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Garnet-kyanite schists from the Ograzhden Mountain, SW Bulgaria

Stefka Pristavova, Milan Ichev, Maria Komsalova

Abstract. High-aluminum metapelites are enriched in mineral phases which are informative for *P/T* condition of metamorphic processes and thus they are preferable object for investigation in the high-grade metamorphic terrenes. Object of the present study are the metapelites cropping out in the region of the village of Lebnitsa, Blagoevgrad district. The studied rocks are characteristic component of the Gneiss-migmatite Complex – Maleshevska Group (Ograzhden block, Vlahina block, and southwestern part of the West Rila block). Investigated garnet-kyanite schists are performed by several separate bodies among migmatized augen, augen-layered and layered two-mica gneisses (metagranites). They are characterized by complex mineral composition and presence of two mineral associations: a) relict one, kyanite$_1$ + garnet$_1$ + staurolite$_1$ + biotite$_1$ + white mica$_1$ + quartz, and b) second one, garnet$_2$ + kyanite$_2$ + biotite$_2$ + white mica$_2$ + staurolite$_2$ + chloritoide + chlorite + sillimanite + quartz ± plagioclase. The determined *P/T* conditions for the formation of the second mineral association are with a peak of the metamorphism at 689-638^{o}C and a pressure of about 7 kbar, and values in the range of 598-534^{o}C during the attenuation of the process. The authors of this study suppose that intensive alteration of the minerals from the relic association is a result of the active influence of the fluids, connected with the granitoid intrusions and strong processes of deformation and assimilation in them. Formation of the second mineral association is connected to the metamorphism of the hosted granitoids.

Key words: metapelites, metamorphic evolution, metagranites, assimilation

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Стефка Приставова, Милан Ичев, Мария Комсалова. Гранат-кианитови шисти от Огражден, ЮЗ България

Резюме. Високоалуминиевите метапелити в метаморфните терени са предпочитан обект за изследване поради факта, че са богати на минерални фази, информативни за температурните и барични условия на метаморфните процеси. Обект на разглеждане в настоящата работа са гранат-кианитови шисти, разкриващи се в района на с. Лебница, Благоевградска област. Те са характерна съставна част от Малешевската група, разкриваща се във Влахински и Огражденски блок, както и в югозападните части на Западнорилския блок. Изследваните в тази работа метапелити се разкриват сред мигматизирани очни до очноивичести двуслюдени гнайси (метагранити) като няколко изолирани тела с неправилна форма. Притежават богат минерален състав с присъствие на две минерални асоциации:

1) реликтова – кианит$_1$ +гранат$_1$+ ставролит$_1$ + биотит$_1$ + бяла слюда$_1$ + кварц; 2) гранат$_2$ + кианит$_2$ + биотит$_2$+ бяла слюда$_2$ + ставролит$_2$ + хлоритоид + хлорит + силиманит + кварц ± плагиоклаз. Определените *P/T* условия за формиране на втората минерална асоциация са с данни за пик на метаморфизма при 689-638°C и налягане около 7 kbar. При затихване на процеса стойностите са 598-534°C. Авторите предполагат, че интензивната промяна на минералите от първата асоциация са резултат от активното въздействие на флуидна фаза, която би могла да бъде свързана с внедряването на гранитоидите, съпроводено с интензивни деформации и процеси на асимилация, а образуването на втората асоциация е синхронно с метаморфизма на вместващите ги метагранити.

Introduction

Several small bodies of garnet-kyanite schists, well described by the geological mapping in a scale 1:25 000*, crop out to the southwest of Lebnitsa village, Blagoevgrad district (Ograzhden block). The schists have been explored in details for a kyanite row material through canvases and chemical analyses. In the same region graphite-bearing gneiss-schists (containing up to 6% graphite) are well-known and previously explored. The authors of the report consider that "the graphite is formed at the expense of the floral remains in the sediment rocks during the processes of the regional metamorphism".

Interesting ideas about the transformations of the mineral and chemical composition of the rocks connected to the shearing zones have been published recently (Kozhoukharova, 1996, Kozhoukharova, Kozhoukharov, 2005; Macheva et al., 2005). Shearing zones (brittle, plastic, brittle-plastic) are performed very often in the modern geological maps and interprettations but the data about their morphological, petrostructural and mineralogical features are still not completed. An attempt to be characterized "a shear zone" has been made in the study by Macheva et al. (2005). The same authors supposed an orthometamorphic origin of the garnet-kyanite schists from the region of Lebnitsa village "through a drastic alteration of the chemical and mineralogical composition of metagranites in a deep shear zone with an active participation of fluids".

The aim of the present study is to clarify the origin of these rocks and the metamorphic conditions of their formation based on the previously published and new data.

Geological setting

The rocks studied are characteristic component of the Gneiss-migmatite Complex – Maleshevska Group (Ograzhden block). The last one crops out in the northern parts of the Vlahina block, Ograzhden block (Ograzhden, Belasitsa and Maleshevska Mountains) and southwestern parts of the West Rila block (Zagorchev, 1984, 1989). It is mainly built up of gneisses (two-micas and biotite, augens, layered and augens-layered). Uncontinous layers and lenses of amphibolite, garnet-kyanite schists and gneiss-schists (metapelites) as well as not large bodies of metagabroides and metaultramafites are performed among them. Based on the presence of metapelites (garnet-mica schists) in the Gneiss-migmatite Formation, three formations have been distinguished (Dimitrov, Zidarov, 1969): lower – two-micas migmatites; middle – garnet-mica schists and gneiss-schists; upper – biotite-migmatites.

High-aluminum metapelites of the Maleshevska Group crop out northeastern of the village of Tserovo (West Rila block), western of the village of Moravska (Maleshevska Mountain), southwestern of the villages of Lebnitsa and Nova Topolnitsa (Ograzhden) and others. Object of the present study are the metapelites cropping out in the region of the village of Lebnitsa, whose mineralogical and petrological compositions

*Zidarov, N., I. Kostov, B. Stoeva, L. Martinov, D. Dimitrov, P. Ignatovski. 1967. Report about geology of Ograzhden Mountain and southern parts of Malechevska Mountain. GEOFOND, Ministry of water and environment, Sofia /in Bulgarian/

have been investigated by Macheva et al. (2005). According to the last authors 4 mineralogical zones can be recognized in the investigated out crop: zone I, strongly foliated metagranites; zone II, highly deformed melanocratic two-mica schists with garnet and tourmaline; zone III, coarse-grained schists built up of garnet poikiloblasts and kyanite segregations; zone IV, alteration of kyanite- and quartz enriched layers). The same authors distinguished two mineral paragenesis in the schists: (1) HT/MP (HP?) – garnet + kyanite + quartz + white $mica_1$ + tourmaline; (2) MT?MP-LP – staurolite + chloritoide + quartz + white $mica_2$ ± biotite.

Garnet-kyanite schists from the Lebnitsa region are performed by several separate irregularly shaped bodies; the biggest one is 500 × 250 m in sizes (Fig. 1). They are one of the largest schist outcrops in the range of the Maleshevska Group and a key-object to clarify the metamorphic evolution of the region. They are positioned among migmatized augen, augen-layered and layered two-mica gneisses with unclear contacts between them. Migmatized two-micas gneisses are intensively deformed – strongly folded and blasto-mylonitized. They are considered to be metagranites (porphyric by K-feldspar or regularly grained) altered in the amphibolite facies of the regional metamorphism (Titorenkova et al., 2002). The published

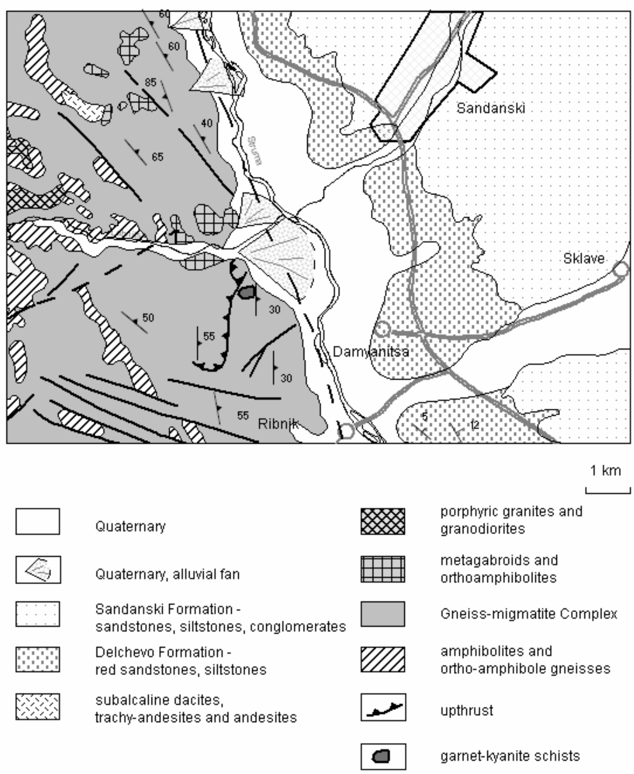

Fig. 1. Geological map of Bulgaria in scale 1:100 000, sheet Petrich (Cheshitev et al, 1990): 1 - Quaternary; 2 - Quaternary, alluvial fan; 3 - Sandanski Formation – sandstones, siltstones, conglomerates; 4 - Delchevo Formation – red sandstones, siltstones; 5 - subalcaline dacites, trachy-andesites and andesites; 6 - porphyric granites and granodiorites; 7 - metagabroids and orthoamphibolites; 8 - Gneiss-migmatite Complex; 9 - amphibolites and ortho-amphibole gneisses; 10 - upthrust; 11 - garnet-kyanite schists

isotopic data according to the Pb and Hf analyses of zircons (459±7.6 Ma и 451+18/9 Ma) show the age of the granite intrusion (Zidarov et al., 2003).

Petrological characteristics of the garnet-kyanite schists

Mineral composition

The investigated schists are red-brownish in colour, fine- to medium grained with well performed metamorphic foliation. Intensive plastic deformations are observed in the rocks – formation of metric in size folds, characteristic of highly plastic rock matrix (Fig. 2a). Monomineral lenses, up to 4 cm in width, build up of quartz, and parallel to the main metamorphic foliation, can be followed amongst the schists. Mineral composition of the rock is garnet, biotite, white micas, kyanite, staurolite, chloritoide, quartz, plagioclase, sillimanite, chlorite, tourmaline, zircon, apatite, ore minerals. Irregular distribution of the main rock-forming minerals garnet and kyanite is the characteristic feature of the studied rocks. The thickness of the strips, enriched in these minerals, varies from few centimeters up to 1-2 m. Some strips are built up to 80% of garnet and kyanite (Fig. 2b, d, e).

Petrostructural analysis (Spray, 1969) has been applied to determine the relative succession of formation of rock-forming minerals and two mineral associations are detached. The first one is presented by relict minerals of the earlier metamorphic event: kyanite$_1$ + garnet$_1$ + staurolite$_1$ + biotie$_1$ + white mica$_1$ + quartz. All of them have typical features of intensive brittle and plastic-brittle deformations. Kyanite from this association is presented by long prismatic crystals (cracked, bent) in maximal sizes up to 6.0, 6.5 cm along long prism, and these with sizes 1.0 – 1.4 cm dominate (Fig. 2c). The main part of this kyanite is strongly altered into aggregates of white micas and single relicts of kyanite are observed among micas (Fig. 3a). The garnet$_1$ is observed as strongly cracked to de-fragmented grains with "pressure shadows" formed around them. It contains inclusions of quartz, white mica, kyanite, staurolite, and together with garnet they are referred to the relict mineral association (Fig. 2f). Fine-flaked biotite-chlorite aggregates replace garnet grains along cracks and periphery parts.

The second mineral association in the schists include: garnet$_2$ + kyanite$_2$ + biotite$_2$ + white mica$_2$ + staurolite$_2$ + chloritoide + quartz ± plagioclase. Kyanite from this association forms small to micro-prismatic crystals with sub parallel orientation and segregated in lenses aggregates or/and aggregates with radial structures, elongated parallel to the main metamorphic foliation (Fig. 3c). The garnet, here, is presented by two morphological types – large porphyroblasts with zonal structure (central part enriched in quartz inclusions and clear periphery), and skeletal structure and small in sizes clear grains (Fig. 3b, d). High content of Alm (80.85-87.72%), Pyr (in the limits of 5.76-12.68%), Gross (0.60-2.54%) and Spess (0.73-8.27%) characterize this garnet (Fig. 4). Well manifested chemical zonality with razing MnO from core to rim and decreasing FeO, MgO and CaO in the same direction has been determined in some garnet porphyroblasts (Table 1). The composition of the garnet from the second morphological type (small in sizes clear grains) is analogous to the periphery of the larger porphyroblasts and it is chemically homogeneous.

The biotite from the second association is segregated in the layers with sub parallel orientation, marking the main metamorphic foliation in the rocks. It is characterized with high $FeO_t/(FeO_t+MgO)$ ratio – 0.54-0.59 (Table 2). Some aggregates – along cracks and cleveages are affected by chloritization (fine flaked pale greenish chlorite is formed at the expense biotite) with separation of dusty to fine grained Fe-Ti products.

The white mica is represented by two morphological types, which are different by its sizes and structural position. The first type is a large flake (0.5–1.5 mm) associated with

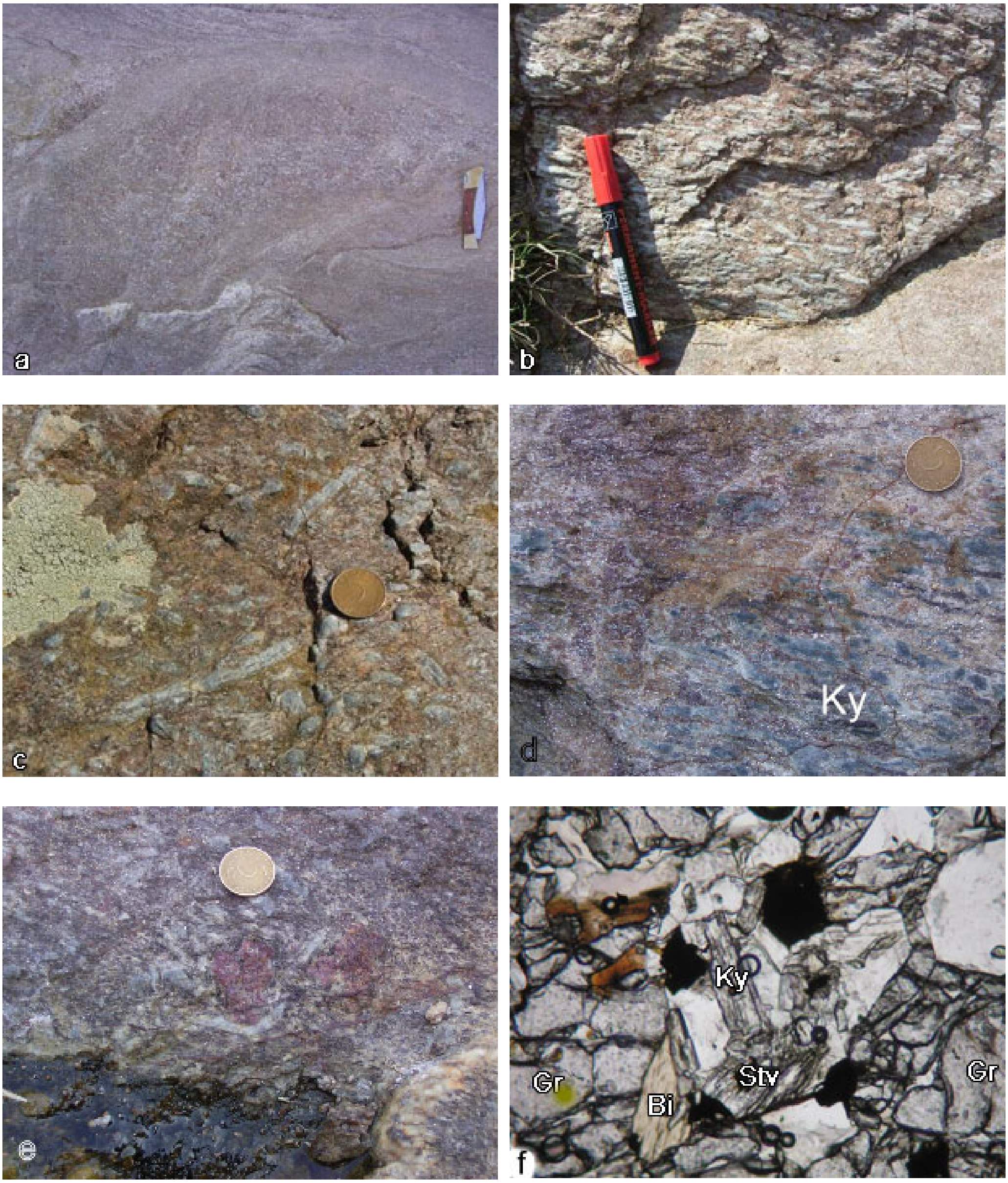

Fig. 2. (a) metric sized folds in the studied rocks marked intensive deformations in the highly plastic rock matrix; (b) kyanite enriched and garnet areas in the schists; (c) relicts of kyanite in long prismatic shapes (cracked and folded). The main part of this kyanite is altered of white mica aggregates; (d) and (e) kyanite enriched and garnet porphyroblast areas in the schists; (f) central part of the garnet (Gr) from relict association with kyanite (Ky), staurolite (Stv) and biotite (Bt) inclusions; × 100, plan-polarized light

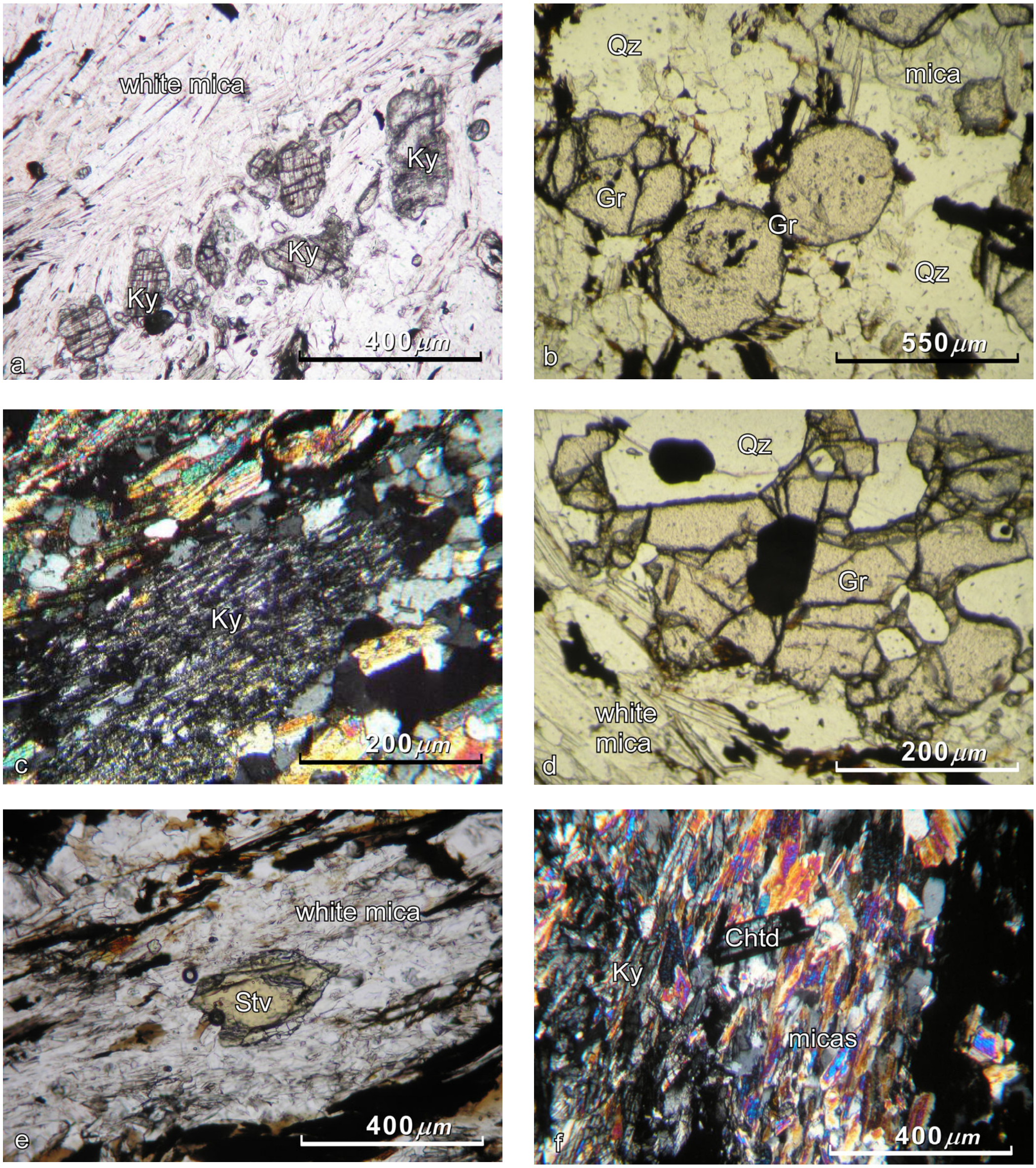

Fig. 3. (a) relicts of kyanite (Ky) among fine flaked aggregates of white mica; (b) small clear grains of garnet (Gr) from the second association; (c) micro-prismatic crystals with sub parallel orientation and segregated in lenses aggregates of kyanite$_2$ (Ky); (d) porphyroblasts of garnet$_2$ (Gr) with skeletal structure; (e) fine prismatic crystals of staurolite; (f) latest formed small prismatic crystals of chloritoide (Chtd) among fine flaked aggregates of white mica; a, b, and e - plan-polarized light; c and f - cross-polarized light

Table 1. *Chemical composition of selected garnet crystals and calculated formulae (based on 12 oxygens) of the second mineral association from the studied rocks*[1]

Sample	L1			L2		L3
Analysis	an. 5	an. 4	an. 3	an. 8	an. 7	an. 15
Mineral zone	core	center	rim	core	rim	core
SiO_2	37.140	36.670	36.570	36.540	32.530	36.160
TiO_2	0.000	0.000	0.050	0.000	0.000	0.060
Al_2O_3	21.220	21.230	22.140	20.880	19.120	20.890
FeO	36.310	36.580	34.960	36.580	43.160	35.670
MnO	1.340	1.530	1.750	2.560	2.810	3.540
MgO	3.160	2.900	2.830	2.960	1.590	2.010
CaO	0.880	0.840	0.780	0.500	0.280	0.890
Na_2O	0.000	0.000	0.000	0.000	0.000	0.000
K_2O	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.070	99.770	99.120	100.040	99.500	99.240
Si	2.993	2.970	2.972	2.958	2.705	2.964
Ti	0.000	0.000	0.003	0.000	0.000	0.004
Al^{IV}	0.007	0.030	0.028	0.042	0.295	0.036
Al^{VI}	2.006	1.995	2.090	1.948	1.578	1.981
Fe^{3+}	0.000	0.030	0.000	0.089	0.712	0.041
Fe^{2+}	2.447	2.448	2.376	2.388	2.290	2.404
Mn	0.091	0.105	0.120	0.176	0.198	0.246
Mg	0.380	0.350	0.343	0.357	0.197	0.246
Ca	0.076	0.073	0.068	0.043	0.026	0.078
Alm.	81.730	82.260	81.730	81.130	87.720	80.850
Pyr.	12.680	11.770	11.790	11.700	5.760	8.260
Gross.	2.540	0.990	2.340	1.420	0.730	0.600
Spess.	3.060	3.530	4.140	5.750	5.790	8.270
Andr.	0.000	1.460	0.000	0.000	0.000	2.020

$biotite_2$ and $kyanite_2$. It marks opened folds, which are formed around garnet porphyroblasts and follows main metamorphic foliation. This mica forms glomeroblastic segregation, usually, and replaces $kyanite_1$. Chemically this mica is determined as phengite ± paragonite component. The white mica which is formed at the expense of kyanite is muscovite (Table 2, an. L17).

Staurolite is presented as single sporadic grains with irregular habit or as small fine prismatic crystals (Fig. 3e). It is characterized

[1] Analyses in Table 1 and 2 are made on JEOL JSM 35 CF RMCA TRACOR NORTHERN TN–2000. Used standards - JEOL "Eurotest-Control", analyst Hristo Stanchev

Table 2. *Chemical composition of the selected minerals and calculated formulae (based on 22 oxygens for micas and 46 for staurolite) of the second mineral association from the studied rocks*

Sample	L1	L2	L3	L1	L2	L1		
Analysis	an. 2	an. 9	an. 16	an. 13	an. 6	an. 10	an. 17	an. 1
Mineral	Bt			white mica			Ms	Stv
SiO_2	34.530	30.940	35.700	46.260	46.100	46.940	45.350	26.660
TiO_2	1.040	0.700	1.270	0.450	0.330	0.650	0.470	0.180
Al_2O_3	19.900	20.920	18.770	36.760	36.450	35.430	34.920	53.090
FeO	22.550	23.450	22.810	1.010	0.820	1.030	0.860	-
Fe_2O_3	-	-	-	-	-	-	-	13.170
MnO	0.000	0.260	0.000	0.000	0.000	0.000	0.000	0.000
MgO	8.680	11.130	8.230	0.260	0.640	0.690	0.250	2.380
CaO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na_2O	0.000	0.000	0.000	1.340	1.360	0.930	0.000	0.000
K_2O	8.460	5.380	8.990	9.530	8.740	9.370	9.760	0.000
ZnO	-	-	-	-	-	-	-	3.040
Total	95.190	92.820	95.800	95.640	94.460	95.070	91.640	98.350
Si	5.313	4.870	5.471	6.102	6.122	6.211	6.218	7.610
Ti	0.120	0.083	0.146	0.045	0.033	0.065	0.048	0.039
Al	3.608	3.881	3.390	5.714	5.705	5.525	5.643	17.860
Fe^{2+}	2.901	3.086	2.923	0.111	0.091	0.114	0.099	0.000
Mn	0.000	0.035	0.000	0.000	0.000	0.000	0.000	3.184
Mg	1.991	2.612	1.880	0.051	0.127	0.136	0.051	0.728
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.000	0.000	0.000	0.343	0.350	0.239	0.000	0.000
K	1.660	1.080	1.757	1.603	1.481	1.582	1.707	0.000
Fe/Fe+Mg	0.590	0.507	0.580	-	-	-		-
Mg/Mg+Fe	-	-	-	-	-	-		0.16

with low Mg content (XMg 0.16), high ferruginous (XFe 0.65) and high content of ZnO (3.04%).

The chloritoide is the latest formed mineral in these rocks. It is observed as small idioblastic crystals with fine prismatic shape, lamellar structure among aggregates of white micas (Fig. 3f). The quantity in the studied schists is about 1 to 6%.

The feldspars are present in a small quantity in the schists. They are observed as single grains with xenoblastic habits, no big in sizes (up to 0.3 – 0.4 mm) and fine lamellare structure.

Quartz is widely accepted in the schists. The grain size varies, but often is fine grained with xenoblastic contours. It is segregated in the lens-like aggregates parallel to the metamorphic foliation, where shows wave-like (undulatory) to mosaic extinction.

Accessory minerals in the schists are zircon, apatite, tourmaline, rutile which are presented as small in sizes single grains. Ore minerals are present too – pyrite is diagnosed by RDA in quantity up to 2-4%.

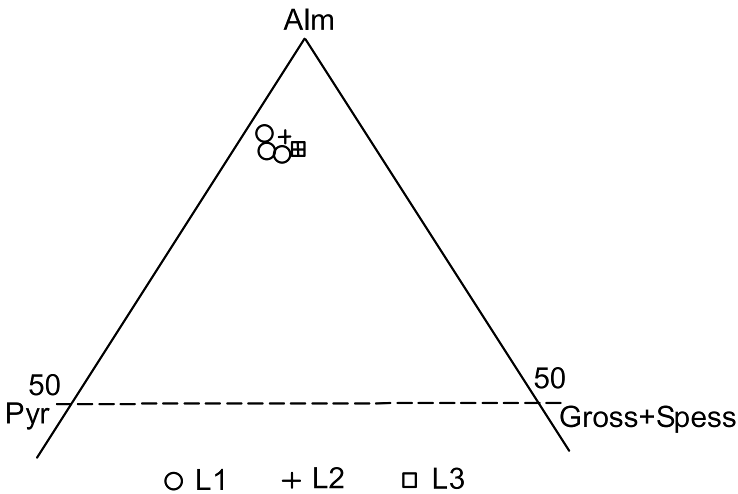

Fig. 4. Composition of the analyzed garnets from the garnet-kyanite schists

Chemical composition

The studied rocks consist of SiO_2 in the frame of 47.67-54.11%. The quantities of Al_2O_3 are in the limits 23.33 – 31.55% and the highest quantities are well correlated with high content of kyanite and staurolite in the rocks. The content of Fe_2O_3 varies from 4.46 to 11.30%. The rocks contain less than 1% MnO and CaO and permanent quantity of K_2O (2.98-3.68%). On the petrochemical diagram the schists follow in the fields of micas schists and Si-Al gneisses (Fig. 5).

Metamorphic condition

For determination of *P/T* condition of the metamorphism in the investigated garnet-kyanite schists garnet-biotite thermometer has been applied to the second mineral association. The results are calibrated by seven authors using GTB Program of Spear and Kohn (2001). The values for the temperature maximum by pairs garnet (core) – biotite (core) are in the limit of 689-638°C in pressure 7 kbar. For pairs garnet (periphery) - biotite (periphery) - 598-534°C. These data correspond very well with established retrograde zonality in the garnet porphyroblasts and appearance of staurolite and chloritoide with development of the metamorphic process.

Conclusions and discussion

In the present work the following conclusions can be made based on the petrological characterrization of the garnet-kyanite schists cropping out in the region of Lebnitsa village, Blagoevgrad district: (1) The rocks consist a complex mineral composition – main rock-forming minerals established are kyanite, sillimanite, biotite, white micas, staurolite, chloritoide, quartz, acid plagioclase, and accessories – zircon, apatite, rutile, tourmaline, and ore minerals; (2) the petrochemical features of the rocks defined them as mica schists/Si-Al gneisses; (3) the structural relationships observed allow distinguishing of two mineral associations: (a) a relict one – kyanite$_1$ + garnet$_1$ + staurolite$_1$ + biotite$_1$ + white mica$_1$ + quartz; and (b) a second one – garnet$_2$ + kyanite$_2$ + biotite$_2$ + white mica$_2$ + staurolite$_2$ + chloritoide + chlorite + sillimanite + quartz ± plagioclase. We assume that the intensive alteration of the relict association might be a

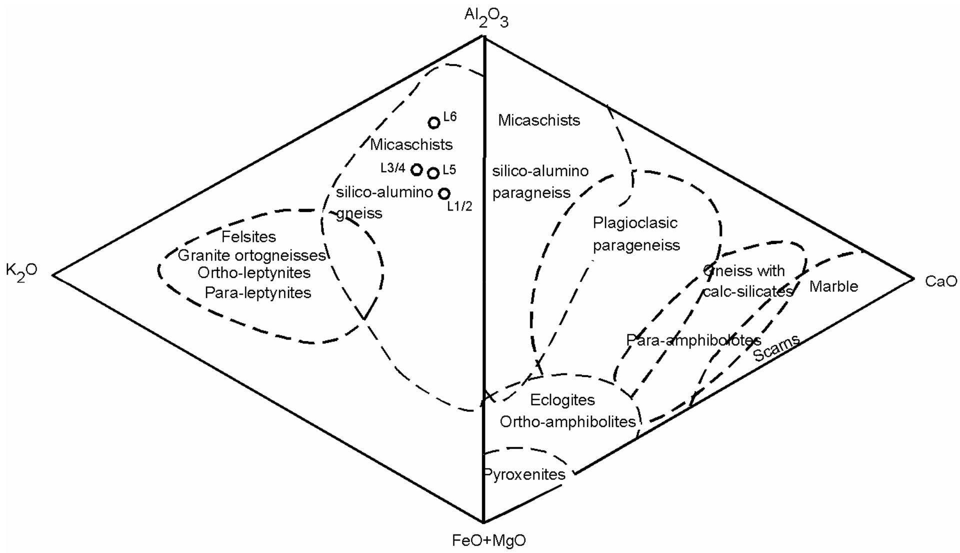

Fig. 5. Petrochemical diagram (after Bard, 1986) for regional metamorphic rocks with plotted sample of the garnet-kyanite schists

result of the active impact of a fluid phase connected to the granitoid intrusion accompanying by intensive deformations and assimilation processes; (4) the *P/T* conditions determined are characteristic for the formation of the second mineral association with a peak of the metamorphism at 689-638°C and a pressure of about 7 kbar, and values in the range of 598-534°C during the attenuation of the process; (5) the garnet-kyanite schists show a limited occurence among the intensively migmatized gneisses of the Maleshevska Group which is possibly a result of superimposed processes and substitutions of the rock-forming minerals – garnet, kyanite and staurolite.

Discussion on the rocks investigated can be focused on the problem of their origin. For a long period they have been recognized as parametamorphites – metapelites in the amphibolite facies of the regional metamorphism, and an element of the Ograzhden Supergroup. An alternative point of view has been performed in the study of Macheva et al. (2005) where "an orthometamorphic origin of the schists through a drastic alteration of the chemical and mineral composition of the metagranites in a deep shear zone and an active fluid impact" has been supposed. Such metasomatic interpretation of the processes would require a presence of distinct successive metasomatic zones and a calculated balance of the chemical components.

The results of the present study of the rocks from the region of the village of Lebnitsa and of other outcrops of garnet-kyanite schists from Maleshevska Group in Southwestern Bulgaria, as well as the presence graphite-mica schists associated with them make us suppose that their protholites have been high-aluminum pelites as a component of the frame of the metagranites. Possibly, a part of the schists has been "grabbed" and partially assimilated by the granite intrusion. Subsequently, together with the granites, they have been subjected to highly metamorphic alterations in the range of the amphibolite facies of the regional metamorphism marked by a second metamorphic mineral association. Data on a second metamorphic event in the vicinity of the rocks studied has been published by Machev et al. (2005).

Examination of these rocks as a potential aluminum raw material should be carefully approached due to the fact of their limited occurrence (0.5 – 0.7 km^2) and highly variable kyanite content which is probably a result of the all over kyanite alteration and substitution by the white mica.

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