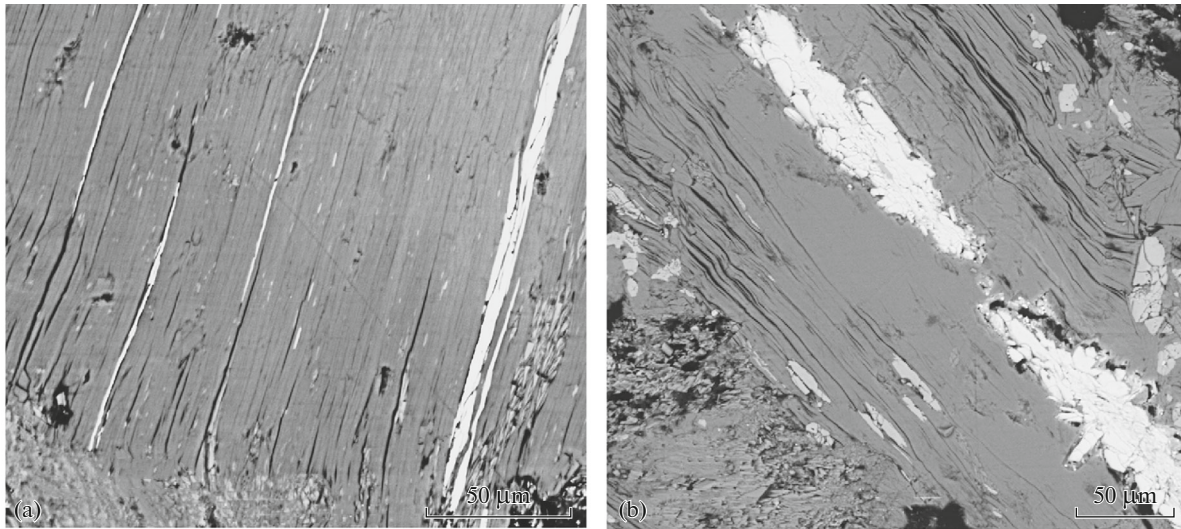


Fig. 2. Pseudomorphs after deformed phlogopite phenocrysts: Clusters of small prismatic allanite crystals (white) among clinocllore sheets with titanite inclusions (light gray). (a, b) Metakimberlite from Kimozero area. BSE images.

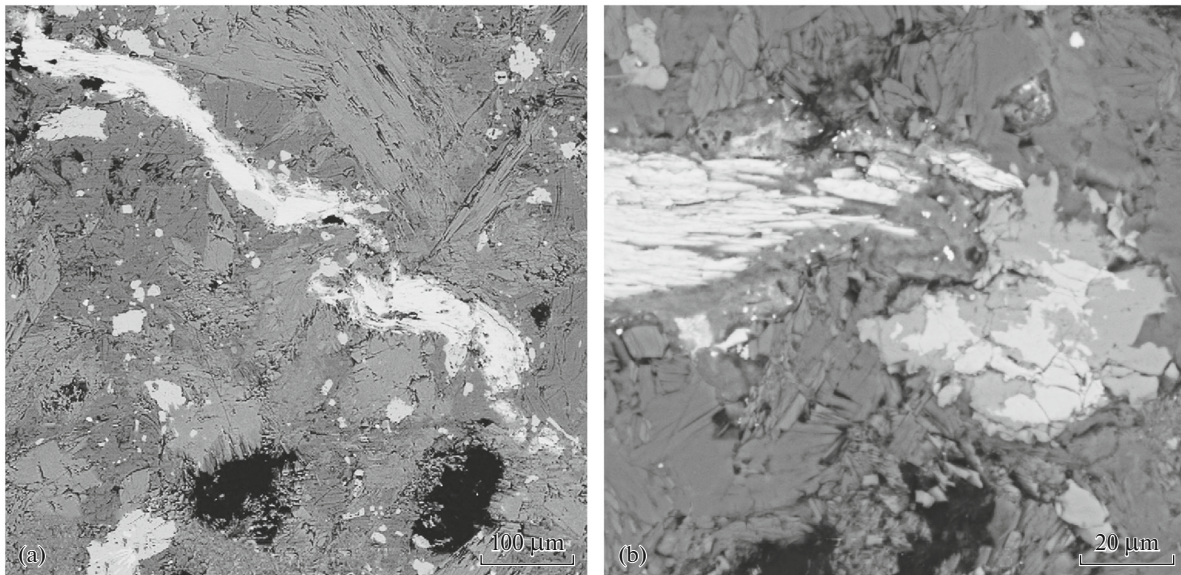


Fig. 3. Conformal plicated clusters of small long-prismatic allanite crystals (white) among intergrowths of calcite (dark gray) and tremolite–actinolite (gray) with titanite inclusions (light gray); defects of polishing are black. Metakimberlite from Kimozero area. BSE images.

CONCLUSIONS

Paleoproterozoic kimberlites from the Kimozero area, Karelia, were transformed to a significant degree into metakimberlites of prehnite–pumpellyite facies with abundant tremolite–actinolite, antigorite, clinocllore, calcite, and titanite. Metamorphic allanite-(Ce) is relatively widespread. Contacts between allanite and titanite crystals, as well as allanite and tremolite–actinolite are represented by inductive surfaces of the joint growth. The metamorphic allanite inherits Ce, Ce–La, and Ce–La–Nd specificity of

magmatic calcite and perovskite of kimberlite. Allanite as a component of clinocllore aggregates is depleted in Ti, Cr, and V; it contains 1–2 wt % TiO_2 in intergrowths with titanite, and up to 9 wt % Cr_2O_3 at contact with ferrichromite. Most of the Kimozero allanite belongs to the allanite–ferriallanite series (up to 30% ferriallanite endmember), and a smaller part is related to the allanite–Cr-bearing allanite series. The features of metamorphic allanite-(Ce) as a characteristic mineral of metakimberlite of prehnite–pumpellyite facies comprise (1) no zoning of crystals, (2) significant vari-

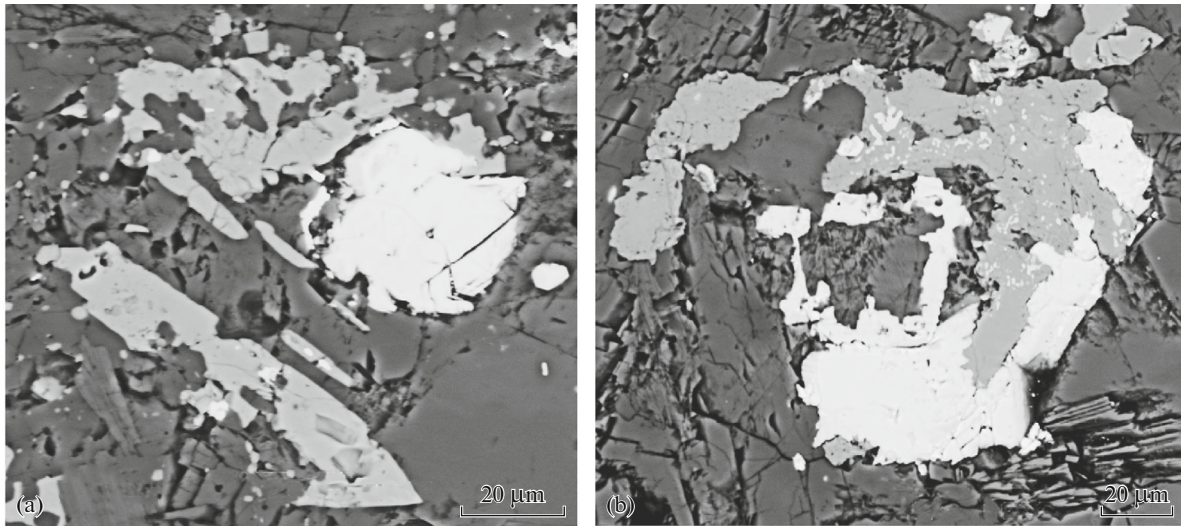


Fig. 4. Allanite (white) and titanite (light gray) grains with irregular shape hosted in tremolite–actinolite aggregate. Metakimberlite from Kimozero area. BSE images.

ability of lanthanide contents and the $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratio in crystals a few tens of microns apart from one another, and (3) diverse lanthanide compositions: some crystals are selectively enriched in Ce and others are characterized by abundant La or $\text{Nd} > \text{La}$. This indicates a smaller mobility of lanthanides in the course of low-grade metamorphism, a microheterogeneous distribution of lanthanides in initial kimberlite, and appreciable variations of f_{O_2} in metamorphic

fluid. At the late stage of metamorphism, allanite is partly replaced with parisite, bastnaesite, or monazite.

In metakimberlite of zeolitic facies in the East Siberian Platform, lanthanide minerals are unknown (Spiridonov et al., 2000, 2010; Sokolova and Spiridonov, 2006, 2012). It is thought that at a low ($<290^\circ\text{C}$) temperature of zeolitic facies, lanthanides are not mobilized. In metabasalts of higher-temperature prehnite–pumpellyite facies at the East Siberian Platform, newly formed monazite and xenotime have been identified (Spiridonov et al., 2000). Thus, the

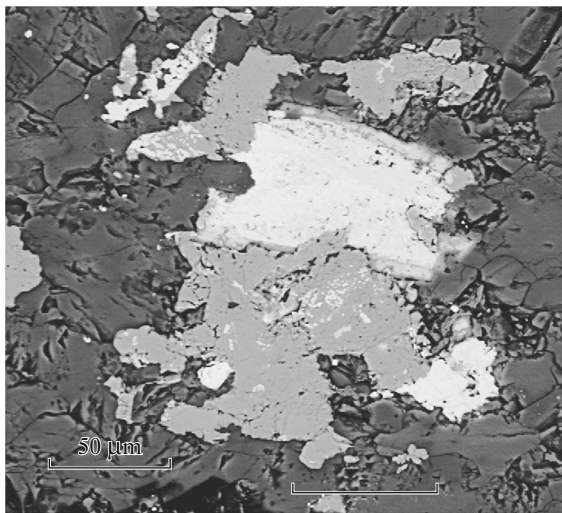


Fig. 5. Intergrowth of allanite and titanite in tremolite–actinolite aggregate. Allanite varies in composition: bottom right (white), enriched in Ce (Table 1, analysis 9); center (white and gray), enriched in Fe with standard REE content (analysis 7); allanite rim around it (light gray) is depleted in Fe and REE (analysis 8). Metakimberlite from Kimozero area. BSE images.

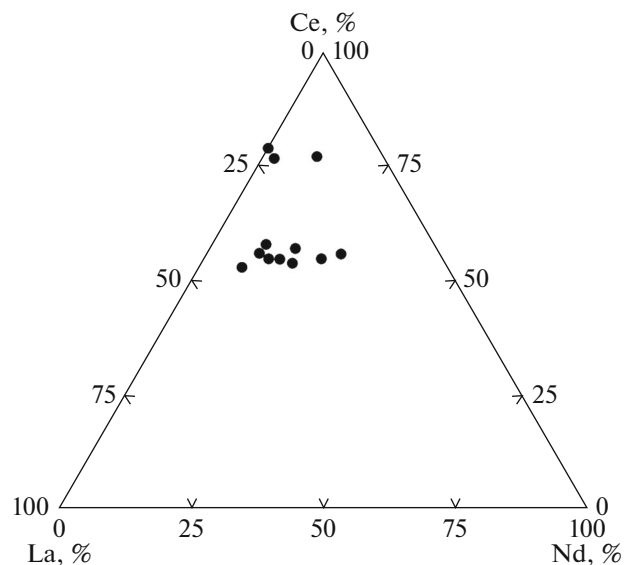


Fig. 6. Chemical composition of allanite from Kimozero metakimberlite plotted in Ce–La–Nd diagram.

Table 1. Chemical composition of allanite (wt %) among pseudomorphs of clinocllore after phlogopite (nos. 1–5) and in intergrowths with tremolite–actinolite, calcite, and titanite (nos. 6–9) from metakimberlites of Kimozero area, Karelia

Components	1	2	3	4	5	6	7	8	9
SiO ₂	29.64	30.01	31.17	29.46	28.72	30.22	30.18	30.68	29.39
TiO ₂	0.95	0.50	0.43	0.98	0.75	2.00	1.59	1.45	1.45
Cr ₂ O ₃	b.d.l.	b.d.l.	b.d.l.	0.16	b.d.l.	0.30	b.d.l.	b.d.l.	b.d.l.
V ₂ O ₃	0.32	"	"	b.d.l.	"	b.d.l.	"	0.70	0.93
Al ₂ O ₃	14.39	14.79	14.94	11.84	12.69	10.61	10.61	13.92	12.90
Fe ₂ O ₃	5.55	5.21	4.03	5.85	–	6.63	7.44	4.01	–
FeO	9.29	9.48	11.74	10.45	12.48	11.74	11.46	11.45	12.23
MnO	b.d.l.	0.14	b.d.l.	0.24	Traces	0.38	0.34	0.15	b.d.l.
MgO	0.12	0.19	0.37	0.66	"	1.09	0.90	0.08	"
CaO	10.63	10.54	9.73	9.75	8.63	9.15	9.44	10.83	9.77
Na ₂ O	0.23	0.15	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.
La ₂ O ₃	8.09	8.24	4.74	5.47	4.96	9.35	10.16	7.77	6.77
Ce ₂ O ₃	13.80	14.45	13.92	12.96	26.50	13.32	13.80	13.77	24.05
Pr ₂ O ₃	0.96	1.00	1.58	1.34	b.d.l.	0.76	0.52	1.07	b.d.l.
Nd ₂ O ₃	3.21	2.78	6.35	5.42	3.98	2.56	2.05	3.58	Same
Sm ₂ O ₃	b.d.l.	b.d.l.	0.38	0.60	b.d.l.	b.d.l.	b.d.l.	b.d.l.	"
Gd ₂ O ₃	Same	Same	b.d.l.	0.29	Same	Same	Same	Same	"
Yb ₂ O ₃	"	"	0.34	b.d.l.	"	"	"	"	"
Total	97.18	97.48	99.92	97.47	98.71	98.34	98.49	99.46	97.49
Coefficients in formulas calculated for eight cations									
Si	2.925	2.952	2.999	3.000	2.990	2.998	2.999	2.966	2.999
Ti	0.071	0.037	0.031	0.075	0.058	0.149	0.119	0.105	0.111
Cr	–	–	–	0.013	–	0.023	–	–	–
V	0.025	–	–	–	–	–	–	0.055	0.076
Al	1.674	1.714	1.694	1.421	1.556	1.237	1.242	1.586	1.551
Fe ³⁺	0.412	0.384	0.292	0.449	–	0.495	0.556	0.292	–
Fe ²⁺	0.766	0.780	0.945	0.890	1.085	0.974	0.952	0.926	1.042
Mn	–	0.012	–	0.021	–	0.032	0.028	0.012	–
Mg	0.018	0.028	0.082	0.100	–	0.166	0.133	0.012	–
Ca	1.124	1.111	1.003	1.064	0.857	0.972	1.005	1.122	1.068
Na	0.044	0.028	–	–	–	–	–	–	–
La	0.295	0.299	0.168	0.206	0.190	0.349	0.372	0.277	0.255
Ce	0.499	0.520	0.490	0.483	1.116	0.484	0.502	0.487	0.898
Pr	0.034	0.036	0.055	0.050	–	0.028	0.019	0.038	–
Nd	0.113	0.097	0.218	0.197	0.148	0.090	0.073	0.124	–
Sm	–	–	0.013	0.021	–	–	–	–	–
Gd	–	–	–	0.010	–	–	–	–	–
Yb	–	–	0.010	–	–	–	–	–	–
ΣREE	0.941	0.952	0.954	0.967	1.454	0.951	0.966	0.926	1.153

b.d.l., below detection limit; Sr, P, Th, U, Y and Eu not detected; Fe²⁺ and Fe³⁺ contents calculated from stoichiometry.

Table 2. Chemical composition of allanite (wt %) in intergrowths with titanite at contact with ferrichromite from metakimberlites of Kimozero area, Karelia

Components	10	11	12	13	14	15
SiO ₂	30.32	28.61	31.04	29.80	30.95	30.53
TiO ₂	0.99	1.45	1.92	0.88	1.32	2.03
Cr ₂ O ₃	0.25	0.37	1.13	2.99	6.90	9.12
V ₂ O ₃	0.77	b.d.l.	0.55	0.47	0.84	0.58
Al ₂ O ₃	14.13	11.24	13.08	12.42	10.55	9.35
Fe ₂ O ₃	5.75	—	1.62	3.91	4.16	4.48
FeO	10.18	11.57	12.40	9.91	8.46	7.88
MnO	b.d.l.	0.23	0.20	0.14	0.43	0.75
MgO	0.10	1.40	0.50	0.22	0.38	0.45
CaO	10.62	7.65	10.24	10.32	11.24	11.14
Na ₂ O	0.17	b.d.l.	0.23	0.16	0.38	0.48
La ₂ O ₃	6.75	11.38	8.47	8.43	6.07	5.45
Ce ₂ O ₃	13.75	19.21	14.33	14.02	11.83	11.36
Pr ₂ O ₃	1.24	1.22	0.82	1.06	1.01	1.00
Nd ₂ O ₃	4.13	3.40	2.28	2.53	3.73	3.31
Total	99.05	97.73	98.81	97.26	98.32	98.31
Coefficients in formulas calculated for eight cations						
Si	2.925	3.000	3.004	2.965	2.992	2.946
Ti	0.072	0.114	0.139	0.066	0.095	0.147
Cr	0.019	0.031	0.087	0.235	0.527	0.696
V	0.060	—	0.043	0.038	0.065	0.045
Al	1.607	1.388	1.493	1.456	1.202	1.064
Fe ³⁺	0.417	—	0.218	0.293	0.303	0.355
Fe ²⁺	0.821	1.015	1.004	0.824	0.686	0.636
Mn	—	0.020	0.017	0.012	0.039	0.061
Mg	0.014	0.219	0.072	0.033	0.055	0.064
Ca	1.098	0.807	1.062	1.100	1.165	1.152
Na	0.032	—	0.044	0.031	0.071	0.090
La	0.263	0.441	0.302	0.309	0.217	0.194
Ce	0.486	0.791	0.507	0.510	0.419	0.401
Pr	0.044	0.047	0.029	0.038	0.035	0.035
Nd	0.142	0.127	0.079	0.080	0.129	0.114
ΣREE	0.935	1.353	0.917	0.947	0.800	0.744

b.d.l., below detection limit; Sr, P, Th, U, Y, Sm, Eu, Gd and Yb not detected; Fe²⁺ and Fe³⁺ contents calculated from stoichiometry.

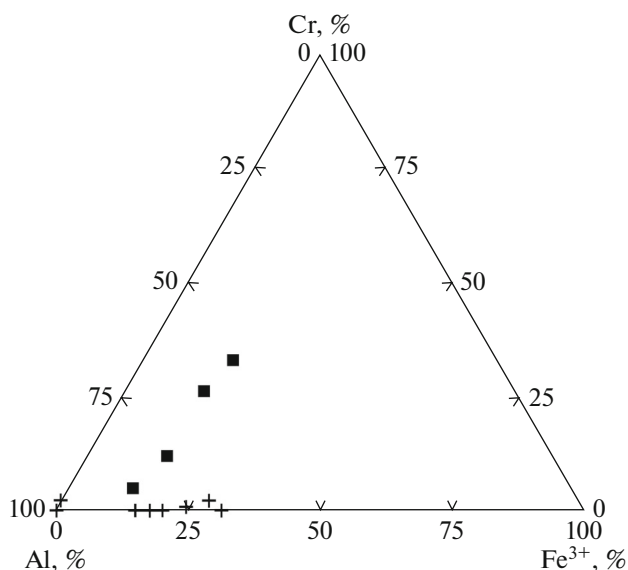


Fig. 7. Chemical compositions of allanite from Kimozero metakimberlites plotted in Al–Fe³⁺–Cr diagram. Data points denoted by crosses are related to allanite–ferriallanite series, whereas data points denoted by squares are related to allanite–Cr-bearing allanite series.

metamorphosed rocks of prehnite–pumpellyite facies in the East Siberian Platform and the Fennoscandian (Baltic) Shield of the Russian (East European) Platform underwent appreciable mobilization of lanthanides with the formation of their minerals proper.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research (project no. 16-05-00241).

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Translated by V. Popov