Khodorevskaya L.I. Diffusional interaction of haplogranite melt with amphibolite (experimental modeling).

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When host rocks (metabasites, metapelites) are assimilated by granites, their components transfer into a melt which becomes more or less saturated in the latters. Herewith, there form more basic (granodiorite, diorite or monzonite) endocontact facies of granitoids. Host rocks at the exocontact undergo silica-alkali metasomatosis (Korzhinsky, 1955). If a melt is oversaturated with mafic components, upon the rock interaction there occurs crystallization of minerals with excess, as compared to melt, components, the melt itself becoming leucocratic. Field irradiation at the contacts of granitoids with a host aluminosilicate rock reported in literature (Koptev-Dvornikov, 1953, Ponomarev, 1975,11978, 1990, Kotova, 1988 etc.) and experimental data (Ostrovsky, 1956, Letnikov et.al,1978, Johnston, Wyllie, 1988, Skjerlio, Patino Douce, 1995) show that at the contact of granitoids with metamorphic rocks with increased lime concentration hornblende, clino- and orthopyroxene, biotite, apatite, sphene are observed. Garnet, cordierite, biotite form at the contacts of granitoids with high alumina substratum.

The study of peculiarities of mineral formation in the endocontact regions lets us be aware of physical-chemical parameters characteristic of these processes: temperatures and pressures, water saturation of the system, as well as the characteristics of the substratum the magma interacts with.

This paper presents the results of the investigation of contact zones forming upon the interaction of amphibolite with preliminarily synthesized glass of haplogranite composition at 800-950°C and 7 kbar in the presence of the fluid H$_2$O, 0.2m HCl, 0.5 m KCl.

Experimental technique.

Experiments were run on the high gas pressure apparatus with internal heating using a quenching method. Starting materials were fine-grinded (5-20μ) amphibolite 13/2 and preliminarily synthesized glass of haplogranite composition. Amphibolite is formed by hornblende, biotite and plageoclase , accessories are sphene, magnetite. Composition of the starting rocks, experimental details and analysis results are given in (Khodorevskaya, Zharikov, 2001).

Table. Experimental parameters, composition of the fluid phase and main mineral associations at the contact.

№	№ run	T^o, C	P, kbar	wt%. fluid phase	main mineral associations a the contact
1	1D	800	7	12 % H$_2$O	Gl+Bt+Hbl
2	2D	800	7	13 % 0.2m HCl	Gl+Bt+Hbl
3	8E	900	6.7	5.9% H$_2$O	Gl+Bt+Hbl
4	9D	950	7	7% H$_2$O	Gl+Opx+Cpx?
5	8D	950	7	8% 0.2m HCl	Gl+Bt+Hbl
6	G/D	950	7	30% 0.5m KCl	Gl+Cpx
	2Ж	950	7	без H$_2$O	Gl+Hbl+Pl+Bt

After the experiments the samples were dense partially melted and then crystallized rock unequally colored dark grey. Amphibolite section of the sample was dark grey, starting synthetic granite after melting and consequent quenching turned colorless transparent glass, slightly grey in the vicinity of the contact, i.e. the contact itself remained visible. Changes in granite may be considered endocontact, apogranitic, and those in amphibolite related to the substitution of the edge part of amphibolite by a melt – exocontact ones.

The photos of the amphibolite-granite contact zones of the samples are presented in fig.1 a-d. Starting rocks practically are out of the picture and only a part of them can be seen (melted amphibolite to the left and granite glass to the right). Amphibolite-granite contact before the experiment is designated by a wide solid line. A microprobe study of the compositions of minerals and quenched glass was carried out on the profiles perpendicular to the contact (curves AA).

The pictures show that the contact zone (bold black line) is inhomogeneous: the amount of quenched glass (dark grey color) and mineral composition change along the lines AA.

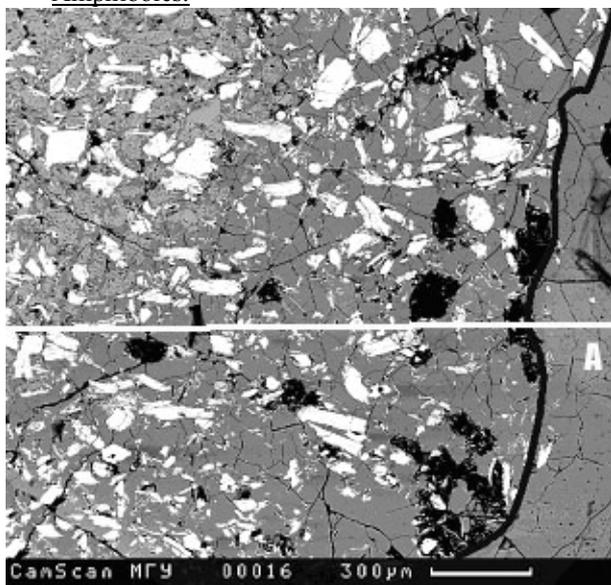The composition of mineral phases at the amphibolite-haplogranite contacts.

Biotite.

At 800°C in the near contact zone a mineral was registered both in purely water (sample 1D, fig.1a) and acidified (sample 2D, fig.1b) fluids. In size and chemical composition biotite is divided into two fractions: coarse crystals (Bt1 > 50 mkm) are preserved in the amphibolite area whereas small and rare ones (Bt2< 20 mkm) are observed at the near contact zone of each sample. Biotites of the first fraction contain somewhat more Al$_2$O$_3$ (1.44 form.un.) than the starting one (1.36 form.un.), iron concentration being fairly close (f= 43-46 %). Chemical composition of biotite of the first fraction remains practically constant from the contact to unchanged amphibolite. The coarse biotites are obviously borrowed from amphibolite because they do not differ in size and composition from the micas of the unchanged rock. Biotites of the second fraction have lower iron (f= 34-36%) and Ti contents. Al$_2$O$_3$ content in biotites of the second fraction in sample 1D is higher than in sample 2D (1.59 form.un against 1.44 form.un). Biotites of the second fraction have quite different composition and size. They most likely crystallized immediately from the melt.

In sample 8D (fig.1c) by contrast to samples 1D, 2D the near contact zone is marked pretty well because both needle and lamellar with 100 μ awns biotites are abundant there. Needle biotite is close in iron and alumina content to Bt1 of the previous samples and is likely to be a residual unmelted starting mineral. The central zone of a lamellar biotite is close in composition to Bi2 of the previous samples. The marginal zone – awns (Bt3) is more magnesian than central one. This is apparently due to the melting of the starting biotite and formation of Bt2 with increasing temperature (t= 650°C).

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At 950°C highly magnesian biotite was synthesized at the edges alongside with amphiboles. However, the formation of well marked magnesian biotite crystals was impossible because of the insufficient amount of magnesium in the melt. Thus, biotite composition and iron content in it reflect the following experimental temperatures: Bt1 – temperatures below 800°C, Bt2 = 800°C, Bi3 = 950°C.
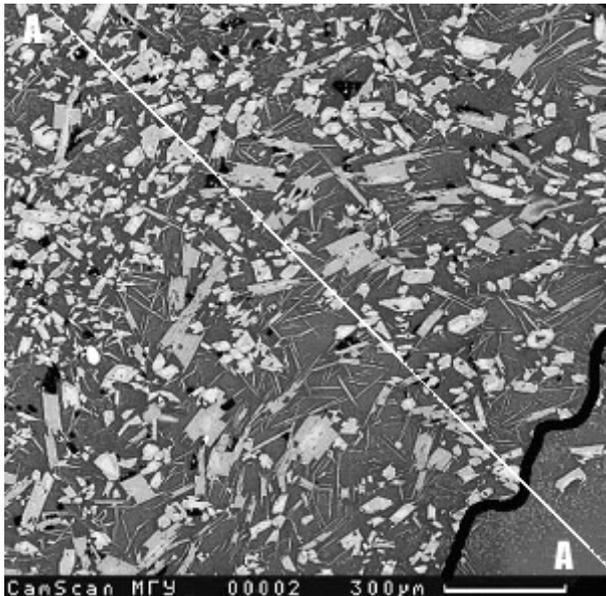
Amphiboles.

1D 800°C, H_2O

a)

2D 800°C, 0.2m HCl

b)

Fig.1. a-e. The general view of the contact zones of the samples.
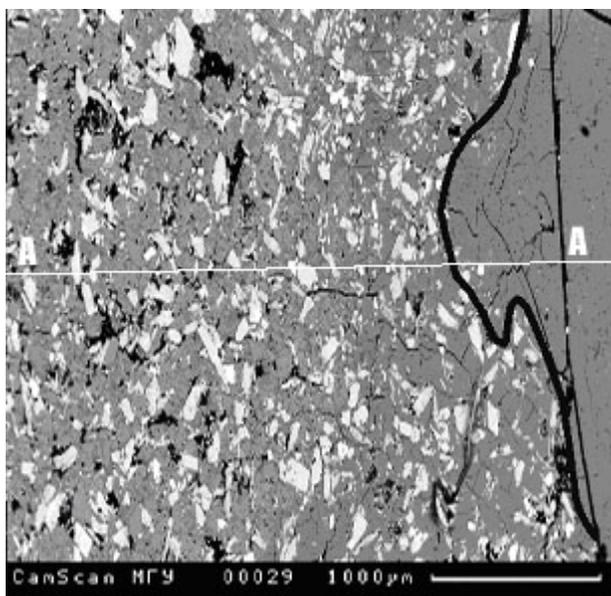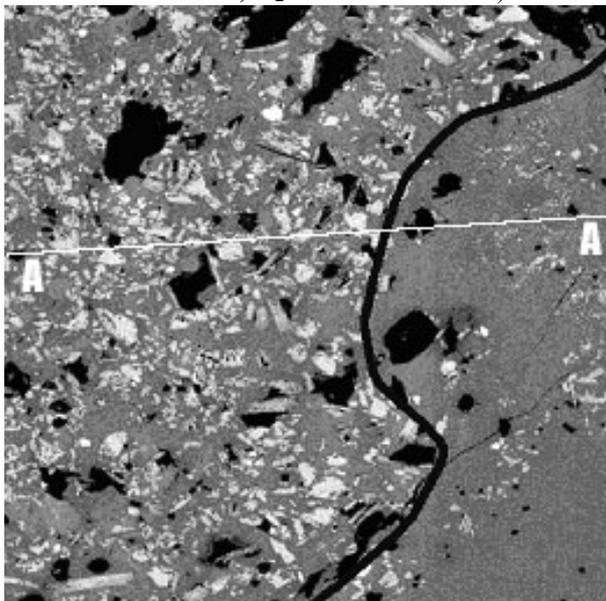
8D 950°C, 0.2m HCl   c)
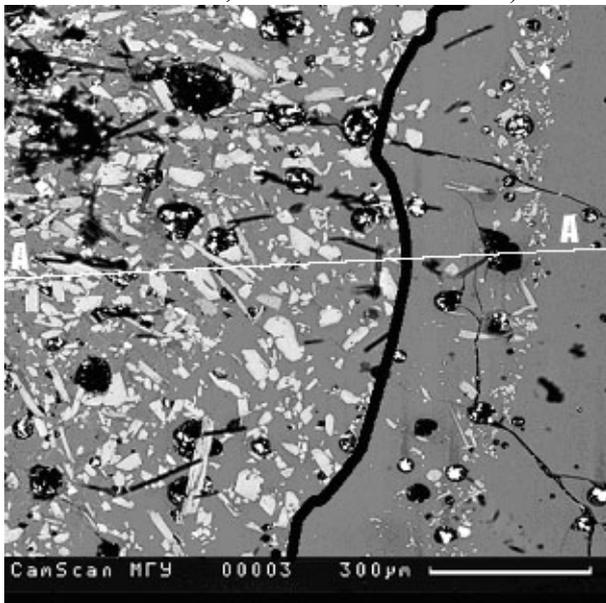
9D 950°C, H₂O   d)

G/D 950°C, 0.5m KCl   e)

According to Leak et al. (1977) starting amphiboles correspond to hornblendidte-oligoclase. They are detected in all the samples.

The size of amphibole crystals varies from several to 100μ. At 800°C amphiboles are not zonal and can be referred to hastingsite or pargasite with close iron content. At 950°C zoning of amphiboles is distinctive for all the samples. An edge part of crystals compared to a central one is enriched in titanium, alumina and alkalis, the Mg/Mg+Fe2+ratio increasing towards the edges. The very edge layer of the of grains (a micron thick) has a higher iron content than the rest of the edge. After acidification of the starting fluid the fe2+-fe3+substitution in sample 8D proceeds to a greater degree than in samples 9D and G/D. That is why paragsite forming in near neutral fluid at 950°C transforms into hastingsite due to an increase in acidity. As a whole it can be noted that hastingsite and pargasite amphiboles are characteristic of the granulitic facie (Korikovsky, 1967).

Pyroxenites. Pyroxenites develop at the endocontact at 950°C in the presence of a neutral fluid (H₂O, KCl). Glass and orthopyroxene were registered at the endocontact in sample 9D (fig.1d). However, a more careful analysis shows that clinopyroxene is also present in this zone. But the sizes of individual clinopyroxenes are so inessential that their composition cannot be determined by microprobe analysis. Orthopyroxene is enststite with iron content f=26%.

Glass and zonal diopside are registered at the endococntact in sample G/D (fig.1e). The alumina content grows from 0.06 up to 0.12 and magnesium content increases from 0.71 to 0.84 in the direction from the center to edge. Pyroxene is not practically found with moving away from the contact towards amphibolite.

Thus, clino- and orthopyroxe forms at the cocntact granite-amphibolite at high (=950°C) temperatures. Amphibole and biotite were marked at the contact of the two rocks at 800-900°C.

Distribution of major petrogenic elements in quenched glasses throughout the samples from unchanged granite to unchanged amphibolite.

Alkalis. Maximum contents of sodium and minimum of potassium are registered at the contact zones of quenched glasses at 800°C, an increase in acidity of starting solutions having no remarkable effect on them. At 950°C potassium content at the contact zone increases relative that of sodium, but potassium is uniformly distributed along the contact whereas sodium accumulates in the narrow near contact zone. The introduction of KCl into the system leads to the even distribution of sodium and a decrease of potassium content at the contact.

The above peculiarities of alkalis behavior are responsible for the type of melts at the contact zones: At 800-900°C the interaction of granite melt with high potassium amphibolite in the presence of starting water fluid results in the formation of trondhjemite fusions in association with amphibole and/or biotite. At temperatures above 900°C the fusions have more potassium granite composition in association with pyroxenite.

FeO. No essential changes in Fe and Mg content at the contact zone were observed in quenched glasses at 800°C. With temperature an increasing diffusion of

these components leads to their accumulation at the endocontact in the presence of both purely aqueous starting fluid and that containing HCl.

<u>CaO.</u> Ca is more intensively lost by host rocks at high temperatures than at relatively low ones. An insignificant increase in Ca content of glass connected with plagioclase melting in a host rock was mainly observed at the endocontact in aqueous fluid at high temperatures.

The dependence of contact column shape on the independent parameters.

The experimental study of the interaction of amphibolite with the melt of a preliminarily synthesized glass of haplogranitic composition at 800-950°C and 7 kbar in the presence of water fluid (Khodorevskaya, Zharikov, 2001) allowed to discover the following alterations of compositions at the contact of granite melt and amphibolite depending on temperature:

- at 800°C amphibolite debasification and partial melting take place, the associations characteristic of the amphibolite metamorphic facie being conserved. At the endocontact there form the melts of trondhjemite composition substituted by granodiorite-monzonite ones as the granite-amphibolite interaction weakens;
- at 950°C partial decomposition of starting amphiboles with formation of granulite paragenesis of clinopyroxene and pargasite takes place (the latter is certainly a more high temperature modification of amphibole compared to primary edenite. Hybrid granitoids at the endocontact are represented by charnockitoid (Opx-bearing) varieties. Herewith, a high-melting residue restite resulting from the simultaneous partial melting gets enriched in Mg and Fe, i.e. it becomes more melanocratic;

- an obvious high migration activity of alumina is most likely due to its transition into the melt (Zaraisky et al., 1986);
- balance calculations (Khodorevskaya, Zharikov, 2001) show that due to different-directed migration of componenets both from granite into amphibolite and vice versa at the formation 1m^{3} of granitoids by means of the substitution of 1m3 of biotite amphibolite by granite melt at 800-950°C there occurs the gain of 334-588 kg SiO$_2$, 53kg K$_2$O and the loss of 239-253 kg FeO, 122 kg MgO, 134-253 kg Al$_2$O$_3$.

The main difference between two samples is as follows: in sample 9D obtained at high (950°C) temperature (fig.1d) the endocontact is well shown as an interlayer of small orthopyroxene crystals (zone 2-100μ wide), and a 100μ wide band of pure quenched glass. This is a leucocratic zone whose appearance can be explained as follows. At high temperature the interaction of overheated granite melt with amphibolite leads to the assimilation of the latter by the melt. Herewith, it takes place the oversaturation of a melt by amphibolite components which results in crystallization of pyroxene containing excess components relative to the melt. While pyroxene crystallization the melt gets undersaturated in Ca, Fe, Mg and exists as a single leucocratic zone. Crystallization of pyroxene proceeds just from the melt and not upon quenching which is testified by well shown idiomorphic shape of crystals. At lower temperatures (800°C) the diffusion of elements from amphibolite leads to the crystallization of magnesian biotite from the melt.
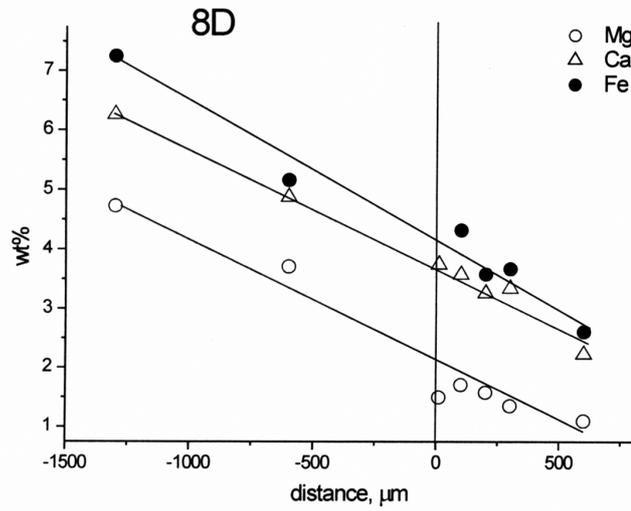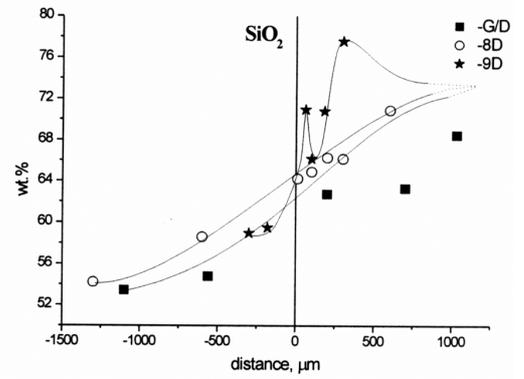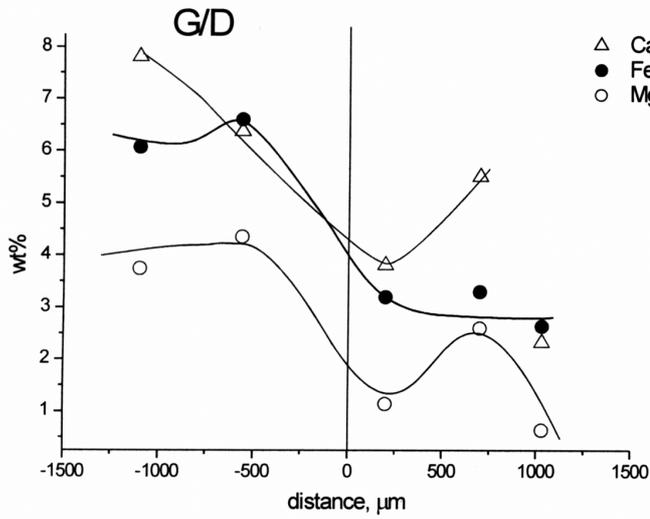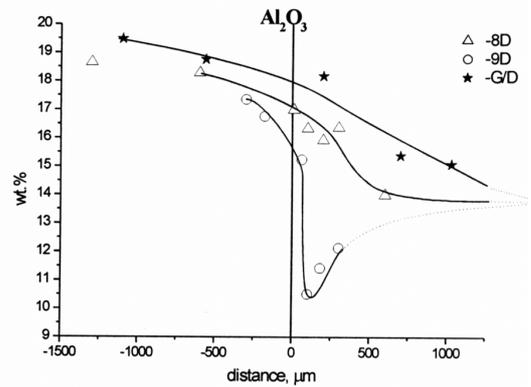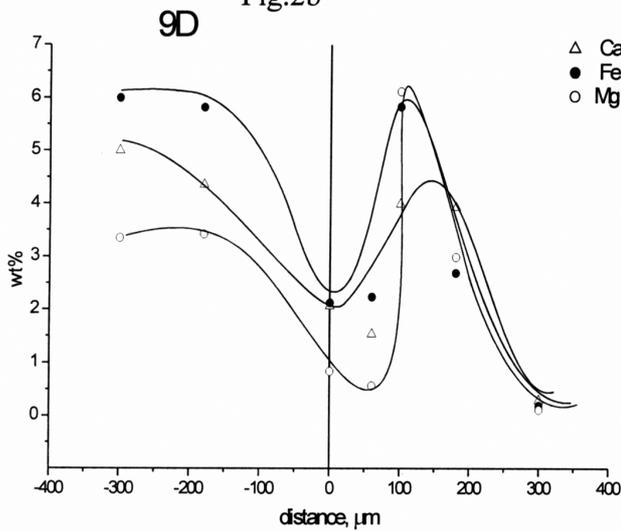
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Fig.2a

Fig.2b

Fig.2c

Fig.2d

Fig.2e

Fig. 2. a-h. Dependence of the bulk content of oxides at the near contact zone on fluid composition at 800-950°C.

The effect of acidity and composition of solutions.

The acidity and composition of solutions have an essential effect on the changes in the contact zone. This is explained by the fact that the velocity of component diffusion from amphibolite into granite melt depends on the viscosity of the melt. The viscosity in its turn is to a considerable extent controlled by the composition of the coexisting fluid phase. At 950^oC the viscosity of granite melt decreases in a series: 0.2mHCl (run 8D), 0.5 KCl (G/D), H_2O (9D). A decrease in melt viscosity produces an increase in the velocities of diffusion of amphibolite components into granite which is shown at the near-contact changes of the rock. Figs. 1a, 1b, 1c show that in the presence of HCl no endocontact changes are observed. In the presence of KCl the inhomogeneous discontinuous endocontact zone forms, whereas the presence of H_2O leads to the formation of a distinct endocontact zone. The acidity and composition of solution influence the bulk composition of the rock (melt+mineral) in the near-contact zones. Let us consider the changes in bulk composition across the contact in the samples in more detail.

In sample 8D at the dissolution of amphibolite in the melt the oxides forming the interacting rocks migrate with the same diffusion coefficients: CaO, FeO, MgO, Al_2O_3 (fig. 2a, 2d, 2c) from amphibolite into granite, SiO_2 from granite into amphibolite. The marked in the sample regular change of CaO, FeO, MgO, AlO_3 and SiO_2 concentrations across the contact stand for the merely diffusional interaction of two rocks.

In sample G/D (fig.2b) with additions of KCl in the starting solutions the distribution of Al_2O_3 and SiO_2 across the contact is similar to that in sample 8D. However, the distribution of CaO, FeO, MgO in the contact differs from the diffusional one and is characterized by individual lower than in sample 8D diffusion coefficients. This governs the appearance of the endocontact zone with clinopyroxene. It should be noted that this zone in the sample is slightly pronounced and in places is almost absent.

In experiments with pure water (9D) the stoichiometric ratio of all the components set by the interacting rocks is disturbed at the contact. So in the starting amphibolite the content of FeO>CaO>MgO whereas at the endocontact MgO>=FeO>CaO or CaO>MgO>=FeO i.e. migration activity of Mg increases essentially resulting in the precipitation of magnesian orthopyroxene. On the other side of the starting granite toward the contact the content of silica in glass grows up to the formation of about pure quartz melt (SiO_2 = 80 wt%) due to the loss of alkalis from granite. Thus, the distinctive feature of this sample is the absolute absence of the diffusional distribution of any oxides in the granite melt. As a result a distinct zone with pyroxene forms at the endocontact of sample 9D.

Conclusion.

Experimental study of amphibolite interaction with the melt of preliminarily synthesized glass of haplogranitic composition at 800-950°C, 7 kbar in the presence of a fluid (H_2O, 0.2m HCl, 0.5m KCl) suggested that alongside with partial melting the following transformations take place:

a) at 800°C the associations characteristic of the amphibolite metamorphic facie preserve;

b) at temperatures above 800°C amphibolite associations at the exocontact are replaced by the granulite ones;

c) the compositions of the present fluids assign the existence and thickness of the endocontact zone of granite-amphibolite interaction. Pyroxene forms at the endococntact at temperatures above 850°C, which attests that acidic components are absent in the composition of the fluid phase.

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