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Geology

Geochemistry of the Kirari- Abakuri Magmatic Complex of the Southern Slope Zone of the Greater Caucasus

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The Kirari-Abakuri magmatic complex is exposed within the Dizi Series of the Southern Slope zone of the Greater Caucasus. In the Bathonian time, the rocks of the Dizi Series were intruded by the Kirari-Abakuri magmatic complex. The complex includes the Kirari and Abakuri intrusions and the intrusions of the village Dizi, and numerous smaller bodies. They are represented mainly by granitoids, pyroxenites, gabbros, diorites, syenites and monzonites. Despite the well-studied magmatism of the Dizi Series, the issues of geochemistry are insufficiently investigated. Having studied the geochemistry of the Kirari-Abakuri magmatic complex, we found that they have geochemical characteristics of volcanic arc magmatic rocks, indicative of subduction conditions. Namely, we believe that magmatic activity in the Dizi Series was most likely associated with a northward inclined subduction zone along the Lesser Caucasus. *© 2022 Bull. Georg. Natl. Acad. Sci.*

Greater Caucasus, Dizi Series, Middle Jurassic magmatism, geochemistry

The Kirari-Abakuri magmatic complex (KAC) is exposed within the Dizi Series (DS) of the Southern Slope zone of the Greater Caucasus. In the Caucasus, during the Mesozoic, intrusive magmatism was most intense in the Middle Jurassic and Late Cretaceous. In the Greater Caucasus Southern Slope zone, there are numerous formations of Middle Jurassic magmatism [1]. At the end of the Bajocian time, gabbroic melts intruded rocks of the DS and later on, in the Bathonian, felsic melts emplaced into the rocks of the series.

Despite the well-studied magmatism of the DS, the issues of geochemistry are insufficiently investigated. Moreover, there is no consensus on geodynamic setting of the region until today [2, 3]. There are suggestions that Middle Jurassic volcanism in the Caucasus is the result of back-arc spreading of the subduction zone south of the Transcaucasian terrane in the Lesser Caucasus, or the result of Bajocian arc volcanism in the Greater Caucasus, caused by shallowing of the subducting slab. The authors aimed to conduct the detailed geochemical investigations and thus clarify a number of issues, which to some extent will be an attempt to find out the certain aspects of geodynamic evolution of the region.

Table 1. Main Components (wt %) of KAC

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SrO	BaO	Cr_2O_3	LOI	Total
Dz-1a	63.71	0.29	18.03	4.26	0.03	3.31	0.4	5.91	0.82	0.07	0.01	<0.01	<0.01	3.44	100.28
Dz-3	58.91	0.43	18.42	5.09	0.16	1.17	5.16	4.07	4.14	0.17	0.08	0.11	0.01	0.95	98.87
Dz-4	60.21	0.48	18.07	5.37	0.18	1.31	4.94	4.1	3.71	0.18	0.08	0.11	0.01	0.87	99.61
Dz-5	61.13	0.42	17.92	4.75	0.19	1.12	4.78	3.79	4.29	0.2	0.07	0.11	0.02	0.98	99.76
Dz-6	60.52	0.41	18.05	4.77	0.14	1.14	4.6	3.87	4.17	0.17	0.07	0.1	0.01	1.13	99.15
Dz-7	58.38	0.46	17.81	5.06	0.18	1.3	4.12	4.73	4.06	0.16	0.04	0.09	<0.01	1.77	98.16
Dz-8	63.97	0.4	16.26	4.73	0.13	1.36	4.68	3.07	3.14	0.14	0.05	0.08	0.02	1.07	99.1
Dz-9	60.48	0.47	17.62	5.67	0.15	1.7	5.36	3.47	2.85	0.19	0.05	0.07	0.02	1.31	99.4
Dz-11	62.06	0.37	17.76	3.86	0.1	0.93	3.13	6.25	1.77	0.11	0.04	0.06	0.01	2.64	99.11
Dz-12	61.89	0.38	17.89	3.92	0.16	0.93	3.37	4.58	4.35	0.12	0.06	0.13	0.01	0.96	98.75
Dz-13	62.26	0.42	19.7	4.35	0.1	1.06	5.1	4.11	2.14	0.19	0.06	0.05	0.02	1.24	100.8
Dz-14	63.67	0.33	16.41	3.97	0.13	1.06	4.48	3.41	3.02	0.12	0.05	0.08	0.01	1.81	98.56
Dz-15	47.13	0.02	0.84	8.95	0.13	34.02	5.52	0.03	0.01	0.02	0.01	<0.01	0.4	3.92	101
Dz-16	57.81	0.56	17.24	6.16	0.15	1.92	5.98	2.97	4.26	0.26	0.06	0.09	0.01	0.96	98.41
Dz-17	60.65	0.48	17.32	5.32	0.15	1.54	5.2	3.42	3.79	0.2	0.06	0.08	0.01	0.76	98.97
Kr-X1	60.96	0.45	16.4	5.73	0.15	1.82	4.42	3.11	4.39	0.17	0.05	0.09	0.02	1.32	99.07
Kr-X2	53.91	0.69	17.48	7.73	0.15	3.24	7.2	2.72	3.17	0.25	0.05	0.08	0.02	1.37	98.07
2-15	47.68	1.15	18.38	11.6	0.22	6.24	11.5	1.72	1.13	0.18	0.05	0.02	0.02	1.7	101.58
11-15	43.16	0.97	22.23	8.85	0.15	6.53	12.94	0.83	1.74	0.13	0.04	0.03	0.04	3.22	100.87
14-15	58.22	0.49	21.53	4.25	0.08	1.53	7.4	3.81	1.35	0.16	0.07	0.04	0.01	1.42	100.36
4-19I	64.63	0.27	16.29	3.17	0.13	0.67	4.22	3.41	3.55	0.08	0.05	0.08	0.04	2.75	99.36
5-19I	41.34	0.07	1.37	8.85	0.22	42.8	1.54	<0.01	0.02	0.03	0.01	<0.01	0.24	3.95	100.43
Ab-3	63.07	0.60	15.16	4.66	0.08	2.75	4.47	4.86	1.69	0.20	0.04	0.03	0.02	-	97.69
Ab-4	56.25	0.72	18.34	5.56	0.04	9.03	0.80	2.86	1.78	0.24	0.01	0.01	0.01	-	95.77
Ab-5	56.85	1.19	24.54	2.84	0.02	1.57	0.38	3.02	4.99	0.10	0.02	0.04	0.01	-	95.77
Ab-8	43.55	1.12	15.2	10.16	0.21	11.8	9.72	1.53	1.55	0.36	0.06	0.04	0.07	-	95.57
Ab-9	45.49	0.37	5.81	10.69	0.18	20.73	16.28	0.14	0.39	0.00	0.02	0.01	0.17	-	100.63
Ab-10	43.31	0.49	10.28	11.7	0.22	18.57	14.81	0.14	0.25	0.13	0.04	<0.01	0.13	-	100.24

Pyroxenite: Ab-4, Ab-10. Gabbro: Dz-15, Kr-X2; Ab-8; Ab-9, 2-15, 11-15, 5-19I. Diorite: Dz-3, Dz-4, Dz-5. Diorite-Porphyrite: Dz-14, 4-19I.Syenite: Dz-1a, Dz-7, Dz-11, Dz-12.Monzonite: Dz-6, Dz-8, Dz-9, Dz-16, Dz-17, Ab-5.Granitoid: Dz-13, Kr-X1, Ab-3, 14-15.

Table 2. REE concentrations (ppm) in KAC

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Dz-1a	18.8	33.8	4.11	16.1	3.58	0.54	3.24	0.47	2.74	0.63	2.22	0.41	2.98	0.46
Dz-3	62.6	117.7	12.11	45.4	8.89	1.91	7.45	1.04	6.08	1.29	3.92	0.62	3.55	0.55
Dz-4	62.2	117	11.63	44.2	8.24	1.85	7.03	0.95	5.41	1.18	3.66	0.6	3.77	0.59
Dz-5	61.9	109.7	10.58	39.1	6.83	1.69	6.07	0.84	4.79	1.02	3.13	0.53	3.43	0.55
Dz-6	60	105.7	10.42	38.4	6.67	1.71	6.08	0.84	4.74	1.04	3.25	0.49	3.48	0.54
Dz-7	77.5	138.9	13.44	49.2	8.21	2.11	7.75	1.02	5.8	1.3	4.13	0.66	4.31	0.7
Dz-8	37.4	67.1	6.48	22.6	4.29	1.01	3.92	0.55	3.07	0.64	2.06	0.34	2.23	0.36
Dz-9	45.1	79.6	7.7	27.8	4.54	1.27	4.31	0.59	3.31	0.74	2.35	0.34	2.38	0.4
Dz-11	76.3	129.8	12.31	44.5	7.19	1.69	6.78	0.94	5.29	1.1	3.52	0.6	3.68	0.62
Dz-12	74.5	128.1	12.14	43.4	6.78	1.74	6.52	0.87	5.26	1.17	3.55	0.58	4.02	0.64
Dz-13	33	59.5	5.65	20.9	3.33	1.41	3.3	0.44	2.43	0.54	1.66	0.26	1.92	0.33
Dz-14	42.3	77.1	7.47	26.6	4.26	1.14	3.88	0.52	3.05	0.66	2.14	0.34	2.17	0.4
Dz-15	0.6	1.1	0.15	0.7	0.12	0.06	0.2	0.03	0.18	0.04	0.11	<0.01	0.08	0.01
Dz-16	73.9	128.5	12.06	43.5	6.95	1.55	6.1	0.78	4.18	0.84	2.54	0.36	2.34	0.38
Dz-17	48.4	90.1	8.93	33.4	5.67	1.43	5.45	0.75	4.27	0.92	2.89	0.47	2.97	0.5
Kr-X1	43.8	83.6	8.17	30.8	5.43	1.25	5.13	0.67	3.79	0.81	2.47	0.41	2.7	0.44
Kr-X2	28.7	56.4	5.96	24.2	4.76	1.37	4.54	0.61	3.46	0.71	2.11	0.3	2.09	0.32
2-15	14.7	37.2	5.01	23.8	6.7	1.6	6.55	0.92	5.54	1.19	3.28	0.58	3.02	0.42
11-15	39.8	70.5	6.81	26	5.28	1.56	4.68	0.62	3.67	0.85	2.39	0.43	2.48	0.45
14-15	22.3	42.3	4.44	18.2	3.57	1.4	3.07	0.47	2.79	0.56	1.74	0.27	1.8	0.28
4-19I	45.1	79.3	7.54	26.5	3.93	1.07	3.3	0.47	2.87	0.58	2.01	0.32	2.48	0.4
5-19I	2.4	4.8	0.55	2.3	0.34	0.11	0.38	0.06	0.35	0.06	0.21	0.04	0.19	0.03

Names of the rocks see in Table 1.

Geological Background

The KAC is confined to the Svaneti anticlinorium of the Layla subzone of the Chkhalta-Layla fold-imbricated zone of the Greater Caucasus [4]. The anticlinorium is built of slightly metamorphosed Devonian-Triassic rocks of the DS, which includes the KAC exposures. There are distinguished the large polyphase intrusions of Kirari and Abakuri and the intrusions of the environs of Dizi village, as well as numerous smaller bodies (with thickness 1-100 m) in the KAC.

The Abakuri intrusive (3km^2) is intruded into the upper part of the DS and is located along the watershed ridge of the rivers Enguri and Khumpreri at 1.8 km. The intrusive is a stock-like body slightly overturned to the south. The Kirari stock-like intrusive (5.5 km^2) cuts the lowest formation of the DS along the watershed ridge of the rivers Nakra and Nenskra. In the environs of the Dizi village, in the Enguri, Khumpreri and Lukhra river gorges, 6-10 igneous bodies with a total area of 1.5 km^2 are exposed.

The petrological and mineralogical similarities, morphology and spatial distribution of intrusive bodies in the DS, indicates that all these intrusions represent parts of a single magma chamber. The K-Ar age of the rocks of the intrusions is 162-176 Ma [1], and the U-Pb zircon age obtained by the LA-ICP-MS method [5] is 166.5±4.6 Ma, which corresponds to the Bathonian orogeny.

Analytical Methods and Results

Samples were collected from all existing outcrops of intrusions in the KAC. More than 250 samples were selected for petrographic study and 46 characteristic samples - for geochemical analysis of major elements and RE. Rock samples were studied using optical microscopy, XRF and ICP-MS analysis methods. Chemical analysis of rocks for the main components was carried out by the ED-XRF method at the A. Janelidze Institute of Geology, in Tbilisi. The control of the chemical composition of rocks, as well as analysis for RE and REE, was determined by the ICP-MS method in the MSALABS ltd., laboratory, Langley, Canada.

Rocks of the KAC are represented by granitoids, pyroxenites, gabbro, gabbro-diorites, anorthosites, diorites, syenite-monzonites and diorite-porphyrites. Variations in the composition of rocks of the KAC are shown in the Table (Table 1). The obtained data were plotted on various petrochemical diagrams.

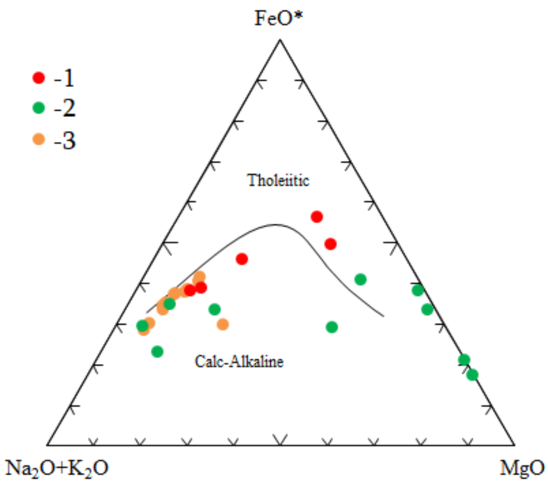

Fig. 1. Alkalis-FeO^{tot}-MgO (AFM) diagram, Intrusions: 1) Kirari, 2) Abakuri and 3) Dizi.

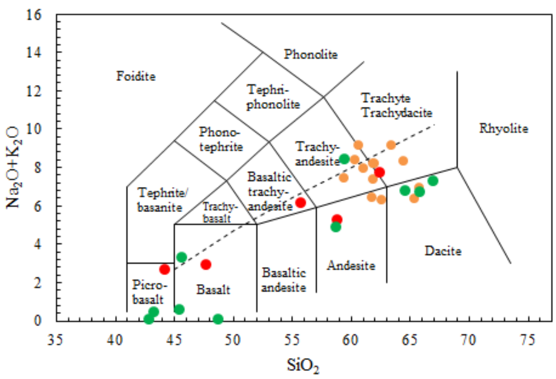

Fig. 2. TAS classification diagram.

According to the AFM classification diagram [6], the igneous rocks of the DS belong to the calc-alkaline series (Fig.1); according to Total Alkali VS Silica (TAS) [7] (Fig.2), they show a trend from subalkaline to alkaline and vary in composition from picrobasalt to trachydacite; according to the K_2O vs Na_2O diagram [8], most of the magmatites of the DS are located in the "shoshonite" field. According to the diagrams of Frost et al. [9], most of the points from the Abakuri and Dizi intrusions occupy the "ferroan" field and the points from the Kirari intrusion into the "magnesian" field. According to the Na_2O+K_2O-CaO vs SiO_2 diagram by the same authors [9], the points from the entire KAC disposed in the fields from "Calcic" to "Alkalic". The vast majority of rocks are metaluminous (Fig. 3) [9].

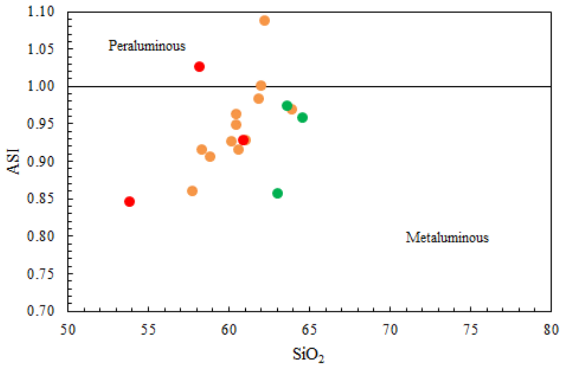

Fig. 3. ASI vs SiO_2 diagram.

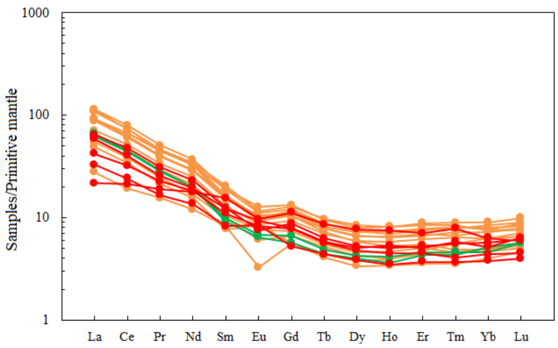

Fig. 4. Spidergram of REE.

A clearly expressed increase in the acidity of the rocks indicates the polyphasic nature of the complex. The amount of alkaline components in the rocks is generally less than 7%, and TiO_2 content is low (Table 1).

All collected samples have similar REE compositions (Table 2), with the exception of sample Dz-1a taken from the direct contact with the rocks of the DS that is REE-depleted and has a more distinct negative Eu anomaly. The exceptions are also: sample Dz-13 with a positive Eu anomaly and the samples Dz-15 and 5-19I that are heavily depleted in REE (Fig. 4) [10].

Discussion

The Middle Jurassic epoch of the northern part of the Mediterranean belt, including the territory of the modern Caucasus, is marked by significant tectonic and magmatic activation. According to [1], all magmatites are characterized by a similar geochemical composition and age, indicating their possible synchronism.

Comparing the geochronological data [1, 5] obtained from different rocks of the KAC, we can assume that magmatic activity within the DS began at the end of the Toarcian epoch, attained its peak in the Bathonian time and continued throughout the Middle Jurassic up to the beginning of the Upper Jurassic. At the end of the Toarcian active gabbroid magmatism began in the DS, and later, in the Bathonian time, an acid melt, formed during the melting of the crystalline basement, intruded into the series.

As noted above, the igneous rocks of the DS belong to the calc-alkaline series, although subalkaline-alkaline magmatites are noted in a lesser amount. According to our data, the igneous rocks of the DS have geochemical characteristics of volcanic arc magmatites, indicating subduction conditions. Similar data were obtained for the ratios of RE and REE elements, and the ratios Na_2O+K_2O vs 1000*Ga/Al, as well as Zr vs 1000*Ga/Al [11] in KAC rocks show that these formations are not anorogenic; according to the Zr/Y vs Ti/Y ratio, they formed at the plate boundary [12] (Fig. 5). Rb vs Yb+Ta, Rb vs Nb+Y, Nb vs Y, and Ta vs Yb ratios (Fig.6) [13] show that rocks were crystallized under the conditions of volcanic island arcs and syncollision, or under the continental island arcs conditions. As noted above, the amount of alkaline components in KAC rocks is generally less than 7%, and the content of TiO_2 is low that is typical for andesites [14], and is explained by their relation to the subduction zone volcanites [15].

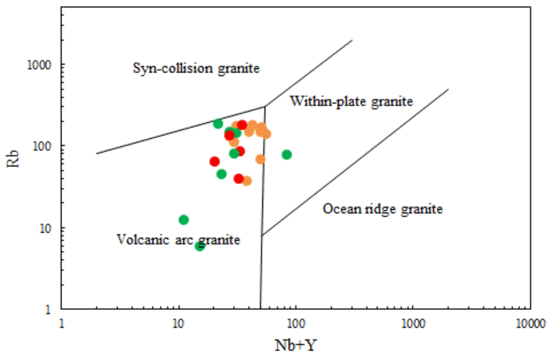

Fig. 5. Tectonic interpretation diagram Rb vs Nb+Y.

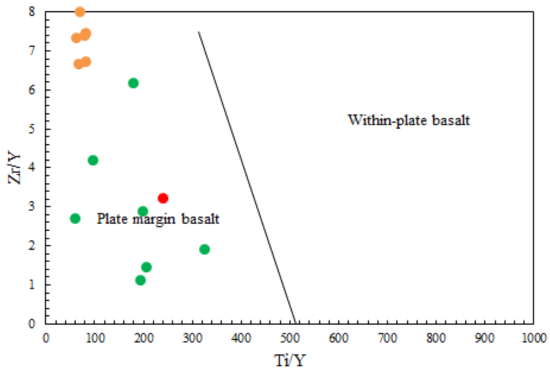

Fig. 6. Tectonic interpretation diagram Zr/Y vs Ti/Y.

It is interesting to note that detrital zircons of ancient (ca. 2200 Ma) and middle (458±29 Ma) ages were found in KAC. The first ones are products of the Archean rocks re-melting - most likely from the East European Platform, while analysis of mid-aged zircons indicate a Paleoproterozoic and Mesoproterozoic crustal melt source [5]. The REE composition in these zircons is similar to that in zircons from the pegmatites of the basic rocks [16]. According to Belousova et al. (2002) [17], low concentrations of Y, Th, and U also indicate the main composition of the melt. Thus, it can be assumed that the Middle Jurassic igneous rocks of the DS were formed along the continental arc associated with the subduction of the oceanic Tethys plate under the Eurasian plate.

According to Dudauri and Togonidze [1], the Middle Jurassic intrusive complexes are synorogenic formations dating back to the time when the regime of subsidence, extension and destruction of the Earth's crust that existed in the Bathonian time was replaced by the regime of compression and uplift, granitization and transformation into the folded belts.

It is believed that the Greater Caucasus Middle Jurassic magmatism has a subduction-related signature. However, it has been proposed that the volcanics resulted from back-arc spreading in the vicinity of a subduction zone south of the Transcaucasian terrane in the Lesser Caucasus, or that the volcanic arc encompassed the Greater Caucasus in the Bajocian time, due to a shallowing of the subducting slab, causing island arc-volcanism in ~200 km from the trench [2, 3, 18].

The geochemical and geochronological data obtained by us show that magmatic activity in the DS was most likely associated with a northward inclined subduction zone on the northern margin of the Lesser Caucasus ocean basin (Neotethys), which existed here in the Jurassic period [19]. In support of this, we can note the presence of clearly expressed polyphases with the predominance of felsic rocks in the magmatites of the DS; and their belonging to the calc-alkaline or, according to some diagrams, shoshonite series indicates their connection with the subduction setting. It is known that the geochemical specificity in many cases makes it possible to distinguish these magmatites from the magmatites of different origin [20].

Conclusions

Igneous rocks of the DS have geochemical characteristics of volcanic-arc magmatic rocks, indicating subduction conditions. According to most classification diagrams, the magmatites of the DS belong to the calc-alkaline series; all rocks are metaluminous and have similar RE and REE compositions; according to different chemical characteristics, they were formed at the plates boundary. Based on these, as well as geochronological data obtained by us, we believe that magmatic activity in the DS was most likely associated with a northward inclined subduction zone on the northern margin of the Lesser Caucasus ocean basin (Neotethys).

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გეოლოგია

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კავკასიონის სამხრეთი ფერდობის ზონის დიზის სერიის ფარგლებში განვითარებულია კირარი-აბაკურის მაგმური კომპლექსი. ბათურის დროს დიზის სერიის ქანები გაკვეთა მაგმური ინტრუზივების კომპლექსმა, რომელიც მოიცავს კირარის და აბაკურის ინტრუზივებს, სოფ. დიზის მიდამოების ინტრუზივებს და, ასევე, რიგ პატარა სხეულს. კირარი-აბაკურის მაგმური კომპლექსის ქანები ძირითადად წარმოდგენილია გრანიტოიდებით, პიროქსენიტებით, გაბროებით, დიორიტებით, სიენიტებითა და მონცონიტებით. მიუხედავად იმისა, რომ დიზის სერიის მაგმატიზმი კარგადაა შესწავლილი, გეოქიმიის საკითხები არასაკმარისადაა გამოკვლეული. კირარი-აბაკურის მაგმური კომპლექსის ქანების გეოქიმიის შესწავლის შედეგად გაირკვა, რომ მათ აქვს ვულკანური რკალის მაგმური ქანებისთვის დამახასიათებელი გეოქიმიური მახასიათებლები, რაც სუბდუქციის პირობებზე მიუთითებს. კერძოდ, მიგვაჩნია, რომ მაგმური აქტივობა დიზის სერიაში, მცირე კავკასიონის ოკეანური აუზის (ნეოტეთისის) ჩრდილოეთ კიდეზე არსებულ, ჩრდილოეთისკენ დაქანებულ სუბდუქციის ზონასთან უნდა იყოს დაკავშირებული.

REFERENCES

1. Dudauri O., Togonidze M. (2016) Petrologiia i izotopnaia geokhronologiia Mezozoiskikh intruzivnykh kompleksov Gruzii. *Proceed. of Al. Janelidze Inst. of Geol.*, **128**: 370 p. (In Russian).
2. McCann T., Chalot-Prat F., Saintot A. (2010) The Early Mesozoic evolution of the Western Greater Caucasus (Russia): Triassic–Jurassic sedimentary & magmatic history. Geol. Soc. of London.
3. Saintot A., Stephenson R., Stovba S., Brunet M., Yegorova T., Starostenko V. (2006) The evolution of the southern margin of eastern Europe (Eastern European and Scythian platforms) from the latest Precambrian–Early Palaeozoic to the Early Cretaceous, 481–505. Geol. Soc. of London.
4. Gamkrelidze I. (2000) Once more on the tectonic zoning of the territory of Georgia, *Proceed. Geol. Inst*, **115**: 204–208.
5. Javakhishvili I., Shengelia D., Shumlyanskyy L., Tsutsunava T., Chichinadze G., Beridze G. (2021) Metamorphism of the Dizi Series Rocks (the Greater Caucasus): petrography, mineralogy and evolution of metamorphic assemblages, *Baltica*, **34**, 2: 185–202. Vilnius. ISSN 1648-858X, https://doi.org/10.5200/baltica.2021.2.5
6. Irvine T., Baragar W. (1971) A guide to the chemical classification of the common volcanic rocks, *Canadian J. of Earth Science*, **8**: 523–548.
7. Le Bas M., Le Maitre R., Streckeisen A., Zanettin B. (1986) A chemical classification of volcanic rocks based on the total alkali-silica diagram, *J. of Petrology*, **27**, 3: 745–750.
8. Foley S., Venturelli G., Green D., Toscani L. (1987) The ultrapotassic rocks: characteristics, classification, and constraints for petrogenetic models, *Earth-Science Reviews*, **24**: 81–134.
9. Frost R., Frost C. (2008) A geochemical classification for feldspathic igneous rocks, *J. of Petrology*, **49**, 11: 1955–1969.
10. Palme H. O'Neill H. S. C. (2014) Cosmochemical estimates of mantle composition. In: Carlson R.W. (ed.) *Treatise on Geochemistry,* **3**: 1–39. The Mantle and Core. Elsevier.
11. Whalen J., Currie K., Chappell B. (1987) A-type granites: geochemical characteristics, discrimination and petrogenesis, *Contrib. Mineral. Petrol.,* **95**: 407–419. https://doi.org/10.1007/BF00402202
12. Pearce J., Gale G. (1977) Identification of ore-deposition environment from trace-element geochemistry of associated igneous host rocks, *Geological Society*, **7**: 14−24.
13. Pearce J., Harris N., Tindle A. (1984) Trace element discrimination diagrams for the tectonic interpretation of granitic rocks, *J. of Petrology*, **25**, 4: 956–983. https://doi.org/10.1093/petrology/25.4.956
14. Raymond L.A. (2002) Petrology: the study of igneous, sedimentary and metamorphic rocks, **2**: 720 p. McGraw Hill, New York.
15. Gill J.B. (1981) Orogenic Andesites and plate tectonics. *Minerals and rocks,* **16**: 390 p. Berlin, Heidelberg, New York: Springer-Verlag.
16. Shumlyanskyy L., Belousova E., Petrenko O. (2017) Geochemistry of zircons from basic rocks of the Korosten anorthosite-mangerite-charnockite-granite complex, North-Western region of the Ukrainian Shield. *Mineralogy and Petrology,* **111**: 459–466. https://doi.org/10.1007/s00710-017-0514-2
17. Belousova E., Griffin W., O'Reilly S.Y., Fisher N. (2002) Igneous zircon: trace element composition as an indicator of source rock type. *Contrib. Mineral. Petrol.,* **143**: 602–622. https://doi.org/10.1007/s00410-002-0364-7
18. Meijers M., Vrouwe B., Van Hinsbergen D., Kuiper K., Wijbrans J., Davies G., Stephenson R., Kaymakcı N., Matenco L., Saintot A. (2010) Jurassic arc volcanism on Crimea (Ukraine): Implications for the paleo-subduction zone configuration of the Black Sea region, *Lithos,* **119**, **3-4**: 412–426. https://doi.org/10.1016/j.lithos.2010.07.017
19. Gamkrelidze I. (2016) Geological structure of Georgia and geodynamic evolution of the Caucasus. *Proceed. of the fourth plenary conf. of IGCP* 610: 69-76.
20. Khain V., Lomize M. (1995) Geothectonics with the basics of geodynamics (Geotektonika s osnovami geodinamiki), 480 p. M. MSU (in Russian).

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