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Evolution of the Variscan orogenic plutonic magmatism: the Greater Caucasus

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ABSTRACT

A petrogenetic model of Variscan plutonic magmatism in the Greater Caucasus is introduced in this article and is based on geological, petrological, geochemical, and mineralogical data. Four Variscan plutonic series are distinguished, from south to north these are: 1 - Gabbro-Plagiogneiss (Plagiogneiss age: 355±15 Ma, Rb-Sr; Isr=0,70343); 2- Diorite-Adamellite (Adamellite age: 310±12 Ma, U-Pb); 3- Plagiogranite-Granite (Plagiogranite age: 318±7 Ma, Rb-Sr; Isr=0,709132; Granite age: 315±5 Ma, Rb-Sr, Isr=0,71134); 4 - Granodiorite-Alaskite (300±5 Ma, U-Pb; 295±5 Ma, Rb-Sr, Isr=0,71572). The sources of Variscan plutonic magmatism of the Greater Caucasus were both mantle and crustal. Each plutonic series was formed at a different geodynamic position, from different protoliths, and in each series the mechanism of magma generation was different. They are oriented along strike of the Greater Caucasus (NW-SE) and notwithstanding strong underplating, some zoning is still detected in their arrangement.

Based on the petrogenesis of the Variscan plutonic series and their zoning, we infer that during the Middle-Late Carboniferous, northward subduction of the PaleoTethys oceanic crust was activated (PaleoThethys closing and Neo-Tethys opening). Its activity on the southern margin of Eurasian continent caused island arc complex collision, as well as Variscan orogenic magmatic events.

Keywords:, Orogen, Variscan plutonic magmatism, the Greater Caucasus

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INTRODUCTION

Collision orogens are typically formed on the margins of stable continents, where blocks of different ages, composition and history are accumulated. As a result of remelting of accumulated material, composite plutons can be formed and their structural zones can be difficult to detect. As this study shows, the tectonic-thermal activation process in the Phanerozoic is one mechanism of continental crust growth.

The Phanerozoic collisional orogen of the Greater Caucasus is a poorly studied segment of the Alpine-Himalayan mobile belt. This study presents a petrogenetic model of plutonic magmatism of the orogen based on analysis and interpretation of actual material obtained from 10 year field and laboratory study. More than 2000 petrographic samples have been taken. Over 1000 rock analyses and 250 complete silicate analyses of minerals have been performed, and numerous microprobe analyses have been conducted. In more than 100 rock samples gas-liquid inclusions have been investigated by cryometric method and in 50 samples chromatography has been performed.

Complex field and laboratory data analysis revealed that in the Greater Caucasian orogen development of Variscan plutonic magmatism was occurring in different geodynamic regime, in the conditions of different magma generation mechanism. However, they were accumulated at the continental margin. The series are in close genetic interconnection and we consider them to represent an entire system of tectono-thermal activity.

TECTONIC SETTING OF THE REGION

The Caucasus represents a Phanerozoic collisional orogen formed along the Euro-Asian North continental margin, in a NW-SE direction, between the Black and Caspian seas and connecting the European and Asian branch of the Alpine-Himalayan mobile belt. Currently, it is an expression of continental collision between the Arabian and Eurasian lithospheric plates.

Paleomagnetic and geological data indicate that within the oceanic area of Tethys, which separated Afro-Arabian and Eurasian continental plates, there were relatively small continental or subcontinental plates (terranes) having various geodynamic and geological histories (Gamkrelidze 1997; Somin 2007; Stampfli et al. 2002; Roumer et al. 2003). During the Neoproterozoic, Paleozoic and Early Mesozoic, these terranes underwent horizontal displacement within the oceanic area of Proto-, Paleo- and Meso-Tethys, followed by accretion and, ultimately, merging with the Eurasian continent. The Arabian and Eurasian lithospheric plates

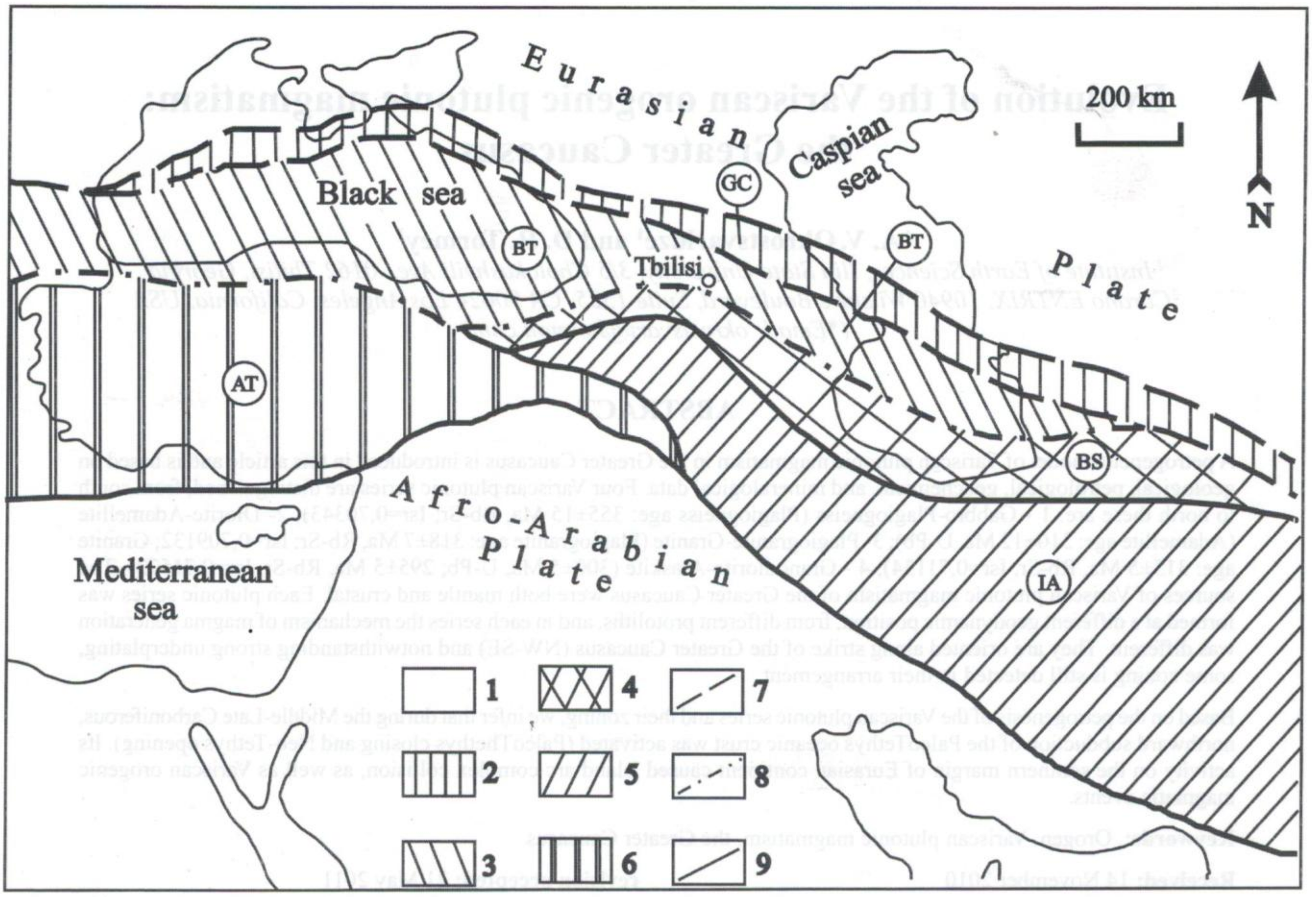

Fig. 1: Tectonic zoning of the Caucasus and adjacent area on the basis of the terrane analysis (Gamkrelidze 1997), 1- Continental frame of the Mediterranean mobile belt; Terranes: 2 - Greater Caucasian (GC), 3 - Black Sea-Central Transcaucasian (BT), 4-Beiburt-Sevanian (BS), 5-Iran-Afganian (IA), 6-Anatolian (AT); Ophiolite suture (marking the location of small and large oceanic basins): 7- Late Pre-Cambrian, 8-Paleozoic, 9- Meso-Cenozoic

are separated by the Greater Caucasian, Black Sea-Central Transcaucasian, Baibut-Sevanian and Iranian-Afghan terranes (Gamkrelidze 1997), which in the geological past represented island arcs or microcontinents (Fig. 1).

The Greater Caucasus (GC) is the northernmost expression of the Caucasus orogen and is linked to the southern margin of the Eurasian continent. It is currently a folded-nappe polycyclic formation extending more than 1200 km between the Black and Caspian Seas; its width reaches 170 km in the central part. Two major stages are distinguished: Pre-Alpine crystalline basement (CB) and Alpine volcanic-sedimentary cover. Crystalline basement complex (200 km x 40 km) (Fig. 2) is mainly constructed of Precambrian and Paleozoic crystalline schist, amphibolites, gneisses, migmatites and granitoids. Four regional structural-tectonic zones are traditionally recognized: Southern Slope, Main Range, Front Range and Bechasyn (Somin 1971).

During the Alpine tectonic-magmatic events these units underwent several tectonic uplifts and as a result of these processes the crystalline basement of the Greater Caucasus acquired the current structural aspect. The Main range zone is the best exposed part of the crystalline basement of the Greater Caucasus and is divided into two sub-zones: the Pass and the Elbrus. Different from the other zones, Variscan metamorphism and granitoid magmatism are extensively represented in this zone. Metamorphic facies of the crystalline basement complex of the Greater Caucasus range from greenschist to granulite, but amphibolite facies predominates (Shengelia et al. 1991; Gamkrelidze and Shengelia 2005).

FIELD RELATIONS AND PETROGRAPHY

The Variscan orogenic plutonic magmatism has played significant role in the formation of the Greater Caucasian crystalline basement complex. Field and petrographic investigations indicate that plutonic magmatism is represented by different types localized in distinct tectono-structural zones, or terranes. Four plutonic series (from the South to the North) have been distinguished: 1. gabbro-plagiogneiss, 2. diorite-adamellite, 3. plagiogranite-granite, and 4. granodiorite-alaskite.

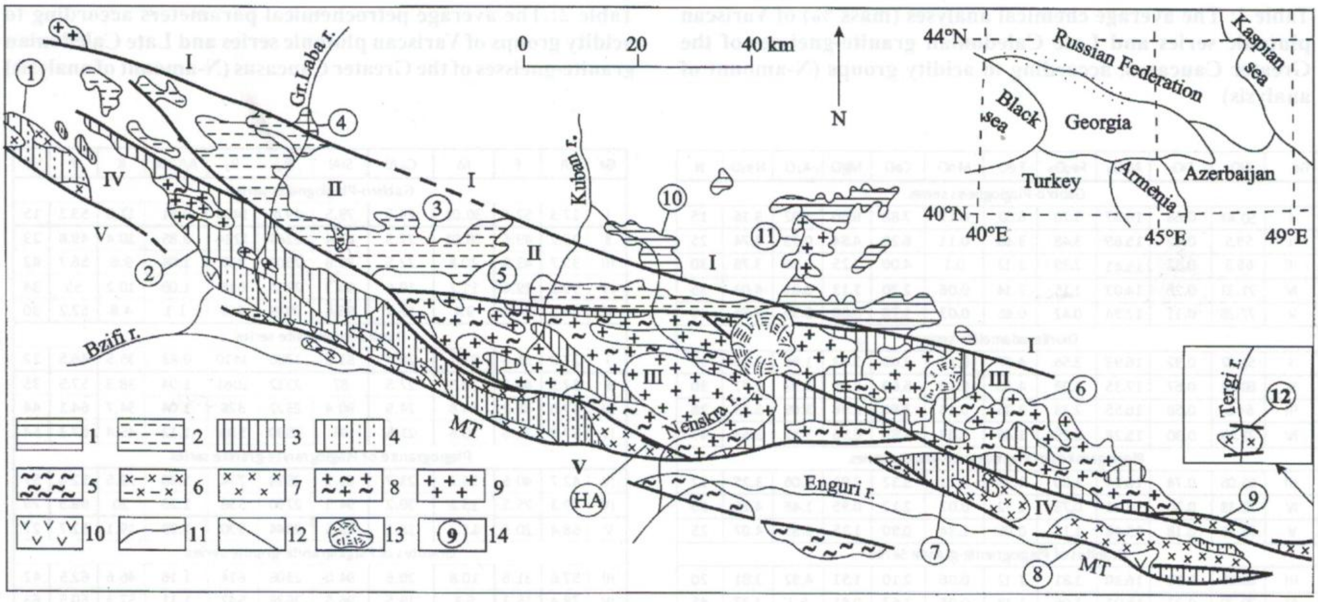

Fig. 2: Schematic geological map of the crystalline basement of the Greater Caucasus and its geographical position (marked dotted line). Structural zones: I. Bechasyn; II. Front Range; III. Elbrus Subzone of Main Range; IV. Pass subzone of Main Range; V. Southern Slope. Conditional mean of exposes: 1 – Bechasyn zone; 2 – Front Range zone; 3 – Elbrus subzone of Main Range; 4 – Pass subzone of Main Range; 5. Sothern Slope zone; Variscan plutonic series (6-9): 6. Gabbro-plagiogneiss, 7. Diorite-adamellite, 8. Plagiogranite-granite, 9. Granodiorite- alaskite, 10. Middle Jurassic granitoid intrusive, 11. Stratigraphic and magmatic boundary, 12. Fold systems (MT -main trust); 13. Glaciers, 14. Number in the circle-the main tectonic uplifts: 1. Chugushi, 2. Sofia, 3- Blibi, 4. Beskes, 5. Teberda, 6. Digori, 7. Shkhara, 8. Adaikhokh, 9.Unal, Kuban, 11. Kislovodsk, 12. Dariali. (The Dariali tectonic uplift transfers from East); HA- Hokrila-Achapara (Sakeni) goldfield

The Gabbro-plagiogneiss series is exposed in the southern slope of the GC, and is related to Beshta, Kamenistaia and Sgimazuki tectonic uplifts, distributed along the Main thrust. The protolith of the gneiss consists of plagiogranites and subordinate quartz-diorites, diorites and gabbros. They occur as lenses of variable thickness. Plagiogneisses are composed mainly of sodic plagioclase and quartz (composition: Pl+Qtz+Chl+Ep±Hbl±Grt±Sf+Mgt). Gabbros and diorites represent restite of the protolith (composition: Pl+Qtz±Cpx+Hbl±Chl±Ep±Ap±Sf±Grt±Mgt). The age of crystallization of plagiogneiss was defined by Rb-Sr method and it corresponds to 355±15 Ma (I_{sr}=0,70343) (Okrostsvaridze 2007).

The Diorite-adamellite series is structurally connected with the subzone and occurs as wide exposures. The rocks of the series participate in the construction of Dariali, Kasar, Adaikhokh, Skhara, Sofia and Chugush tectonic uplifts. This series are exposed in the form of intrusive bodies of different thickness. They are mainly constructed of quartz-diorites and granodiorites, but gabbros, diorites and adamellites also occur. There are no strict borders between them and they gradually substitute each other. They are dark gray, medium grained, massive rocks (composition: Pl+Qtz±Ksp+Bt±Hbl+Ep±Chl±Sf+Apt+Zr+Ort+Mgt). The series is characterized by a large number of fine-grained spherical mafic inclusions. Partial melting and hybridism represented the magma generation mechanism for this series. The isotopic data of adamellite corresponds to 310±12Ma (U-Pb method) (Okrostsvaridze 2007).

The Plagiogranite-granite series is structurally connected with the Elbrus subzone of the Main Range zone and lesser part is also encountered in the subzone. This series is genetically connected with migmatites that were formed under the HT-LP metamorphic conditions, mainly from metapelite protolith. Plagiogranites make lens-shaped conforming bodies of different thickness, which are often gneissose (composition: Pl±Qtz±Mik±Bt±Ms±Sill±Andl ±Gor±Crt+Zr+Ap±Orth±Mgt; age: 318±7 Ma Rb-Sr method; I_{sr}=0,70834). Granites principally cross cut the plagiogranites, and are represented by microcline porphyries (composition: Pl+Mic+Qtz±Bt±Ms±Chl±Ep±Ap±Grt±Zr±Sf±Orth±Mgt; age: 315±8 Ma Rb-Sr method; I_{sr}=0,71134).

The Granodiorite-Alaskite series is localized in the Elbrus sub-zone of the Main Range zone and is represented by intrusive granodiorite, granite and alaskite (composition: Pl±tz+Mik±Bt±Ms+Ser±Chl±Ep±Crt+Ap±Zr+Orth+Mgt) (granite age: 300±5 Ma U-Pb method; and 295±10 Ma Rb-Sr method; I_{sr}=0,71472)). The magma generation of this series took place as a result of remelting of the Caledonian granite-gneisses (400±10 Ma, U-Pb) (Somin 2007), that is clearly seen in the field, particularly in the ovoid restites of granite-gneisses that are frequently observed, but petrochemically they represent identical formations.

Table 1: The average chemical analyses (mass %) of Variscan plutonic series and Late Caledonian granite-gneisses of the Greater Caucasus, according to acidity groups (N-amount of analysis)

Gr.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	N
Gabbro-Plagiogneiss series											
I	50.47	0.68	16.57	3.70	6.52	0.17	7.88	6.50	1.02	3.16	15
II	59.5	0.42	15.69	3.48	3.68	0.11	6.28	4.84	0.75	3.74	25
III	65.3	0.32	15.41	2.39	3.12	0.1	4.00	2.25	0.66	3.76	30
IV	71.33	0.25	14.03	1.15	2.14	0.06	2.70	1.13	0.81	4.03	35
V	77.28	0.11	12.94	0.42	0.65	0.03	1.78	0.60	0.39	4.85	20
Diorite-adamellite series											
I	52.87	0.92	16.93	3.56	4.87	0.17	7.60	5.43	1.66	3.16	17
II	60.02	0.67	17.35	3.29	4.60	0.12	5.60	2.39	1.97	2.77	30
III	64.6	0.58	16.55	2.33	3.26	0.14	3.86	1.96	3.09	3.43	38
IV	71.09	0.30	15.28	1.29	1.40	0.07	1.89	0.86	3.57	3.65	47
Plagiogranites of Plagiogranite-granite series											
III	65.05	0.74	16.14	1.60	3.29	0.11	3.32	2.09	2.06	3.25	12
IV	72.18	0.30	14.71	0.73	1.72	0.07	2.12	0.95	1.48	4.25	35
V	75.56	0.18	13.48	1.13	0.05	1.34	0,90	1.35	1.35	4.07	25
Granites of Plagiogranite-granite Series											
III	66.06	0.58	16.30	1.81	2.12	0.06	2.10	1.51	4.92	3.01	20
IV	70.70	0.32	15.01	1.06	1.18	0.05	1.67	0.81	5.2	3.27	45
V	75.95	0.05	12.77	0.27	0.77	0.03	0.57	0.43	5.92	2.6	25
Granodiorite – alaskite series											
III	67.55	0.61	15.66	1.66	2.54	0.07	2.59	1.50	2.81	3.58	8
IV	71.85	0.25	14.97	0.87	1.22	0.04	1.21	0.65	4.55	3.48	120
V	75.75	0.15	13.14	0.67	0.77	0.02	0.79	0.51	2.87	3.80	7
Late Caledonian granite-gneisses											
II	60.53	0.60	17.81	2.17	3.77	2.24	3.12	2.98	2.92	2.78	5
III	65.53	0.70	16.38	1.87	2.99	0.12	1.72	2.18	3.27	3.36	15
IV	70.94	0.45	15.49	1.12	2.02	0.06	1.32	1.16	3.83	3.55	15

Petrochemistry

Petrochemistry was based on various method investigations of magmatic system. The method gives an opportunity of systematization of great number of chemical and petrochemical data and, at the same time, shows graphically their variation tendencies. According to this method, chemical analysis are divided into I, II, III, IV and V groups of acidity, where I<57,00% SiO_2, II=57,00-61,99% SiO_2, III=62,00-67,99% SiO_2, IV=68,00-75,00% SiO_2; V>75,00% SiO_2 (Velikoslavinsky et al. 1994). For each oxygen group chemical and petrochemical parameters (Tables 1, 2) are calculated as average statistic data.

Diagram-model represents (Mg-Fe)O-CaO-$2Al_2O_3$-SiO_2 tetrad projection (Fig. 3) and gives an opportunity to discuss according to a single diagram the fractioning of multi-component magma systems. It is known that on a TiO2-(TiO_2+FeO) diagram co-magmatic rocks are distributed on a straight line, and hybrid and metasomatic rocks are distributed on unstraight line (Evrard 1947). This conformity is greatly revealed in the Greater Caucasus variscan plutonic series and represents good criteria for their genetic separation. Analyzing Fig. 3, it is evident, that different plutonic series start forming in different magmatic sources. Gabbro-plagiogneiss represents magmatic system which is formed in the area rich in aluminous and femic elements and they trend to eutectic zone. Diorite- adamellite series is also formed in the area rich with these elements, but in their formation the processes of assimilation and hybridization was important.

Table 2: The average petrochemical parameters according to acidity groups of Variscan plutonic series and Late Caledonian granite-gneisses of the Greater Caucasus (N-amount of analysis)

Gr	A	F	M	CaAl	SiAl	R_1	R_2	A/CNK	K	f	N
Gabbro-Plagiogneiss series											
I	17.3	52.6	30.01	29.5	79.5	1978	1486	0.81	11.5	53.3	15
II	22.2	49.6	28.01	27.3	82.4	2264	1214	0.85	10.4	49.8	23
III	35.7	43.5	20.8	22.5	89.8	2600	836	1.04	9.6	56.7	42
IV	59.2	29.6	11.2	19.6	94.3	2714	616	1.09	10.2	55	34
V	76.5	14.1	9.4	17.7	96.6	2949	460	1.1	4.8	52.2	30
Diorite-Adamellite series											
I	27.3	51.6	21.1	28.7	81.5	1780	1410	0.82	35.5	46.5	22
II	37.3	44.2	18.5	27.5	87	2212	1061	1.04	38.3	57.5	35
III	47.6	38.2	14.8	24.9	90.4	2322	828	1.04	34.7	64.1	44
IV	57.8	31.6	10.6	21.5	94	2530	538	1.12	45.4	67.3	54
Plagiogranite of Plagiogranite-granite series											
III	42.7	40.6	16.7	23.7	89.1	2514	774	1.20	29.5	52.4	57
IV	59.3	25.5	15.2	20.2	94.5	2790	556	1.20	20	68.5	79
V	68.4	20.3	11.3	18.1	96.5	2944	320	1.29	19.1	52.7	27
Granites of Plagiogranite-granite series											
III	57.6	31.6	10.8	20.6	94.0	2306	614	1.16	46.6	62.5	42
IV	78.4	15.3	6.3	19.5	96.5	2638	542	1.11	52.3	60.5	63
V	87.6	9.4	3.0	17.21	98.7	2750	354	1.11	63.0	66.5	47
Granodiorite – alaskite series											
III	58.1	30.8	10.1	22.0	93.11	2451	674	1.12	37	60.6	42
IV	70.2	21.5	8.7	20.2	96.5	2512	498	1.19	38.3	67.5	49
V	76.6	26.2	7.2	16.8	97.6	2887	364	1.20	34.2	53.3	22
Late Caledonian granite-gneisses											
II	37.9	43.6	18.5	38.8	58.7	25.5	88.1	27.9	37.5	34.6	35
III	47.6	37.4	15.0	37.1	58.7	22.7	91.7	25.7	34.6	39.7	20
IV	62.3	27.2	10.5	38.0	59.0	21.1	95.2	24.0	36.4	39.6	15

$A=Na_2O+K_2O$, $F=FeO+0,9Fe_2O_3$, $M=MgO$; $CaAl=CaO+2Al_2O_3$, $SiAl=SiO_2+2Al2O_3$; $R1=4Si-11(Na+K)-2(Fe+Ti)$, $R2=6Ca+2Mg+Al)$; $A=molAl_2O_3$, $C=molCaO$, $N=molNa_2O$, $K=molK_2O$; $k=K/(K+Na)\,x100\%$, $f=(Fe_2+Fe_3+Mn+Mg)\,x100\%$.

Plagiogranites of plagiogranite-granite series are formed in the area of poor of aluminous and femic elements and its composition trends to eutectic field, although silification deviates from this field. As we can see from the diagram the trend of Caledonian granite-gneisses is continued by that of the Variscan granodiorite-alaskite series trend, which confirms even more the opinion that the mentioned series represent the Late Caledonian granite-gneisses remelting products that trend to eutectic zone.

AFM diagram (parameters Table 2) analysis shows that the first oxidize point of gabbro-plagiogranite series is situated in the tholeiite field, but evolution trend goes through andesite and dacite fields. Diorite-adamellite series evolution trend follows tholeiite and calc-alkaline field divisions line and ends in dacite area. The evolution trends of the rest of the series are distributed in dacite and rhyolite fields. The analysis of kf diagram (parameter Table 2) shows that the studied plutonic series are characterized with average acidity (50-65) and potassium wide range as well (5-70). In general, some tendency can be observed according to which potassium content is increasing from Pre-Collisional plutonic series towards Collisional, specifically from gabbro-plagiogranite towards plagiogranite-granite (Okrostsvaridze 2007).

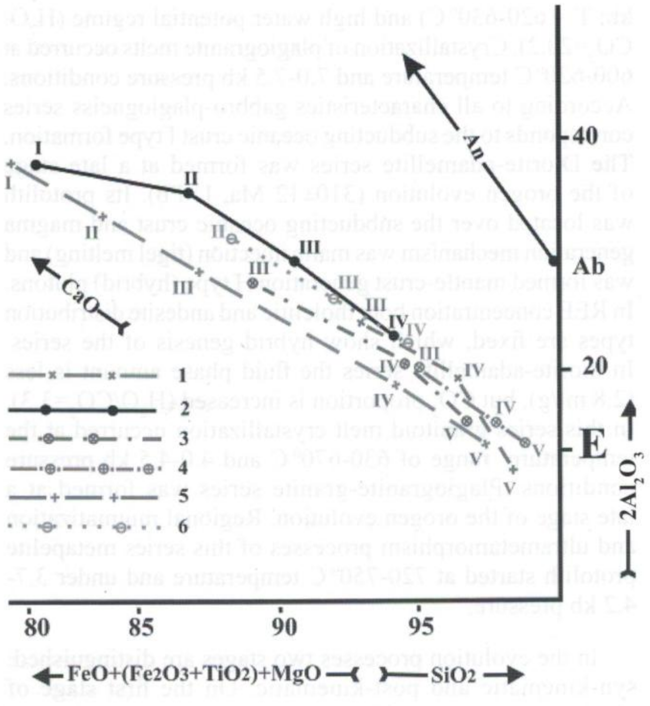

Fig. 3: The (Mg-Fe)O-CaO-$2Al_2O_3$-SiO_2 diagram-model for Variscan plutonic series of the Greater Caucasus, Trends: 1-Gabbro-plagiogneiss series, 2-diorite-adamellite series, 3-Plagiogranites of plagiogranite-granite series, 4-Granites of plagiogranite-granite series, 5-Granodiorite-alaskite series, 6-Late Caledonian granite-gneisses . E-Eutectic zone.

The analysis of R_1-R_2 diagram (parameters Table 2) reveals, that two average acidity points of gabbro-plagiogneiss and diorite-adamellite series dispose within pre-plate collision field. The last acidity point of gabbro-adamellite series is situated in the syn-collision field, and of gabbro-plagiogranite series in the borders of syn-collision and mantle fractionated fields. According to this diagram, plagiogranite-granite and granodiorite-alaskite series can be treated as syn-collision formation (Okrostsvaridze 2007).

The fluid regime of formation

The cryometric method shows that the gabbro-plagiogneiss series keeps the information about only slightly mineralized postmagmatic, hydrothermal fluids, the concentration of which does not exceed 5 mass% Equivalent NaCl ($Å_{NaCl}$). The fluids, which participate in the formation of diorite-adamellite series, have Na-Cl speciation and the concentration does not exceed 8-9 mass% ($Å_{NaCl}$). Two types represent the system of saline water inclusions in plagiogranite-granite series. The first type of inclusions has Na-Ca-Cl composition, its concentration ranges between 20-30 mass% ($Å_{NaCl}$). The isochors of these fluids are near PT parameters of metamorphism and ultrametamorphism (Fig. 4). The second type of saline water inclusions in plagiogranite-granite series are represented by weakly mineralized K-Na-Cl liquids, the concentration of which does not exceed 8-10 mass% ($Å_{NaCl}$). Two types of Ca-Na-Cl saline water liquids are already widely present in the granodiorite-alaskite series.

The concentration of the first one varies between 14 and 19 mass%, as of the second between 1 and 9 mass% ($Å_{NaCl}$). Paleosomes of migmatites, which are genetically related to plagiogranite-granite series practically, have no fluid inclusions. The evolution of the fluid system of this series is characterized by regular change. The earliest inclusion in leucosomes of migmatites consists of pure or nearly pure CO_2, but the latest of H_2O. As H_2O, CO_2, CH_4, N_2 and their mixture that determine the whole fluid composition, that suggests heterogeneous fluid participation in the process of ultrametamorphism (Roedder 1984). The appearance of CO_2 in fluid system is related to the process of migmatization, which occurred in conditions of amphibolite and partially granulite facies (Williams-Jones and Samisom 1990).

The chromatographic method has been applied to the following gases: H_2O, CO_2, CH_4, C_3H_8, H_2, N_2, SO_2, O_2, H_2S, HCl, HF. The results show that the Variscan plutonic series of the Greater Caucasus are sharply different according to their gas composition. Plagiogneiss of the gabbro-plagiogneiss series are distinguished by the large sum composition of gas phase (11.2 ml/g) and concentration of water is the highest in the fluid phase of these rocks ($H_2O/CO_2=20.2$). The gas sum amount in diorite-adamellite series is sharply decreased (2.80 ml/g), but CO_2 proportion is increased ($H_2O/CO_2=3.3$). The gas sum amount in protoliths (migmatites) of plagiogranite-granite series is low and does not exceed 2.2 ml/g, and the parameter $H_2O/CO_2=5.3$. In plagiogranites of this series the gas chemical amount does not increase as compared to migmatites, but CO_2 percentage clearly increases ($H_2O/CO_2=2.8$). As compared to plagiogranites in porphyroblastic granites of this series the fluid phase sharply increases and its chemical amount reaches 6.2 ml/g. At the same time CO_2 proportion is decreased and H_2O/CO_2 parameter goes up to 12.7. The gas chemical amount (4.5 ml/g) is also high in granodiorite-alaskite series; the water proportion ($H_2O/CO_2=8.2$) is also high.

It is known that N/C parameters ($N=2N_2$; $C=CO_2+CH_4+3C_x$) for the continental crust formation ranges in the interval of 0.15-0.50, whereas for the oceanic crust it is lower than 0.15 (Norman and Sawkins 1987). According to these parameters gabbro-plagiogneiss series corresponds to oceanic crust formation (N/C=0.077) and diorite-adamellite series both to the oceanic (N/C=0.117) and to the continental crust (N/C=0.330). This parameter in plagiogranite-granite series is 0.236 and in granodiorite-alaskite series 0.231, which points to their upper crust genesis.

PT regime of formation

The Granite-biotite geothermobarometer and granite-cordierite barometer (Perchuk et al. 1993) showed consistent results in the Variscan orogenic plutons of the Greater Caucasus. The data is most informative in plagiogranite-granite and granodiorite-alaskite series. In protoliths of plagiogranite-granite series, the regional migmatization and

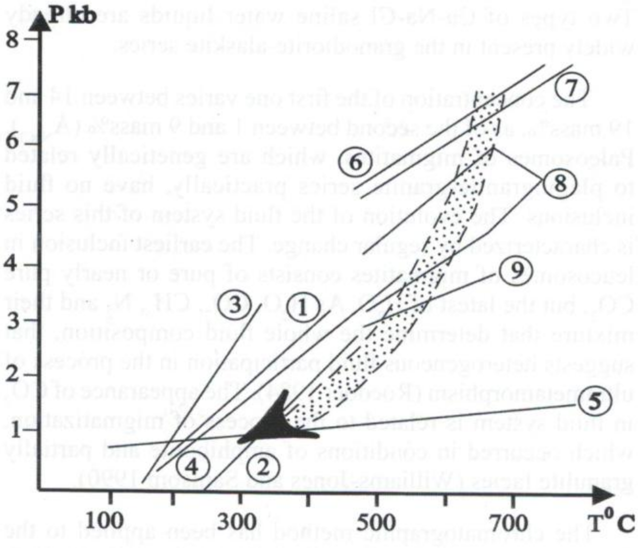

Fig. 4: Fluid evolution PT diagram for the Variscan plutonic series of the Greater Caucasus. Trends: 1- Saline-water system, T_{hom} = 100°C, 10 mass% (E_{NaCl}); 2- Saline-water system, T_{hom} = 200°C, 10 mass% (E_{NaCl}); 3- Saline-water system, T_{hom} = 150°C, 10 mass% (E_{NaCl}); 4- Saline-water system, T_{hom} = 120°C, 25 mass% (E_{NaCl}); 5- Nitrogen system, S_N = 3.289 cm³/gr; 6- Carbon-dioxide gas system, S_{CO_2}=0.92 cm³/gr; 7- Carbon-dioxide gas system, S_{CO_2}=0.93 cm³/gr; 8- H_2O-CO_2 system, H_2O 40 mass% and 20 mass%; 9- Carbon-dioxide gas system, S_{CO_2}=1.16 cm³/gr. Regression trend of plutonic formation marked by arrow.

ultrametamorphic processes started at 730-750°C temperature range and under 3.7-4.2 kb pressure. The microclinization and pegmatization process thermal regime reaches up to 600-620° C and 2.2-2.7 kb pressure. Granodiorite-alaskite series formation temperature interval is very small (710-735° C) and pressure ranges in the interval of 3.2-3,5 kb. According to amphibole geothermobarometer (Okrostsvaridze 2007) the maximal PT regime in the gabbro-plagiogneiss series protoliths reached 8.2-8.7 kb pressure and 620-630° C temperature. The crystallization of the plagiogneiss melt occurred at the regression stage of regional metamorphism and ultrametamorphism at about 600-620°C temperature and 7.0-7.5 kb pressure conditions. In diorite-adamellite series according to this geothermobarometer the granitoid melt crystallization occurred in the range of 4.0-4.5 kb pressure and 630-670° C temperature regime.

Petrogenetic model

Fig. 5 summarizes the petrogenetic model of the Greater Caucasus Variscan plutonic magmatism from these data. The gabbro-plagiogneiss series, which is exposed along the main fault in the form of lesser tectonic uplift, was formed at an early stage of the Variscan orogen evolution (355±15 Ma; I_{sr}=0,70343). This series both for gabbro and for plagiogneiss is characterized by tholeiitic type REE distribution, which is one more confirmation of their genetic unity. According to the discussed data, the series should have been formed as the result of subducting oceanic crust partial melting (P= 8.2-8.7 kb; T = 620-630° C) and high water potential regime (H_2O/CO_2=20.2). Crystallization of plagiogranite melts occurred at 600-620° C temperature and 7.0-7.5 kb pressure conditions. According to all characteristics gabbro-plagiogneiss series corresponds to the subducting oceanic crust I type formation. The Diorite-adamellite series was formed at a late stage of the orogen evolution (310±12 Ma, U-Pb). Its protolith was located over the subducting oceanic crust and magma generation mechanism was mafic injection (tigel melting) and was formed mantle-crust generation H type (hybrid) plutons. In REE concentration both tholeiitic and andesite distribution types are fixed, which show hybrid genesis of the series. In diorite-adamellite series the fluid phase amount is less (2.8 ml/g), but CO_2 proportion is increased (H_2O/CO_2=3.3). In this series granitoid melt crystallization occurred at the temperature range of 630-670° C and 4,0-4.5 kb pressure conditions. Plagiogranite-granite series was formed at a late stage of the orogen evolution. Regional migmatization and ultrametamorphism processes of this series metapelite protolith started at 720-750° C temperature and under 3.7-4.2 kb pressure.

In the evolution processes two stages are distinguished: syn-kinematic and post-kinematic. On the first stage of plagiogranite composition anatectic magma was formed (318±7 Ma; I_{sr}=0,70843)), which made conforming bodies, and on the second stage the granite composition melts were formed, which mainly made cross-cutting bodies (315±5 Ma; I_{sr}=0,71134). In early syn-kinematic phase in plagiogranites the fluid phase amount is detected (2 ml/g) and CO_2 share is high (H_2O/CO_2=2.8). Ion the late syn-kinematic granite, a sharp increase can be seen in the fluid phase (6.2 ml/g), but CO_2 share is decreased (H_2O/CO_2=12.7). According to all characteristics, plagiogranite-granite series belongs to syncollisional anatectic melts, typical of S-type granitoid formation.

The Granodiorite-alaskite series was formed at a late stage of the orogen evolution (295±10 Ma; I_{sr}=0,71572) and it ended the Greater Caucasian Variscan plutonic magmatism. Magma in this series was formed as a result of remelting of Upper Caledonian granite-gneiss. In this series as compared to plagiogranites of plagiogranite-granite series the fluid phase is increased (4.5 ml/g) but CO_2 share is low (H_2O/CO_2=8.2). The PT regime of crystallization temperature ranges in the interval of 710-735°C and pressure is in 3.2-3.5 kb interval. This series corresponds to syn-collisional remelting, leading to formation of a S type granitoid.

DISCUSSIONS

This study shows that the Greater Caucasus Pre-Alpine basement represents a collage of complexes with different geological histories, which in Late Paleozoic as a result of Palaeo-Tethys oceanic crust subduction approached each other and sometimes subducted. In these formations protoliths were differents as well as the mechanism of magma generation and evolution. Thermobaric and fluidal regimes differed, resulting in S, I, and H type plutonic

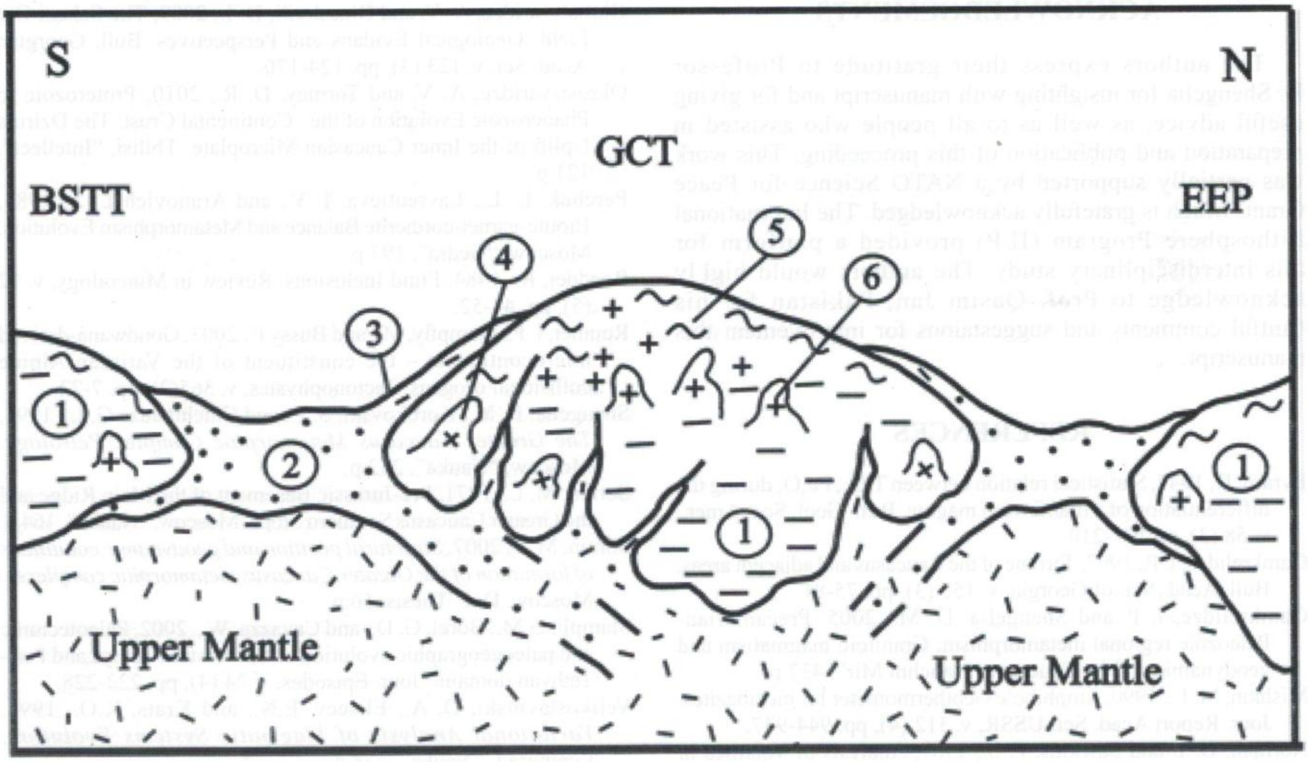

Fig. 5: Hypothetical geological cross section through the Greater Caucasus Orogen and of the Variscan Tectonic-thermal events (Late Carboniferous –Early Permian). It is shown on the figure how Great Caucasus Terrane (GCT) go through collision between Black Sea Central Transcaucasian terrane (BSTT) and East European Platform (EEP). Pre-Variscan rocks (1) undergo intensive reworking. In subduction zones gabbro-plagiogneiss associations (3) are formed, over subducted oceanic crust (2) hybrid diorite-adamellite plutons (4) undergo generation, as a result of metapelite anatexis plagiogranite-granite series (5); Pre-Variscan Caledonian granite-gneisses recycling results in the formation of the diorite-alaskite (6) plutonic associations undergo.

series. Ore-concentrating mineralization is also different among the series; only in diorite-adamellite series contact zones does gold-quartz-low sulphide mineralization occur (Sakeni Goldfield) (Okrostsvaridze and Bluashvili 2009). There are still uncertainties in the development of the Greater Caucasus, including the role of plume magmatism, as well as exhumation processes. Also, the Pre-Variscan terranes may be of Gondwanian or Eurasian affinity (Roumer et al. 2003). The Caucasus inner microplate is considered to be part of the Gondwana north edge fragments (Okrostsvaridze and Clarke 2004; Somin 2007; Okrostsvaridze and Tormey 2010).

It is evident, that the Greater Caucasian crystalline basement is a collision-accretion construction of a complicated history, where Variscan orogenic magmatism played an important role. Based on the petrogenesis of the Variscan plutonic series and their zoning, we consider that during the Middle-Late Carboniferous northward subduction of the PaleoTethys oceanic crust was activated (Paleo-Tethys closing and Neo-Tethys opening process). Its activity on the southern margin of Eurasian continent caused island arc complex collision, as well as Variscan orogenic magmatic events. This activation also comprised the Euro-Asian plate southern edge which is demonstrated by the existence of Variscan recycling plutonic magmatism.

CONCLUSIONS

Evolution of plutonic magmatism is clearly observed in the Variscan tectonic-thermal events of the Greater Caucasus. Mantle origin gabbro-plagiogranite series is formed (355±15 Ma) at the initial stage of the process at the south margin of the orogen in subduction zone. During 320±8 Ma mantle-crust generated gabbro-adamellite series formed just above the subduction zone. Much later (315±7 Ma; 310±5 Ma) crustal anatectic plagiogranite-granite series started formation in the arched part of collision structure. The Greater Caucasian Variscan plutonic magmatism is ended by granodiorite-alaskite series (300±5 Ma), which formed at the expense of the upper Caledonian granite gneisses as a consequence of the East-European platform felsic rock recycling. Thus, a reduction in the share of the mantle source material and increase in the crustal source is clearly observed in the evolution of the Greater Caucasian Variscan plutonic magmatic evolution.

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