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Plutonic Magmatism of the Greater Caucasus Svaneti Segment: Zircon U-Pb Geochronology, Petrochemistry and Geodynamic Setting

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The Greater Caucasian fold-and-thrust belt is part of the Alpine-Himalayan collisional orogenic belt. It experienced complex polycyclic development during the Late Precambrian and throughout the Phanerozoic. This article discusses new U-Pb LA-ICP-MS U-Pb geochronology and petrochemistry data on zircons from the plutons of the Svaneti segment (Georgia) of this orogen. U-Pb geochronological data indicate three main stages of plutonic magmatic activity: 1- Ordovician, 2- Upper Carboniferous, and 3- Middle Jurassic (Aalenian-Bajocian). At the first stage, Ordovician biotite orthogneisses (~488-475 Ma) were formed during the Caledonian orogeny in supra-subduction conditions. At the second stage, the Upper Carboniferous granodiorite–granite plutons (~320–310 Ma) were formed during the Late Variscan Orogeny also in supra-subduction conditions, while Middle Jurassic plutons were formed in post-accretional ones. At the end of the Late Triassic, during the Early Cimmerian (Indosinian) orogeny, the oceanic basin of the southern slope of the Greater Caucasus was closed. Later, at the beginning of the Jurassic, the process of stretching of the Earth's crust began, during which in the Middle Jurassic (in the Aalenian-Bajocian) stage predominantly the monzosyenitic of pluton formation took place (the third stage). The age of these plutons gradually decreases from the north to the south (~177, ~168, ~164 Ma). This indicates the spread of the process of crustal stretching from north to south. The formation of the plutons of the Main Range zone of the Greater Caucasus (island arc) took place in supra-subduction conditions of the active margin of the back-arc small oceanic basin of its southern slope, while the monzodiorites, monzosyenite and monzinite plutons, located in the Paleozoic-Triassic Dizi series and Lower Jurassic black shales, were formed on the passive margin of this basin, in conditions of continental slope and foot, which have a thin sub-oceanic Earth's crust. *© 2023 Bull. Georg. Natl. Acad. Sci.*

Greater Caucasus, Svaneti segment, U-Pb geochronology, petrochemestry, Geodynamic setting

The Greater Caucasus orogeny, is an excellent study area to investigate the interaction between tectonics and plutonic magmatism, because it records a critical transitional stage of Earth's crustal formation during the period from the Neoproterozoic to the Late Paleozoic. Therefore, a detailed investigation of the plutonic magmatism of the region provides temporal and compositional constraints on the formation of continental crust and geodynamic processes. This paper discusses the Svaneti segment of this orogeny, which is located in Georgia and is the highest, most exposed central part of The Greater Caucasus. Numerous plutonic bodies of different ages, scales and genesis make this segment the perfect site for the investigation of tectonics and plutonic magmatism.

Although Svaneti plutonic magmatism has been studied broadly in terms of age groups (Paleozoic and Jurassic) [1-5], for this investigation we have analyzed almost all the age groups of plutonic formations of the region using zircon LA-ICP-MS U-Pb geochronological data and petrochemical study.

We have used these new data in combination with existing geological data to develop probable scenarios of the geodynamic nature of Svaneti plutonic magmatism from the Early Devonian to the Middle Jurassic in order to better understand the early development of continental formation and growth through collisional orogenic plutonic magmatism.

Overview of Regional Geology

The Greater Caucasian fold-and-thrust belt extends in a NW-SE direction over 1,200 km from the Black Sea to the Caspian Sea. It represents the central segment of the Alpine-Himalayan collisional belt, between the still converging Gondwana-derived Arabian plate and Scythian platform of the Eurasian plate. The Greater Caucasus is the northern most expression of the Caucasus and is accreted to the southern margin of the Precambrian Scythian platform. [e.g., 5, 1, 2, 4]. In the Greater Caucasus two major formations are defined: pre-Jurassic crystalline basement and Meso-Cenozoic magmatic and sedimentary formations.

The basement complex of the Greater Caucasus along the Main Thrust of the Greater Caucasus overthrusts to the south of the Lower Jurassic formations. In the construction of the basement complex four regional tectonic zones are recognized from S to N: Southern Slope, Main Range, Forerange and Bechasyn. The Main Range zone is the best exposed part of the basement complex and is divided into two subzones based on the difference in structure and composition: the Pass and the Elbrus, which are in tectonic contact along the Alibak-Urukh regional fault.

The Elbrus subzone is mainly composed of felsic rocks, which have undergone low pressure-high temperature (LP-HT) supra-subduction regional metamorphism. In contrast to the Elbrus subzone, the Pass subzone protolith contains mostly mafic rocks, however it has also been subjected to LP-HT type of metamorphism [1]. Based on mineralogical, geochemical, Sr isotopical and fluid inclusions investigation of the Elbrus subzone, a significant amount of S-type anatectic magmatism revealed. In contrast, in the Pass subzone magmas consist of hybrids of mantle and crustal origin [7].

The southern slope zone of the Greater Caucasus exposed in the Svaneti segment (Dizi series) is composed of terrigenous, intensely folded sedimentary rocks of ~2,000 m thickness, metamorphosed to the chlorite-sericite subfacies of the greenschist facies [8]. The metasediments are cut by numerous plu tons that are considered in this paper. The Dizi series was deposited during the Devonian to the end of the Triassic period [9]. The Mesozoic period of the Greater Caucasus starts with Jurassic oceanic transgression, when ~3,000 m thick black shales and sandstones were deposited. The middle Jurassic deposits of the Greater Caucasus is cut by gabbros, diorites, syenites and quartz-diorites [4].

The Svaneti segment is located in the central, highest elevated part of the Greater Caucasus and

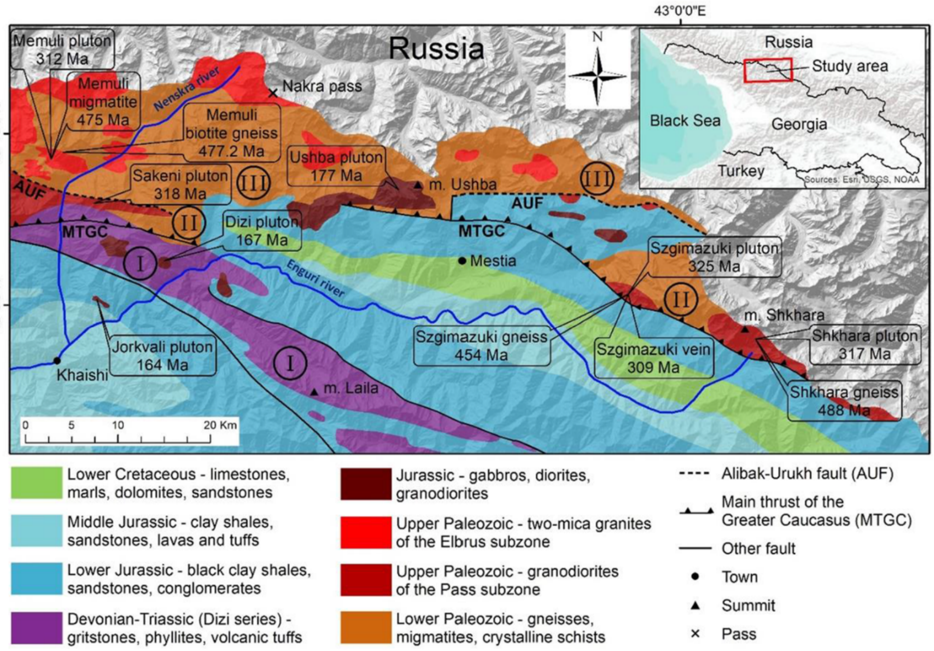

Fig. 1. Geological map and zircon U-Pb geochronological data of the plutons and their xenoliths of the Greater Caucasus Svaneti segment. Roman numerals in a circle: – structural-tectonic zones of the crystalline basement: I – The Southern Slope, II – The Pass sub-zone of the Main Range zone, III – The Elbrus sub-zone of the Main Range zone. The map is modified according to Geological map of Georgia [6].

covers more than 7,000 km^2 area. Crystalline basement is exposed here, underlying the Mesozoic sedimentary cover. Plutons of different ages and genetic types are exposed in the Svaneti segment (see Fig. 1). In this study, we focused on plutons from relatively non-depleted sources, from which we could obtain zircons suitable for geochronological study. These plutons are: Shkhara, Szgimazuki, Memuli, Sakeni, Ushba, Disi and Jorkvali. Since the zircon U-Pb geochronology of the Szgimazuki, Memuli, and Sakeni plutons is discussed in another paper [10], we will not describe them here.

Materials and Methods

A suite of 35 plutonic rocks and their xenolithic samples (~5 kg each) were collected in the Svaneti segment for zircon U-Pb geochronology. Since the rocks undergo intense deformation and fracturing in the structure, good zircons for geochronology were only available for 12 samples.

The U-Pb zircon geochronology was conducted at the Department of Earth and Environmental Sciences of National Chung-Cheng University, Taiwan, via laser ablation inductively coupled plasma mass spectrometry equipped with an Agilent 7500s quadrupole and a New Wave UP213 laser ablation system. Calibration was performed using the GJ-1 zircon standard [11]. All U-Th-Pb isotope ratios were calculated using GLITTER 4.4.2 (GEMOC) software, and the isotope ratio of common lead was corrected using the approach pro- posed by Andersen [12] (2002). A detailed analytical procedure has been described by Chiu et al. [13]. In addition, the 12 samples from which the zircons were separated and dated were analyzed for whole-rock geochemical compositions by a multi-element ICP-AES/MS (48 elements), in MSALABS laboratory, Canada.

Results

Zircons U-Pb geochronology

From 12 samples of Svaneti plutonic rocks and their xenoliths was separated and dated 317 zircon grains.

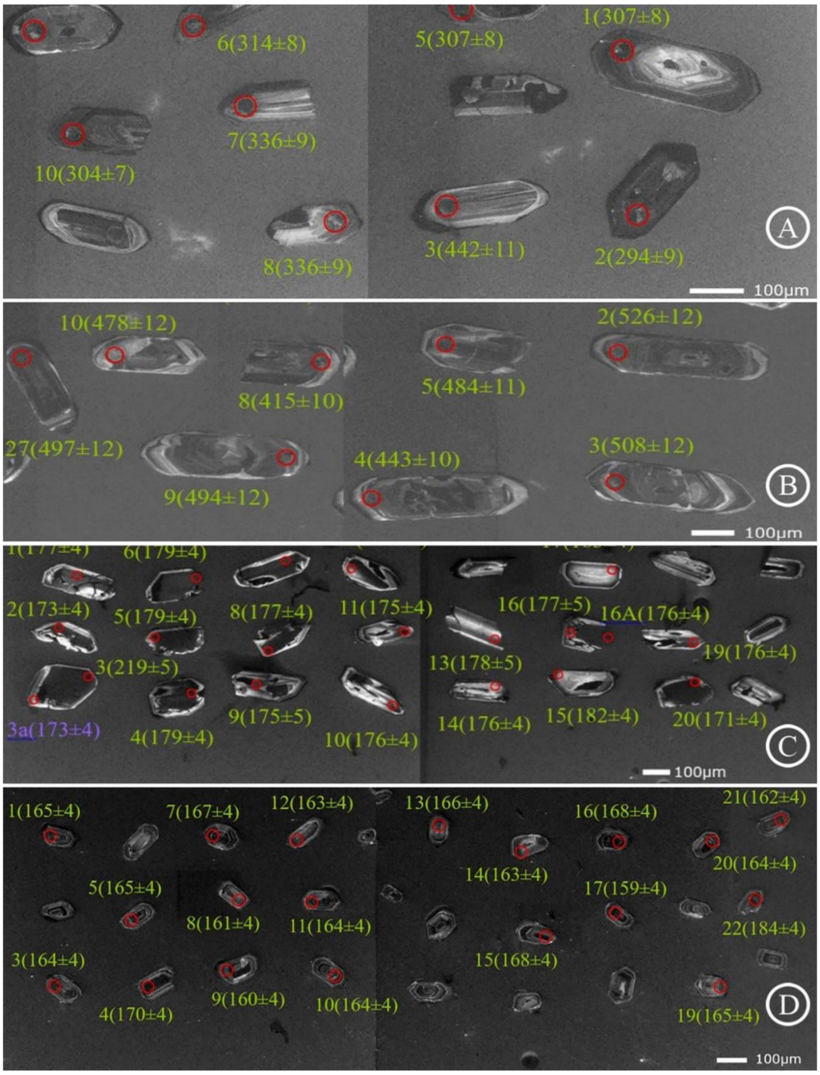

Fig. 2. LA-ICP-MS Cathodoluminescence images and U-Pb ages of the zircons: A – Shkhara pluton granodiorite (12Geo-12), B - Shkhara pluton biotite gneiss xenolith (12Geo-14), C - Ushba pluton granodiorite (12Geo-5) and D - Jorkvali plutone diorite (12Geo-27).

These grains covered almost the full age spectrum of the plutonic magmatic activities of the Svaneti region: Caledonian, Variscan and Middle Jurassic. It should be noted, that in zircons of Ushba, Dizi and Jorkvali plutons, in most cases their Th/U ratios exceed 0.4, which is typical for zircon of magmatic origin [14]. While, in other plutons, this parameter is in most cases less than 0.4. The results for each pluton are discussed in the following paragraphs.

Shkhara pluton

The pluton forms a large part of the Shkhara massif, which is exposed in the headwaters of the Enguri river and creates a ~15 km long and ~5 km high ridge (see Fig. 1) is a metamorphosed formation of the Pass sub-zone, transformed into gneisses and migmatites. The pluton, which cuts the metamorphic rocks is composed mainly of biotite granodiorites and granites. It is characterized by numerous metamorphosed xenoliths, with sizes ~1 m range. The enclaves are represented predominantly by biotite gneisses and migmatites. According to petrochemical and isotopic parameters the pluton is interpreted as I-type granitic formation of mantle-crustal generation [7].

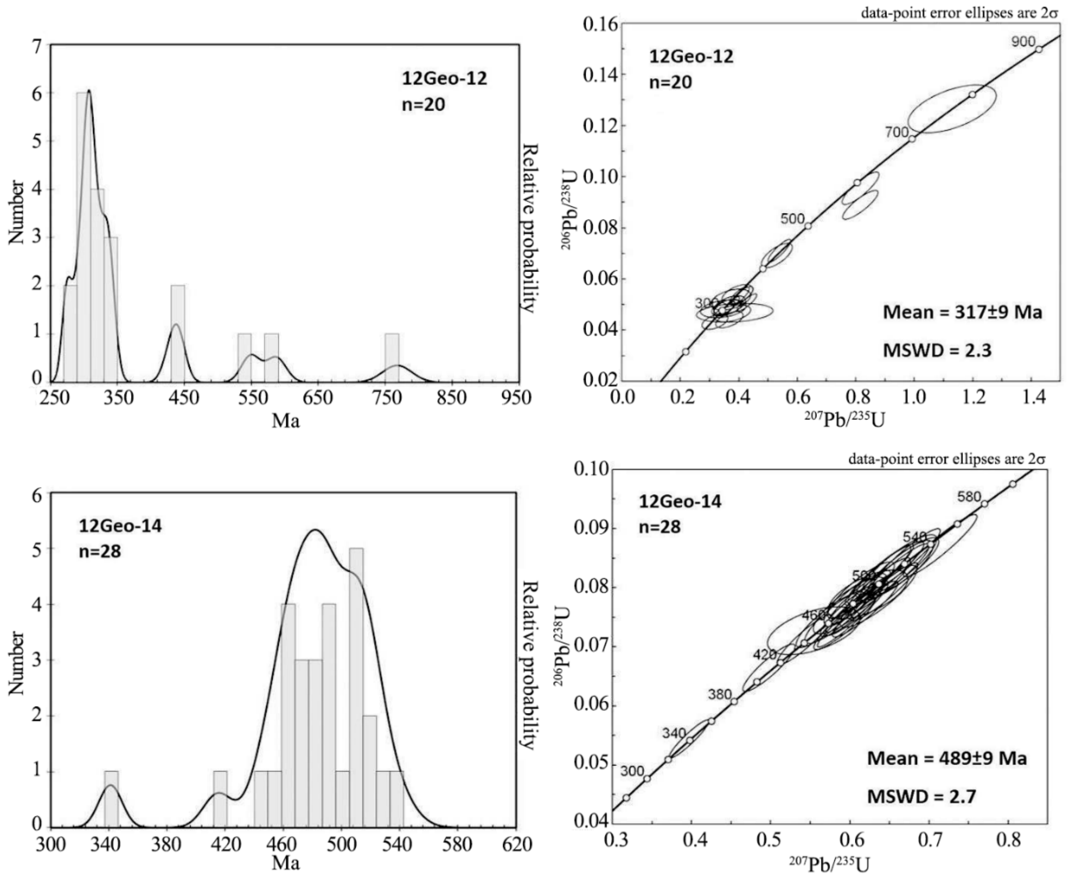

Fig. 3. Right panels: Concordia U-Pb diagrams of the Shkhara pluton granodiorite zircons (12Geo-12) and for their biotite gneiss xenolith zircons (12Geo-14). Left panels: 206Pb/238U ages histograms of Shkhara pluton granodiorite zircons (12Geo-12) and their biotite gneiss enclave zircons (12Geo-14).

One sample was dated from the main phase of this pluton (sample 12Geo-12). It is light gray, massive, medium grained biotite granodiorite, with the following mineral composition: Pl+Qz+Kfs+Bt+Hbl+Chl+Ep+Zrn+Aln. A biotite gneiss xenolith (70 cm × 120 cm) was also dated (sample 12Geo-14) 5 meters from the sampling site. This is a homogeneous, light gray, medium grained, thin-layered biotite gneiss with simple mineral composition: Qz+Pl+Kfs+Bt+Ms+ Grt+Zrn.

From a biotite granodiorite sample (12Geo-12) of the Shkhara pluton 20 bipyramidal zircons (150 µm × 300 µm) were separated. These are zonal grains with two distinct zones: a small number of inherited older zircon cores and a rim (Fig. 2 A). Age spectra of inherited zircon cores in most grains varies between 550–450 Ma, while rim ages are within 275–330 Ma range. Only one detrital zircon dated 768 Ma. The weighted mean 206Pb/238U age of zircon rims from granodiorite host rocks sample of Shkhara pluton is interpreted as 317.9 Ma (12Geo-12), based on sixteen concordant zircon spot analyses (MSWD=2.3, probability=0.009) (Fig. 3).

From Shkhara pluton biotite gneiss xenolith (12Geo-14) 28 zircon grains were separated and dated (~100 µm × ~300 µm) (Fig. 2B). In these crystals core and rim zones can be observed, though the age difference between them is not large and varies between ~450-530 Ma. Zircon's weighted mean 206Pb/238U age of these crystals corresponds to 488.5±8.5 Ma (MSWD=2.7, probability= 0.000) (Fig. 3).

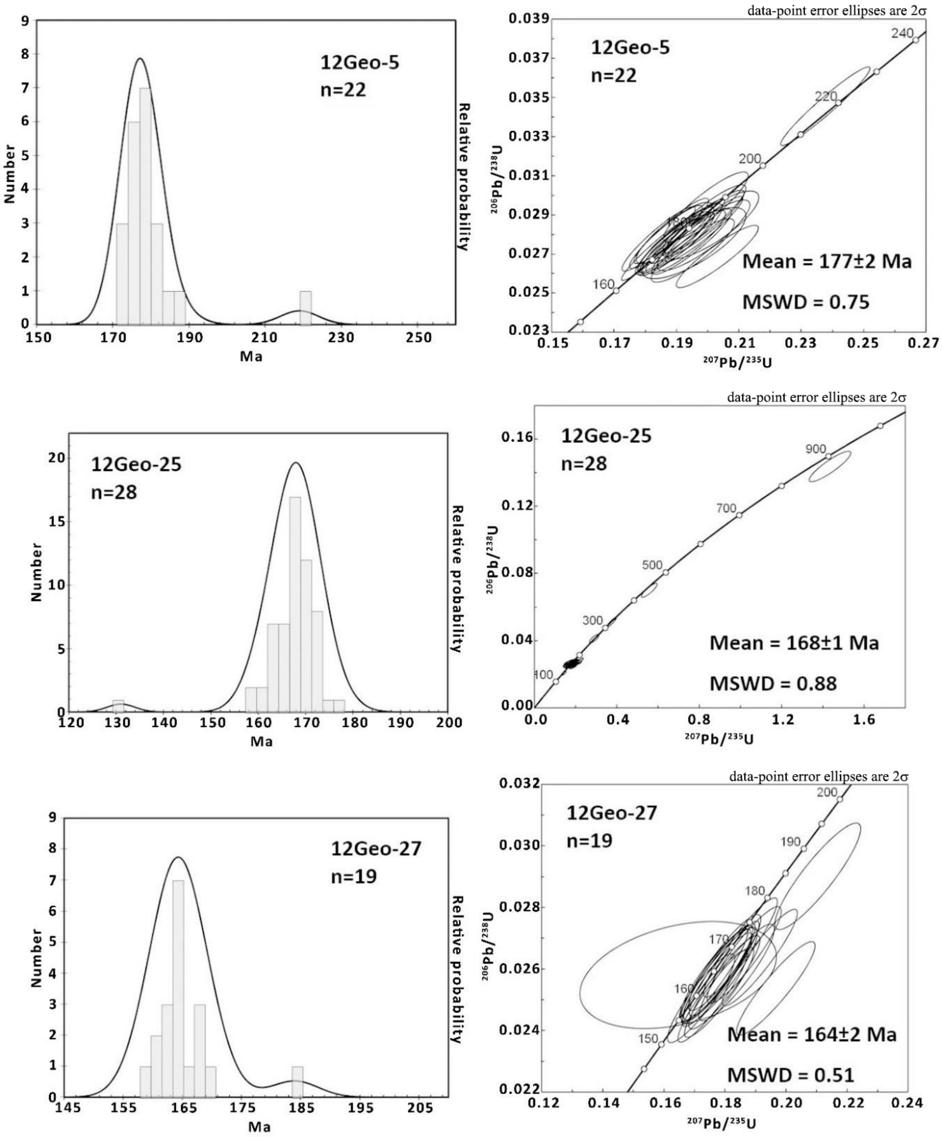

Fig. 4. Zircons concordia U-Pb diagrams (right panels) and 206Pb/238U ages histograms (left panels) of the Ushba (12Geo-5), Dizi (12Geo-25) and Jorkvali (12Geo-27) plutons.

Ushba pluton

This pluton crops out as lens-shaped body along the Main Thrust of the Greater Caucasus (~25 km^2) (Fig. 1). To the north it is in contact with middle Paleozoic schists; to the south – with Late Carboniferous weakly metamorphosed so called "Kvishi Suite". Analogous smaller plutons are exposed to the east (Banguriani, Seri and Tviberi), cutting through Lower Jurrasic shales [3]. Ushba pluton is a complex, hybrid formation, composed and compoused predominantly by monzosyentes and syenites.

One massive, medium grained biotite-hornblende syenite sample was dated from Ushba pluton (12Geo-5). Its composition is follows: Pl+Kfs+Qz+Hbl+Bt+Chl+Ep+Sf+Mag+Zrn. 22 small (150 μm × 100 μm) zircon grains were separated and dated from the sample. These zircons are note zoned, however all of them have thin rims. There is no age difference between crystals' cores and rims and their ages are in the range of 173–219 Ma (Fig. 2C). Zircon's weighted mean 206Pb/238U age of the Ushba pluton granodiorite corresponds to 177.2 Ma, based on nineteen concordant zircon spot analyses (MSWD=0.75, probability=0.78) (Fig. 4).

Dizi pluton

This pluton is exposed as several apophyses in the Dizi series at the Dizi village in the Enguri river valley (~1.2 km^2) (see Fig. 1). Analogous plutons are exposed in this series to the East Abakuri and to the West Kirari. All of these plutons are in active contact with host rocks of Dizi series and compoused predominantly by monzosyentes and syenites. One fine grained, massive syenite sample was dated from the Dizi pluton (12Geo-25). Its mineral composition is: Pl+Kfs+Hbl+Bt+Chl+Ep+Mag+Zrn. 28 small (150 µm × 120 µm), bipyramidal zircons were separated. Although these zircons have slight zonality, there is no age difference between zones. Detrital zircons were not found; however, two inherited older zircon cores were identified, with the ages – 436 and 320 Ma. Zircon's weighted mean 206Pb/238U age of the Dizi pluton syenite corresponds to 168.11.0 Ma (12Geo-25) based on twenty-one concordant zircon spot analyses (MSWD=0.88, probability=0.73) (Fig. 4).

Jorkvali pluton

This pluton crops out in Enguri river valley to the south of Dizi pluton at the Jorkvali village and cuts lower Jurassic shales. It is composed predominantly by monzodiorites and monzinite of ~100 m thickness, can be observed at 4 km long. Similar ~120 m thick pluton cuts lower Jurrasic shales in Tskhenistskali river valley to the East of Jorkvali pluton [3]. One massive, fine grained monzonites sample (12Geo-27) was dated from the Jorkvali

Table 1. Summary of LA-ICP-MS U-Pb zircon dating results of plutons and their xenoliths of the Greater Caucasus Svaneti segment

Sample	Location	Lat (°N)	Long (°E)	Petrography	Age (Ma)[1]	MSWD [2]	n [3]	Rocks Type
12Geo12	Shkhara pluton	42.9719	43.0919	Granodiorite	316.9±8.8	2.3.	20	Main phase
12Geo14	Shkhara pluton	42.9717	43.0919	Bt. gneiss	488.5±8.5	2.7	28	Xenolith
12Geo15	Szgimazuki massif	43.0534	42.8997	Plagiogneiss	454.4±9.3	2.2	39	Host rock
12Geo18	Szgimazuki pluton	43.0312	42.9218	Plagiogranite	324.9±3.5	2.5	28	Main phase
12Geo17	Szgimazuki pluton	43.0312	42.9218	Alaskite	309.2±7.5	2.5	33	Vein
12Geo30	Memuli massif	43.1345	43.1856	Migmatite	475±12	2.0	25	Host rock
12Geo32	Memuli pluton	43.1134	43.1746	Two-mica Granite	312±6	1.4	30	Main phase
12Geo33	Memuli pluton	43.1134	43.1746	Bt. Gneiss	477.2 ± 9.7	2.5	25	Xenolith
12Geo28	Sakeni Pluton	43.0331	42.1212	Granodiorite	318±5.8	2.3	20	Main phase
12Geo5	Ushba pluton	43.1180	42.7251	Syenite	177±1.8	0.75	22	Main phase
12Geo25	Dizi pluton	43.0301	42.3539	Syenite	167.6±1.0	1.3	25	Main phase
12Geo27	Jorkvali plutom	43.0403	43.3344	Monzinite	164.3±1.8	1.01	22	Main phase

[1] $^{206}Pb/^{238}U$ weighted mean ages

[2] Mean square of weighted deviates

[3] Excluding discordant and outlier spot analyses, and xenocrystic zircons

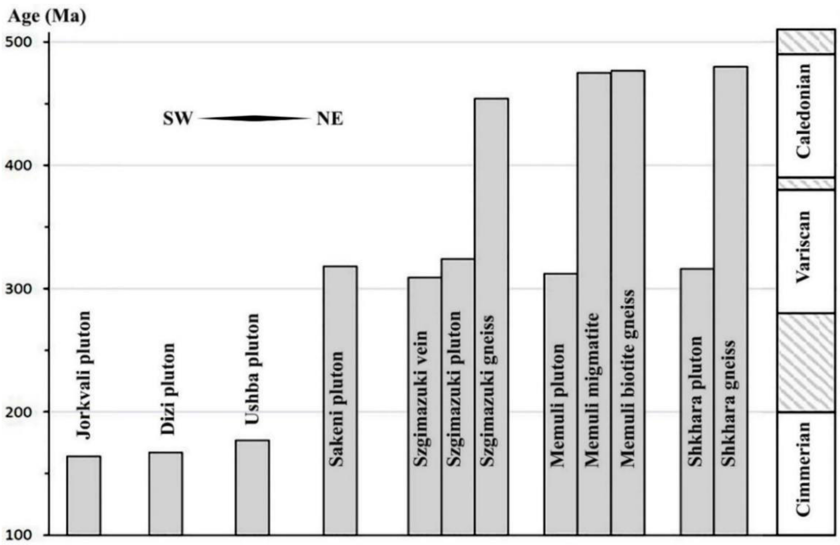

Fig. 5. Summary diagram of zircon LA-ICP-MS U-Pb dating results of the Greater Caucasus Svaneti segment plutons.

pluton. Its mineral composition is: Pl+Qz+Hbl+Bt+Chl+Ep+Mag+Zrn. 19 small (120 μm × 80 μm), bipyramidal, almost isometric zircon crystals were separated from the sample. These zircons have weak zonality, however, core and rim ages are almost identical (Fig. 2D). Zircon's weighted mean 206Pb/238U age of the Jorkvali pluton diorite corresponds to 164.31.8 Ma, based on fourteen concordant zircon spot analyses (MSWD=0.51, probability=0.95) (Fig. 4).

The results of the zircon new LA-ICP-MS U/Pb geochronological data of plutons and their xenoliths of the Svaneti segment of the Greater Caucasus are summarized in Table 1 and Fig. 5. There are three major age groups, corresponding to different geodynamic settings in this region: Caldonian, Variscan and Middle Jurassic.

Petrochemistry

Petrochemical analysis of Svaneti segment of the Greater Caucasus showed that major magmatic phases of dated plutons are represented by different petrotypes (Table 2; Fig. 6). On TAS discrimination diagram (Fig. 6A) the Late Carboniferous plutons are placed in granite and granodiorite fields. They are Al-rich rocks with SiO_2 contents varying between ~68-74 wt %, while total alkalis (Na_2O+K_2O) content does not exceed 7.5 wt %. In contrast with the Late Carboniferous plutons, the Middle Jurassic plutons are represented by monzodiorites, monzinites and and syenites (Fig. 6A). SiO_2 content in these plutons varies between ~58-67 wt %, while total alkali content exceeds 7.5 wt %. It should be noted that the SiO_2 content in these plutons decreases from the Ushba pluton (~67%) to the Jorkvali pluton (~58%) (from the north to the south). As for the Ordovician biotite gneisses and migmatites, on TAS discrimination diagram they are placed within granite field (Fig. 6A).

On AFM discrimination diagram Svaneti segment plutons and their xenoliths are placed almost entirely within the calc-alkaline series field; only one point of Sakeni pluton is placed within the tholeitic series field (Fig. 6B).

Below, we used Rb-(Nb+Y) geodynamic discrimination diagrams for syn-collisional and post-collisional geodynamic settings, since accretional processes are similar to collisional ones.

On Rb-(Nb+Y) geodynamic discrimination diagram Late Carboniferous plutons are placed within the syn-collisionional (syn-accretional granite field, while the Middle Jurassic Middle Jurassic

Table 2. Major and some trace elements chemical analyses of the plutons and their xenoliths of the Greater Caucasus Svaneti segment

Sample	12Ge12	12Ge14	12Ge15	12Ge17	12Ge18	12Ge30	12Ge32	12Ge28	12Ge05	12Ge25	12Ge27	12Ge33
Major elements (wt.%)												
SiO_2	68.27	71.43	70.97	76.97	73.47	71.37	72.05	64.8	66.80	63.65	57.82	71.23
Al_2O_3	15.40	14.98	16.42	14.34	15.24	16.10	15.12	15.13	15.20	16.37	16.86	15.18
Fe_2O_3	4.55	2.23	1.45	0.75	0.77	2.19	2.38	6.04	3.70	4.24	6.78	2.33
CaO	2.33	0.95	2.78	2.00	2.10	1.91	1.24	5.32	3.55	3.87	5.57	0.85
MgO	1.31	0.52	0.38	0.88	0.96	0.59	0.61	1.83	1.34	2.91	3.77	0.72
Na_2O	4.34	3.75	5.53	4.26	6.12	4.24	3.17	2.60	3.62	4.22	4.88	3.55
K_2O	2.27	4.76	1.25	0.12	0.68	2.52	4.25	2.50	4.18	3.05	2.85	4.56
MnO	0.05	0.05	0.09	0.04	0.07	0.04	0.04	0.25	0.10	0.21	0.17	0.25
TiO_2	0.63	0.29	0.09	0.08	0.15	0.33	0.49	0.39	0.55	0.46	0.56	0.53
P_2O_5	0.39	0.31	0.37	0.15	0.13	0.17	0.22	0.47	0.13	0.28	0.27	0.49
Some trace elements (ppm)												
Co	31	45	33.4	24.4	18.7	21	5.3	35.9	8.3	6.3	5.7	18
Hf	3.3	3.76	2.90	0.91	1.7	3.23	1.03	2.3	1.12	0.95	0.78	3.89
Nb	3.2	17.5	22.56	15.93	8.86	7.2	12.6	4.8	11.9	17.8	15.3	11.2
Rb	385	317	105.5	485.4	434	288	543	456	83.6	90.6	65.8	249
Sr	581	397	173	212.7	198,6	649	457	567	358	573	345	136
Ta	3.4	2.16	2.13	1.84	2.75	2.57	3.2	2.8	2.21	1.96	1.83	2.26
Th	8.7	17.7	29.7	12.24	17.8	8.2	15.3	8.7	10.7	51.5	37.5	29.8
U	4.5	2.2	2.77	0.75	1.99	3.5	7.8	6.5	2.4	9.23	7.57	17.4

Location, coordinates, rock type and petrography of the samples see in Table 1.

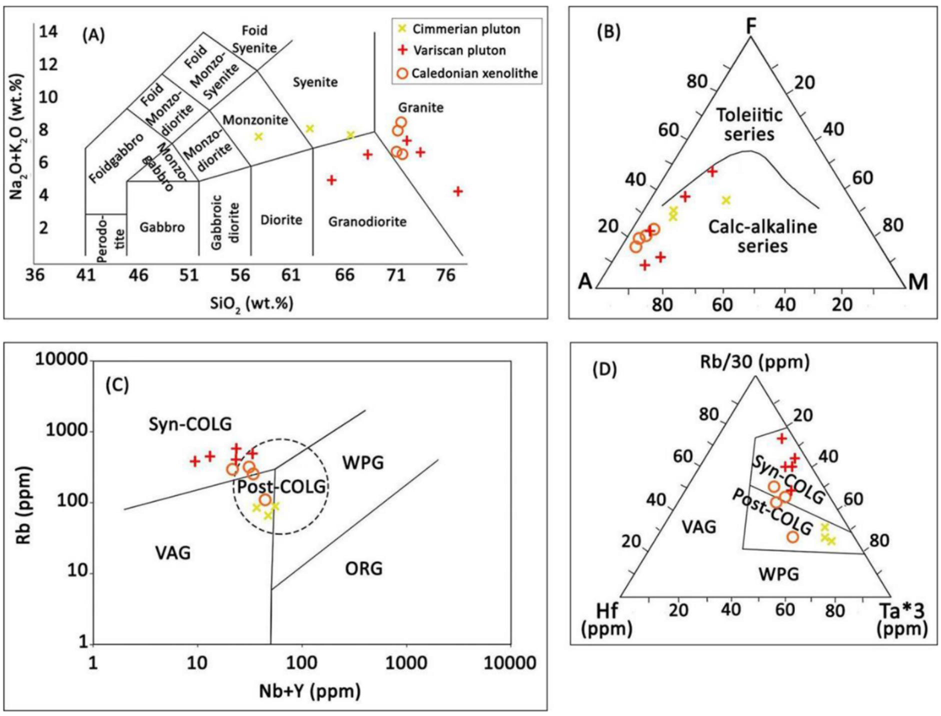

Fig. 6. Petrochemical diagrams for the plutonic rocks and their xenoliths of Greater Caucasus Svaneti Segment. (A) - TAS discrimination diagram [15]; (B) - AFM discrimination diagram [16]. (A=Na_2O+K_2O wt.%; F=FeO total wt.%; M=MgO wt.%), (C) - Rb-(Nb+Y) geodynamic discrimination diagram [17]; (D) - Hf-Rb/30-TaX30 geodynamic discrimination diagram [18]. Abbreviations: syn-COLG=syn-collision granite; post-COLG=post-collision granite; VAG = volcanic arc granite; WPG = within-plate granite; ORG = ocean ridge granite.

plutons are fully within the post-collisional (post-accretional) granite field. Te As for Ordovician biotite xenoliths of gneisses, they are mostly placed within an island-arc granite field and only one point is placed within a syn-collisionional (syn-accretional) granite field (Fig. 6C).

Almost identical geodynamic settings can be seen on Hf-Rb/30-Ta*3 discrimination diagram (Fig. 6D). The Late Carboniferous Variscan plutons on this diagram are fully placed within the syn-collisional (syn-accretional) granite field, while the Middle Jurassic plutons are placed within the post-collisional (post-accretional) granite field. In contrast with the previous diagram, here large parts of the Ordovician biotite gneisses Calledonian xenoliths are placed within the syn-collision (syn-accretional) granite field and one point is placed within an island-arc granite field.

Geochemical investigation is particularly interesting for the Middle Jurassic plutons. In particular, from the Ushba pluton to the Jorkvali pluton (from north to south), the SiO_2 concentration decreases in the following order: 66.80%, 63.65% and 57.82%. In contrast to these parameters, the Na_2O/K_2O ratio gradually increases from the Ushba pluton to the Jorkvali pluton. This ratio corresponds to 0.87 in the Ushba pluton syenite, 1.38 in the Dizi pluton syenite, and 1.71 in the Jorkvali pluton monazite. The MgO/FeO ratio in these rocks shows similar variations, namely 0.36, 0.68 and 0.97, respectively.

The investigation of the 87Sr/86Sr parameters in these samples provides additional constraints. In the gabbro of the Ushba pluton, the ratio is typical for mantle sources at 0.70612. However, the syenite member of the same pluton has a more crustal value of 0.71253. In the syenite of the Dizi pluton, this parameter corresponds to 0.70967, and in the monzonite of the Jorkvali pluton, it corresponds to 0.70789. Thus, according to the isotopic investigation, in the studied plutons there is clearly an increase of the mantle component from north to south.

Geodynamic settings of plutonic magmatism formation

The reconstruction of past geodynamic settings seeks to establish the nature and location of paleooceanic basins, along with their active and passive margins. Previously, it was shown [18, 19, 1] that a location of Proto-Paleotethis Ocean in the Caucasus and adjacent areas was to the south of the Black Sea-Central Transcausian terrane (microcontinent) (Fig. 7). The existence of Paleozoic and older oceanic basins is suggested also in the regional geology of the Greater Caucasus. It is confirmed by the existence of Paleozoic ophiolites in the Fore Range zone of the Greater Caucasus indicative of the existence of the Archyz small oceanic basin and also a small oceanic basin of the Southern slope of the Greater Caucasus [1], as indicated by the intrusive complex of Beshta-Kamenistaia in its Pass subzone, which is composed of tonalitic gneisses that genetically resemble granites of the tholeitic series of the ophiolite complex [20]. It was overthrust from south to north, on the Greater Caucasus Island arc during the Early Variscan (Bretonian) orogeny [21] (Fig. 7 III).

The rest part of the oceanic crust of the back-arc small oceanic basin of the Southern Slope of the Greater Caucasus, as previously suggested [1] to be completely absorbed in the subduction zone along the southern edge of the Greater Caucasus Island arc.

Taking into account the paleomagnetic data and age of supra-subduction regional meteamorphism in the Greater Caucasus [4] it can be assumed that the back-arc basin of the Southern slope of the Greater Caucasus was formed in the Late Precambrian and represented a relatively small spreading oceanic basin [1].

In the Main Range zone of the Greater Caucasus (island arc), on the active margin of back-arce oceanic basin of the Southern slope of the Greater Caucasus in Ordovician Esrly Caledonian biotite orthogneisses, gneisses and migmatites of Shkara pluton and Late Caledonian Szgumazuki plagio-

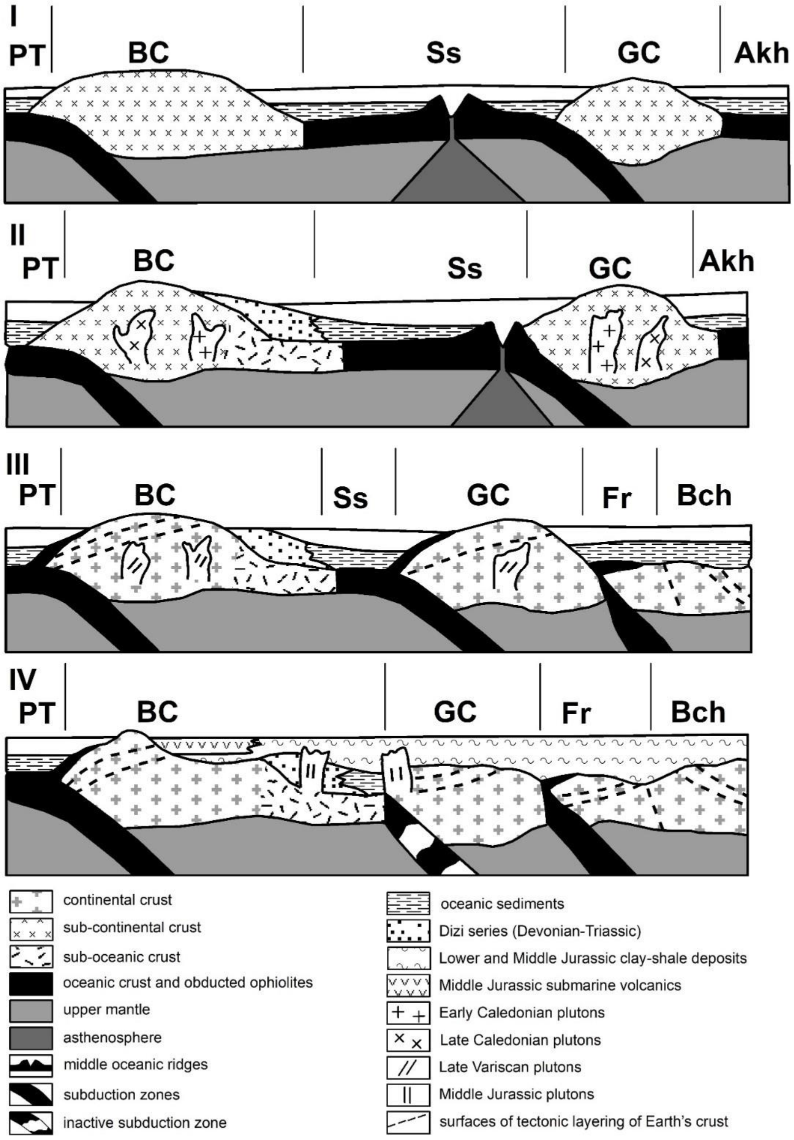

Fig. 7. Paleotectonic profiles of the Caucasus and adjacent areas for the Paleozoic and for the Middle Mesozoic. Time intervals: I – Late Cambrian, II – Ordovician-Devonian, III – Early and Middle Carboniferous, IV – from Late Triassic-up to Middle Jurassic. The vertical scale is exaggerated by about 10 times.
Paleooceanic basins: PT – Proto-Paleotethis; Ss – of the Southern slope of the Grater Caucasus; Akh – Arkhys. Continental plates (terranes): BC – Black Sea-Central Transcaucasian microcontinent; GC – Greater Caucasus island arc. Contemporary tectonic zones: Fr – Forerange, Bch – Bechasin.

gneisses were formed. (Fig. 7 I). Caledonian intrusive activity is developed in the Black Sea Central Transcaucasian microcontinent as well (Fig. 7 II).

In the Late Carboniferous the second phase of large-scale supra-subduction plutonic magmatism occurred. During these processes, both the Pass and the Elbrus subzones of the Greater Caucasus, as well as the Black Sea Central Transcaucasian microcontinent were migmatised and formed gneissic infrastructures, which were cut by large plutonic bodies of granitoids. Later, plutonic bodies were cut by leucocratic vein systems. These processes are related to Late Variscan subduction and orogeny, when typical continental crust was formed [21] (Fig. 7 III).

Then at the end of the Late Triassic, during Early Cimmerian (Indosinian) orogeny, there is a closure of the oceanic basin of the southern slope of the Greater Caucasus, as well as the Arkhiz one (Fig. 7 IV).

Plutons located in the Paleozoic-Triassic Dizi series and in the Early Jurassic black shales, (Dizi and Jorkvali plutons) (Fig. 7 IV) were formed in different geodynamic settings and were connected with stretching of the Earth's crust. It should be noted that the Early and Middle Jurassic is the time of the most significant stretching and subsidence of the Earth's crust in the entire Caucasus. At this time, the subduction zone along the northern edge of the oceanic basin of the Southern Slope of the Greater Caucasus was inactive (Fig. 7 IV). Therefore, clay-sandy deposits are deposited here. However, further south, within the Transcaucasian microcontinent, they are replaced by andesitic submarine island-arc volcanic rocks (the so-called Bajocian porphyrite series), which were formed in supra-subduction conditions (Fig. 7 IV).

It has previously been argued (Gamkrelidze and Shengelia, 2005) that the deposits of the Dizi series were formed under the conditions of the continental slope and the foot of the southern passive margin of the small oceanic basin of the Southern Slope of the Greater Caucasus. This position is confirmed by our data on the nature of the plutons located within the Dizi series. In particular, as noted above according to the isotopic investigation, in the Middle Jurassic plutons there is clearly an increase of the mantle component from north to south, from Ushba pluton, which is located along the Main Thrust of the Greater Caucasus to plutons located in Dizi series. Therefore, it is natural to assume that the sediments of the Dizi series, developed on the continental slope and the foot of the southern passive margin of the small oceanic basin of the southern Slope of the Greater Caucasus, are underlain by thinned sub-oceanic crust (Fig. 7 II, 7 III, 7 IV).

Conclusion

As a result of our multidisciplinary investigation of the plutonic magmatism in the Svaneti segment of the Greater Caucasus (zircon U-Pb geochronology, petrochemisty, geodynamic settings), the following conclusions can be made:

Based on new results of zircon LA-ICP-MS U-Pb geochronology, three large plutonic magmatism stages were distinguished in the Svaneti segment: 1-Ordovician, 2-Late Carboniferous and 3- Middle Jurassic. At the Early Ordovician stage (~488-475 Ma) biotite orthogneisses of the Greater Caucasus crystalline basement were formed. This stage of plutonic magmatism is related to Early Caledonian orogeny. At the Late Ordovician stage (~455 Ma) crystallized Szgimazuki plagiogneisses of possible accretionary wedge of the Greater Caucasus crystalline basement. Their formation is related to Late Caledonian orogeny.

In the Late Carboniferous (~320-312 Ma) the second phase of large-scale plutonic magmatism occurred. During these processes, both the Pass and the Elbrus subzones were migmatised and formed gneissic infrastructures, which were cut by large Late Variscan plutonic bodies granodiorite-granites. Later (~310 Ma), plutonic bodies were cut by leucocratic vein systems. These processes are related to Late Variscan subduction and orogeny.

During the Middle Jurassic in the Svaneti segment, the third phase of plutonic activity occurred, which is observed basically in the Dizi series and Lower Jurassic clay-shales. This process was related to crustal stretching.

During these processes at the southern margin of the crystalline basement (Main Range zone), the Ushba pluton (~177 Ma) and its analogues were emplaced. Later, to the south of Ushba pluton formed the Dizi pluton and its analogues (~168 Ma), which cut the Dizi series. Then the Jorkvali pluton and its analogs formed (~164 Ma), which cut Dizi series and Lower Jurassic clay-shales.

Petrochemical study show that Caledonian biotite orthogenesis and migmatites were formed in syn-collisional (syn-accretional) geodynamic settings. Late Variscan generation granodiorite-granite plutons were formed in syn-collisional (syn-accretional) geodynamic settings, though Middle Jurassic monzo-syenite plutons-in the post-collisional (post-accretional) ones. Despite such differences in petrotypes and geodynamic settings, all plutonic melts belong to calc-alkaline magmatic series.

The formation of the plutons of the Main Range zone of the Greater Caucasus took place in onditions of the active margin of the small oceanic basin of it's the Southern slope while the Middle Jurassic plutons were formed in conditions of crustal stretching and rifting. In the Middle Jurassic plutons there is clearly an increase of the mantle component from north to south, from Ushba pluton, which is located along the Main Thrust of the Greater Caucasus to plutons located in Dizi series. Therefore, it is natural to assume that the sediments of the Dizi series, developed on the continental slope and the foot of the southern passive margin of the small oceanic basin of the Southern Slope of the Greater Caucasus, are underlain by thinned sub-oceanic crust.

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საქართველოს მეცნიერებათა ეროვნული
აკადემიის წევრის, პროფესორ
*ერეკლე გამყრელიძის **90** წლის საიუბილეოდ*

კავკასიონის სვანეთის სეგმენტის პლუტონური მაგმატიზმი: ცირკონების U-Pb გეოქრონოლოგია, პეტროქიმია და წარმოშობის გეოდინამიკური პირობები

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§ჩუნგ-ჩენგის ნაციონალური უნივერსიტეტი, ჩიაუი 2018, ტაივანი
#გარემოსდაცვითი გადაწყვეტილებების ბიურო, სანტა-მონიკა, კალიფორნია, აშშ

კავკასიიონის ნაოჭა-შეცოცებითი სარტყელი ალპურ-ჰიმალაიური კოლიზიური ოროგენული სარტყლის ნაწილია. მან განიცადა რთული პოლიციკლური განვითარება გვიან კამბრიულისწინა პერიოდში და მთელი ფანეროზოურის განმავლობაში. სტატიაში განხილულია ახალი მონაცემები ცირკონების LA-ICP-MS U-Pb გეოქრონოლოგიისა და პეტროქიმიის შესახებ ამ ოროგენის პლუტონური მაგმური აქტივობის სამ ძირითად ეტაპზე: 1-ორდოვიციულზე, 2-გვიან კარბონულზე და 3- შუაიურულზე (აალენურ-ბაიოსურზე). პირველ ეტაპზე (~488-475 მლნ) ორდოვიციული ბიოტიტიანი ორთოგნეისები წარმოიქმნება კალედონური ოროგენეზისის დროს სუპრა-სუბდუქციურ პირობებში. მეორე ეტაპზე (~320-310 მლნ) ზედა კარბონული გრანოდიორიტ-გრანიტული პლუტონები ჩამოყალიბდა ვარისკული ოროგენეზისის პროცესში, ასევე სუპრა-სუბდუქციურ პირობებში. მესამე ეტაპზე შუაიურული პერიოდის მონცოსიენიტური პლუტონური აქტივობა გამოვლინდა ადრეკიმერიული (ინდოჩინური) დანაოჭების შედეგად კავკასიონის მცირე ოკეანური აუზის დახურვის შემდეგ, პალეოზოურ-ტრიასულ დიზის სერიასა და ქვედაიურულ შავ ფიქლებში და დაკავშირებული იყო დედამიწის ქერქის გაჭიმვასთან. პლუტონების ასაკი თანდათან მცირდება ჩრდილოეთიდან სამხრეთისაკენ (~177, ~168, ~164 მლნ), რაც მიუთითებს გაჭიმვის პროცესის ამავე მიმართულებით გავრცელებაზე. პლუტონების პეტროქიმიური კვლევის მიხედვით, კალედონური ორთოგნეისები ჩამოყალიბდა გარდამავალ, სინ-აკრეციულ გეოდინამიკურ პირობებში. გვიან ვარისკული პლუტონები ასევე წარმოიქმნა სინ-აკრეციულ გეოდინამიკურ პირობებში, ხოლო შუაიურული პლუტონები – პოსტ-აკრეციულში. მიუხედავად პეტროტიპებისა და გეოდინამიკური პირობების ასეთი განსხვავებისა, ყველა პლუტონური მდნარი მიეკუთვნება კირ-ტუტე მაგმურ სერიას. კავკასიონის მთავარი ქედის (კუნძულთა რკალი) პლუტონების ფორმირება მიმდინარეობდა სუპრა-სუბდუქციურ პირობებში კავკასიონის სამხრეთი ფერდობის მცირე ოკეანური აუზის

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