საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 7, №3, 2013
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 7, no. 3, 2013

Petrology

Petrogenetic Model of the Precambrian Regional Metamorphism of the Khrami Crystalline Massif

Ketevan Tedliashvili

A. Janelidze Institute of Geology of I. Javakhishvili Tbilisi State University, Tbilisi

(Presented by Academy Member David Shengelia)

ABSTRACT: The Khrami crystalline massif is built up mainly of the Precambrian gneiss-migmatitic complex and Late Variscan granitoids. The greatest part of gneiss-migmatitic complex is represented by biotite-cordierite plagiogneisses (paragneisses) and granite migmatites. Plagiomigmatites and biotite-hornblende quartz-diorite gneisses (orthogneisses) are in less quantities. In the complex two stages of regional metamorphism are established – the Precambrian prograde (HT/LP) and the Late Variscan retrograde (LT/LP). The mentioned stages of regional metamorphism have been ascertained according to geological data and isotopic determinations. PT conditions of polycyclic regional metamorphism (the Precambrian prograde T=720-770^{0}C, P<1.5 kb and the Late Variscan retrograde - T=430-510^{0}C, P=1.3-0.6 kb) of the Khrami crystalline massif is evaluated using geothermometers, reference mineral parageneses and also standard petromineralogic schemes. In the article, a petrogenic model of regional metamorphism is presented. In the Khrami crystalline massif the Precambrian prograde HT/LP (T=720-770^{0}C, P<1.5 kb) and the Late Variscan retrograde LT/LP (T $\approx$ 430-510^{0}C, P $\approx$ 1.3-1.6 kb) stages of regional metamorphism are developed. By U-Pb LA-ICP-MS zircon dating the age of both stages respectively corresponds to 931±16 and 325±6 Ma. *© 2013 Bull. Georg. Natl. Acad. Sci.*

Key words: *Khrami massif, gneiss-migmatitic complex, regional metamorphism*

The Khrami crystalline massif is a salient of pre-Alpine basement of the Black Sea-Central Transcaucasian terrane. It is located in the Khrami river basin, about 100 km southwest of Tbilisi. The massif is built up mainly of the Precambrian gneiss-migmatitic complex, Late Variscan granitoids and pre-Variscan metagabbro. A small size protrusive body of serpentinites is observed in the massif.

The greatest part of the gneiss-migmatitic complex is represented by biotite-cordierite plagiogneisses (paragneisses) and granite migmatites. Plagiomigmatites and biotite-hornblende quartz-diorite gneisses (orthogneisses) are in less quantities [1-5].

Two stages of regional metamorphism are established in the complex – the Precambrian prograde (HT/LP) and the Late Variscan retrograde (LT/LP). The mentioned stages of regional metamorphism have been ascertained according to geological data [5,6] and isotopic determinations [5,7].

In 25 zircon crystals of Late Variscan granitoids of the Khrami massif 27 point by point measurements

Table 1. Composition of Minerals of the Gneiss-migmatitic complex of the Khrami Massif (Mass %)

Sample #	Mineral	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
1	2	3	4	5	6	7	8	9	10	11
10-kh	Crd	48.52	0.07	33.45	8.87	0.15	6.02	0.51	0.35	0.68
	Crdp	46.08	0.07	32.61	8.25	0.14	6.79	0.38	0.43	0.81
	Bt	36.25	2.68	18.43	19.13	0.10	10.68	0	0.04	9.38
	Pl	56.14	0	27.25	0.09	0	0	10.54	5.87	0.12
	Ort	63.88	0	17.96	0.25	0.01	0	0.03	1.60	16.08
	Ms	48.83	0	34.65	0.15	0	2.33	0	0.70	10.21
	Chl	28.45	0.13	23.81	31.44	0.06	14.46	0.03	0.02	0.01
21-kh	Grd	47.65	0.09	33.54	9.78	0.28	7.04	0.12	0.03	0.19
	Crdp	46.15	0.05	32.38	8.47	0.16	6.05	0.40	0.22	0.78
	Bt	37.13	3.12	18.70	21.43	0.05	9.97	0.03	0.12	9.41
	Pl	56.47	0.02	27.53	0.10	0	0	10.41	6.00	0.10
	Ort	64.66	0	27.00	0.08	0	0	0.02	0.88	16.16
	Ms	48.26	0	35.27	0.17	0	2.02	0	0.65	16.975
9	Hbl	44.52	0.76	10.00	18.14	0.50	9.53	11.30	1.30	0.51
	Pl	56.00	0	27.50	0.08	0.01	0	11.54	4.87	0.13
	Bt	35.54	2.92	17.00	22.99	0.20	8.62	1.00	0.39	7.90
	Chl	27.40	0.14	24.85	30.90	0.07	14.81	0.02	0.02	0.03
10	Hbl	45.90	0.50	10.91	13.66	0.14	10.24	11.32	1.54	0.40
	Pl	55.80	0.01	28.02	0	0	0.02	11.41	5.90	0.10
	Bt	35.70	2.48	14.24	21.88	trace	9.60	0.45	0.41	8.20
	Chl	27.90	0.12	23.60	31.24	0.02	15.03	0.02	0.03	0.02

Note: Sample #10-kh – plagiogneiss (Crd_{46}+Crdp+Pl^{44}+Bt_{50}+Ort^{18}+Ms+C±Chl_{40}), sample #21-kh – restite of plagiomigmatite (Crd_{44}+$Crdp_{44}$+Pl^{43}+Bt_{55}+Ort^{18}±Ms), sample #9 – quartz-diorite orthogneiss (Pl_{45}+Hbl_{55}+Bt_{60}), sample #10 – leucocratic part of plagiomigmatite (Pl^{35}+Hbl_{40}+Qtz±Bt_{63}). Crd-cordierite, Bt-biotite, Pl-plagioclase, Qtz-quartz, Ort-orthoclase, Hbl-hornblende, Cum-cummingtonite, Crdp- pinitizated cordierite, Ms-Muscovite, Chl-chlorite. Microprobe analyses were performed in the laboratory of the Local Methods of the Department of Petrography of Lomonosov Moscow State University, using a scanning microscope Scan-4DV (operator E.Guseva).

were performed by U-Pb LA-ICP-MS method. Results of 26 measurements show the concordant age 319-332±6 Ma (mean 325.6±2.3 Ma). Only in one case, in the zircon crystal core the inherited age 931±16 Ma is recorded that shows the Grenville age of regional metamorphism developed in the gneiss-migmatite complex of the Khrami massif [8].

The indicative mineral parageneses of the Precambrian regional metamorphism are: Crd+Bt+Pl+Qtz±Ort, Hbl+Bt+Pl±Qtz, Bt+Pl±Cum±Qtz.

The last stage of regional metamorphism has a distinct retrograde character. It takes place in subisobaric conditions and is a low temperature process (T=430-510^{0}C, P=1.3-1.6 kb) compared to the previous regional metamorphism. Within the Khrami crystalline massif this retrograde process is of regional scale and covers all the Late Variscan formations.

Petromineralogy of the Gneiss-migmatitic Complex

The rock-forming minerals of biotite-cordierite plagiogneisses and migmatite restites of the Precambrian regional metamorphism are cordierite, plagioclase, biotite, quartz and orthoclase. In migmatites cummingtonite is recorded. The results of microprobe measurements of minerals are given in the Table 1.

Cordierite is one of the main rock building minerals of the above rock. In some samples its percentage exceeds 50%. Its porphyroblasts in most cases are fully pinitized and often producing an impression of main matrix. Very seldom intact areas of cordierite are observed. Due to cordierite alteration besides the pinite, muscovite of late generation, FeO and rarely chlorite appear.

Chemical content of cordierite (Table 1) and a microprobe profile (Fig.1) ascertains high Fe content

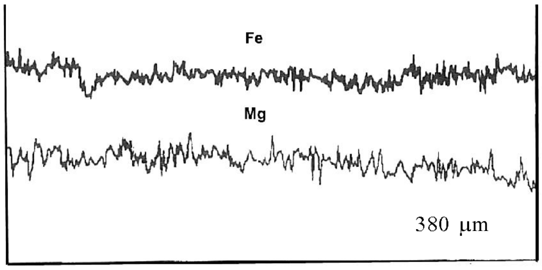

Fig. 1. Microprobe profile of cordierite (sample 10-kh)

(X_{Fe}≈44-46), it is homogenous and is not characterized by zonality.

Biotite is mainly muscovitized and chloritized. The intact biotite has a high Ti-content (TiO_2 2.68-3.12 mas. %, X_{Fe}=50-55, see Table 1).

Plagioclase is observed mainly as porphyroblasts. It is of oligoclase-andesine order (Table 1) and is frequently sericitized, muscovitized, albitized and replaced by latticed microcline.

K-feldspar is represented by lattice-free (disordered) porphyroblasts (Table 1) where the amount of albite molecule reaches 7-13%, and 2V is within the limits of 59-71^0. In the rock intact latticed (high-order) K-feldspar – microcline is more abundant. It is a secondary mineral and is induced by the Late Variscan granite-formation. Unlike the cordierite-bearing plagiogneisses and migmatites, primary K-feldspar is not observed in biotite- hornblende bearing orthogneisses.

Muscovite, as a product of regional metamorphism of the Precambrian stage is not established. It is always a secondary product replacing cordierite, biotite and plagioclase. Chemical composition of muscovite (Table 1) established the presence of a

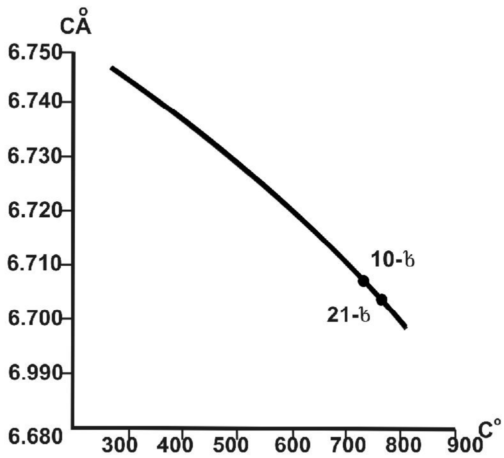

Fig. 2. Relation of C (Å) parameter of elementary graphite cell to temperature [18]. Sample #10-kh–Plagiogneiss Crd_{46}+Crdp+Pl^{44}+Bt_{50}+Ort^{18}±Ms+C±Chl_{40}), sample #21-kh – restite of plagiomigmatite Crd_{44}+$Crdp_{44}$+ Pl^{43}+Bt_{55} +Ort^{18}±Ms+C)

small amount of phengite and paragonite.

Plagioclase, hornblende and quartz are main rock-building minerals of biotite- hornblende bearing quartz-dioritic orthogneisses. Biotite is in less quantities, rarely lattice free K-feldspar is recorded.

Plagioclase is mainly sericitized, saussuritized and albitized. It often undergoes microclinization. Plagioclase relicts correspond to oligoclase-andesine (Table 1).

In most cases, hornblende underwent biotitization and chloritization. Its relicts are represented by green or grey varieties (Table 1).

Intact flakes of biotite are rarely observed. It is muscovitized and chloritized. Here, as well as in paraplagiogneisses, high Ti biotite is recorded (TiO_2 2.48-2.92 Mas.%, X_{Fe}=60-63; Table 1).

Table 2. Temperature parameters of the Precambrian regional metamorphism of the gneiss-migmatitic complex of the Khrami crystalline massif

Sample #	Parageneses	T^{0}C, geothermometer				
		Graphitic [18]	Pl-Ort [20]	Bt-Crd [21]	Hbl-Bt [21]	Hbl-Pl [21]
10-kh	Crd_{46}+$Crdp_{54}$+Pl^{44}+Bt_{50}+ +Ort^{18}±Ms+C±Chl_{40}	720	730	750	-	-
21-kh	Crd_{44}+$Crdp_{44}$+Pl^{43}+ +Bt_{55}+Ort^{18}±Ms+C	760	770	660	-	-
9	Pl^{45}+Hbl+Bt+Qtz	-	-	-	750	680
10	Pl^{35}+ Hbl+Bt+Qtz	-	-	-	760	620

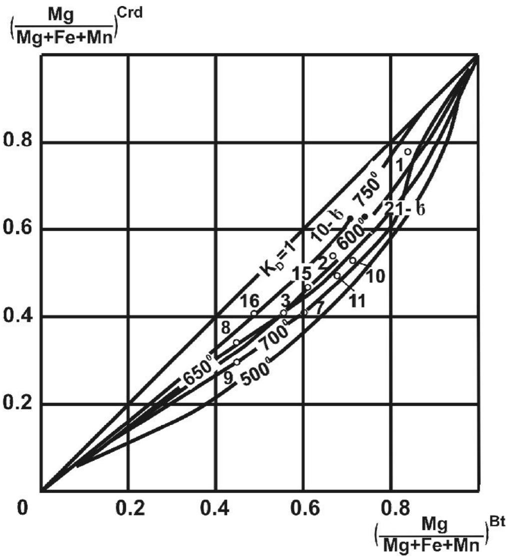

Fig.3. Cordierite-biotite geothermometer

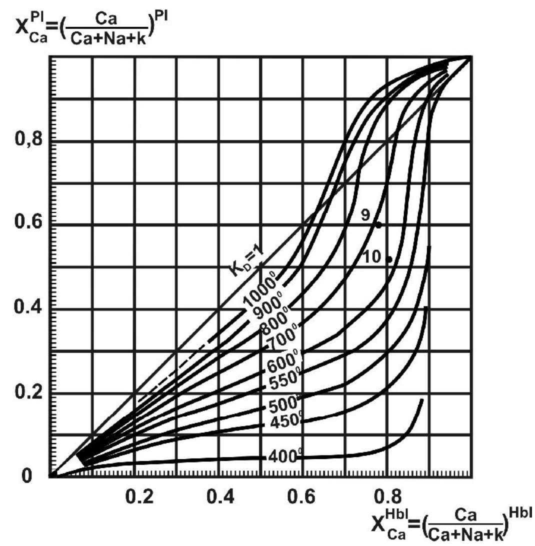

Fig. 4. Hornblende-plagioclase geothermometer

PT Conditions of the Precambrian Regional Metamorphism of the Khrami Crystalline Massif

PT conditions of the Precambrian regional metamorphism of the Khrami crystalline massif is evaluated applying geothermobarometer and standard petrogenetic schemes of reference mineral parageneses.

We could not use the conventional garnet-biotite [9-14] and garnet-cordierite [10,15] geothermometers, as in the products of the Precambrian regional metamorphism typical metamorphic mineral garnet is not recorded. At it is known, coexistence of garnet and cordierite is limited under low- and moderate-thermal conditions as well as under high temperature and low pressure (P<1.5 kb) conditions. Absence of garnet and silimanite in the alumina-rich high-temperature rocks of the Khrami massif is explained by wide spreading of cordierite and rather low pressure conditioned by the reaction: Ms+Bt+Qtz Crd+Ksp+H_2O.

To establish the temperature regime of the Precambrian prograde regional metamorphism of paraplagiogneisses and migmatites of the Khrami crystalline massif we have used the graphite thermometer [16-18]. As it is known, this thermometer is unique because even when progressively transformed rocks experienced diapthoresis or a retrograde process, it records the first maximal temperature that had ever transformed the above rock. Some other known geothermometers show temperature conditions of the last metamorphism only. Data of graphite thermometer are given in Fig. 2 and Table 2. According to the C (Å) parameter of elementary cell (6.704-6.707) temperature conditions of the Precambrian regional metamorphism are within the limits of 720-760^{0}C.

During the research A.Whitney and S.Stromer's [20] K-feldspar-plagioclase thermometer is used as well.

The data in Table 2 show that the used K-feldspar thermometers record slightly higher temperature than the graphitic one - 730-770^{0}C.

The cordierite-biotite thermometer [21] records the temperature within the limits of 660-750^{0}C (Fig. 3, Table 2).

By means of hornblende-plagioclase and hornblende-biotite geothermometers, forming the temperature of leucocratic part of quartz-dioritic orthogneiss (sample #9) and of plagiomigmatite (sample #10) was specified. It covers the range 620-720^{0}C (Fig. 4, 5; Table 2).

Thus, we consider it more authentic that temperature conditions of the Precambrian stage of regional metamorphism of the Khrami crystalline massif falls within 720-770^{0}C and corresponds to the high-tem-

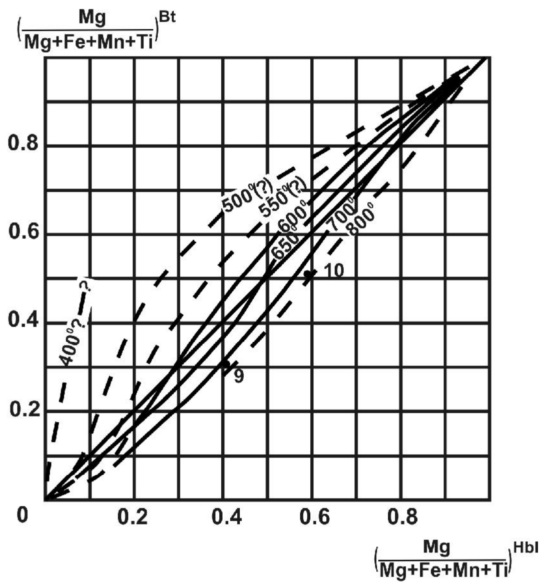

Fig. 5. Hornblende-biotitic geothermometer

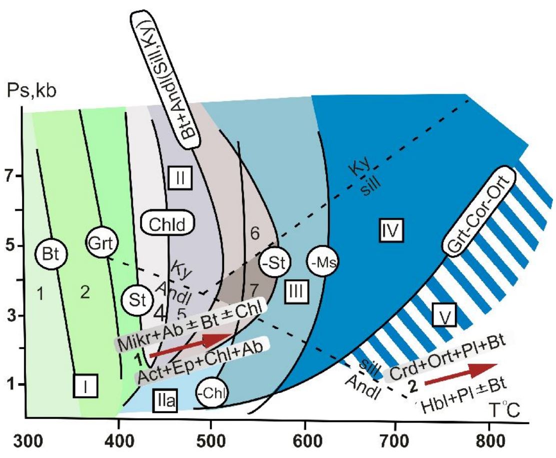

Fig. 6. Trends of the Precambrian and Late Variscan regional metamorphism of the Khrami crystalline massif.
Roman figures –facies of metamorphism: I – green schists, II (IIa) – staurolite, III – biotite-muscovite bearing gneisses, IV – biotite-sillimanite-K-feldspar, V – garnet-cordierite-K-feldspar.
Trends of regional metamorphism: 1 – the Late Variscan, 2 – the Grenville

perature biotite-sillimanite-K-feldspar and garnet-cordierite-orthoclase facies parameters.

To define pressure conditions of the Precambrian regional metamorphism of gneiss-migmatitic complex of the Khrami crystalline massif we were not able to use geobarometry, as all the known geobarometers were used for parageneses of high-temperature rocks, where garnet and sillimanite are spread. However, in the gneiss-migmatitic complex of the Khrami massif garnet and sillimanite (andalusite) do not occur.

When defining the pressure conditions we used petrogenetic schemes [5, 22] showing that pressure conditions of the Precambriam regional metamorphism of rocks of gneiss-migmatitic complex of the Khrami crystalline massif is < 1.5kb (Fig. 6).

Petrogenetic Model of the Precambrian Regional Metamorphism of the Gneiss-migmatitic Complex of the Khrami Crystalline Massif

As mentioned above, in the pre-Alpine formations of the Khrami crystalline massif polycyclic character of regional metamorphism was established [5, 6, 23, 24], the Precambrian (Grenville) and the Late Variscan stages of regional metamorphism are distinguished. The age of each stage of regional metamorphism was dated by geological-geochronological data.

Prograde regional metamorphism of the ancient rocks of the Khrami crystalline massif was dated at 931±16 Ma by U-Pb LA-ICP-MS zircon age method [8, 25, 27]. The thermobarometric data show that regional metamorphism of the Pecambrian stage was of isobaric character. Limits of pressure variation are insignificant (P<1.5 kb) and temperature range is wider (720-770^{0}C) (Fig. 6). Conditions of regional metamorphism correspond to the biotite-sillimanite-K-feldspar and garnet-cordierite-orthoclase facies conditions. The products of metamorphism – cordierite-bearing plagiogneisses, plagiogranites, plagio- and granitic migmatites and also less quantities of hornblende-bearing plagiogranites and orthoquartz-diorites form a subcontinental crust, where prevail K nonsaturated metapelites and less amounts of K-saturated metapelites are present. Amount of CaO rich rocks is insignificant. The latter points to the unimportant role of overheated ascending fluid currents induced by the center of basite formation in the development of regional metamorphism. To our assumption, along with the subduction heat radioactive heat is the main heat source of regional metamorphism.

Conclusions

In the Khrami crystalline massif the Precambrian prograde HT/LP ($T=720\text{-}770^0C$, $P<1.5$ kb) and the Late Variscan retrograde LT/LP ($TH \approx 430\text{-}510^0C$, $PH \approx 1.3\text{-}1.6$ kb) stages of regional metamorphism are developed. By U-Pb LA-ICP-MS zircon dating the age of both stages respectively corresponds to 931±16 and 325±6 Ma.

პეტროლოგია

ხრამის კრისტალური მასივის კამბრიულისწინა რეგიონული მეტამორფიზმის პეტროგენული მოდელი

ქ. თედლიაშვილი

ი. ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტის ა. ჯანელიძის გეოლოგიის ინსტიტუტი, თბილისი

(წარდგენილია აკადემიის წევრის დ. შენგელიას მიერ)

ხრამის კრისტალური მასივი აგებულია ძირითადად კამბრიულისწინა გნეისურ-მიგმატიტური კომპლექსით და გვიანვარისკული გრანიტოიდებით. გნეისურ-მიგმატიტური კომპლექსის უდიდესი ნაწილი წარმოდგენილია ბიოტიტ-კორდიერიტიანი პლაგიოგნეისებით (პარაგნეისებით) და გრანიტული მიგმატიტებით, დამორჩილებულ როლს თამაშობს პლაგიომიგმატიტები და ბიოტიტ-რქატყუარიანი კვარციან-დიორიტული გნეისები (ორთოგნეისები). კომპლექსში გამოვლენილია რეგიონული მეტამორფიზმის ორი ეტაპი — კამბრიულისწინა პროგრადული (HT/LP) და გვიანვარისკული რეტროგრადული (LT/LP). აღნიშნული ეტაპები დადგენილია როგორც გეოლოგიური, ასევე იზოტოპური განსაზღვრების მონაცემებით. გეოთერმომეტრების, საყრდენი მინერალური პარაგენეზისების, ასევე სტანდარტული პეტრომინერალოგიური სქემების გამოყენებით შეფასებულია ხრამის კრისტალური მასივის პოლიციკლური რეგიონული მეატმორფიზმის PT პირობები: კამბრიულისწინა პროგრადული – T=720-7700C, P<1,5 კბარი და გვიანვარისკული რეტროგრადული – T=430-5100C, P=1.3-1.6 კბარი. წარმოდგენილია რეგიონული მეატმორფიზმის პეტროგენული მოდელი. ხრამის კრისტალურ მასივში განვითარებული რეგიონული მეტამორფიზმის კამბრიულისწინა პროგრადული HT/LP (T=720-7700C, P<1,5 კბარი) და გვიანვარისკული რეტროგრადული LT/LP (T ≈ 430-5100C, P ≈ 1.3-0.6 კბარი) ეტაპები ცირკონების LA-ICP MS U-Pb მეთოდის მონაცემებით, შესაბამისად, შეადგენს 931±16 და 325±6 Ma.

REFERENCES:

1. *G. Zaridze, N. Tatrishvili, I. Khmaladze, O. Dudauri* (1965), Tr. Geol. Inst. AN GSSR. Novaya seriia, 1: 33-79 (in Russian).
2. *M. Kekelia, O. Khutsishvili* (1980), Tr.Gruz.Politekhn.Inst., 9: 109-115 (in Russian).
3. *D. Shengelia, N. Ikoshvili* (1998), Tr.Gruz. Politekhn.Inst., 1(417): 72-79 (in Geogrian).
4. *T. Tsutsunava, N. Ikoshvili* (1998), Tr.Gruz. Politekhn.Inst., 4(418): 78-85 (in Geogrian).
5. *I.P. Gamkrelidze, D. M.Shengelia* (2005), Dokembriysko-paleozoiskiy metamorfizm, granitoidniy magmatizm i geodinamika Kavkaza, M., 458 p. (in Russian, English summary).
6. *K. Tedliashvili, N. Kvakhadze, N. Maisuradze, G. Beridze* (2012), Science and Technologies, 1: 30-38 (in Geogrian).
7. *O. Dudauri, M. Togonidze, G. Vashakidze* (1990), Vortrag in der Internat. Isotopen Kolloquium. Freiberg, 42-44.
8. *I. Gamkrelidze, D. Shengelia, et al.* (2010). XIX Congress of the Carpathian-Balkan Geological Associacion. Thessaloniki, Greece, 23-26 September. Abstract. 120-121.
9. *L. Perchuk* (1967), Dokl. AN SSSR, **177**, 2: 1106-1110 (in Russian).
10. *L. Perchuk, I. Lavrentieva, et al.* (1983), Biotit-granat-kordieritovye ravnovesiia i evoliutsiia metamorfizma. M.,197 p. (in Russian).
11. *A. Thompson* (1975), Mineral reactions in pelitic rocks: II. Calculation of some P-T-X (Fe-Mg) phase relations. Am. Sci.: 276.
12. *D. Goldman, A. Albee* (1977), Am. J. Sci., 277: 750-767.
13. *J. Ferry, F. Spear* (1978), Contrib.Mineral.Petrol., 66: 52-88.
14. *U. Kleemann J. Reinhardt* (1994), Europ. J. Mineral., 6: 925-941.
15. *I. Lavrentiev, L. Perchuk* (1981), DAN SSSR, **259**, 3: 697-700 (in Russian).
16. *D. Shengelia, R. Akhvlediani, D. Ketskhoveli* (1976), Soobshch. AN GSSR, **83**, 3: 661-664 (in Russian).
17. *D. Shengelia, R. Akhvlediani, D. Ketskhoveli* (1977_2), DAN SSSR,**235**, 6: 1407-1409 (in Russian).
18. *D. Shengelia, R. Akhvlediani, I. Soldatov* (1977_1), Soobshch. AN GSSR, **86**, 2: 388-392 (in Russian).
19. *R. Akhvlediani, D. Ketskhoveli, D. Shengelia* (1978), III Reg. Petrological Meeting on the Caucasus, Crimea and the Carpathians., 20-21 (in Russian).
20. *A.J. Whitney, C.J. Stormer, Jr.* (1977), Am. Mineralogist., **62**: 687-891.
21. *L. Perchuk* (1970), Ravnovesiia porodoobrazuiushchikh mineralov. M., 391p. (in Russian).
22. *S. Korikovsky* (1979), Fatsii metamorfizma metapelitov. M., 260p. (in Russian).
23. *D. Shengelia* (2000), Proceedings of the Geol. Inst. of Georgia, New ser., **115**: 282-299 (in Russian).
24. *D. Shengelia, N. Poporadze, T. Butulashvili* (2006), Proceedings of the Georgian Technical University, 2: 24-29 (in Georgian).
25. *I.P. Gamkrelidze, D.M. Shengelia, T.N. Tsutsunava* (2011), Bull. Georg. Natl. Acad. Sci., **5**, 1: 64-76.
26. *T. Tsutsunava I. Gamkrelidze, D. Shengelia* (2011), International Congress „Natural Cataclysms and Global problems of the Modern Civilization". 19-21 September, Istambul, 66-67.
27. *D.M. Shengelia, O.Z. Dudauri, K.S. Chikhelidze* (2010), Proceedings of the Geol. Inst. of Georgia, New Ser., **117**: 51-61 (in Georgian).

Received May, 2013