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Alkali-Metasomatites from the Polar Urals

By Oxana V. Udoratina[1]

THEME 8: Polar Urals, Novaja Zemlya and Taimyr: The Northern Connection of the Uralides

Summary: Rare-metal alkali (quartz-feldspathic) metasomatites are considered in terms of their geologic position, structure, and composition. Their petrochemical and geochemical characteristics are given. In the Polar Urals, the metasomatites occur as lenticular and tube-like bodies in the fault zones of the Cambrian basement within the Kharbey block. Three types of the metasomatites, dated at ~300 Ma, have been recognised: quartz-bifeldspathic (kvalmites), quarzt-albitic, and albitites. They belong to the formation of quartz-feldspathic metasomatites of the fault zones.

INTRODUCTION

Alkali, mostly rare-metal, metasomatites were first described from the Polar Urals in the sixties. During the past thirty years, they have been an object of many investigations providing insights into their nature (APELTSIN et al. 1967, GRYAZNOV et al. 1981, DVORNIKOV et al. 1981, YESKOVA 1976, KALINOVSKY 1988, 1988, 1992).

The Polar Urals metasomatites are found along the eastern margin of the East-European platform, in the faults crosscutting scarps of the basement (Precambrian blocks, microcontinents). The metasomatites are of quartz-albite-microcline composition and, according to standard classifications, belong to the formation of alkali metasomatites of the regional fault zones (GINZBURG et al. 1973, ZHARIKOV & OMELYANENKO 1978, ZHDANOV et al. 1983, Omelyanenko 1975, PLUSHEV & USHAKOV 1972, RUDNIK & TERENTYEV 1966).

GEOLOGICAL POSITION

The metasomatites are located in the Longotyugan transversal antiform structure in the Kharbey block (Fig. 1A). The metasomatite bodies occur either at contacts with granites or in their vicinity (Mount Taikeu, brook Magnetitovy in the Polar Urals), in enclosing schists. Occasionally, however, no spatial link to granitoids is observed. The parent rocks for the metasomatites are granitoids (O_1) and rocks of an ancient metamorphic complex (Nyarveysk PR_2nr). The granites are described as "synfolding" intrusions, a result of layer-by-layer penetration of melt along fractures and cracks (APELTSIN et al. 1967) as was the case for cracked plutons (MAKHLAYEV 1996). The granites occur as essentially gneissoid microcline varieties. The country rocks are represented by volcanics altered by greenschist metamorphism: albite-epidote-chlorite, albite-epidote-zoisite schists, and phyllite-like rocks. The slaty parent rocks underwent intense schist formation, cataclasm, and mylonitization; the granites were reworked by retrograde metamorphism. The metasomatite bodies are confined to the marginal parts of large gneissoid microcline granites but largely replace the enclosing green schists. The metasomatite/schist boundary is distinct and abrupt, while the metasomatite/granite transition is gradual. The metasomatite bodies vary in length and thickness; they have inherited the layer structure of the cataclasm and mylonitization zones (coinciding with the zones of metasomatism) and the directions of their dip. The metasomatites are observed as conformable elongated lenses alternating along strike and dip. According to APELTSIN et al. (1967), the metasomatite occurrence pinches out with depth. The distribution of the metasomatites in the parent rocks is shown in the cross sections (Fig. 1B-C).

Native elements:	Gold, copper, bismuth.
Tellurides:	Sylvanite, calaverite.
Sulphides:	Pyrite, pyrrhotite, chalcopyrite, sphalerite (Fe-sphalerite, Cu-sphalerite), galenite, chalcosine, bornite, famatinite, molybdenite, arsenopyrite, bismuthine.
Oxides:	Magnetite, alumospinelide, hematite, ilmenite, fergusonite, Ca-pyrochlore, Pb-pyrochlore, (Y-Pb-pyrochlore), U-pyrochlore, columbite, (Mg-columbite), tantalite, samarskite, ilmenorutile, loparite, thorianite, cassiterite.
Hydrous oxides:	Limonite.
Silicates:	Quartz, albite (oligoclase), microcline, muscovite, Fe-muscovite, phengite, (Fe-muscovite-phengite, Fe-muscovite-Fe-phengite), muscovite-zinnwaldite, biotite, lepidomelane, actinolite, glaucophane, hastingsite, riebeckite, aegirite-augite, aegirite-jadeite, acmite, amesite-magnesium-prochlorite, diabantite-Fe-pyrochlore, thuringite-stilpnomelane, epidote, zoisite, clinozoisite, allanite, (chevkinite), sphene, garnet, topaz, kyanite, zircon (malacon), thorite (auerlite, Fe-thorite, U-thorite, U-Fe-thorite), beryl (aquamarine), gadolinite, phenacite, genthelvine, epididymite.
Phosphates:	Apatite, monazite, xenotime.
Tungstates:	Scheelite, wolframite, ferberite.
Carbonates:	Calcite, dolomite, ankerite, TR-F-carbonate, malachite, cerussite.
Halogenides:	Fluorite

Tab. 1: Compilation of minerals of the rare-metal alkali metasomatites

[1] Institute of Geology, Komi Science Centre, Uralian Division of the Russian Academy of Sciences, Russia

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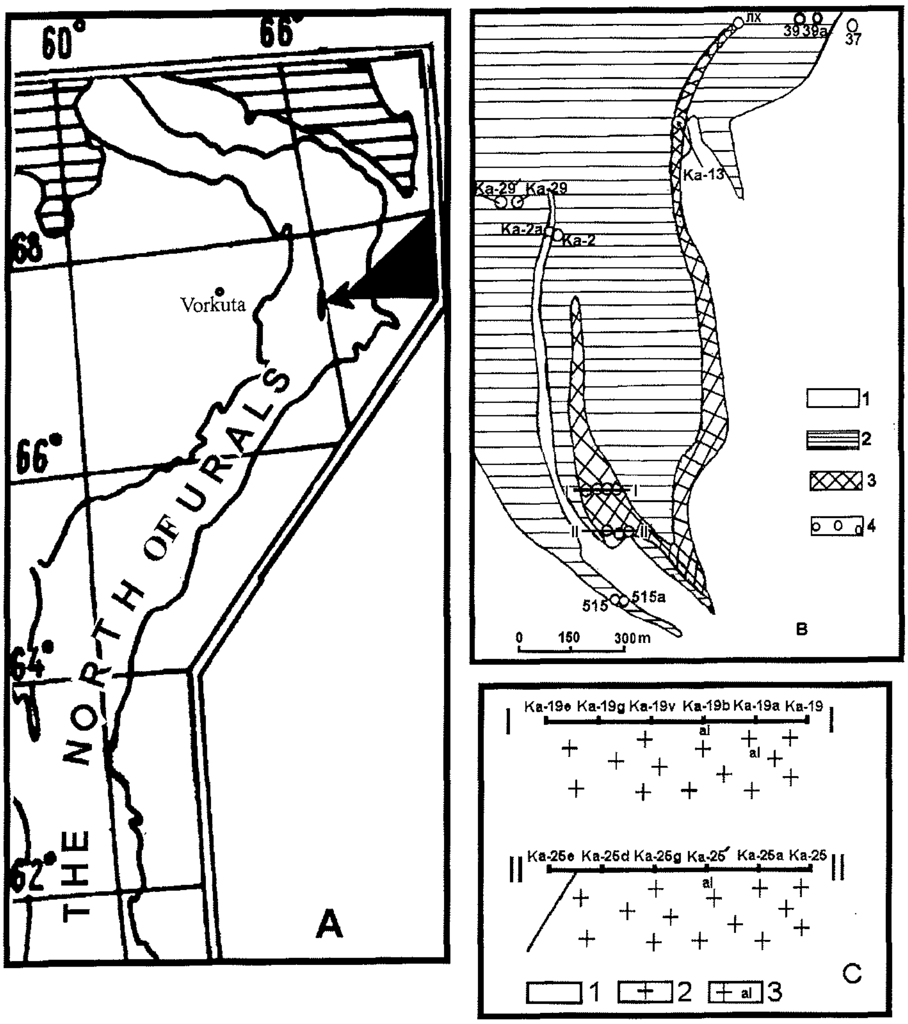

Fig. 1: A) Areas with alkali metasomatites in the Polar Urals.
B) Sampling points in quartz-microcline-albite metasomatite areas in Taikeu. 1 = schists; 2 = granitoids; 3 = granitoid rare-metal metasomatites; 4 = sampling point.
C) Profile I–I, II–II. 1 = schists; 2 = granitoids; 3 = granitoid rare-metal metasomatites.

STRUCTURE AND COMPOSITION

The alkali metasomatites are weakly gneissoid, of leucocratic composition (light-coloured, light-grey, pink, cream-coloured) and submassive texture. The rock textures are variable depending on the mineral content: the most common ones are grano- and heteroblastic, cataclastic, and blastogranitic with abundant splitting and folding. Lepido- and nematoblastic textures are observed where secondary dark-coloured minerals are abundant.

The major minerals are plagioclase, potassium feldspar, quartz, and muscovite. Rock-forming, accessory, secondary, and ore minerals are listed in Table 1.

The evolution of the metasomatism is reflected in the transition from the earlier to younger parageneses: albite - relict (in inclusions) (Fig. 2a, b), lath-like of two generations, chessboard (Fig. 2c, d), laminar (Fig. 2e, f); microcline - of pertitic and clearly latticed textures; the group of alternating mafic minerals - pyroxenes, amphiboles, micas.

The parent rock composition, with its tendency to variation, is the determining factor for the kvalmites. The composition of fluids and duration of the process are of lesser importance. New generations of rock-forming minerals inherit structural and, frequently, compositional peculiarities of the altered rock. At first glance, however, the metasomatites seem to be devoid of such features. Yet, a detailed petrochemical investigation has revealed several generations of minerals, both relict (inherited) and newly formed. Thus, studying the structure and texture of the rocks (as least subject to alteration), one can understand stages of the process, as they are manifested in the change of mineral generations.

Two typical features of the alkali metasomatites in the Polar Urals (derived from granites or mixed parent rocks) are (i) relative stability of the quantitative proportions of the major rock-forming minerals (quartz, albite, and microcline) and (ii) great thicknesses (to 200 m) of the bodies. Another distinctive feature of the rocks is their «complexity», or polymineralic composition in relation to rock-forming minerals. Even in the most affected back zone, albite accounts for more than 50 %, that's why these rocks have been referred to as albitites. Because the metasomatites universally comprise quartz, microcline, and albite, they can be described as granite-like. The common tendency of metasomatites to form monomineral zones is seldom observed here. That is why these rocks are mistaken for granites, even their names, "granitoid", "granite-like", suggest difficulties in determination. Coexistence of two minerals, albite and microcline, is a characteristic feature of this group of metasomatites (in literature, such a paragenesis is described as possible in case one of the minerals (K- or Na-bearing) behaves as an inert (inactive) one (OMELYANENKO 1975).

The typical mineral content of this type of metasomatites is: quartz 20-25 %, albite 25-30 %, microcline 30-40 %, mafic minerals 5-15 %. The chemical and geochemical compositions of the metasomatites are reflected in Table 2.

Compared to the kvalmites, the quartz-albite metasomatites and albitites are enriched in Na_2O, TiO, LREE more than HREE, Ba, Sc, Sb, Ta, U and depleted in MgO, K_2O and F, Rb, Sr, Cs, Cr, Zn, Au, SiO_2 and Al_2O_3 concentrations remain the same during the entire process. The alternating supply or wash away tendencies are typical for MnO, CaO, CO_2 and Co, Ni, Se, Hf, Zr, Ag. Concentrations of two- and three-valent iron, La and Lu, As, Th fluctuate around the initial value.

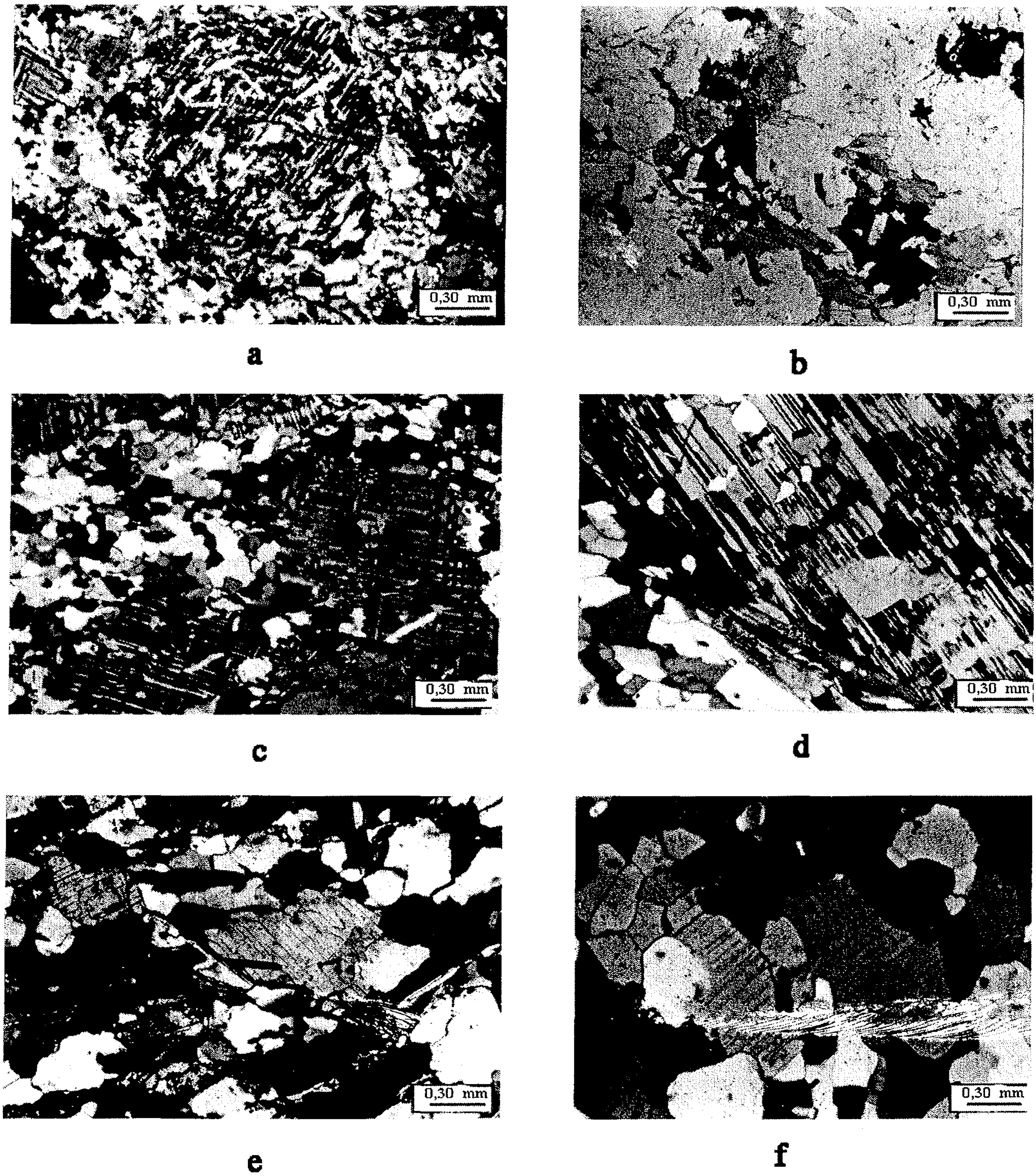

Fig. 2: Examples of rock textures in the metasomatites. (a) lath-like albite of generation I; (b) lath-like albite of generation II; (c) and (d) chess-board albite; (e) and (f) laminated albite.

	Metasomatites																		Parent rocks			
	Kvalmites								Quartz-albite				Albitites						Schists			
	Ka-19g	Ka-25	Ka-25a	Ka-25g	T-39a	T-515	Ka-19w	Ka-19e	T-515a	Ka-25'	Ka-29	Ka-29'	T-39	Ka-19b	Ka-2	Ka-13	Ka-19a	LX	Ka-2a-90	Ka-25e-90	T-37-90	
SiO2	73,7	72,54	71,96	74,42	77	75,14	76,8	72,32	64,03	80,82	76	71,7	81	73,46	75,64	76,86	73,74	79,04	56,72	58,26	60,4	SiO2
TiO2	0,04	0,04	0,04	0,13	0,1	0,06	0,05	0,04	0,64	0,05	0,02		0,1	0,04	0,12	0,05	0,07	0,13	0,52	0,52	1,14	TiO2
Al2O3	13,24	12,92	15,08	13,57	12,4	12,84	11,57	13,57	16,66	9,46	12,23	11,6	10,3	13,57	13,96	13,24	14,52	11,86	17,35	14,52	16,8	Al2O3
Fe2O3	0,53	0,57	0,57		0,27	0,98	0,69	0,53	3,51		1,57	6,8	0,1	1,13	0,2		0,37	0,65	1,89	0,6	0,7	Fe2O3
FeO	1,58	0,72	1,29	1,44	1,7	0,89	1,15	2,16	1,5	1,29	1	1,58	1,44	0,86	1,16	1,44	0,86	0,86	4,32	5,18	7,2	FeO
MnO	0,04	0,03			0,08	0,007	0,03	0,06	0,11		0,06	0,06	0,08	0,03	0,02	0,04		0,03	0,12	0,1	0,2	MnO
MgO	1,13	0,16	0,97	1,29	0,48	0,28	0,87	1,45	0,65	0,32	0,4	0,32	0,32	0,97	1,62	0,32	0,4	0,4	4,05	2,59	3,45	MgO
CaO	0,24	3,14		0,48	0,18	0,39	0,12	0,72	1,85	1,45	0,24	0,24	0,24	0,48	1,1	0,48	0,36	0,36	4,59	4,84	0,48	CaO
Na2O	4,24	3,74	3,88	3,5	3,5	3,6	4,24	4,5	5,25	3,62	4,64	4,32	3,3	5,72	6,11	6,14	6,14	6,12	3	3	2,24	Na2O
K2O	3,53	4,2	5,16	3,94	4	4,85	3,27	3,11	3,76	1,63	3	2,28	3	2,72	0,12	0,4	2,31	0,22	3,81	2,98	3	K2O
LOI	0,3	0,79	0,39	0,38	0,4	0,87	0,28	0,67	1,53	0,04	0,2	0,25	0,15	0,07	0,15	0,16	0,09	0,27	1,44	3,37	3,3	LOI
P2O5	0,12	0,12	0,15	0,15	0,12	0,01	0,09	0,12	0,18	0,15	0,03	0,18	0,06	0,12	0,03	0,15	0,12	0,05	0,37	0,33	0,33	P2O5
H2O-	0,12			0,06			0,12	0,12	0,06					0,22		0,1	0,52		0,06	0,08		H2o-
CO2	0,53			0,35		0,12	0,14		0,24	0,78	0,14	0,14	0,35	0,14	0,21	0,17			1,07	3,18	0,7	CO2
F	0,39	1,2	0,16	0,05			0,31	0,5		0,04	0,06	0,07		0,19	0,02	0,02	0,07		0,36		0,08	F
S	0,02												0,02	0,02		0,02				0,07		S
Sum	99,75	100,17	99,65	99,76	100,20	100,04	99,73	99,87	99,97	99,65	99,59	99,54	100,46	99,74	100,46	99,59	99,57	99,99	99,67	99,62	100,02	Sum
La	9,2	4,28	6,52	7,84	9,7	49,4	20,3	4,37	56,3	22,8	54,4	0,87	10	12,3	25,1	19,2	7,9	8	22,5	23,3	21,5	La
Ce	25,9	11	18,1	18,6	24,5	103	53	15,8	114	50	129	1,95	26	32,2	57	59	27,5	17,7	49	49	42,1	Ce
Pr	4,1	1,7	3,02	2,62	3,5	12,1	7,91	3,28	14	6,62	16,8	0,26	3,6	4,8	6,1	11	5,1	2,28	5,8	6,1	5	Pr
Nd	22,7	8,55	17,6	12,9	18	50,2	41,4	23,9	60	30	75,5	1,18	18,9	24,6	22,3	71	32	10,5	22,3	26,6	20	Nd
Sm	8,36	2,93	6,46	4	5,7	14,3	14	11,7	16,7	8,95	23,6	0,37	5,8	8,53	5,5	31	10,9	3	6	7,6	5,1	Sm
Eu	0,03	0,12	0,08	0,2		0,37	0,041	0,068	3,78	0,12	0,01	0,26	0,1	0,16	0,3	1,1	1,5	0,6	1,9	1,35	0,9	Eu
Gd	16,1	8,8	14	4,5	4,3	17,8	25,1	22,3	18,6	13,3	44,9	1,7	4	19	5,1	35,5	10	3,55	6,9	9,91	6,4	Gd
Tb	2,88	1,91	2,72	0,9	0,75	2,67	4,5	4,1	2,66	2,22	7,8	0,5	0,69	3,7	0,88	6,8	1,9	0,6	1,11	1,5	1,02	Tb
Dy	19,9	15,8	20	7,5	5,2	15,4	30	28,5	14,5	14	52,5	5	4,8	27,4	5,9	46	12,6	4,1	7,2	8,57	6,4	Dy
Ho	5,1	4,97	5,51	2,08	1,4	3,5	7,65	7,51	2,98	3,57	13,6	2	1,2	7,44	1,51	12,5	3,3	1,02	1,7	1,86	1,5	Ho
Er	16,8	19,8	19,3	8	4,7	9	24,3	25	7,5	10,2	45	10	3,9	25,5	4,9	40,1	10,1	3,15	5,3	5,1	4,4	Er
Tm	2,96	4,15	3,61	1,58	0,8	1,33	4,23	4,54	1,04	1,68	7,34	2,65	0,62	4,9	0,83	7,4	1,87	0,52	0,85	0,71	0,68	Tm
Yb	18,2	33,8	25,6	11	5	6,97	27,2	30	5,1	9,91	48,1	27,5	4,1	34,2	5,3	50	11,3	3,2	5,25	4	4,2	Yb
Lu	3,65	7,8	5,17	2,65	0,96	1,18	5,07	5,8	0,79	1,74	9,3	8	0,71	6,82	1,01	8,9	2,2	0,58	0,94	0,62	0,72	Lu
Rb	2346,8	2583,9	3226,5	270	180	171,1	1468,5	1823,9	102,8	448,1	1319,9	1247,7	140	1207,3	21	430	1770	-	950	323	86	Rb
Cs	28	12,5	21,8	1,32	2	0,65	14,7	23,1	2,67	5,45	4,75	6,72	0,97	23,4	0,18	3,3	11,5	0,18	12,2	4,31	2,92	Cs
Sr	-	930	330	200	24	160	985	-	16	10	73	515	59	52	300	400	120	60	49	120	210	Sr
Ba	610	420	535	360	190	460	10,25	1185	2110	420	870	725	230	1600	400	100	180	150	290	845	980	Ba
Sc	0,48	0,31	0,47	1,5	0,56	0,95	0,31	0,34	13,8	0,28	0,22	0,39		0,27	1,6	0,3	0,16	2	16	19,8	19,1	Sc
Cr	33	37,4	50,9	29,5	35,4	8,16	40,6	59,8	6,23	30,5	35,3	35,1	20,8	29,5	4,5	0,5	10,8	20,2	22,2	61	74,3	Cr
Co	2,3	0,8	1,05	1,13	0,27	0,79	1,5	1,13	3,49	1,38	0,8	1,05	0,39	1,32	0,24	1,93	0,7	0,28	12,4	15,4	0,52	Co
Ni	160	-	720	-	6	110	-	140	210	230	-	350	26	450	7	-	-	8	36	440	150	Ni
Zn	2600	1320	2070	-	24	320	1550	2430	170	700	80	630	7	1350	-	-	11	-	-	300	-	Zn
Se	11,5	27,5	33,8			4	17,7	11,6	6,6	8,2	18,5	35,2	-	27,7	-	-	-	-	-	8,1	-	Se
As	37,5	28,7	20	5	18,4	10,7	9,34	12,2	13,6	11,7	20,4	34,7	5	14,2	32,7	61,8	6,9	37,3	5	27,4	21,6	As
Sb	2,31	0,2	1,13	1,5	0,76	0,76	0,24	2,75	0,52	1,82	7,7	4,23	0,2	1,74	2,88	3,3	0,8	1,94	0,71	0,78	0,2	Sb
Th	191,6	516,2	402,8	12,8	24,6	13,5	151,2	333,2	105	64,8	456	677,7	16,3	144,1	20,9	655	133,8	22,4	10,9	7,2	9,9	Th
U	81,6	74,4	6,65	12,5	10,8	1,32	47,7	75,4	3,64	39,9	360	48	7,1	31,3	4,6	255	13,4	4,7	9,7	14,3	1,4	U
Br	0,07	0,07	0,14	0,07	0,69	0,02	0,01	0,03	0,07	0,04	0,02	0,03	0,12	0,03	0,46	0,32	0,1	0,04	0,58	0,05	0,05	Br
Hf	57,8	244,5	156,8	3,1	10,7	4,94	57,4	94,4	18,7	23,5	228,4	237,3	10,6	52,2	4,2	136	31,9	4,43	2,4	3,81	3,4	Hf
Ta	59,3	186	135,2	1,4	2,03	0,9	34	85,5	1,59	21,6	166,5	158,1	1,59	40,4	1,57	720	14,6	1,38	1,54	1,37	1,12	Ta
Zr	550	2100	1350	105	125	50	330	700	420	170	2300	1800	190	290	24	1350	75	86	160	230	45	Zr
Au, ppb	-	0,24	-	0,04	0,02	-	-	-	-	-	0,035	-	0,02	-	-	-	-	0,01	0,03	-	0,03	Au
Ag, ppb	-	-	-	--	-	-	-	-	-	-	3,9	1,6	-	-	-	-	-	-	-	-	-	Ag

Tab. 2: Main elelemt (%) and trace element (ppm) compositions of the metasomatites and parent rocks

Decreasing potassium content is balanced by increasing sodium proportion. Mineralogically, it is expressed in the lowering of the amount of potassium and iron-magnesium minerals, namely microcline and dark-coloured minerals.

CHARACTERISTICS OF THE METASOMATISM

Distribution of the mineral and elemental patterns in the zones of the (summary) metasomatic column based on petrographic and chemical data can be given as follows:
Zones of the column
0 - altered granite (Q+Mi+Ab+mafic);
1 - quartz-microcline-albite metasomatite (Q+Mi+Ab+mafic), where (Q+Mi+Ab, Mi >20 %);
2 - quartz-albite metasomatite (Q+Ab), where (Q+Mi >>Ab, Mi <20 %);
3 - albitite (Ab), where (Ab >50 %).

Strictly speaking, albitites are quartz-microcline-albite metasomatites (because they, too, contain potassium feldspar), but this further subdivision was possible on the basis of microcline proportions. Patterns of elements are observed at the following stages: 1) early alkaline (potassium); 2) late alkaline (sodium); 3) silicium-sodium; 4) fluorine-silicium.

The origin of such rocks can be approached in terms of the evolution of the fluid; the main question, however, is the origin of the fluid itself: it will allow an understanding of the source of the mineralization.

CONDITIONS OF FORMATION

The origin of the granite-like metasomatites may be ascribed to the action of transmagmatic solutions from which the metasomatic granites were deposited. Yet, the metasomatites in the areas under study occur in rather narrow tectonically active zones: in conjugation zones of asynchronous rocks or in fault intersection zones. The metasomatites were produced from rocks of different metamorphic grades that underwent dynamic and retrograde reworking. Solutions responsible for diffusional and infiltrational alterations must have been of a composite nature: together with juvenile sublimates (transmagmatic solutions, or granite-forming fluids) they must have comprised metamorphogenic fluids. The deep (juvenile) origin of the solutions is indicated by their O_2 isotope composition (KALINOVSKY 1988). A metamorphogenic source seems obligatory because the metamorphic grade corresponds to the epidote-amphibolite and greenschist facies, which means that the rocks are not necessarily dehydrated and contain not only water-bearing minerals but free water as well. That the rocks were heated is considered certain, as it is suggested by the high plasticity of the metasomatites at the early stages of their alteration, the resultant parageneses, and the chemical composition of the minerals. The metasomatites formed at variable temperatures, but the general tendency for the temperature was to fall from 500-550 °C down to 250-200 °C.

Tectonic processes (brecciation, mylonitization) also played an important part: they produced zones with freely circulating fluids that favoured heating and transport as well as zones of fluid dischargement, where certain components precipitated.

Two points should be emphasized in relation to the kvalmites: the area of their occurrence is confined to the zones of meridional and sublatitudinal rapture distortions. Their parent rocks were affected by cataclasm and mylonitization, and the initial stage of the metasomite formation was synchronous with the still continuing movements, which is suggested by synkinematic and paracrystallizational deformations. Formation of the metasomatites was completed under quiescent conditions indicating that both the parent rocks (granites, amphibolites, schists) and the metasomatites were formed over long periods of time.

What is the source of rare metals in the kvalmites? Is it linked to the type and genesis of the fluids or the type of the parent rocks? Acid quartz-feldspathic (or quartz) rocks acted as a geochemical trap, in which alkali-halogen complexes of rare metals decomposed. It can take place when fluids pass through granitoids. If these rocks are absent, then a period of "pre-ore" metasomatism is necessary, feldspar alteration of basic schists to achieve some minimal sum of quartz + albite + microcline (KALINOVSKY 1988).

The Rb-Sr age of the alkaline metasomatism is determined as 300 ±20 Ma (KALINOVSKY 1988, KALINOVSKY & IGNATOV 1987).

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