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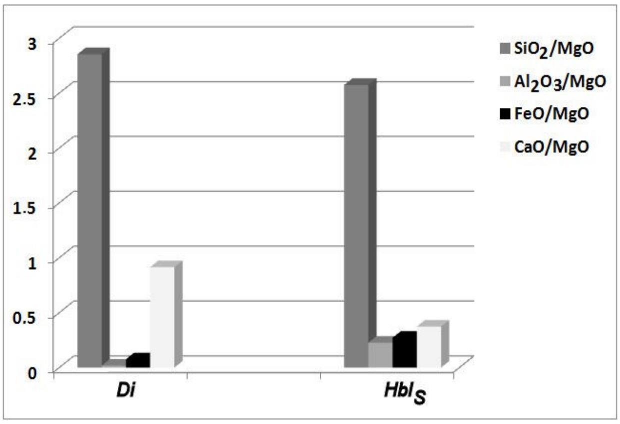

Fig. 3. SiO_2-normalized FeO, MgO, CaO and Al_2O_3 concentrations in Hbl_{Di} and Hbl_S.

Fig. 3 shows that SiO_2 and particularly CaO concentrations in Hbl_S (MgO-normalized) are lower than those in Hbl_{Di}. Consequently, part of Si and Ca is dissolved and Al_2O_3 and FeO in *HBls* increase slightly in comparison to Hbl_{Di}.

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Kovalskaya T.N., Varlamov D.A., Shapovalov Yu.B., Kotelnikov A.R., Kalinin G.M. The specification of amphibolization process in gabbroids of Tiksheozerskiy massif (by experimental data)

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Abstract: Experimentally studied the formation of alkaline amphibole rims around grains of clinopyroxene (diopside-hedenbergite-augite composition) encountered in the study of mineral characteristics Tiksheozerskiy masisif. Gabbro from Lukkylaisvaara massif was used as a starting material, because it is less susceptible to secondary changes, in contrast to Tiksheozerkiy massif. In the experiments with a concentration of KCl and KF 1 M was obtained amphiboles range pargasite-cataphoric, the composition closest to the natural.

Keywords: *amphibole,experiment, postmagmatic processes, alkaline massifs, gabbro*

Within the Fenno-Scandinavian shield, the development of amphibolites in the main rocks is quite common (Khodorevskaya, Varlamov, 2018, Safonov et al., 2014), however, the alkaline nature of postmagmatic changes in the main rocks of the Tiksheozero massif is most interesting.

The central part of the massif is composed by olivinites, in places heavily serpentized and chloritized, interspersed with aluminum chromites, relics of olivine and clinopyroxene (fig. 1). The basic rocks are pyroxenites and gabbroids, which are also quite strongly modified. Pyroxenites are composed of clinopyroxene (diopside-hedenberigit and augite), phlogopite, and titanium magnet. In gabbroids, pyroxene of diopside-hedenbergite composition, plagioclase with an anortic component of 70-75%, amphibole of two generations, corresponding to pargasite and richterite-cataphorite, are also observed. The first amphibole forms independent grains, the second is found in rims around the clinopyroxene grains of the diopside-hedenbergite composition, which is probably the result of postmagmatic high-temperature alteration of the rocks of the massif. An example of the relationship between clinopyroxenes and amphiboles is shown in Fig.2. Within the same breed, amphiboles of different composition are found, which is a consequence of the change in the physicochemical conditions of rock formation and the potential of alkaline components.

The paragenetic analysis carried out earlier and geothermometers applied on its basis (Perchuk, 1970) made it possible to calculate the formation temperatures of amphibole parageneses. The formation temperatures of amphibole-pyroxene parageneses of the Tikshozero massif using clinopyroxene-amphibole, biotite-amphibole, and pyroxene-biotite geothermometers (Perchuk, Ryabchikov, 1976) are estimated at 710-980°C. It was not possible to estimate the formation pressure of amphibole rims using an amphibole geothermometer (Simakin, Shaposhnikova, 2017) because of the alkaline nature of amphiboles. The pressure values during the formation of the Tikshozero massif, based on the literature data (Metallogenia ... 2001), are estimated at 3-4 kbar. Therefore, to reconstruct the mechanism and conditions of the process of amphibolization of Tikshozero gabbroids, an attempt was made to experiment it with experimental parameters with parameters similar to those calculated. This method is described in detail in the work (Suk et al., 2007). The study of sodalite-containing parageneses in the rocks of the later phases of the formation of the Tiksheozero massif and the thermometry carried out using the data obtained showed that these

Table 1. The average composition (wt.%) of gabbroids from the Lukkulaisvaara and Tikshozersky massifs

Component	Luckulais-vaara	Tiksheozero
SiO_2	49.27	47.13
TiO_2	1.03	3.16
Al_2O_3	13.43	11.46
Cr_2O_3	0.13	0.18
FeO*	14.94	13.98
MnO	0.14	0.67
MgO	5.21	5.98
CaO	6.24	7.02
Na_2O	4.35	6.16
K_2O	1.81	3.86
Total	**99.56**	**99.60**

associations were formed at a temperature of about 450 ° C (Ustinov et al., 2006). The anionic group in sodalite is represented only by the Cl- ion. These data make it possible to use KCl solution as a fluid in modeling the amphibolization process.

For the experiments, crushed gabbro of the Luckulaisvaara massif (Karelia) were used as starting materials, since the composition of the main rocks of the Lukkulysvaara massifs is similar in chemical composition to Tiksheozersky (Table 1), while they were significantly less subjected to secondary changes in contrast to the Tikshozero massif. The fluids used were KCl and KF solutions with concentrations of 0.5, 1 M, and 2 M, respectively. All experiments were carried out in high-pressure gas installations with internal heating UVGD-10000.

The starting materials were loaded into platinum ampoules of Ø5×0.2×50 mm or Ø4×0.1×50 mm, the required amount of fluid solution was added, weighed and brewed. The filled ampoules were loaded into the reactors of the plants, put into operation and maintained at the experimental parameters for 10 days.

First, the reaction mixture was heated to 1100 ° C at 3 kbar, kept for 3 hours, then isobaric cooling to 850 ° C followed by aging for 10 days. In the course of the two series of experiments (with KF and KCl solutions with a concentration of 0.5 M, 1 M, 2 M), the following results were obtained: the products of the experiments were a fine-crystalline mass (Fig. 3, 4) of a greenish-gray color; individual crystallites.

Table 2. Compositions (wt.%) of Tikshozero amphiboles and synthesized amphiboles

Com-ponent	Natural samples						Experimental samples	
	pyroxenite	gabbro	gabbro	iolite-urtite	syenite	carbonatite	Synthetic amphibole (1M KF)	Synthetic amphibole (1M KCl)
SiO_2	44.08	41.33	43.27	49.10	40.21	51.91	47.18	46.12
TiO_2	0.48	0.06	1.41	0.91	1.07	0.94	1.32	0.86
Al_2O_3	11.20	17.28	10.91	6.53	14.30	4.06	12.78	10.42
Cr_2O_3	-	-	-	-	-	-	-	-
FeO^*	16.43	20.44	18.57	13.23	19.38	13.75	14.94	15.91
MnO	0.00	0.13	0.05	0.00	0.19	0.09	0.25	0.03
MgO	11.81	6.36	10.81	15.60	9.06	14.70	12.32	13.81
CaO	13.47	11.96	9.00	8.68	10.93	7.30	6.14	8.01
Na_2O	1.29	1.85	5.16	5.43	3.57	6.66	2.24	3.71
K_2O	1.24	0.58	0.81	0.52	1.30	0.59	1.83	1,13
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

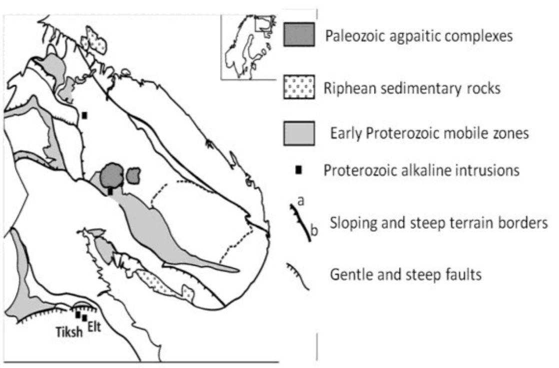


Fig. 1. Schematic position of the Tikshozero and Eletozero massifs.

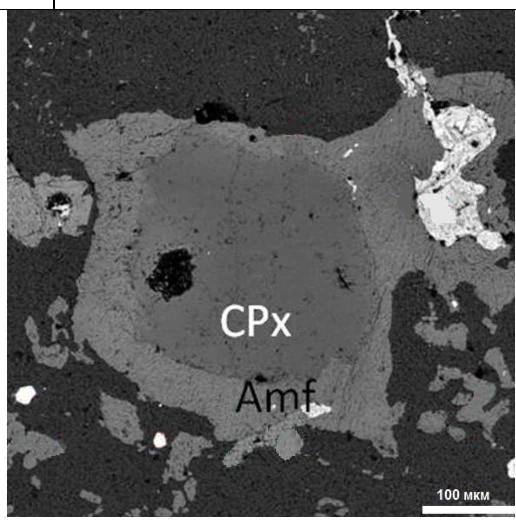
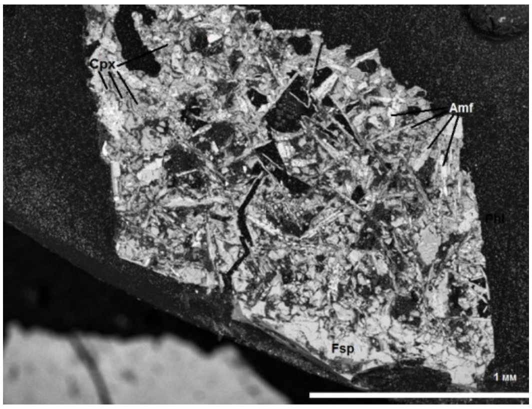


Fig. 2. Natural amphibole rims around clinopyroxene.



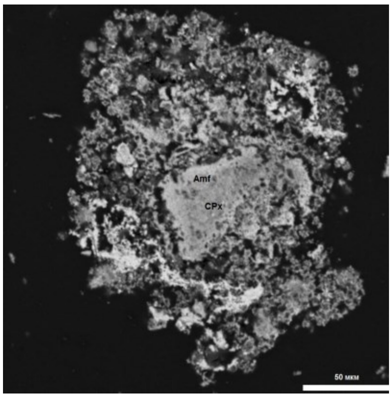


Fig. 3. Products of experiments with 1 M KCl solution at a temperature of 850 ° C and a pressure of 3 kbar.

Fig. 4. Products of experiments with 1 M KF solution at a temperature of 850 ° C and a pressure of 3 kbar.

Experiments with 0.5 M KCl solution. Analysis of the products of experiments with a fluid concentration of 0.5 M KCl revealed no formation of alkaline amphiboles. In the interstitium between the newly formed clinopyroxene are fine grains of potassium feldspar

Experiments with 1M KCl solution. In experiments with such a salt concentration in the fluid, clinopyroxenes of diopside-hedenbergite and amphiboles were obtained in terms of their composition corresponding to richteritol cataphorite observed in Tiksheozero gabbroids (Fig.3, 4, Table 2). The size of the individual grains reaches 100 microns.

Experiments with 2M KCl solution. Among the products of this series of experiments, alkaline amphiboles, which differ greatly in composition and single grains of clinopyroxenes, were noted; titanomagnetite was found as an accessory mineral.

Experiments with 0.5M KF solution. As in the experiment with 0.5 M KCl as a fluid, no alkaline amphiboles were observed in this experiment. In the products of experience diagnosed with allocation of clinopyroxene and phlogopite. The crystallite size in the products of experience does not exceed 50 microns.

Experiments with 1M KF solution. As in the experiments with 1 M concentration of KCl, clinopyroxenes of diopside-hedenbergite series (Table 2) and alkaline amphiboles of the riherite-cataphorite series were diagnosed in the products of these experiments. However, amphiboles of such composition were encountered by us in the ijolit-urtites of the Tikshozero massif. It is possible that subsequent post-magmatic carbonatization of the massif influenced the differences in the compositions of amphiboles.

Experiments with 2M KF solution. In the products of these experiments, the formation of a noticeable amount of fluorite was observed, which, apparently, is due to the high concentration of F- ions in the fluid, as well as the acicular release of fluorine-containing phlogopite.
The conducted series of experiments showed the following results: The process proceeded at the high-temperature post-magmatic stage at a temperature of the order of 850 ° C. The salt concentration (KCl or KF) in the fluid with high-temperature post-magmatic changes in gabbroids of the Tiksheozero massif fluctuated within 1 M. At lower concentrations, the formation of amphiboles did not occur, at large concentrations phlogopite and fluorite were formed. One of the possible mechanisms for amphibolization of the Tiksheozersky gabbroids was the separation of volatiles upon subsequent introduction of alkaline rocks, namely, ijolite-urtites, which is indicated by the similarity of late-generation amphibole compositions in gabbroids, iyolite-urtites, and in samples obtained in the course of the conducted experiments. Thus, our data characterize the temperature and fluid formation of amphibole rims around the clinopyroxenes in the Tiksheozero gabbroids, and also shows that a complex of differentiated rocks of the massif could be formed as a result of a complex evolution of the heterogeneous fluid-magmatic system.

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