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THE PETROCHEMICAL EVOLUTION OF BASIC GRANULITES IN TECTONIC NAPPES (THE COLA PENINSULA, U.S.S.R.)

(Figs. 2, Tabs. 2)

Abstract: A rock association represented by granite-gneisses, garnet amphibolites, anorthosites, eclogites, basic and acid granulites is quite common in the NE Baltic Shield, Lapland. It has been established that the subhorizontal structure of these complexes is related to the thrusting of deep-seated granulite rock masses upon the Precambrian granite-gneisse basement. Garnet amphibolites are polygenic tectonised rocks of the thrust basement after primary rocks of two types: basic granulites and porphyrites from the Late Archaean greenstone belts that had been involved into the process of thrusting. Anorthosites mark the planes of maximum displacements and, in some cases, are of indisputed crustal autochthon origin. Geochemically, acid granulites confined to the upper parts of the nappes can be considered as a kind of facial analogues of granites that were formed under compression. Chemical changes in the matter of the rocks of tectonic nappes followed a certain tendency that was reflected by the redistribution of elements: most of trace elements were dejected from the rear zones in the thrust plates and accumulated in the frontal ones, with Na, SiO_2, Ba, Zr, Rb and Sr being introduced from great depths.

Резюме: На северо-востоке Балтийского щита, в Лапландии, широким распространением пользуется ассоциация пород представленная: гранито-гнейсами, гранатовыми амфиболитами, анортозитами, эклогитами, основными и кислыми гранулитами. Установлено, что субгоризонтальная структура этих комплексов образована в результате надвига глубинных гранулитовых масс на докарельский гранито-гнейсовый фундамент. Гранатовые амфиболиты являются полигенными тектонизированными породами основания надвига и образованы по исходным породам двух типов: основным гранулитам и порфиритам позднеархейских зеленокаменных поясов, вовлеченным в надвигообразование. Анортозиты маркируют плоскости максимальных перемещений и в ряде случаев имеют несомненно коровую автохтонную природу. По геохимическим особенностям кислые гранулиты, приуроченные к верхним частям покровов, являются своеобразными фациальными аналогами гранитов сформированными в обстановке сжатия. Химическая направленность процессов преобразования глубинного вещества в тектонических покровах заключается в перераспределении большинства рудных и петрогенных элементов, которые выносятся из тыловых зон и накапливаются во фронтальных частях надвиговых пластин, при глубинном привносе: Na, SiO_2, Ba, Zr, Rb, Sr.

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tectonics. The problem presents a certain difficulty as it is not always possible to find direct analogues in recent geology. It primarily concerns the processes of formation of linear belts of deeply metamorphosed rock series of granulite and amphibolite facies metamorphism. The rocks of these belts had undergone a tectonic reworking of an extraordinary long duration over I Ga mostly under the regime of high P-T conditions. Therefore, these belts are looked upon as favourable objects to study the Early Precambrian structural and rock-forming processes.

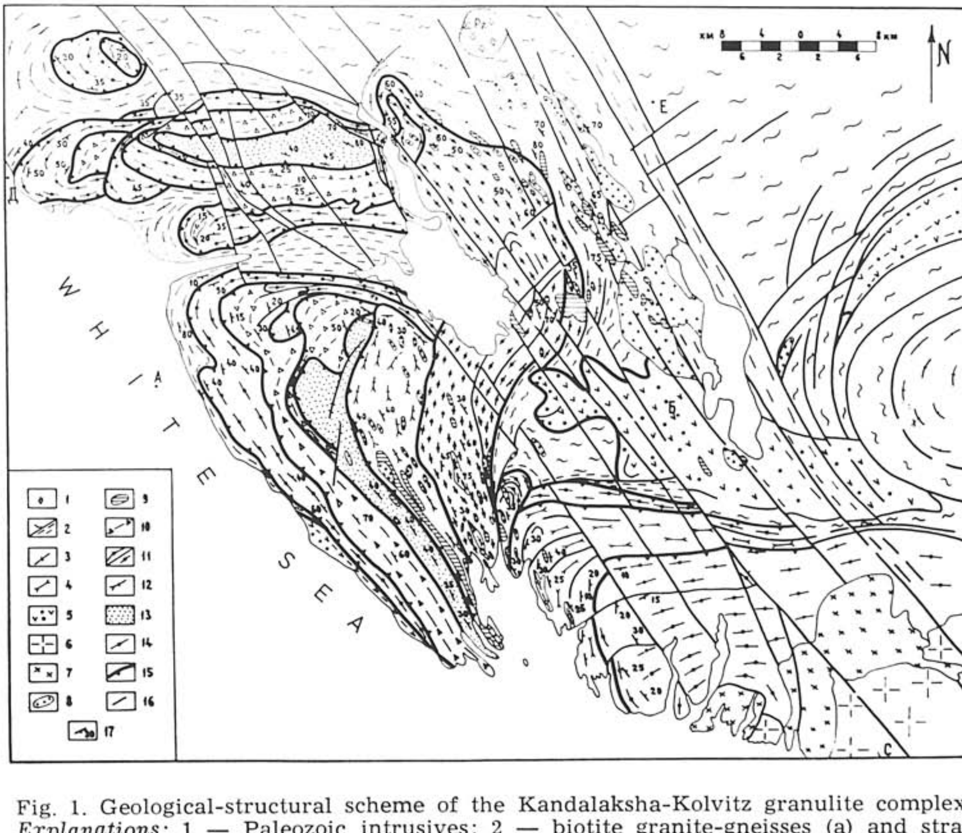

Fig. 1. Geological-structural scheme of the Kandalaksha-Kolvitz granulite complex. *Explanations:* 1 — Paleozoic intrusives; 2 — biotite granite-gneisses (a) and stratified migmatites-blastomilonites (b); 3 — biotite-amphibole granite-gneisses bearing high-pressure relics; 4 — hypersthene granulites; 5 — supracrustal Late Archaean complex represented by porphyrites, gneisses, calciphyres, conglomerates; 6 — the Umba rapakivi-like granites; 7 — enderbites; 8 — microcline and alkali granites; 9 — mafic and ultramafic intrusives; 10 — anorthosites; 11 — garnet amphibolites: foliated polygenic ones (a), more massive diaphthorites after basic granulites (b); 12 — two-pyroxene granulites; 13 — eclogites; 14 — acid granulites, high-alumina gneisses are rare; 15 — main faults and thrust planes; 16 — faults; 17 — strike and dip.

The Lapland-Belomoridic belt located in the east of the Baltic Shield is a geological structure of the above said type. This paper deals with one of its fragments — the Kandalaksha-Kolvitz structure. The geological structure and main types of magmatic, metamorphic and metasomatic rocks of this geological object have been thoroughly described in numerous publications (V i n o g r a d o v—B o g d a n o v a—Y e p h i m o v, 1980; P r i y a t k i n a—S h a r k o v, 1979; K r y l o v a, 1983; B e l y a e v, 1981 and others).

We have been carrying out structural-petrogeochemical investigations in this area for several years with the aim to understand better the evolution of the petrogenetic processes. The Kandalaksha-Kolvitz structure is a system of tectonic nappes composed of basic granulites and ultrabasic intrusives of various me-

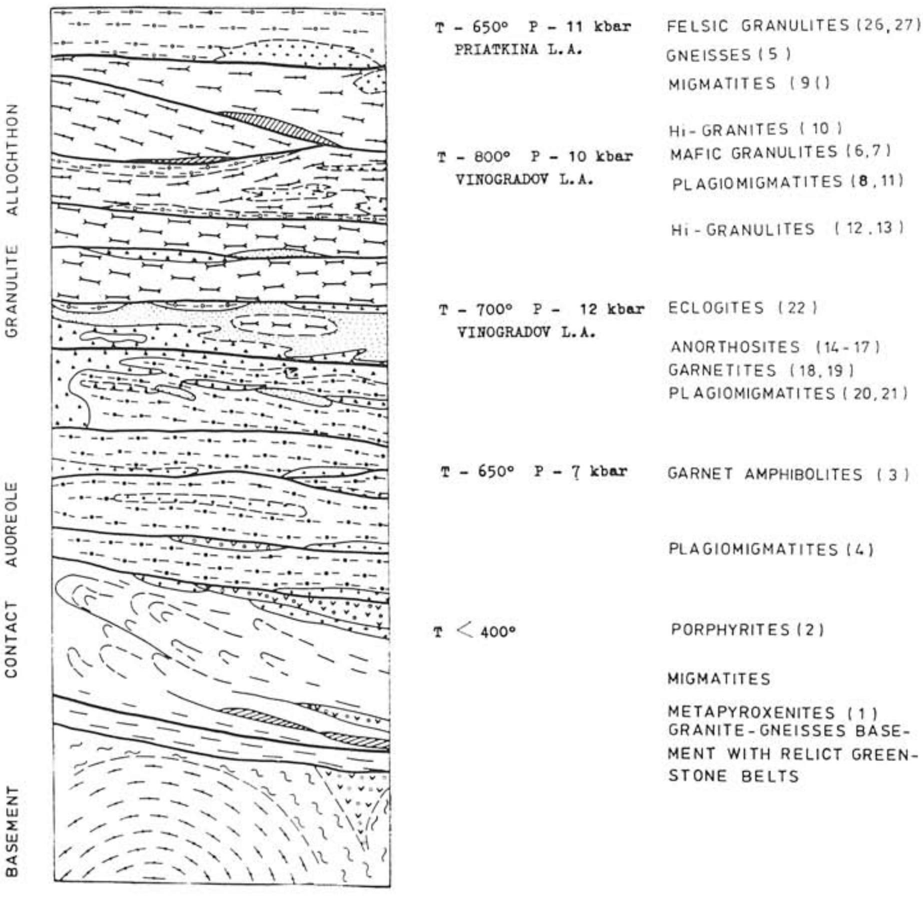

Fig. 2. Schematic presentation of the "cross-section" of the Kandalaksha-Kolvitz granulite complex.

Explanations: Symbols are the same as in Fig. 1. The numbers of the analyses are given in Tab. 1, 2.

tamorphic grade. It has been established that the rocks that were metamorphosed under the conditions of granulite facies are thrust upon the migmatite-granite complex of the basement, garnet amphibolites being formed at the base of the nappe (Fig. 1). At the surface, a series of nappes can be observed as flat cuplike synforms. The central parts of them are composed of rocks that were metamorphosed under the conditions of granulite facies at moderate and high pressures (The Granulite Facies, 1972), eclogite-like rocks and gabbro-anorthosites; the marginal ones are built by garnet amphibolites and migmatites. The rocks of the granulite facies are exposed as flat-lying horizons that armour the summits of major mountains that dominate over the smaller hills of the marshy arctic prairies. The migmatite-granite basement can be observed at the base of the hills and is overlain by "contact aureole" composed of tectonically altered rocks of the nappe's basement and of basic granulites of the nappe itself (Fig. 2).

Migmatite-granite basement

The migmatite-granite (granite-gneiss) basement is characterised by isometric dome features from 5 to 60 km in size (T e r e k h o v, 1982). The basement itself is built by rocks of at least three genetic types. The first group is constituted by biotite, biotite-amphibolite migmatites which include relics (skialiths) of older rock associations represented mostly by basic granulites that were metamorphosed under the conditions of granulite facies at moderate pressures. The rocks of the second group can be encountered in the nappes of dome structures. They are composed of faintly foliated massive granite varieties: granites, charnokite-enderbites, shadow migmatites. Rootless bodies of basic and ultrabasic composition — drusites — are widespread there as well. Geological mapping indicates that there are occasional occurrences of volcanic-sedimentary rock series in the fringes of the domes. They are encountered as separate fragments of irregular shape from I to tens of kilometers in size and are represented by slightly granitized basic metavolcanites, gneisses, conglomerates, marbles. These fragments can be correlated with those of the Late Archaean greenstone belts in Karelia (The Evolution . . . , 1984) and Central and Northern Finland (C a a l, 1978; B a r b e r y, 1980). Metamorphic changes in the rocks of this dome structure followed a certain tendency which revealed itself in the sequential character of their alterations: granulites-plagiomigmatites-shadow migmatites-granitoids. The radiometric age of zircon seems most reliable and dates the process of granitization back to 2.8—2.7 Ga (Magmatic . . . , 1985).

Contact aureole

Metamorphites that were formed under high P-T conditions are known to be present in the nappe basement of the thrust faults of subduction zones. These metamorphites are thought to belong to the rocks of contact aureole (C o l e m a n, 1979). Assuming, the Lapland granulite complex is the analogue of the cited geological features, we infer that the member of altered rocks underlying the former refers to the rocks of contact aureole on these grounds. Contact aureole is actually a zone of viscous flow at the base of a hot thrust fault. The bottom of contact aureole is difficult to trace amongst the migmatite-granites of the basement. With the said rocks approaching granulites, sub-horizontal zones of plagiomigmatites start to appear in them. These zones cut the dome structure of the basement. Gradually, the volume of these plagiomigmatites increases, while the number of relict areas of the basement reduces. The thickness of the transitional zone is about 1 km. Small recumbent drag folds composed of plagiomigmatites are widespread there. Axial fold planes, as well as other structural elements with angles 20—30°, dip under the granulites. In the upper part of the zone of recumbent folds, lenses of supracrustal rocks conformable to the schistosity appear: non-granitized gneisses, porphyrites (Tab. I, an. 2), garnet-muscovite schists 1—20 m thick (Fig. 2). Numerous bodies of ultrabasic rocks fill the interbed spaces (Tab. 1. an. 1). Rocks that exhibit signs of primary volcanic-sedimentary genesis are not typical for the granulite complex and their presence in the "cross-section" as a result of tectonic huddling seems to be the only reasonable explanation. Garnet amphibolites after porphyrites can be observed in the upper part of the supracrustal rock series. At first, they appear only at the base of tectonic plates that make up the "cross-section". Gradually, garnet amphibolites grow in number untill completely substitute the relics of volcanic rocks. Garnet amphibolites are rather monotonous rock types of dark colour. They differ in the garnet size, varying from 1 mm to 10—15 cm, their number and ratio to plagioclase, hornblende and diopside. Garnet amphibolites are characterised by significant foliation both at small (thin layers of 1—5 cm) and large scale (1—15 m) that can be traced for many kilometers. Garnet appears as regularly or irregularly disseminated bands, veins, porphyroblasts. As compared with primary rocks (porphyrites), garnet amphibolites are poor in Al_2O_3 and Fe_2O_3 (Tab. 1, an. 3). Some garnet amphibolites after basic granulites, undistinguishable from the above described ones in appearance, contain relict grains of hypersthene (Krylova, 1983; Vinogradov et al., 1980).

Notes to Tab. 1.: n — number of samples. Over the fraction bar the number of the analyses used to calculate mean petrogenic elements comtent, below the fraction bar the number of samples that were analysed for rare elements; 1—4 — chemical analysis of the samples from contact aureol (elements of the iron group of the granulite thrust): 1 — metapyroxenite, 2 — metaporphyrites (our data; Bogdanova — Ephimov, 1976; Vinogradov et al., 1980), 3 — garnet amphibolites (our data; Vinogradov et al., 1980), 4 — plagiogranites ("pseudoconglomerates"); 5—7 — the composition of rocks that were metamorphosed under the moderate P conditions of granulite facies and encountered as relics in the migmatite-granite basement and granulite thrust (allochthon): 5 — average composition of the sillimanite-garnet-biotite, cordierite-sillimanite-garnet-biotite, biotite-garnet rock types (our data; Vinogradov et al., 1980), 6 — two-pyroxene-with garnet-and biotite gneisses, 7 — two-pyroxene, two-pyroxene-hornblende, hypersthene-plagioclase basic granulites (our data; Vinogradov et al., 1980; Krylova, 1983; Priyatkina — Sharkov, 1979); 8—11 — ultrametamorphic rocks: plagiomigmatites after basic granulites (8), K-feldspar shadow migmatites after alumina gneisses (9), enderbites after basic granulites (10), biotite and biotite-garnet granites (11); 12—13 — hypersthene granulites from the western (12) and eastern (13) parts of the area; 14—17 — gabbro-anorthosites: 14 — average composition of gabbro-anorthosites (Priyatkina — Sharkov, 1979; Vinogradov et al., 1980; our data), 15 — norite-anorthosites (kataranscites), 16 — anchimonomineral anorthosites, 17 — diorite-anorthosites — granitized anorthosites.

Table 1

Chemical composition of metamorphic, magmatic and ultrametamorphic rocks

Sampling interval	1	2	3	4	5	6	7	8	9
n	1	13/1	10/7	7/3	20/3	3/1	23/9	5/3	2/2
SiO_2	50.26	48.22	49.04	73.48	66.54	61.56	49.94	60.24	75.47
TiO_2	0.62	0.75	0.98	0.15	0.66	0.60	0.83	0.74	0.18
Al_2O_3	9.55	18.04	15.79	14.23	16.08	17.37	17.06	16.01	12.04
FeO_t	12.04	10.68	12.40	2.39	7.34	16.53	10.70	8.6	3.21
MnO	0.21	0.17	0.18	0.03	0.06	0.09	0.17	0.13	0.04
MgO	14.26	6.79	7.30	0.56	2.71	2.90	7.29	3.47	1.34
CaO	9.79	10.37	10.37	2.89	1.10	5.67	10.48	5.66	0.64
P_2O_5	0.09		0.10	0.02	0.05	0.17	0.12	0.20	0.04
K_2O	0.46	0.95	0.56	0.54	3.06	1.13	0.52	0.90	5.09
Na_2O	1.40	2.71	2.67	5.08	1.79	3.44	2.43	3.28	1.66
Li	19		9	5	22	25	7	7	11
Rb	16	17	8	13	113	46	11	15	93
Cr	2100	—	310	13	140	36	263	89	11
V	280	—	300	44	150	130	263	198	46
Ni	540	78	110	17	66	36	112	51	22
Co	66	—	45	13	22	25	43	27	7
Cu	8	73	230	27	49	7	86	30	4
Zr	86	26	85	185	183	90	52	112	165
Sc	42	—	72	4	39	37	45	43	24
Ba	140	—	155	205	503	710	144	432	1165
Sr	180	234	160	330	122	700	352	140	140
Zn	91	78	79	15	70	42	90	77	30
Pb	1.8	—	3.7	29	18	9.5	8	16	26
Sn	1.9	—	1.9	1.4	4.7	2.7	2.3	3.3	2.5

Continuation of Tab. 1

Sampling interval	10	11	12	13	14	15	16	17
n	2/2	3/3	4/3	4/4	19/2	6/1	7/1	7/2
SiO_2	60.45	73.59	48.83	48.87	49.83	49.20	51.01	50.42
TiO_2	0.88	0.09	0.80	0.95	0.44	0.14	0.12	0.56
Al_2O_3	16.52	15.42	16.18	18.25	20.40	27.09	29.50	18.65
FeO_t	8.14	1.97	11.92	12.16	7.92	4.51	1.60	6.28
MnO	0.20	0.04	0.15	0.20	0.12	0.09	0.06	0.10
MgO	2.95	0.64	7.36	6.55	7.54	3.43	0.61	3.01
CaO	5.27	1.20	10.91	10.33	10.90	12.33	12.52	6.12
P_2O_5	0.21	0.07	0.08	0.24	0.03	0.01	0.01	0.24
K_2O	1.41	5.32	0.77	0.67	0.41	0.44	0.45	1.08
Na_2O	4.08	2.26	2.80	1.94	2.41	2.55	3.82	4.54
Li	11	4	11	6	8	10	9	11
Rb	18	115	9	14	23	200	7	20
Cr	44	15	340	192	347	9	7	32
V	79	23	277	287	135	47	10	89
Ni	35	11	157	59	164	98	10	56
Co	15	5	47	38	37	18	3	21
Cu	43	7	190	54	87	17	13	25
Zr	180	30	71	65	41	10	10	22
Sc	47	12	60	45	37	16	1.6	23
Ba	1170	2800	161	60	176	57	100	455
Sr	495	300	157	442	175	250	270	385
Zn	77	18	78	90	38	17	40	55
Pb	6.3	32	3.8	11	2.5	1.0	3.8	10
Sn	2.8	1.8	1.9	2.8	2.1	0.7	1.6	1

The lower member of garnet amphibolites comprises a great number of linear veins of migmatites, the final products of which are represented both by plagiogranites (Tab. 1, an. 4), that had been earlier taken for conglomerates (Magmatic . . . , 1985), and alkaline granites. Higher in the "cross-section", thin veins and lodes of essentially plagioclase composition (Tab. 2, an. 20, 21) start to appear. Plagioclasites are foliated, rarely massive, rocks that are conformable to amphibolites. In smaller bodies the contacts with the rocks of the frame are gradual; towards the center of the beds the number of plagioclase increases. Dark-coloured minerals tend to form lense-like associations of eclogite-like rocks of garnet-clinopyroxene composition (Tab. 2, an. 18, 19). The lack of magmatic structures in the plagioclasites of this type suggests their autochthonous origin. Their modern position corresponds to the level of origination of high--alumina melts. Following the strike of the granulite thrusts, one can trace all the products of alterations from autochthonous plagioclasites to large isolated bodies of allochthonous anorthosites containing typical magmatic structures.

Granulite allochthon

The results of structural analysis, field geological and petrogeochemical investigations evidence that the rocks that have been referred to the Lapland supracrustal granulite complex (Belyaev, 1971) or to the tectonically altered rocks of the Cola series (Granulite Facies, 1972) had, in most cases, originated at great depths, been uplifted to the level of amphibolite and epidote-amphibolite facies and tectonically superimposed upon the Archaean and, partly, Early Proterozoic complexes. The thermoisochrone emission Pb-Pb age of zircon refers

Notes to Tab. 2.: n — number of samples. Over the fraction bar the number of the analyses used to calculate mean petrogenic elements content, below the fraction bar the number of samples that were analysed for rare elements: 18—21 — contact aureole: 18—19 — plagioclase-quartz-garnet rocks with various leucocratic minerals garnet ratios, the latter being from peripheral zones of metasomatic rock bodies: 20 — quartz-garnet-plagioclase rock from the central parts of the same bodies; 22 — garnet-clinopyroxene-with plagioclase eclogite-like rocks after schists; 23—27 — granulite allochthon: 23—25 — melanocratic metasomatites from peripheral and intermediate parts of the quartz-silimanite-garnet rock bodies (23) (Priyatkina — Sharkov, 1979), essentially hypersthene monomineral varieties and with garnet, sillimanite, cordierite and anorthosite admixtures (24) (Belyaev, 1981: Krylova, 1983), garnet-sillimanite-quartz varieties (25) (Priyatkina — Sharkov, 1979); 26—27 — leucocratic, essentially quartz-with hypersthene-garnet-silimanite-biotite-K-feldspar rocks — acid granulites from the central parts of the metasomatic rock bodies (Priyatkina — Sharkov, 1979; Belyaev, 1981: Krylova, 1983); 28 — essentially amphibole rocks after basic granulites and melanocratic metasomatites.

Rare elements and Li nad Rb contents were measured by means of qualitative spectral analysis technique (Emission . . . , 1979) and atom absorption method respectively. The authors would like to thank Mrs. L. N. Odareev, A. I. Kuznetzov and D. Ya. Orlov of the Vinogradov Institute of Geochemistry of the U.S.S.R. Academy of Sciences, the Siberian Branch, who were in charge of the measurements.

Table 2

Chemical composition of metasomatic rocks from the zone of tectonic nappe

Sampling interval	18	19	20	21	22	23	24	25	26	27	28
n	1	5/3	6/3	5/4	3/2	1	2	1	6	3	3/2
SiO_2	46.66	47.09	53.14	63.07	46.78	44.90	54.26	59.65	69.4	75.62	41.37
TiO_2	3.08	2.13	1.64	0.66	1.64	1.10	1.01	0.72	0.37	0.60	1.60
Al_2O_3	13.55	14.19	13.99	17.56	16.22	27.02	12.31	23.82	14.30	9.84	13.38
FeO_t	22.77	17.94	15.26	6.57	14.92	16.10	12.98	10.54	6.4	8.07	21.02
MnO	0.39	0.26	0.20	0.09	0.19	0.22	0.37	0.07	0.12	0.13	0.15
MgO	4.21	5.90	4.33	1.12	7.25	7.55	15.13	3.26	7.49	3.22	7.85
CaO	10.00	10.52	8.10	4.45	10.46	1.94	0.47	0.66	0.27	0.66	11.54
P_2O_5	0.53	0.32	0.27	0.08	0.21		0.07		0.01		0.16
K_2O	0.50	0.66	0.46	0.47	0.19	0.24	1.64	0.60	0.60	0.74	1.12
Na_2O	0.34	1.42	2.16	5.48	2.24	0.68	1.02	0.49	0.49	0.98	1.41
Li	7	7	10	4	11						12
Rb	8	8	9	10	8						14
Cr	9	62	17	19	43		330				430
V	220	280	383	40	245		210				370
Ni	31	96	47	14	155		76				300
Co	30	44	42	15	50		24				79
Cu	140	250	190	36	215		26				24
Zr	570	310	207	193	126		74				100
Sc	50	49	69	8	45		60				54
Ba	120	117	143	230	65		520				100
Sr	41	62	142	296	120						55
Zn	270	173	113	29	160						180
Pb	17	7	16	7	2						1.2
Sn	7.2	4.3	6.0	2.4	3.1						2.1

the beginning of the deep-seated rock masses uplifting to 2.7—2.5 Ga and its termination to about 1.9—1.7 Ga. At that time the formation of the structure had completed. Tha granulite allochthon is composed of a series of flat-lying plates that centerwards become steeper. The rocks of the allochthon make up 4 groups according to their matter composition and genetic types.

I. *Rock associations similar to those of the basement* (biotite-amphibole-hypersthene migmatites and granulites) occur in the eastern part of the area. Here relict associations of two-pyroxene, hypersthene, hypersthene-hornblende plagioschists (Tab. 1, an. 7, 13) and, rarely, plagiogneisses, as well as gneisses containing biotites, garnet, cordierite, sillimanite (Tab. 1, an. 5, 6) can also be identified. Younger granites form zones of irregular cutting bodies and always contain relics of older granulites and gneisses. As they approach the rapakivi-like granites of the Umba Massiff in the east, migmatites become abundant. Chemical alterations trends are characterised by the increase of SiO_2, Na_2O, K_2O, Ba content and decrease of that of Fe, Mg, Ca (Tab. 1 an. 8, 9, 10, 11) in the newly formed rocks as compared with the primary ones (Tab. 1, an. 5, 6, 7). That tendency agrees with that typical of the ultramafic rocks.

II. *Granulites and gneisses that were metamorphosed under the conditions of granulite facies at moderate pressures* with imprints of the granulite facies paragenesis of high pressures predominate in the nappes. Two-pyroxene, amphibole-two-pyroxene and biotite-pyroxene basic granulites prevail. A characteristic feature of the rocks of the granulite thrust is their having been intensively altered. That process had led to the formation of mineral associations related to the granulite facies conditions of higher pressures which, in their turn, were reflected by active development of garnet from 2—5 cm to 10 cm in size and large hypersthene followed by granitization, silicification and amphibolitisation that produced both porphyroblasts and monomineral rock types. On the whole, basic granulites of the Kandalaksha-Kolvitz structure are in close affinity with the tholeiites of greenstone belts (TH-I (Condi, 1983), the only difference being higher Ba and Sr content (Tab. 1, an. 7), and, according to modern views, correspond to the tholeiitic basalt of island arcs and active continental margins (Lutz, 1979). Geochemically, there are two groups of the main rock types (Tab. I, an. 12 and 13). Pronounced geochemical difference between the two rock types showing close petrochemical affinity probably indicates the difference in the mechanisms or depth of their formation.

III. *Basic and ultrabasic rocks* with preserved magmatic textures are widespread within the allochthon. They include: a) basic and ultrabasic rock types that correspond to hypersthene, norites, garnet pyroxenites, websterites (10 % of the area); b) gabbro-anorthosite rocks (20 % of the area). It's worth mentioning that in some cases it is impossible to distinguish between these rock types and the enclosing granulites on the ground of the former's composition and geological, mineralogical and geochemical features. A complex of gabbro-anorthosites attracts special attention. It can be observed as sills confined to the granulites/garnet-amphibolites contact (Priyatkina — Sharkov, 1979; Vinogradov et al., 1980). The Kolvitz Massif forms a body 2 km thick and 60 km long. Starting from the lower hollow contact and upwards, the following rock types have been mapped: melanocratic and mezocratic gabbro-anorthosites with eruptive breccias, leucocratic anchimonomineralic anorthosites, gabbroanorthosites, norties. Gabbro-norite-pegmatites (cataranscites) and plagioclase pyroxenite-websterites occur in close association with granites. The contacts are usually tectonic. Garnet-pyroxene (eclogite-like) rock types are confined to the upper contact. The granulite/anorthosite contact is marked by granitization.

Rocks of essentially plagioclase composition are encountered within the area of development of the rocks of the granulite facies. These former contain admixture of quartz and garnet that can be met with as bodies of irregular shape, beds and veins up to tens of meters thick. Their composition is similar to that of gabbro-anorthosites, the only difference being smaller sizes and occurrence amongst the granulite rocks. Chemical composition of gabbro-anorthosites depends upon the mineral one (Tab. 1, an. 14—17). SiO_2 content in both anorthosites and the enclosing basic granulites is alike. Melanocratic varieties confined to the marginal parts of the massif are rich in Mo, Fe, Co, Ni, Cr, V, while leucocratic ones confined to its central part are poor in these elements and rich in Al_2O_3. Low Ba, Sr, Zr content is characteristic for all the anorthosite rock types. High concentrations of these elements is a peculiar feature of the rocks that had undergone ultrametamorphic changes: diorite-anorthosites after gabbro-anorthosites (Tab 1, an. 17).

IV. *Metasomatic rocks* are widespread in the granulite allochthon and contact aureole. They occur most commonly in the contact area of tectonic plates. It is these rock series that can be indicative of the evolutionary processes and chemical trends of petrogenesis in the zones of thrusting. Geologically, two groups of metasomatic rock series can be distinguished. The first, older, group reflects the granulite and high-temperature amphibolite facies ultrametamorphism under the regime of high pressures. The metasomatites of this stage are characterised by rocks containing porphyroblasts of garnet hypersthene and plagioclase that can be seen as regular or irregular dissipations, bands, nests. Zoned metasomatic bodies are rare. The second group refers to the postultramafic (postmigmatite, postmagmatic) stage and is characterised by isolated beds and veins of irregular shape that often displey zonal texture. At the metamorphic stage, garnet amphibolites originated from basic granulites and porphyrites at the lower and root part of the granulite allochthon.

The composition of the evolving mineral associations in a great extent depends upon the metamorphic grade of the primary rocks and their position in the zone of thrusting. Grossularite end member prevails in the garnets of garnet amphibolites after the rocks rich in Ca, while pyrope end member constitutes the largest part of those rich in Mg. The mineral assemblages typical of the rocks after porphyrites in the eastern, least metamorphosed, part of the thrust, are: garnet amphibolite - melanocratic plagioclase-quartz-garnet rocks - mezolitic quartz-garnet-plagioclase rocks - leucocratic garnet-quartz-plagioclase rocks - substantially plagioclase-quartz rocks. Metasomatic changes in the rocks of contact aureole followed a certain tendency reflected by a gradual fading out of garnet and still wider development of quartz and plagioclase. Petrochemically, that resulted in the increase of SiO_2, Na_2O content and decline of that of Ca, Mg, Al, Fe, Ti, the latter being accumulated in the intermediate zones (Tab. 2, an. 18, 19, 20) where V, Cu, Zr, Sn, Zn concentrations have been found higher than in the primary rocks (Tab. 1, an. 2, 7). Leucocratic varieties of these metasomatites are similar to plagiogranites (pseudoconglomerates) (Tab. 1, an. 4). Numerous bodies of eclogite-like rocks can be observed in the upper part of gabbro-anorthosites. They are encountered as isolated sills in anorthosites, basic granulites and, most commonly, at their contact. The composition of the above rocks is alike regardless their respective position. They are constituted by garnet (35 %—55 % of pyrope, 10 %—20 % of grossular) and pyroxene of the diopside-hedenbergite series (f = 17—40 %) (Krylova, 1983). These rocks display compositional affinity to basic granulites, are characterised by low Cr and Co concentrations. (Tab. 2, an. 22) and exhibit only slight similarity to ultramafic rocks in REE content. Since the aforesaid disagrees with the available data (Golovnya-Khvostova, 1974; Krylova, 1983), they cannot be regarded as magmatic ultrabasic rock types on these grounds. We suggest that these rock types were formed after basic granulites in close association with gabbro-anorthosites and are actually a kind of residual matter (restite) after the origination of calc-alkaline magma by partial melting.

The most common metasomatic rock series in granulite allochthon are the so-called "acid granulites". Their metasomatic origin had been suggested by many investigators (Priyatkina — Sharkov, 1979; Belyaev, 1981), though some authors referred them to metamorphic rock types (Scherbakova, 1984). Acid granulites exhibit specifically inhomogenous composition, structure and texture. The are encountered as beds, lenses and veins whithin which they display gradual transition from essentially leucocratic to basic granulite composition from the center to periphery respectively. Acid granulites mark upper contact of the allochthon where they lie more flatly and regularly than basic varieties. Occasionally they are met with in the inner parts of the shear zones of the granulite nappe where the strike of the flattened lenses is conformable to that of schistosity. The rocks there are composed of plagioclase (often antiperthite one), K-feldspar, quartz with insignificant garnet admixture, rhombic or, occasionally, monoclinal pyroxene, brown hornblende, sillimanite. On the contact with the primary rocks melanocratic minerals grow in number and bring about the development of monomineral and bimineral rock types. The rocks of the inner parts of the lenses are poor in Fe, Mo, Al and rich in SiO_2 and Na_2O (Tab. 2, an. 25, 26, 27), while those of the periphery exhibit high concentrations of Fe, Mo, Al and Zr (Tab. 2, an. 23, 24). Chemically, the development of acid granulites is the same as that of migmatites and implies dejection of the elements of iron group and introduction of silicon and alkalies, the former being accumulated in the peripheral zones. The undisputed characteristic feature of acid granulites is the presence of high alumina rhombic pyroxenes (up to 14 % of Al_2O_3; f = 20—23 %) and high magnesian garnet (f = 33—40 %, up to 59 % of pyrope) (Priyatkina — Sharkov, 1979; Scherbakova, 1984).

The postultrametamorphic changes were reflected by the development of essentially biotite and amphibolite rock types both as disseminations and monomineral rocks. The low-temperature metamorphism yielded cummingtonite after ferrogenous-magnesial silicates and ferrogenous carbonates. That stage is characterised by the accumulation of Fe, Cr, V, Ni, Co and decline of the Sr and Ba content as compared with primary rocks (Tab. 2, an. 28).

Specific features of petrochemical evolution of granulites in tectonic nappes

The geological environments under which high-pressure granulites, eclogite--like rocks, anorthosites and garnet amphibolites are thrust on the granite-gneiss basement is a phenomenon that can be explained only on the grounds of geological and petrogeochemical data on the development of packet of plates within the Lapland-Belomoridic belt. The plates are supposed to be transferred from different distances and include basic granulites that had been altered under various thermodynamic conditions and later occurred on the same level. The rocks that exhibit the highest degree of alterations pertain to the plates' contacts, garnet amphibolites, anorthcsites and eclogite-like rocks being encountered at the thrust basement. Evidence of the longest-distance transferrence was observed at the contacts with anorthosites which are supposed to play an important role of „lubricators". Granulite nappes are characterised by a wide range of basic and ultrabasic rocks of different mineral composition. Significant part of these rocks manifest undoubted features of either magmatic or metasomatic genesis.

Peculiar character of petrogenetic processes in the Kandalaksha-Kolvitz tectonic nappe, as compared with those typical for other areas of the Baltic Shield and the Aldan and Near Baikal regions, is specified by the peculiarity of the ultrametamorphic changes (Petrova — Levitzki, 1984). Slightly granitized rocks prevail here in contrast to migmatites to shadow granites rock series of other areas. Facial analogues of migmatite-granites, acid granulites, quartz--plagioclase rock types and plagioclasites of undisputed metasomatic origin are, however, also widespread in granulite nappes. The ultrametamorphic changes in the rocks of the tectonic nappes of each plate followed the same chemical trend which was reflected by the redistribution of most of the elements: Al, Ca, Mo, Fe, Ti. The elements of the iron group leave the rear zones of the thrust plates (extension zones) and accumulate in favourable structures of their frontal parts (compression zones). Introduction of alkalies (SiO_2, Ba, Zr, Rb, Sr and, mainly, Na) stimulated the formation of metasomatic rocks after basic granulites. At this stage, essentially amphibole rock types form from schists, pyroxene and spinel-pyroxene skarns and calciphyres form from marbles.
bles.

In sense postmetamorphic changes in the rocks were observed in the area under study. There are occurrences of amphibolite rocks from dark green hornblende to light green tremolite. On the whole, from the nappe basement upwards rocks become less amphibolized except on the plates' contacts. It is there where thick, up to several meters, amphibolite rock bodies occur, mafic metasomatites and some minerals of the ultrametamorphic stage being replaced by mica, phlogophite and biotite. The youngest metasomatic rock series are sporadic quartz-kianite and quartz-muscovite rocks after basic granulites. The development of sulphide mineralization that had yeilded pyrite, pyrrotine, chalcopyrite and galenite should also be refferred to the stage.

Conclusions

1) The above data evidence that specific petrogenetic processes, principially similar to those in the upper horizons of the Earth's crust, developed during the formation of tectonic nappes. In the studied area of the Lapland-Belomoridic belt these processes took place in Early Proterozoic. Its development was caused by a high-gradient thermodynamic field that had evolved in the zones of deep-seated thrusts and, subsequently, led to partial melting, injection of melts and to metasomatic substitutions.

2) The said processes that had led to metamorphic and metasomatic differention of the matter followed a certain tendency reflected by the formation of a conjugated rock series. Fe, Mg, Ca, Ti accumulated in melanocratic rocks, while essentially plagioclase and quartz rocks were formed mainly due to the redistribution of trace and rare elements in close association with SiO_2, Na, Ba, Zr, Rb and Sr that were being introduced from great depths. Thus, anorthosites, plagiomigmatites and acid granulites on the one hand, and eclogites and ultramafites-mafites (restites) on the other hand, from the primary rock types represented by basic granulites. Anorthosites and plagiomigmatites are the products of crystallisation and were squeezed into the lower-pressure zones. At the same time, stratified bodies of plagiomigmatite, plagioclasite, acid granulite are localised within supplementary zones through which deep-seated rocks were horizontally slided.

3) Garnet amphibolites confined to the basement of the thrust plates are actually polygenic tectonized rocks formed after primary ones of two types: basic granulites and porphyrites of the Late Archaean greenstone belts. The thrust zone seems to be the only possible environment in which both rock types could undergo complete thermodynamic reworking with subsequent development of substitution reactions and unification of their composition till they formed a united pseudostratified complex of banded garnet amphibolites. The latter are, in fact, specific tectonites of the nappes of the granulite complexes. Development of the granulite rock series may be associated with the long-living mantle convection plume. We suggest that thrusted nappes of high metamorphic grade rocks can be considered as a paleoasthenosphere lense of Postarchaean —Early Proterozoic age.

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