ANAS Transactions Earth Sciences 1 / 2023

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GEOCHEMICAL CHARACTERISTICS OF THE GADABAY INTRUSION COMPLEX IN THE STUDY OF MAGMA EVOLUTION AND TECTONIC PATTERN OF THE REGION (LESSER CAUCASUS, AZERBAIJAN TERRITORY)

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Keywords: *Gadabay intrusion, REE elements, iron group elements, trace elements, classification diagrams, lithospheric mantle, partial melting, composition of primitive melts*

Summary. The Gadabay intrusion complex which is located within the Lok-Garabakh structural-formation zone of the Lesser Caucasus is formed in two magmatic phases – gabbroid and granitic. Quartz diorites as the second phase are the most widespread rocks of the intrusion complex. Alkaline rocks such as monzodiorites and monzonites with limited distribution in the region are considered as a branch of the second phase. However, the results of ilmenite-titanomagnetite geothermometry show equal and higher crystallization temperatures of these alkaline rocks. Despite the detailed petrographic and field studies, the source of magmatic melts that formed the intrusion is not deeply studied. And trace element composition of rocks of Gadabay intrusion complex is worth to be investigated. Furthermore, distribution of trace elements in certain minerals can also be considered as a valuable information source. Distribution of Fe group elements (Ni, Cr, V, Co), alkaline earth elements (Sr, Ba), and rare earth elements (in the rocks of Gadabay intrusion complex is controlled by fractional crystallization. Hence, concentration of coherent elements and heavy rare earth elements decrease towards more evolved rock types, whereas concentration of incoherent elements and light rare earth elements increase. Next fact is that Gadabay intrusion complex has been formed within calc-alkaline magma series and primitive melt was formed as a result of partial melting of an enriched mantle substrate which is proved by diagrams composed base on trace elements' ratios.

Introduction

The behavior of trace elements in magmatic systems can provide highly valuable information about the origin of the rocks and processes they underwent during their evolution (Belousova et al., 2010; Béguelin et al., 2019; Rollinson, 2021). That's why the study of trace elements patterns is very important in petrological research works.

REE normalized spider diagrams show the degree of fractionation and provide an opinion on either enrichment or depletion of studied rocks comparing with standards such as C1 chondrite, MORB, OIB, etc. (Bedard, 2014; Barrat et al., 2012; Sun, McDonough, 1989). As well as, Eu/Eu* ratio shows the nature of magmatic melt sources (Имамвердиев, 2000; Rollinson, 2021). Th/Yb vs. Ta/Yb diagram distinguishes the rocks belonging to different magmatic series and identifies the source origin (Acosta-Vigil et al., 2017; Rollinson, 2021; Садыхов, 2019). Distribution of especially Fe group elements in minerals shows the direction of fractional crystallization (Agrawal et al., 2004).

In this paper the results of the analyses of available samples have been used to obtain information on aforementioned points.

Geology and petrography

The Lok-Garabakh zone with Gadabay intrusion complex is situated in the central part of the Mediterranean folding belt (Панов, 2013; Садыхов, 2019). In more local scale, the intrusion is within the Caucasus-Zagros segment of the belt and is formed as a result of the northern subduction of the Mesotethys ocean (Адамия и др., 1977; Панов, 2013; Рустамов, 2019). The intrusion has been formed during upper Jurassic-lower Cretaceous age (Абдуллаев и др., 1979; Абдуллаев, 1963; Мустафаев, 1977), with determined absolute age of 144-159 Ma (Садыхов, 2019).

The Gadabay-Soyudlu intrusion is divided into two phases based on its geological and petrological features: 1) gabbro and 2) quartz-diorite (Керимов, 1963; Mammadov et al., 2021). Subvolcanic rocks of both phases have been determined in the field observations (Fig.1). Furthermore, melts of quartz-diorite phase have separated into quartz-diorite, granodiorite – normal granite, tonalite-banatite – granitic pegmatite, monzodiorite-monzonite-syenite facies as a result of quantitative behavior of rock forming components in minerals through the evolution of the melt. The transition of facies from one to another is gradual (Mammadov et al., 2021). Bulk chemical composition and TAS diagram (Middlemost, 1994) of the rocks are shown in Table 1 and Fig. 2 respectively. As shown in the diagram, the gradual change in the composition of the rocks proves the evolutionary pattern from gabbronorite toward the granitic rocks. However, there is an obvious break in the trend lines between the rocks of I and II phases. Subalkaline rocks are separated from general direction of the trend lines and are located above their junction. The point merits a mention that biotite-quartz bearing gabbro lies in monzodiorite field. The reason for this exception is high concentration of potassium in the related rock type which can be explained with the presence of biotite in the rock.

The derivatives of the first phase are located in the central part of Gadabay-Soyudlu intrusion and the colour changes from dark black in the center to grey, greyish colours in the periphery (Керимов, 1963; Mammadov et al., 2021). There is a thermal contact between this and quartz-diorite phases (Керимов, 1963). The primitive derivatives of the first phase are considered to be dark black, coarse grained, phaneritic gabbro. These rocks are characterized by gabbro, gabbro-ophitic textures under the microscope. Idiomorphic olivine grains are presented in the rock in quiet large amount (3-6%) and in the form of characteristic loop shaped crystalls. The next or the first crystallic phase of crystallization sequence is plagioclase. In most cases, it makes intergrowth with hypersthene in an amount of 4-5%. Hypersthene is characterized with low Ca concentration. Plagioclases of labradorite-bytownite composition dominate (50-70%) in olivine bearing gabbro and gabbro-norite. They exist in two generations. The first one forms short poly-synthetic prismatic grains and has been exposed to alteration processes in varying degrees. The second phase is unaltered and dominates in the rock. Clinopyroxene dominates over orthopyroxene. According to optical features (Ng=1.72, Np=1.694, 2V=54-56^{o}) this is augite. Besides the described minerals, Cr bearing magnetite, average Ti bearing magnetite and apatite occur in a confined amount (1-2 %) (Kerimov, 1963).

The described rocks are replaced by macroscopically dark grey normal gabbro with the gradual transition. Under the microscope the texture of these rocks is phaneritic, gabbro ophitic. Olivine does not occur in the mineralogical composition of the rock. The amount of ortho- and clinopyroxene decreases greatly in the rock corresponding to general differentiation. In turn, the amount of plagioclase of labradorite composition increases slightly. Besides, the average of Ti bearing magnetite increases in the rock and it forms an intergrowth with clinopyroxene. Finally, leucogabbro as an ultimate derivative of the first phase has been crystallized from the residual melt. This phaneritic rock is distinguished by having macroscopically grey colour and dominance of prismatic polysynthetic plagioclase of silica enriched labradorite and andesine. Besides the ortho- and clinopyroxene in confined amount, partly uralitezed hornblende occurs in the rock. Both unaltered average of Ti bearing magnetite and secondary maghemite are observed in the rock. Quartz grains are present interstitially among plagioclase grains in confined amount (Керимов, 1963).

Indeed, the derivatives of the first phase are formed by the control of the fractional crystallization from petrochemical point of view. Since, olivine, pyroxene, Cr spinel, average Ti bearing magnetite, etc. minerals as concentrators of iron group elements (Fe, Ti, Cr, Ni, Co, V, etc.) have been settled down in the intrusive camera (Mammadov et al., 2021). As a result of this process the concentration of aforementioned elements in the residual melt decreases, hence the concentration of minerals containing these elements decreases in the subsequent rocks. So, in the rocks such as gabbro and leucogabbro aforementioned minerals are not observed. However instead of them, mainly hornblende, uralite, andesine, labradorite and in confined amounts biotite and quartz are present in the rocks. Besides of them, the amount of ortho- and clinopyroxene decreases in the rocks. Uralite and sometimes epidote alteration over pyroxene and epidote, chlorite alteration over plagioclase are observed in the normal gabbro and leucogabbro. Formless quartz grains fill cavities among plagioclase ones.

Dolerite and kersantite dikes of the first phase cutting the parental rocks in different directions are found in the areas where gabbroid rocks are spread. The thickness of these dikes reaches 2-4 meters. They have characteristic micro-gabbro texture and in addition to ortho- and clinopyroxenes in confined amount contain hornblende, biotite and plagioclase of labradorite-andesine composition (Kerimov, 1963).

As we mentioned before, the second phase of the intrusion is quartz diorite. The rocks of this phase are macroscopically in grey, light grey colours. Transparent quartz grains and in confined amount narrow, elongated amphibole grains are distinguishable in the light background colour. However, straw yellow biotite grains are observed in some rock species of the phase. It must be noted that the rocks of the quartz diorite phase are the most common rocks in the area. Xenoliths of the gabbroid phase with the thermal fringe and in different sizes are presented within the second phase rocks. Dike rocks of the quartz diorite phase cut through both their parental rocks and the rocks of the gabbroid phase. Based on petrographic, petrochemical and mineralogical studies quartz diorite-granodiorite-granite pegmatite, quartz diorite-tonalite-banatite and quartz diorite-monzodiorite-monzonite-syenite facies are separated within the quartz diorite phase (Kerimov, 1963).

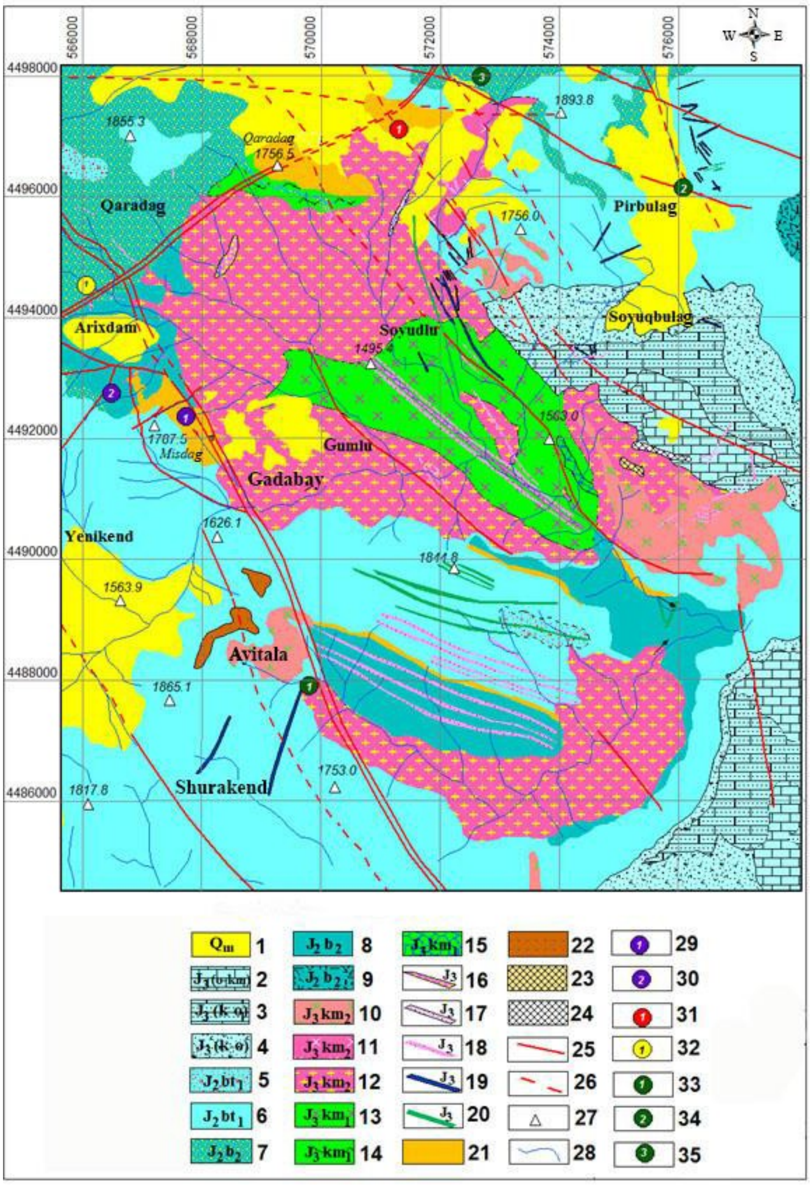

Fig. 1. Lithological-structural map of the south-eastern part of the Gadabay ore region.
(Part of map composed by Azerbaijan Mining Company)

Legend: 1 – Quaternary sediments; 2 – Limestone layer (Lusitanian): alternation of limestones with limestones and tuff-sandstones; 3 – Upper tuff-conglomerate layer: tuff-sandstones, alternation of tuffs and limestones, sandy limestones and sandstones; 4 – Lower tuff-conglomerate layer: tuff-conglomerates, tuff-breccias, tuff sandstones; 5 – Metamorphically altered tuffs; 6. Bathonian sub-volcanic layer: tuff-breccias containing tuff, tuff-conglomerates; 7 – Upper Bajocian stratum: rhyolite-riodacitic lava facies; 8 – Lower Bajocian volcanic layer: andesitic lava facies; 9 – Lower Bajocian stratum: pyroclastic facies of tuff-breccia and andesite porphyries; 10 – Gara-gaya-Garamurad hypabyssal sub-intrusion: diorite, keratospilit; 11 – The second phase of Gadabay intrusion: diorites; 12 – The second phase of Gadabay intrusion: granodiorites, quartz diorites, diorite-syenites, diorites; 13 – The first phase of Gadabay intrusion: gabbro- diorites, gabbro; 14 – The first phase of Gadabay intrusion: gabbro-norites, gabbro; 15 – The first phase of Gadabay intrusion: gabbro- pyroxenites; 16 – Syenite-diorite dykes; 17 – Aplite dyke, 18 – Quartz-diorite dyke; 19 – Andesite dykes; 20 – Diabase dykes; 21 – Metasomatites; 22 – Greisenization (metasomatic quartzites with tourmaline); 23 – Skarns (garnet-vollastanite-calcite facies); 24 – Skarns (carbonate-epidote facies); 25 – Faults; 26 – Presumed faults; 27 – Altitude references, 28 – Rivers; 29 – Gadabay deposit; 30 – Gadir mineralization area; 31 – Great Galacha copper-porphyry ore manifestation; 32 – Cholpan sulfur-pyrite ore manifestation; 33 – Ayitala copper-pyrite ore manifestation; 34 – Pirbulag copper-pyrite ore manifestation; 35. Parakand-su copper-pyrite ore manifestation.

Table 1

Bulk chemical analyses of Gadabay intrusion rocks

Oxides / Samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	∑
1	49.54	0.47	18.21	4.36	5.75	0.18	5.75	9.75	3.26	0.23	0.16	2.3	99.96
2	49.67	0.51	19.21	3.75	5.38	0.16	5.82	8.67	3.16	0.21	0.15	2.75	99.44
3	47.2	0.64	12.46	5.86	11.74	0.16	7.86	10.21	1.78	0.84	0.14	1.05	99.94
4	48.1	0.58	11.76	6.51	10.46	0.14	7.25	9.82	1.64	0.84	0.12	2.4	99.62
5	49.46	0.48	18.75	3.31	5.86	0.16	6.36	9.21	3.42	0.06	0.14	2.8	100.01
6	50.43	0.49	18.82	3.62	5.38	0.14	5.51	10.21	2.75	0.09	0.16	2.2	99.8
7	48.64	0.64	18.64	3.26	5.46	0.16	6.42	9.66	3.22	0.38	0.14	2.855	99.48
8	51.75	0.46	19.31	2.75	4.56	0.16	4.66	7.41	4.21	1.75	0.11	2.46	99.59
9	52.25	0.12	19.36	4.75	4.21	0.11	3.26	8.36	3.75	0.75	0.11	2.78	99.81
10	58.75	0.36	16.64	3.28	4.76	0.16	3.82	6.42	3.78	0.42	0.11	1.43	99.93
11	59.42	0.38	17.46	3.22	4.5	0.16	3.28	5.34	4.46	0.33	0.12	1.24	99.91
12	60.41	0.11	17.43	2.75	3.52	0.11	3.39	6.6	3.42	0.75	0.1	1.2	99.79
13	61.33	0.41	14.94	6.96	-	0.01	4.06	2.76	6.78	1.12	0.15	1.23	99.75
14	52.73	0.67	19.55	3.21	3.27	0.01	4.76	8.7	4.42	0.47	0.01	1.87	99.67
15	65.77	0.38	14.38	3.28	-	0.11	2.63	4.04	5.03	2.36	0.06	1.56	99.6
16	67.85	0.41	14.54	1.96	2.38	0.02	2.24	2.31	5.11	1.54	0.16	1.33	99.85
17	63.51	0.16	15.26	3.23	5.36	0.12	2.12	5.16	2.38	1.1	0.16	1.39	99.95
18	63.8	0.11	16.18	2.23	4.4	0.12	2.46	4.25	2.36	2.38	0.12	1.53	99.94
19	49.35	0.64	16.23	3.26	7.56	0.24	6.73	9.92	3.4	0.76	0.2	1.48	99.77
20	60.54	0.54	16.32	3.44	3.45	0.09	3.06	5.8	3.82	1.56	0.06	0.52	99.14
21	60.3	0.28	16.14	3.24	4.32	0.12	3.37	5.6	3.86	1.64	0.07	0.68	99.62
22	60.25	0.28	15.28	2.74	3.75	0.12	3.42	5.61	3.86	2.75	0.09	1.38	99.53
23	55.64	0.29	16.75	2.64	3.84	0.09	3.32	5.81	4.76	3.68	0.16	2.42	99.4
24	56.58	0.72	17.65	2.38	3.48	0.14	2.98	5.86	4.1	3.38	0.26	1.85	99.38
25	57.1	0.64	16.48	2.56	3.75	0.14	4.21	5.34	3.36	4.28	0.28	1.38	99.52
26	74.23	0.04	10.74	0.36	2.21	0.06	0.75	1.46	5.38	2.75	0.04	1.4	99.42
27	49.56	0.75	18.56	4.75	5.36	0.12	6.6	8.75	2.37	0.81	0.16	1.82	99.61
28	50.74	0.46	18.65	4.8	5.64	0.14	6.14	8.42	2.2	0.42	0.21	1.89	99.71
29	56.48	0.15	18.16	3.36	4.86	0.14	4.2	7.54	2.12	1.54	0.07	1.32	99.94
30	70.5	0.04	12.16	1.28	1.64	0.04	1.38	2.94	4.29	3.54	0.04	1.54	99.39

Names of rocks:1,2,5,6 – gabbronorite; 3,4 – pyroxenite; 7,19 – gabbro; 8 – biotite-quartz bearing gabbro,9 – gabbrodiorite; 10,11,14 – diorite; 12,13,20,21 – quartz diorite; 15,16 – granodiorite; 17 – tonalite;18 – banatite;22-25 – quartz monzonite; 26 – granite pegmatite; 27,28 – diabase; 29 – diorite dike ; 30 – aplite dike

Quartz diorite facies rocks are the most spread rock types comparing to other facies. Rocks of this facies as mentioned before are normal diorite, quartz diorite, granodiorite, normal granite and granite-pegmatite. Plagioclases of andesine-labradorite as main mineral composition of normal diorite and quartz diorite are more idiomorphic than pyroxenes and they form prismatic polysynthetic twinnings. The amount of pyroxenes gradually decreases in the rocks starting from normal diorites toward to granites through quartz diorite and granodiorite. In granites they occur as single grains. The amount of quartz intensely increases in the listed sequence. Dusky grey and xenomorphic orthoclase grains appear in granites and granite-pegmatites. In addition to the aforementioned rock forming minerals, confined amount of hornblende, pargasite also present in quartz diorites, granodiorites and granites (Керимов, 1963).

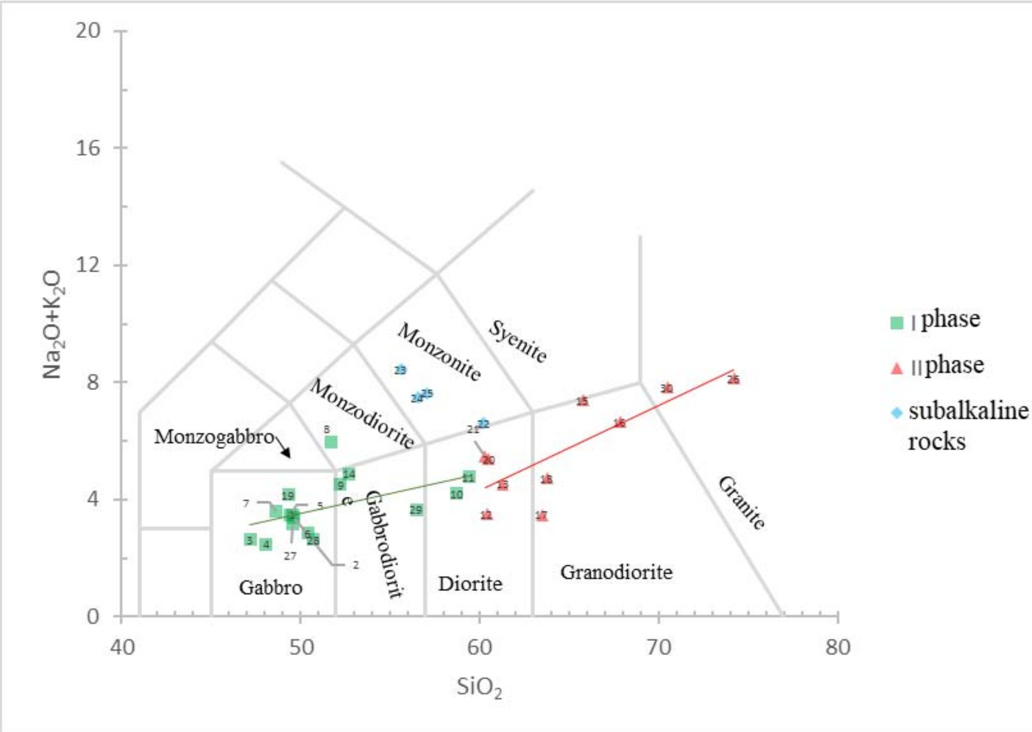

Fig. 2. TAS diagram for Gadabay intrusion rocks (Middlemost, 1994)

Banatite-tonalite rocks gradually path into quartz diorites. The amount of quartz decreases in tonalites and alkali feldspars occur as single grains. However, in tonalites the amount of alkali feldspars partially increases beside the quartz.

Monzodiorites, monzonites and the quartz bearing analogues occur in the area in quite less amount comparing to quartz diorites. Macroscopically these rocks are in pinkish grey colour and are represented by relatively large grains. Mineralogical compositions of the rocks consist of labradorite (An_{51-60}), transitional orthoclase, quartz, hornblende, biotite and average Ti bearing magnetite. Confined amount of augite grains occur beside the listed minerals.

Summarizing, the second phase of the intrusion includes mainly rock types such as diorite-quartz diorite-granodiorite-granite and to some degree granite pegmatite. However, among the main rock types confined amount of tonalite-banatite and monzodiorite-monzonite-syenite also occurs (Керимов, 1963).

Samples and analytical method

We possess results of trace elements analyses of eight samples which have been used in the paper. Trace element concentrations in minerals are also primary important in petrogenetic researches (Bédard, 2014). Hence, the results of trace element (Ni, Co, Cr,V, Ba, Sr) analyses of minerals of six samples have been used, besides to rectify and enhance the interpretation eight rock samples also were studied. Four samples (1,2,3,4) belong to the rocks of the first phase and the other four ones (5,6,7,8) to the second phase. However, Sample 4 on composition is close to the rocks of the second phase because it is the latest rock type of the first phase (Mammadov et al., 2021). The results of analyses are from Prof. Musa Mammadov's data collection. Analyses of rock and monomineralic samples for trace elements have been run by neutron activation method in the laboratory of the Bronnitsa Geological and Geochemical Expedition of the IMGRE (Institute of Mineralogy, Geochemistry and Crystallochemistry of Trace Elements).

Discussion

Discrimination diagrams for tectonic environments

Discrimination diagrams based on couple of trace elements or trace elements ratios are widely used to identify tectonic environments where rocks are formed (Rollinson, 2021). For rocks of Gadabay intrusion the most suitable discriminant diagrams can be considered to be Zr/Y–Zr, Th/Y–Ta/Yb, Nb–Y and Th–Yb diagrams from which first two ones are suitable for mafic rocks and the latter two ones – for more evolved quartz bearing rocks (Pearce et al., 1979).

Table 2

Concentration of trace elements (in ppm) of Gadabay intrusion rocks

Elements	1	2	3	4	5	6	7	8
Rb	0.86	4.5	8.6	10.7	8.21	12.71	12.14	18.16
Sr	111	250	200	178.4	760	760	839	314.1
Y	9.2	7.2	7.8	9.2	8.8	7.4	12.4	10
Zr	40.2	45.4	50.8	61.4	94	90	116.4	131.1
Nb	3.2	3.4	3.8	4.2	3.6	7.2	4.8	6.3
Ba	20.6	90.7	114.3	230.4	154	400	239	182.2
Hf	7.6	7.5	7.8	8.2	2.14	2.39	3.24	3.29
Ta	0.64	0.66	0.82	0.84	0.22	0.46	0.4	0.6
Pb	2.63	2.2	2.1	2.4	2.6	12.16	3.19	1.74
Th	1.73	1.72	1.82	1.84	0.82	2.73	3.6	4.5
U	0.67	0.68	0.7	0.8	0.29	1.52	0.6	2.34
V	318	314	210	180.4	64	68.1	92.4	38.4
Cr	815	388	250	170.4	62	136.4	70.2	90
Co	58.1	45.4	41.2	25.4	16.2	11.2	15.2	6.8
Ni	123	98.2	60.2	30.4	25.12	12.4	12.2	15.4
Cu	94.1	100	120	180	3.72	13.0	12.1	25.7
Zn	111	120	150	154	47.0	46.4	49.8	14.6
La	9.3	11.6	12.5	12.7	15.7	16.8	23.2	25.4
Ce	18.6	20.7	20.7	21.4	32	35.2	49.2	45.9
Pr	2.9	2.9	2.8	3.2	4	4.36	5.82	5.15
Nd	11.2	11.4	11.4	12.4	16	17.24	22.4	19.2
Sm	2.8	3.0	3.1	3.3	3.2	3.16	4.16	3.21
Eu	1.0	0.98	0.98	1.0	1.1	1.0	1.2	0.95
Gd	3.8	2.1	2.8	2.6	2.69	2.4	3.62	2.6
Tb	0.76	0.74	0.78	0.79	0.4	0.36	0.5	0.34
Dy	2.4	2.3	2.5	2.8	1.9	2.42	2.6	1.78
Ho	0.91	0.33	0.34	0.38	0.4	0.44	0.52	0.38
Er	0.91	0.98	1.0	0.86	0.89	1.09	1.12	0.96
Tm	0.31	0.21	0.14	0.16	0.14	0.18	0.2	0.16
Yb	0.91	0.89	0.98	0.99	0.82	1.1	1.14	0.96
Lu	0.16	0.14	0.18	0.2	0.14	0.14	0.2	0.16
Cs	0.19	0.2	0.24	0.18				

Rock names: 1 – Gabbronorite, 2 – Gabbro, 3 – gabbrodiorite, 4 – Diorite, 5 – Quartz diorite, 6,7 – Tonalite, 8 – Granodiorite

In Fig. 3 the Zr/Y–Zr values of rocks are depicted. It can be seen that all rocks are in the continental arc zone which correspond to paleotectonic reconstruction of the region (Рустамов, 2019) and the major element compositions of the rocks (Mammadov et al., 2021). Furthermore, despite the fact that Zr/Y–Zr diagram is good for mafic rocks, depicting of II phase rocks in the diagram shows conspicuous trendline, likely related to assimilation processes. It means that by the time passing the degree of assimilation increases, since Zr is a characteristic incompatible element and is strongly related to continental crust (Pearce et al., 1979; Rollinson, 2021).

Th/Y–Ta/Yb ratios for I phase rocks are shown in Fig. 4. This diagram is important due to its depicting of primitive melt source characteristic. Besides, it shows to which rock suites belong the considered rocks. In our case it is clear that primitive melt of gabbroid rocks is the product of the partial melting of enriched mantle which is characteristic for mantle wedge. Furthermore, rocks are representatives of calc-alkaline series which has been proved by multiple previous studies (Абдуллаев и др., 1979; Абдуллаев, 1963; Керимов, 1963; Mammadov et al., 2021; Мустафаев, 1977).

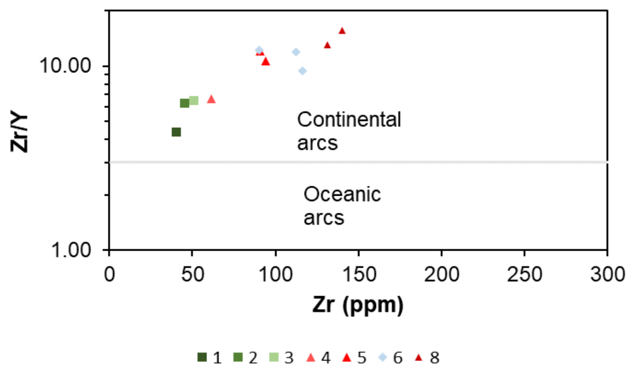

Fig. 3. Zr/Y–Zr diagram for Gadabay intrusion rocks (Pearce, 1979). Sample names are the same with Table 2

As mentioned above, Nb–Y and Th–Yb diagrams are especially useful for rocks containing quartz on the composition. In Fig. 5 and 6, relevant diagrams are composed for II phase rocks. Sample 4 is also added here due to compositional similarity to the second phase. These results are also in coherence with preceding results. Rocks lay within volcanic arc field. However, Nb–Y diagram shows syn-collisional characteristics of the rocks. Nevertheless, early collisional stage of the Lesser Caucasus has started from the late Cretaceous (Imamverdiyev et al., 2013, 2017; Рустамов, 2019).

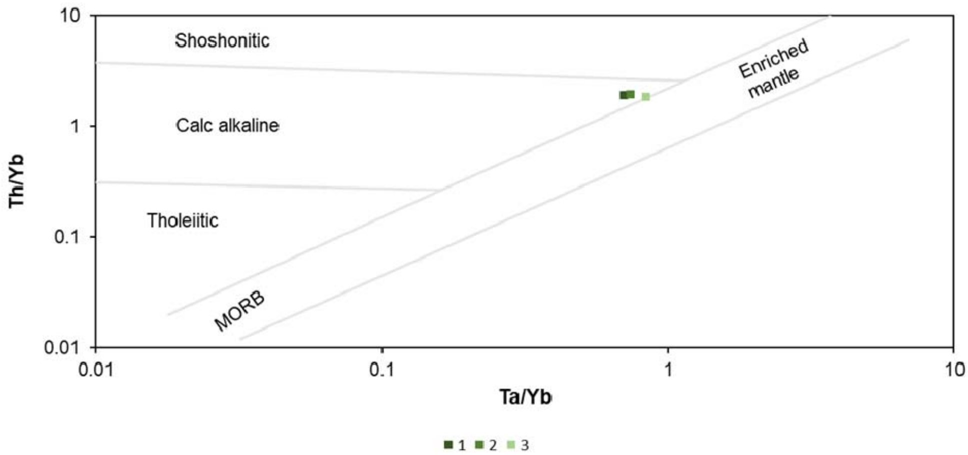

Fig. 4. Th/Y–Ta/Yb diagram for Gadabay intrusion rocks (Rollinson, 2021). Sample names are the same with Table 2

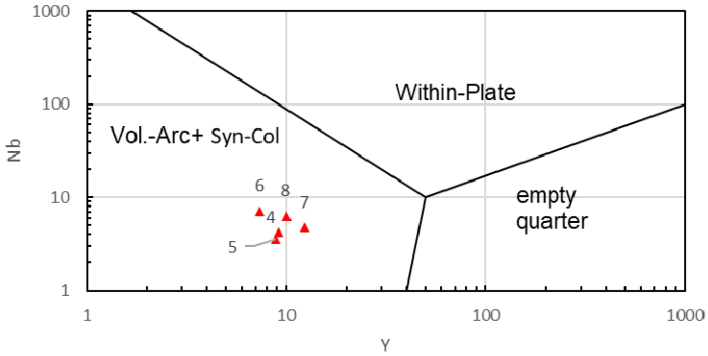

Fig. 5. Nb–Y diagram for Gadabay intrusion rocks (Rollinson, 2021). Sample names are the same with Table 2

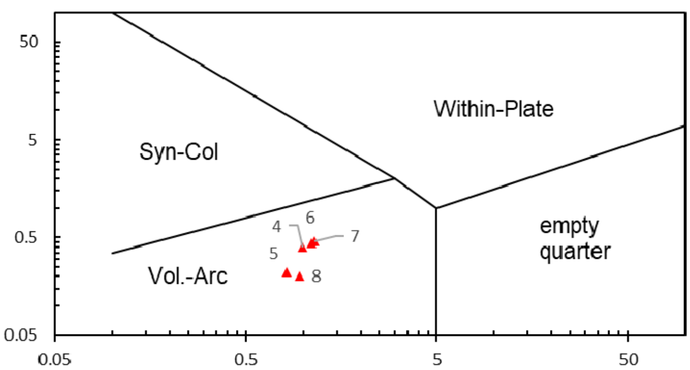

Fig. 6. Th–Yb diagram for Gadabay intrusion rocks (Rollinson, 2021). Sample names are the same with Table 2

Behavior of trace elements

Trace element concentrations of rocks of the Gadabay intrusion are presented in Table 2. As a general pattern it can be distinguished that the concentration of the main compatible elements decreases toward the more evolved rocks. And this is some kind of predictable behavior since in most intrusive magma chambers fractional crystallization is the dominating process. Furthermore, in the C1 chondrite (Sun, McDonough, 1989) normalized REE spider diagram (Fig. 7) LREE enrichment is observed, which also means the fractional crystallization process (Rollinson, 2021). However, the concentration of HREE is very close for all rocks. It can be explained by the fact that, the primitive melt producing Gadabay intrusion has been already fractionated with the accommodation of olivine and might be orthopyroxene crystallization, because gabbro-norite as the closest rock type to the primitive melt on composition has distribution coefficient K_D of 0.59 for Mg-Fe fractionation. Whereas, for unfractionated primitive melts this value must be 0.3-0.36 (Irvine, 1979). Since, fayalite component in olivine can host HREE, during the accumulation of olivine from primitive melt to produce residual melts of gabbro norites some portion of HREE could be extracted from the residual melt. The fact of olivine accumulation from the primitive mantle-derived melt is proved in author's research which has not yet been published. The result of this research shows 31.5% partial melting of metasomatized mantle peridotite with K_D value of 0.33 for Mg-Fe fractionation. Mg value of the melt is calculated to be 0.66.

In Fig. 7 comparison of REE patterns of the intrusion rocks with Normal MORB and Primitive Mantle is also presented. The LREE enrichment and HREE depletion of the rocks compared with MORB and full range of enrichment compared to Primitive mantle can be seen here. This data can be interpreted as enriched mantle source and high volume partial melting of this source which correspond to research results.

From Fig. 7 it can be seen that, the most enrichment in LREE belongs to granodiorite, whereas the least is for gabbro-norite. The second fact deserving attention is that, there are no any Eu anomalies for rocks. This can be explained by the fact that, plagioclase is in the first crystallized mineral paragenesis and the change in plagioclase content of the rocks and Ca concentration in plagioclase occurs gradually.

In Fig. 8 more susceptible to fractionation trace elements are shown. As well-known fact, Ni, Co and Cr, especially Ni is the sign of Mg and Fe^{2+} change in melts, which means fractionation and evolution of melts. At the same time Ba shows increase in K content which can indicate increase in SiO_2 if alkali feldspar crystallizes. And Sr strongly correlates with Ca showing plagioclase content. From the Fig. 8 we can see that, the highest Ni and Co concentrations belong to gabbro-norites and decrease toward the granodiorite smoothly. For Sample 5 trough for Cr is observed, which can be interpreted as depletion in titanomagnetite or clinopyroxene phases. As well as a relatively high spike for Sample 6 (tonalite) may indicate a higher Fe oxidation, which corresponds to a higher magnetite content. As a general trend Sr concentration grows toward more acidic rocks with the increasing of plagioclase content of rocks comparing with pyroxenes. However, amount of anorthite component in plagioclase also influences Sr concentration. That can be the reason of saw teeth like appearance of Sr line with steep ascent from diorite to quartz diorite and steep decline from tonalite to granodiorite. However, the behavior of Cr and Ba are unusual, since the concentration of Ba should have increased and Cr decreased toward the granodiorite.

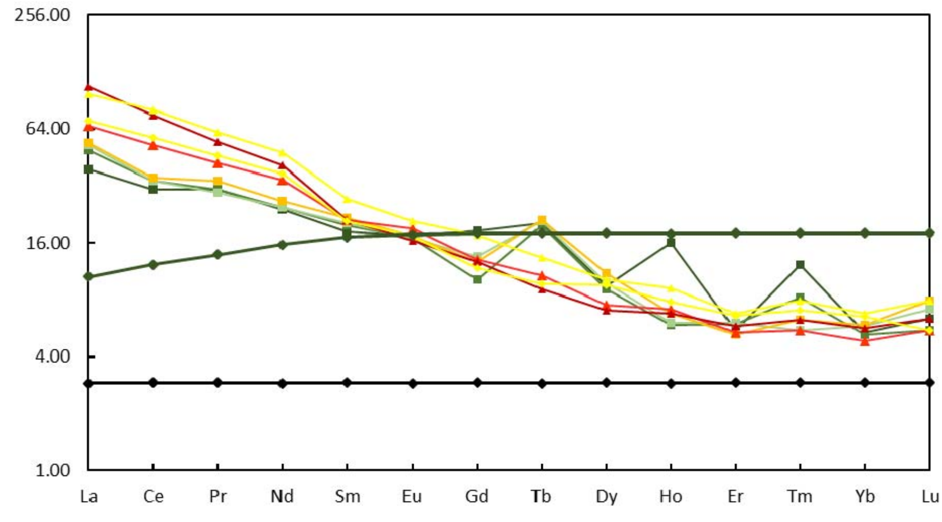

Fig. 7. Normalized REE spider diagram of Gadabay intrusion rocks (Sun, McDonough, 1989). Sample names are the same with Table 2

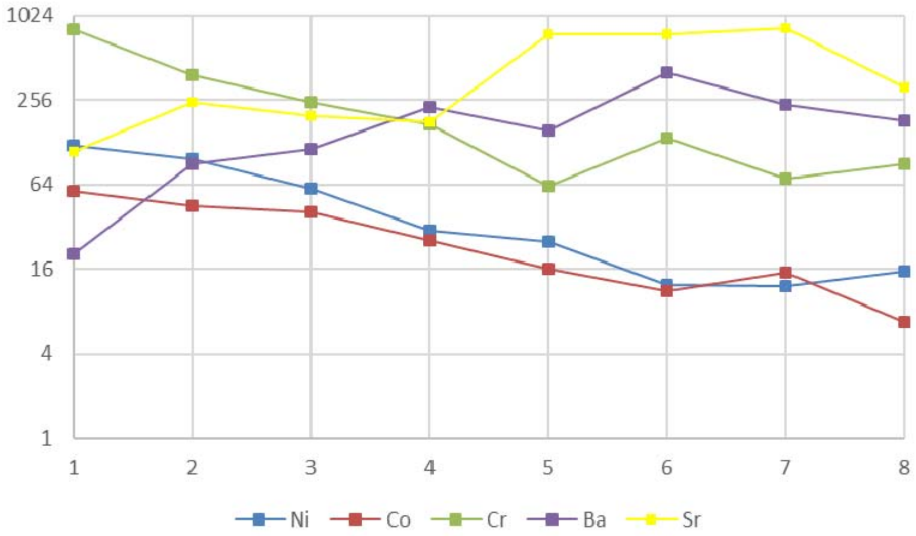

Fig. 8. Behavior of selected trace elements indicating the processes during evolution of the melt. Sample names are the same with Table 2

Results

From conducted study it can be concluded that, Gadabay intrusion rocks belong to calc-alkaline series as has been proved by previous studies. Primitive melt of the intrusion is the result of high degree partial melting of the enriched mantle substrate. Paleotectonic setting corresponds to continental or volcanic arc. Lithofacial studies of the region substantiate that it is mature island arc. Collision stage in the region started in the later Cretaceous whereas, the intrusion is dated to upper Jurassic-lower Cretaceous age (138-159 Ma).

Rocks are enriched in REE comparing to chondrite and primitive mantle which is characteristic for metasomatized mantle wedge. However, they are depleted in HREE comparing to NMORB. This with the behaviour of other trace elements indicates that the main process controlling the evolution of the melts of the rocks of the intrusion complex was fractional crystallization. Furthermore, different residual melts have produced different degree of assimilation of wall rocks. The local scale formation of alkaline rocks such as monzodiorite, monzonite and monzonite may result from this assimilation of wall rocks by the latest residual melts (Mammadov et al., 2021). However, the results of ilmenite-titanomagnetite geothermometry show equal and higher crystallization temperatures for monzonites (Аббасов, 2023). Furthermore, the crystallization depth of alkaline rocks is also the deepest comparing to other rocks of the intrusion complex (Аббасов, 2023). Hence there is a probability that, the main part of alkaline rocks has not yet been exposed by erosion. Considering all the mentioned facts, it would be logical to think that, alkaline rocks are not the branch of the second phase but have been formed as the third phase. Furthermore, high temperature of the melt contributed to the high degree of assimilation of continental wall rocks, which enriched the melt with incompatible and perhaps ore mineralization elements.

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ГЕОХИМИЧЕСКАЯ ХАРАКТЕРИСТИКА ГЯДАБЕЙСКОГО ИНТРУЗИВНОГО КОМПЛЕКСА В ИЗУЧЕНИИ ЭВОЛЮЦИИ МАГМЫ И ТЕКТОНИЧЕСКОЙ ОБСТАНОВКИ РЕГИОНА (МАЛЫЙ КАВКАЗ, ТЕРРИТОРИЯ АЗЕРБАЙДЖАНА)

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Резюме. Гядабейский интрузивный комплекс, расположенный в пределах Лок-Гарабахской структурно-формационной зоны Малого Кавказа, формируется в две магматические фазы – ~~Это~~ габброидную и гранитоидную. Кварцевые диориты ~~породы~~ гранитоидной фазы являются наиболее распространенным в этом районе типом пород. Щелочные породы, такие как монцодиориты и монцониты, имеющие ограниченное распространение в регионе, рассматриваются как ветвь второй фазы. Однако результаты ильменит-титаномагнетитовой геотермометрии показывают равные и более высокие температуры кристаллизации этих щелочных пород. Следовательно, этот факт позволяет предположить, что щелочные породы являются не ветвью второй фазы, а третьей фазой интрузивного комплекса. Несмотря на детальные петрографические и полевые исследования, источник магматических расплавов, сформировавших интрузию, глубоко не изучен. В связи с этим заслуживает изучения микроэлементный состав пород Гядабейского интрузивного комплекса. Кроме того, распределение микроэлементов в некоторых минералах также может рассматриваться как ценный источник информации. Распределение элементов группы Fe (Ni, Cr, V, Co), щелочноземельных элементов (Sr, Ba) и РЗЭ в породах Гядабейского интрузивного комплекса контролируется фракционной кристаллизацией. Таким образом, концентрация когерентных элементов и тяжелых РЗЭ уменьшается в сторону более дифференцированных типов пород, тогда как концентрация инкогерентных элементов и легких РЗЭ увеличивается. Следующим фактом является то, что Гядабейский интрузивный комплекс сформировался в пределах известково-щелочной магматической серии, а первичный расплав являлся результатом частичного плавления обогащенного мантийного субстрата, что подтверждается диаграммами, построенными на основе соотношений микроэлементов.

Ключевые слова: *Гядабейская интрузия, редкоземельные элементы, элементы группы железа, элементы-примеси, классификационные диаграммы, литосферная мантия, мантийные плюмы, парциальное плавление, состав примитивных расплавов*

MAQMANIN TƏKAMÜLÜNÜN VƏ REGİONUN TEKTONİK QURULUŞUNUN ÖYRƏNİLMƏSİNDƏ GƏDƏBƏY İNTRUZİV KOMPLEKSİNİN GEOKİMYƏVİ XÜSUSİYYƏTLƏRİ (KİÇİK QAFQAZ, AZƏRBAYCAN ƏRAZİSİ)

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Xülasə. Kiçik Qafqazın Lök-Qarabağ struktur-formasiya zonasında yerləşən Gədəbəy intruziv kompleksi iki maqmatik fazada formalaşmışdır. Bunlar qabroid və qranitoid fazalarıdır ki, qranitoid fazasının kvars diorit tərkibli süxurları ərazidə ən geniş yayılmış süxur növüdür. Bölgədə məhdud yayılmış monsodiorit və monsonit kimi qələvi süxurlar ikinci fazanın qolu hesab olunur. Hərçənd, ilmenit-titanomaqnetit geotermometriyasının nəticələri bu qələvi süxurların bərabər və daha yüksək kristallaşma temperaturlarını göstərir. Bu fakt isə qələvi süxurların ikinci fazanın qolu deyil, intruziv kompleksin üçüncü fazası olması ehtimalını artırır. İllər boyu ətraflı petroqrafik və çöl tədqiqatlarının aparılmasına baxmayaraq, intruziv kompleksi əmələ gətirən maqmatik ərintilərin mənbəyi dərindən öyrənilməmişdir. Bu baxımdan Gədəbəy intruziv kompleksinin süxurlarının mikroelement tərkibinin tədqiq edilməsi əhəmiyyətlidir. Bundan əlavə, müəyyən minerallarda mikroelementlərin paylanması da qiymətli məlumat mənbəyi hesab edilə bilər. Gədəbəy intruziv kompleksinin süxurlarında Fe qrupu elementlərinin (Ni, Cr, V, Co), qələvi torpaq elementlərinin (Sr, Ba) və NTE-nin paylanması fraksion kristallaşması ilə tənzimlənmişdir. Belə ki, koherent elementlərin və ağır NTE konsentrasiyası daha çox təkamül etmiş süxur növlərinə doğru azalır, inkoherent elementlərin konsentrasiyası və yüngül NTE isə artır. Növbəti fakt ondan ibarətdir ki, Gədəbəy intruziv kompleksi əhəngli-qələvi maqma seriyası daxilində formalaşmış və ilkin ərinti zənginləşmiş mantiya substratının qismən əriməsi nəticəsində əmələ gəlmişdir ki, bu da mikroelementlərin nisbəti əsasında tərtib edilmiş diaqramlarla sübut edilmişdir.

Açar sözlər: *Gədəbəy intruzivi, nadir torpaq elementləri, dəmir qrupu elementləri, mikroelementlər, təsnifat diaqramları, litosfer mantiyası, mantiya plümları, qismən ərimə, ilkin ərintilərin tərkibi*