Baku State University Journal of Earth Sciences & Environment **2025**, v 2(3), p.56-72

journal homepage: http://bsuj.bsu.edu.az/en

MINERALOGY OF THE LATE CRETACEOUS VOLCANIC COMPLEXES OF THE GAZAKH TROUGH OF THE LESSER CAUCASUS

Nazim A. İmamverdiyev[1], Gultekin J. Babayeva[2], Minakhanum Y. Hasanguliyeva[2], Farrukh H. Sariyev[2], Kenan F. Abbasov[2], Rubaba E. Rustamova[1]

[1]Baku State University, 33, Z. Khalilov str. AZ 1148 Baku, Azerbaijan
[2]Geologiya inst. Geology Institute, 119, Huseyn Javid av. AZ 1141, Baku, Azerbaijan

DOI: https://doi.org/10.30546/209805.2025.2.3.1013

Abstract
The article deals with the mineralogical peculiarities of the Upper Cretaceous basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough and the crystallization conditions of mineral parageneses. Separated mineral paragenesis characterizes the stages of crystallization of primary alloys of rock complexes in intermediate magmatic chambers. Mineral paragenesis consists of olivine-chrome spinel-clinopyroxene, olivine-clinopyroxene-plagioclase-titanium magnetite, orthopyroxene-clinopyroxene-plagioclase-titanium magnetite-amphibole, orthopyroxene-clinopyroxene-plagioclase-titanium magnetite-quartz, biotite-plagioclase-titanium magnetite-quartz. The process of crystallization differentiation played a leading role in the evolution of rock compositions of the basalt-basaltic andesite and dacite-rhyolite complexes.

Keywords: Gazakh trough, crystallization temperature, mineral paragenesis, crystallization differentiation basalt-basaltic andesite and dacite-rhyolite complexes.

*Corresponding author.

E-mail address: nazimimamverdiyev@bsu.edu.az (N. Imamverdiyev)

1.Introduction:

Mineral paragenesis is an important source of genetic information to characterize the crystallization stages of alloys released during melting of the upper mantle root in magmatic chambers and intrusive chambers at different depths. At the same time, they contain the evolutionary variability of primary alloys regulated by various geological and geodynamic conditions. Taking into account these peculiarities of mineral paragenesis, the volcanic complexes of the Gazakh trough of the Lesser Caucasus were selected as a suitable object in the article.

The Upper Cretaceous volcanic complexes located in the northwest-southeast direction of the Lesser Caucasus and the intrusives associated with them occur in the geological structures of the Lok-Karabakh (Gazakh, Agjakend, Agdere), Goycha-Hakari (Khojavand, Azikh) and Miskhana-Gafan (Hochas) structural-formational zones, creating a basis for monitoring the evolution of magmatic processes occurring in the region. The geological peculiarities of the abovementioned structural-formation zones were interpreted in detail in the research works by Y.V.Karyakin [4], A.S.Ostraumova et al. [15], R.N.Abdullayev [1], M.A.Mustafayev [14], F.A.Akhundov [2], A.S.Shikhalibeyli [16], M.N.Mammadov et al. [6-11], G.J. Babaeva [3], N.A. Imamverdiyev et al. [5].

Basalt-basaltic andesite, dacite-rhyolite complexes were formed in the Upper Coniacian-Lower Santonian stage in the Gazakh, Agjakend and Agdere troughs of the Lok-Karabakh structural-formational zone. Lava and pyroclastic facies of the basalt-basaltic andesite complex were discovered in the center of the Gazakh trough, and thin sheeted picrodolerite and picrobasalt outcrops were discovered in the south (Fig. 1, 2).

2. Geological peculiarities of the Gazakh trough

The Gazakh trough is mainly covered with Upper Jurassic-Lower-Upper Cretaceous volcanogenic, tuffaceous-sedimentary and sedimentary rocks. The trough rests on the watershed of Tovuz and Akhinjachay to the north and on the lower reaches of Khramchay to the west.

According to R.N. Abdullayev et al. [1], F.A. Akhundov [2], M.N. Mammadov et al. [9], M.A. Mustafayev [14], the abovementioned rock association is divided into the Upper Coniacian-Lower Santonian basalt-andesibasate complexes and Upper Santonian dacite-rhyolite complexes based on their composition, age and facies peculiarities.

The first complex consists of volcanic breccias, flows and thin clay and dolerite dykes. The central part of the complex, i.e., the Hasansu River basin has the greatest thickness (700 m) (Fig. 2). The thickness of the complex decreases significantly and reaches 260 m in the western direction. The periodicity of volcanic activity in the central part of the trough was short, whereas it was prolonged in the north-western and southeastern continuation. In this regard, the thickness of tuffaceous-sedimentary formations is greater in the periclinal parts of the trough, mainly in the southeastern extension. Analysis of the formational peculiarities of the volcanites of the complex shows that basalt and dolerite flows prevail here compared to pyroclastic formations. The thickness of the lava flows varies from several meters to 30-40 meters. Andesite-basalt lava breccias are observed in the lower part of the complex, and basalt flows of small thickness in the upper part in the northwestern continuation of the Gazakh trough, on the left bank of the Agstafa River.

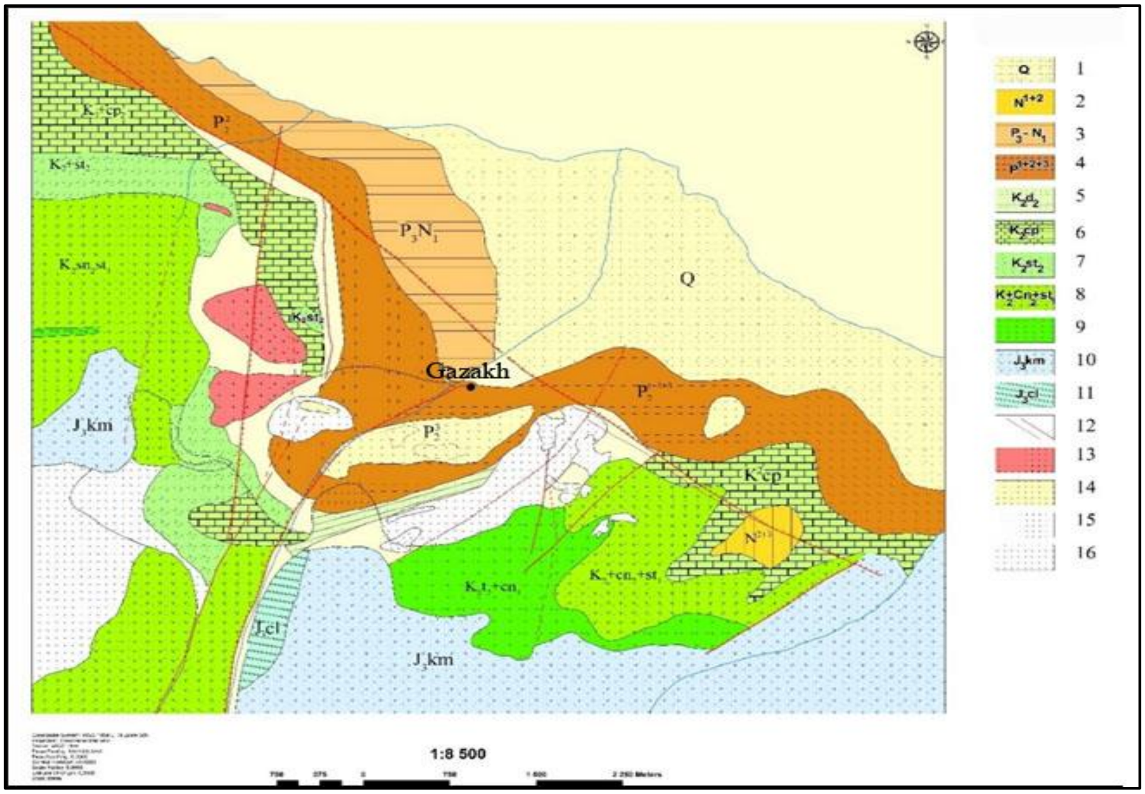

Fig. 1. *Schematic and geological map of the Gazakh trough [4]*

1 – Quaternary sediments, 2 – sandstones, conglomerates, 3 – Maikop: clays, sandstones, 4 – Lower, Middle, Upper Eocene: clays, sandstones, limestones; 5 – Danian: organogenic limestones; 6 – Campanian: pelitomorphic limestones; 7 – Upper Santonian: dacite-rhyolite complex; 8 – Upper Coniacian-Lower Santonian: basalt-basaltic andesite complex; 9 – Upper Turonian – Lower Coniacian: andesites and their tuffs, tuffaceous sandstones; 10 – Kimmeridgian: tuffaceous sandstones, andesites and their tuffs; 11 – Callovian: tuffaceous sandstones, tuffaceous siltstones, lime sandstones; 12 – faults; 13 – diorites; 14 – shoshonites, latites; 15 – gabbroids; 16 – andesites

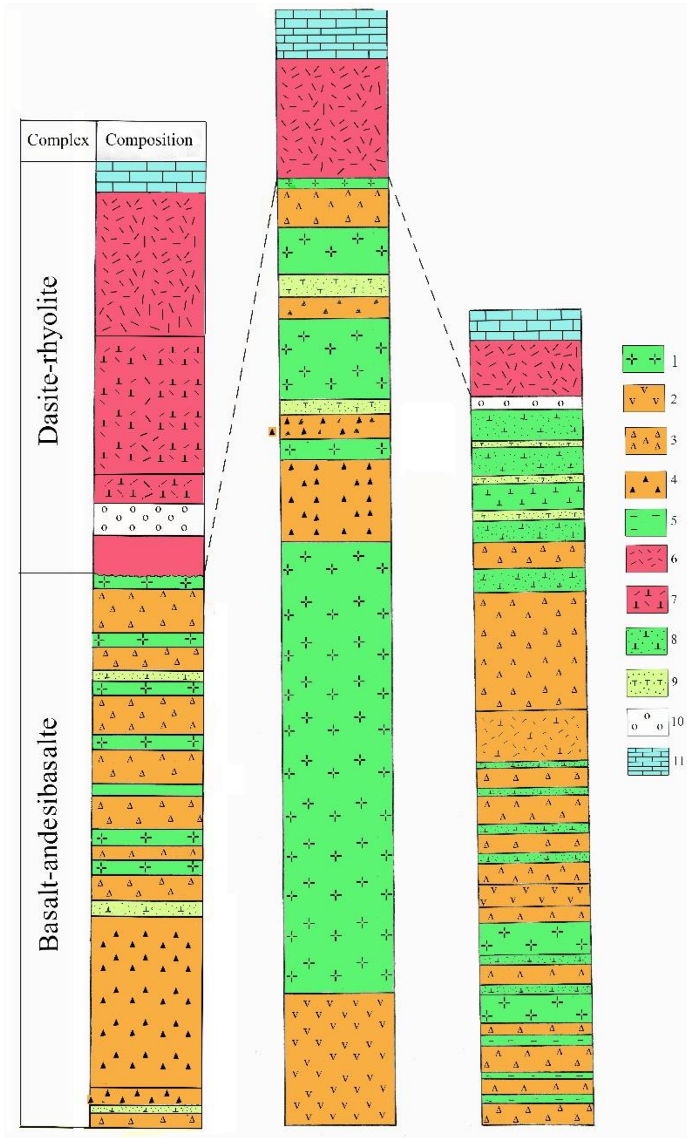

Fig. 2. *Section of the Upper Cretaceous volcanogenic-sedimentary formations of the Gazakh trough*

1 – basalt lava flows, 2 – almond-shaped andesite flows, 3 – volcanic breccias of basaltic andesites, 4 – lava breccias of basaltic andesites, 5 – bentonite clays, 6 – rhyolite lava flows, 7 – rhyolite tuffs, 8 – basaltic andesite tuffs, 9 – tuffaceous sandstones, 10 – conglomerates, 11 – limestones

The Upper Santonian dacite-rhyolite complex is represented mainly by acidic rocks. The rocks of the complex consist of dacite, rhyodacite and rhyolite and their total thickness ranges from 140m to 230 m. The pyroclastic facies is characteristic of the early stage of Upper Santonian volcanism, where agglomerates, tuff breccias, tuffites predominate in the lower part of the complex, and crystallovitroclastic tuffs, zeolitized mordenite-clinoptilolite tuffs predominate in the upper part.

Bentonite clays are also observed here. Agglomerate tuffs often form pillow-like types, zeolitic tuffs occur between limestones in the form of layers up to 40 m thick.

The analysis of the abovementioned materials shows that basalt and basaltic andesite lava flows predominate in the central part of the trough, and thin lava breccias with similar composition are observed among the flows. The thickness and amount of basalt and basaltic andesite flows decrease in the northwestern and southwestern continuations of the trough and pyroclastic and terrigenous-sedimentary formations predominate here.

Since the flank parts of the trough merge with the Allahverdi uplift in the northwest and the Shamkir uplift in the southeast, we can say that these parts of it were formed in the shelf zone of the iron basin. This is evidenced by the decrease of the thickness of the complex on the one hand, the predominance of large, coarse-grained pyroclastic, tuffaceous-sedimentary and sedimentary material in its composition on the other hand.

The thickness of the Earth's crust decreased within the trough in the last stage of Upper Santonian volcanism, creating conditions for the formation of clays, dykes, small laccoliths and stocks with mafic and mafic-medium composition.

1. Mineralogy of Late Cretaceous volcanic rocks of the Gazakh trough

The mineralogical composition of the studied complexes is based on detailed studies (optical, chemical, X-ray structure, X-ray spectral, thermal, thermomagnetic and other analyses). The majority of the rocks of the complexes are characterized by the impregnations of rock-forming minerals. They consist of olivine, rhombic and monoclinic pyroxenes, biotite, plagioclase, hornblende, quartz, titanium magnetite and sometimes sanidine, apatite and chrome spinel.

Olivine occurs in small amounts in clinopyroxene-plagioclase dolerites and basalts. The impregnations are irregularly oval, sometimes dipyramidal in shape. They are often replaced by iddingsite-bowlingite and calcite. Relatively poorly altered grains are observed in the central part of basalt and dolerite lava flows and sheet like intrusives. Macroscopically, the grains are small oval in shape, distinguished by dark gray and black microinclusions.

The chemical and crystallochemical compositions of the impregnations per 4 atoms are given in Table 1. According to chemical and X-ray structural analyses, 16.0-30.5% of fayalite minal was observed in the composition of olivines. Its composition is close to chrysotile and hyalocerite (Table 1).

Olivine is the only impregnated mineral occurred in relatively highly differentiated dolerites. It forms relatively well-polished bipyramidal cleavages and is often replaced by iddingsite-bowlingite. Macroscopically, it is light green to green in color, there are no microinclusions. According to chemical and X-ray structural analyses, olivines occurred in the dolerites are richer in magnesium and contain chrysolite (Fa_{12-18}) (Table 1).

Table 1. Chemical and crystallochemical compositions of olivines in the rocks of the basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough

Mineral	Olivin	
Rock	*Dolerit*	*Bazalt*

components	302a	302b	303a	303b	305	307	326	327	332a	332b
SiO_2	37,98	37,04	38,63	37,98	39,40	38,44	38,70	39,42	38,72	37,04
TiO_2	1,70	0,70	0,20	0,70	0,24	0,30	1,70	0,25	0,42	0,50
FeO	25,79	27,36	20,58	24,94	15,49	15,61	24,19	25,74	26,07	25,72
MnO	0,48	0,42	0,32	0,36	0,23	0,29	0,30	0,36	0,34	0,56
MgO	31,86	32,88	38,45	33,10	43,84	43,78	31,94	33,10	32,76	32,82
CaO	1,04	1,42	0,96	1,28	0,24	0,46	1,28	0,35	0,34	1,28
Na_2O	0,25	0,24	0,33	0,35	0,15	0,18	0,32	-	-	0,30
∑	99,10	100,06	99,47	98,71	99,59	99,06	98,43	99,22	98,65	98,22
cations										
Si	0,984	0,989	1,05	1,011	0,997	0,982	1,032	1,049	1,046	1,998
Ti	0,033	0,014	0,005	0,014	0,005	0,006	0,034	0,005	0,008	0,010
Fe^{+3}	0,016	0,049	0,047	0,074	0,005	0,006	0,024	0,022	0,013	0,075
Fe^{+2}	0,558	0,556	0,430	0,473	0,321	0,327	0,512	0,546	0,569	0,496
Mn	0,016	0,009	0,006	0,008	0,005	0,006	0,007	0,008	0,008	0,013
Mg	1,270	1,308	1,490	1,313	1,653	1,666	1,268	1,306	1,306	1,318
Ca	0,031	0,041	0,027	0,036	0,006	0,012	0,037	0,010	0,010	0,037
Na	0,013	0,012	0,016	0,018	0,006	0,009	0,017	-	-	0,037
Fa	30,5	29,8	22,4	26,5	12	18	28,8	29,5	30,3	27,3

The composition of rocks of the complexes is represented by rhombic and monoclinic types, with pyroxenes predominating over olivine (Table 2).

Ortopyroxene occurs in small amounts as elongated prismatic cleavages in basaltic andesites of the basalt-basaltic andesite complex and in acid differentiates of the rhyolite-dacite complex. Rhombic pyroxene grains have characteristic pleochroism and idiomorphic shape.

According to chemical analysis data and optical studies, hypersthenes occurs in its composition (2V=54-60°) (table 2). As can be seen from Table 2, the content of aluminum and calcium oxide in this pyroxene increased slightly. The high content of the latter indicates the occurrence of kushiroite minal in the composition of hypersthene, which allows to speak about crystallization of acid differentiates at low pressure. At the same time, there is a significant increase in the amount of ferrosilite minal due to the alteration of the composition of the rock, in other words, the increase in the amount of FeO in the composition of the rocks leads to a corresponding increase in divalent iron in the hypersthene.

Clinopyroxene is most common in the rocks of the basalt-basaltic andesite complex, and its content decreases sharply in acid differentiates and finally does not occur in biotite rhyolite and obsidian. Analysis of the distribution and relationships of minerals in the association shows the occurrence of clinopyroxenes in two generations. Early generation is mainly associated with olivine, titanium magnetite, plagioclase, forming light green short prismatic grains.

It forms a close association with olivine, plagioclase and titanium magnetite from impregnations in dolerite and basalts. It often forms mutual associations with titanium magnetite (Fig. 3). In most cases, clinopyroxene impregnations is characterized by weak zoning. The clinopyroxene impregnations of the studied complexes are rich in Al_2O_3 (Table 3). Part of the aluminum atoms is in the fourth coordination.

As can be seen from Table 2, basalt and dolerite are close in composition. In this regard, their composition points are located close to each other in the diagram, at the boundary of augite and salite (Fig. 4).

These peculiarities of clinopyroxenes indicate the crystallization of magmatic alloys at shallow depths. The alteration of the composition of clinopyroxene is associated with crystallization differentiation. The abundance of alumina in their composition is probably the result of mixing of primary magma with crustal material.

It occurs in small quantities in **hornblende** and is mainly accumulated in medium and acidic differentiates (andesite, dacite, rhyolite, perlite). Its impregnations are characterized by a greenish-brown long prismatic habitus and an opacite border.

Sometimes weak chloritization is observed, in which drop-shaped magnetite grains accumulate along the periphery of hornblende secretions. According to their optical peculiarities (2V=-68-76°, N_p=11-14°), they are compatible with common hornblende. Their chemical compositions and crystallochemical formulas are given in Table 4.

Analysis of the obtained results shows that the studied hornblends are characterized by a decrease in the amount of hydroxyl group elements and some increase in the amount of aluminum in the fourth coordination.

Biotite, like hornblende, also occurs in the composition of acidic rocks (rhyolite, dacite, perlite). Biotite impregnations form sheet like, sometimes isometric grains, which contain well-polished small crystals of apatite and zircon as inclusions.

Opacitization is sometimes observed along the periphery and fractures of faults. The analysis of the conducted researches shows that iron oxide of all studied biotites predominates significantly over magnesium oxide.

Fe-Ti-oxide minerals are widely distributed in rocks. They are represented by high-titanium (ulvospinel), moderate and low-titanium magnetite, hematite, maghemite and ilmenite. Olivine dolerites contain chrome spinel. However, it is closely related to olivine, forming mutually adjacent grains with it. According to the results of microprobe analysis, the amount of the following element (in%) were determined: MgO – 9.20; Al_2O_3 – 6.36; TiO_2 – 0.76; NiO – 0.36; CoO – 0.29; MnO – 0.73; Cr_2O_3 – 57.36; Fe_2O_3 – 3.64; FeO – 20.75. As can be seen from its composition, the mineral corresponds to ferrichrome spinel.

Table 3. Chemical and crystallochemical compositions of clinopyroxenes of basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough

Rock	Dolerite								Basalt					Basaltic andesite			Andesite		
Sample / Oxide	300	301	302	303	303	305	307	324	325	326	327	332	310	311	331	312	315	319	323
SiO_2	49,26	48,84	47,60	49,60	48,08	48,32	49,15	49,25	48,90	49,80	49,20	48,75	49,21	48,93	50,46	50,63	49,80	49,75	49,50
TiO_2	1,04	0,95	0,70	0,84	0,82	0,75	0,73	1,12	0,50	0,68	0,67	0,79	0,73	0,82	0,72	0,66	0,66	0,36	0,56
Al_2O_3	3,27	3,24	4,66	3,32	3,40	2,53	2,64	3,26	3,39	3,72	3,80	4,12	3,20	3,25	2,15	3,23	3,01	4,26	4,21
FeO	11,38	11,85	12,25	11,54	13,09	14,15	13,07	12,73	11,74	10,89	11,61	10,89	13,24	11,97	13,40	12,30	13,28	12,45	11,80
MnO	-	0,19	0,19	0,22	0,08	0,19	0,08	0,20	0,14	0,01	0,46	0,28	0,35	0,42	0,40	0,48	0,23	0,05	0,06
MgO	13,04	14,33	13,72	14,42	14,02	14,23	14,18	14,20	14,42	13,96	13,72	14,00	12,21	13,21	13,38	12,45	13,18	13,46	13,75
CaO	20,76	19,68	20,68	19,56	20,10	19,40	19,26	18,72	20,40	20,00	19,41	20,12	20,20	20,63	18,60	19,50	19,09	19,46	19,46
Na_2O	0,53	0,36	0,56	0,21	0,50	0,52	0,51	0,28	0,42	0,69	0,46	0,43	0,52	0,53	0,32	0,26	1,13	0,46	0,37
∑	99,28	99,44	100,36	99,71	100,09	100,09	99,62	99,76	99,91	99,75	99,33	99,38	99,66	99,76	99,43	99,51	100,38	100,25	99,71
Si	1,857	1,833	1,768	1,857	1,795	1,809	1,845	1,850	1,822	1,855	1,849	1,826	1,861	1,837	1,912	1,918	1,854	1,894	1,865
Ti	0,03	0,027	0,020	0,024	0,023	0,021	0,021	0,032	0,014	0,019	0,019	0,022	0,021	0,023	0,021	0,019	0,018	0,010	0,016
Al	0,15	0,143	0,204	0,146	0,150	0,112	0,117	0,144	0,149	0,163	0,168	0,182	0,143	0,144	0,096	0,144	0,132	0,147	0,187
Fe^{+3}	0,12	0,164	0,262	0,108	0,250	0,267	0,190	0,114	0,210	0,139	0,129	0,153	0,131	0,175	0,063	0,001	0,204	0,045	0,051
Fe^2	0,24	0,208	0,118	0,254	0,160	0,176	0,221	0,286	0,156	0,201	0,236	0,188	0,288	0,200	0,362	0,389	0,209	0,317	0,321
Mn	0	0,006	0,006	0,007	0,002	0,006	0,003	0,006	0,004	0,0003	0,015	0,009	0,011	0,013	0,013	0,015	0,007	0,000	0,002
Mg	0,73	0,802	0,760	0,805	0,780	0,794	0,793	0,795	0,801	0,775	0,769	0,782	0,688	0,739	0,756	0,703	0,732	0,740	0,772
Ca	0,84	0,791	0,823	0,785	0,804	0,778	0,775	0,753	0,814	0,798	0,782	0,807	0,819	0,830	0,755	0,792	0,762	0,847	0,786
Na	0,038	0,026	0,040	0,015	0,036	0,038	0,037	0,020	0,030	0,050	0,034	0,031	0,038	0,039	0,024	0,019	0,082	0,000	0,000

Table 2. Chemical compositions of ortopyroxenes in rocks of basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough

Rock / Sample / Components	*Basatic andesite*			*Andesite*			*Dasite*	*Rhyolite*
	331	333	310	312	314	315	320	319
SiO_2	50,94	52,00	52,10	51,16	52,33	51,38	51,36	51,75
TiO_2	0,15	0,30	0,31	0,25	0,45	0,28	0,25	0,36
Al_2O_3	2,07	2,01	1,38	1,64	1,46	1,23	2,11	1,36
FeO	21,17	20,11	20,57	25,63	21,34	26,41	24,85	25,62
MnO	0,83	0,64	0,33	0,25	0,50	0,35	0,38	0,38
MgO	22,55	21,48	23,10	19,20	22,00	18,15	19,20	18,46
CaO	1,94	2,60	1,23	1,75	2,10	1,84	2,08	1,56
Na_2O	0,23	0,67	0,38	0,38	0,36	0,36	0,38	0,32

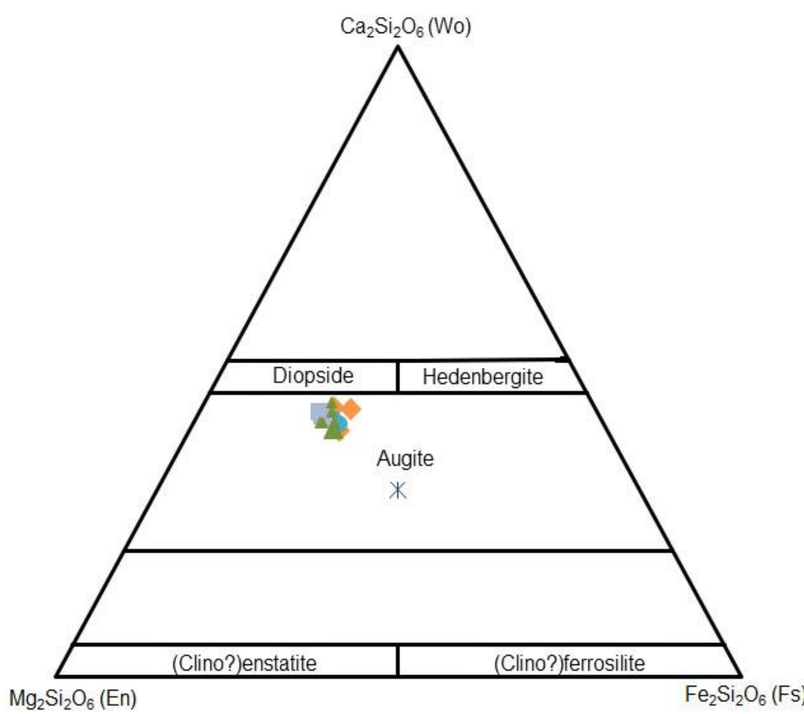

Fig. 4. *Distribution of points of clinopyroxenes of basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough in the classification diagram [18]*

Table 5. Chemical (in%) and crystallochemical compositions of titanium magnetites of basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough

Rock	Dolerite				Basalt				Basaltic andesite				Andesite		Rhyolite		Obsidian
Sample	300	301	303	307	324	326	328	332	310	316	331	333	312	315	322a	322b	323
Oxside	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TiO_2	17,55	18,77	19,97	22,87	19,98	20,42	18,91	19,40	9,48	7,73	9,00	9,11	1,36	3,58	4,23	4,76	10,67
Al_2O_3	0,65	1,08	0,92	0,86	0,58	0,66	0,92	1,33	4,57	3,21	4,36	4,26	3,36	2,73	2,21	2,36	3,21
V_2O_3	0,36	1,21	0,74	0,20	0,73	0,82	0,81	1,24	0,01	0,22	0,32	0,36	0,13	0,11	0,26	0,17	0,20
Cr_2O_3	0,23	0,17	0,16	0,07	0,07	0,19	0,26	0,17	0,01	0,01	0,04	0,09	0,03	0,23	0,01	0,01	0,08
Fe_2O_3	33,95	30,50	29,0	24,02	29,15	28,75	29,25	30,20	48,50	55,36	52,66	50,36	66,40	59,50	63,26	62,18	56,40
FeO	46,85	46,85	48,89	51,89	47,93	47,83	48,66	46,60	34,75	32,20	31,20	33,48	26,38	31,86	29,42	29,34	27,75
MnO	0,20	0,47	0,63	0,16	0,60	0,61	0,36	0,39	0,20	0,57	0,46	0,43	0,50	0,50	0,38	0,52	0,75
MgO	0,29	0,42	0,36	0,34	0,42	0,28	0,52	0,30	1,80	0,56	1,72	1,84	1,34	1,20	0,45	0,66	1,33
∑	100,08	99,47	100,67	100,41	99,46	99,56	99,69	99,63	99,32	99,86	99,76	99,93	99,5	99,71	100,22	100	100,39

Cations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Fe^{+2}	1,473	1,472	1,525	1,616	1,510	1,502	1,496	1,456	1,067	0,995	0,952	1,025	0,820	1,006	0,915	0,911	0,838
Mg	0,016	0,023	0,020	0,019	0,023	0,016	0,029	0,017	0,098	0,031	0,094	0,100	0,074	0,067	0,025	0,037	0,071
Mn	0,006	0,005	0,020	0,005	0,002	0,019	0,012	0,012	0,006	0,018	0,014	0,013	0,016	0,016	0,012	0,016	0,023
Fe^{+3}	0,961	0,863	0,814	0,673	0,827	0,813	0,855	0,849	1,340	1,539	1,447	1,381	1,858	1,690	1,770	1,738	1,523
Cr	0,007	0,005	0,014	0,002	0,002	0,005	0,008	0,005	-	-	0,001	0,003	-	0,07	-	-	-
V	0,011	0,037	0,022	0,006	0,022	0,025	0,024	0,037	-	0,007	0,009	0,011	0,004	0,003	0,008	0,005	0,006
Al	0,029	0,048	0,040	0,038	0,026	0,029	0,041	0,058	0,198	0,140	0,188	0,184	0,148	0,121	0,097	0,104	0,136
Ti	0,496	0,530	0,560	0,641	0,566	0,577	0,535	0,545	0,262	0,215	0,247	0,250	0,038	0,089	0,118	0,133	0,288

Minals	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Mt	48,8	44,9	41,5	34,1	42,4	41,6	44,3	44,9	65,1	75,5	67,3	67,1	76,5	84,9	76,6	76,4	51,0
Usp	49,5	50,1	54,6	64,0	54,6	51,7	53,6	47,2	13,7	-	-	9,1	-	8,9	-	-	-
İl	0,20	2,6	-	-	1,7	5,2	-	6,2	11,7	20,3	23,1	14,9	3,6	0,1	11,2	12,6	25,7
Hm	-	-	1,9	-	-	-	-	-	-	1,3	0,8	-	12,8	-	9,8	7,5	17,3
Sp	1,6	2,4	2,0	1,9	1,3	1,5	2,0	1,6	9,5	2,9	8,8	8,8	7,1	6,1	2,4	3,5	6,1

High-titanium magnetite is present in dolerites and basalts (TiO_2=15.55-22.87%) (Table 5, Fig. 5). They are closely related to clino- and orthopyroxenes. Under the microscope, the grains are homogeneous, i.e. the decomposition of the solid solution is not observed. The ulvospinel component in the minal composition ranges between 24-68%. Titanium magnetite occurs in the form idiomorphic and well-polished grains in clinopyroxene dolerites. It is often found as an inclusion in clinopyroxene grains. According to complex studies, the ilmenite-type decomposition of the solid solution was observed in the impregnations of titanium magnetite. The mild titanium type of titanium magnetite was revealed in the composition of basaltic andesites (Table 5, sampl. 331, 310, 333). The grains are drop-shaped and octahedral. Clinopyroxene and plagioclase are relatively idiomorphic. Mild titanium magnetite is characteristic of the rocks of dacite-rhyolite complex. Hematite and maghemite were formed as a result of oxidation of previously existing femic minerals. Ilmenite occurs in the composition of rhyolites and obsidian.

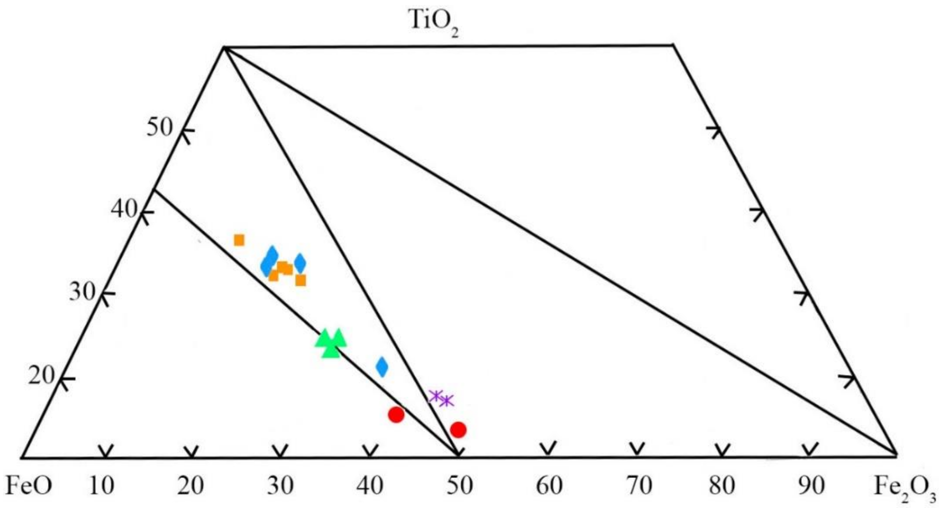

Fig. 5. *Distribution diagram of the composition of titanium magnetites of basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough in the FeO-TiO_2-Fe_2O_3 system*

Feldspars are widespread in the studied complexes, among which plagioclases dominate.

Plagioclase is represented by two generations. Early generation corresponds to the impregnations. It forms short prismatic, elongated prismatic grains. Besides these, there are also irregular oval, zonal individuals. They are weakly dull, sometimes chloritized and have irregular oval microinclusions. The impregnations in dolerite and basalt are close in composition ($An_{78\text{-}90}$) and correspond to bytownite (Fig. 6).

Table 6. Chemical and crystallochemical compositions of plagioclases of the volcanic complexes of the Gazakh trough

Rock	Dolerite			Basalt				Basaltic andesite			Andesite		Dasite	Rhyolite		
Sample / Oxsides	300	302	303	325	326	328	332	310	311	317	314	323a	320	319	322	323
SiO_2	47,16	43,96	47,76	46,37	44,75	46,64	47,27	53,74	56,38	55,30	57,15	58,10	61,35	62,15	62,14	60,10
TiO_2	0,18	0,16	0,17	0,12	0,30	0,22	0,11	0,22	0,11	0,10	0,22	0,11	-	-	-	-
Al_2O_3	32,24	34,22	32,75	33,16	34,58	33,03	33,29	28,54	27,11	28,15	26,03	25,93	23,16	23,22	23,33	24,04
Fe_2O_3	0,46	0,82	0,49	0,93	0,49	0,43	0,90	0,44	0,36	0,35	0,95	0,96	0,16	0,11	0,80	0,96
MnO	0,03	0,03	0,04	-	0,01	0,01	-	0,01	0,02	0,02	-	0,02	-	0,01	-	-
MgO	0,22	0,89	0,24	-	0,23	0,16	-	0,52	0,30	0,29	0,68	0,53	0,13	0,11	0,52	0,30
CaO	16,42	17,80	16,12	17,41	17,86	16,41	17,23	11,65	9,85	9,95	9,11	7,50	3,21	3,96	6,28	6,20
Na_2O	2,32	1,02	2,31	1,16	1,07	2,60	1,36	4,88	5,46	5,57	5,52	6,25	11,84	10,53	6,00	7,25
K_2O	0,25	0,67	0,27	-	0,49	0,49	-	0,30	0,43	0,45	0,25	0,75	0,26	0,23	1,108	0,83
∑	99,28	99,57	100,15	99,15	99,78	99,99	100,16	100,3	100,02	100,18	99,91	100,15	100,11	100,32	100,178	99,68
Cations																
Si	2,165	2,052	2,192	2,152	2,276	2,155	2,169	2,430	2,536	2,489	2,567	2,601	2,740	2,768	2,755	2,695
Al	1,799	1,982	1,772	1,814	1,890	1,799	1,800	1,521	1,437	1,499	1,378	1	1,363	1,219	1,219	1,270
Fe^{+3}	0,016	0,029	0,017	0,032	0,017	0,015	0,031	0,015	0,012	0,012	0,032	0,032	0,005	0,004	0,027	0,032
Mn	0,001	0,001	0,002	-	-	-	-	-	0,001	0,001	-	0,001	-	-	-	-
Mg	0,015	0,002	0,016	-	0,016	0,011	-	0,035	0,020	0,019	0,046	0,035	0,009	0,007	0,034	0,020
Ca	0,808	0,890	0,793	0,866	0,888	0,812	0,877	0,564	0,475	0,480	0,438	0,360	0,154	0,160	0,293	0,298
Na	0,207	0,092	0,207	0,104	0,096	0,233	0,136	0,428	0,476	0,486	0,489	0,543	1,025	0,909	0,516	0,630
K	0,015	0,010	0,016	-	0,029	0,029	-	0,017	0,025	0,026	0,014	0,043	0,045	0,015	0,062	0,017

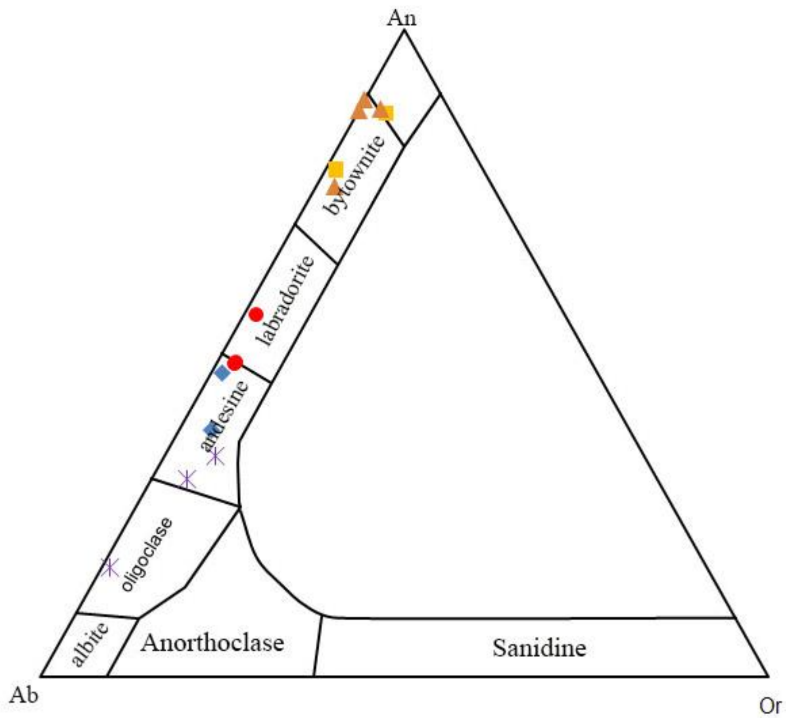

Fig. 6. *Distribution of plagioclase points of basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough in the classification diagram*

Phenocrysts in dolerites have an impregnation-like appearance against the background of the dolerite structure, with small microinclusions. Phenocrysts in basalts are characterized by a sharp impregnation-like structure with strongly eroded edges. They are close to each other in terms of the degree of arrangement (Dp=0.20-0.25). Plagioclase phenocrysts are significantly reduced in basaltic andesites and andesites, and the amount of albite increases (Table 6). More acidic plagioclases are characteristic of dacite and rhyolite. Here, phenocrysts are represented by short prismatic and irregular oval grains. The late stage of plagioclase is represented by lath and microliths and constitutes the main mass.

So, the composition of plagioclases varies from labrador to albite according to the studied rocks (Fig. 6).

Quartz is widely distributed in the rocks of the dacite-rhyolite complex, and also occurs in the main mass in the form of phenocrysts.

6. Mineral paragenesis of Late Cretaceous volcanic rocks of the Gazakh trough

The study of the sequential crystallization process of rock-forming and accessory minerals shows that the initial mineral paragenesis for dolerites in the composition of the studied rock complexes consists of olivine, chrome spinel and clinoproxene (Table 8). According to Fabries' geothermometer [17], the crystallization temperature of this paragenesis is 1100-1200ºC.

Table 8. Results of the balance calculation of rocks of the basalt-basaltic andesite and dacite-rhyolite complexes of the Gazakh trough

Picrodolerite-pyroxene dolerite						
Oxsides	Co	Cp	Ol	CrSp	Cpx	Cd
SiO_2	44,92	45,17	39,34	-	48,27	46,61
TiO_2	1,03	0,82	0,34	0,79	0,75	0,91
Al_2O_3	15,00	14,80	-	6,44	5,62	17,87
FeO	13,14	12,69	15,11	24,24	8,20	12,37
MnO	0,23	0,19	0,26	0,73	0,19	0,17
MgO	12,99	12,92	44,09	9,29	14,31	7,20
CaO	10,30	10,00	0,57	-	22,13	11,56
Na_2O	1,59	2,22	-	-	0,52	2,69
K_2O	0,78	0,49	-	-	-	0,60
Cr_2O_3	0,03	0,25	0,29	58,51	0,01	0,02
			0,15	0	0,02	0,83
$\sum R^2$=0,976						

Pyroxene dolerite-Plagioclase dolerite							
Oxsides	Co	Cp	Ol	Cpx	Pl	TiMt	Cd
SiO_2	46,61	46,59	38,83	47,06	47,68	-	47,19
TiO_2	0,91	1,15	0,20	0,82	0,17	17,36	1,00
Al_2O_3	17,87	17,87	-	6,40	32,70	0,91	18,62
FeO	12,37	12,32	20,69	9,50	0,49	81,10	11,50
MnO	0,17	0,17	0,32	0,08	0,04	0,40	0,17
MgO	7,20	7,24	38,65	14,02	0,24	0,23	6,12
CaO	11,56	11,58	0,97	21,62	16,10	-	11,45
Na_2O	2,69	2,84	0,34	0,45	2,31	-	3,07
K_2O	0,62	0,80	-	0,05	0,27	-	0,89
				0,04	0,03	0,01	0,89
$\sum R^2$=0.120							

Plagioclase dolerite-Plagioclase basalt							
Oksidlər	Co	Cp	Ol	Cpx	Pl	TiMt	Cd
SiO_2	47,18	47,22	37,36	48,30	47,76	-	49,62
TiO_2	1,00	0,90	0,61	0,62	0,12	19,79	0,67
Al_2O_3	18,62	18,61	-	5,80	32,75	1,26	18,11
FeO	11,50	11,52	26,78	9,19	0,39	78,25	11,27
MnO	0,17	0,12	0,49	0,16	0,04	0,50	0,09
MgO	6,12	6,06	33,13	13,73	0,24	0,20	4,90
CaO	11,45	11,40	1,36	21,41	16,12	-	11,29
Na_2O	3,07	2,73	0,27	0,70	2,31	-	3,21
K_2O	0,89	0,65	-	0,10	0,27	-	0,84
			0,07	0,02	0,17	2,02	0,72
$\sum R^2$=0,194							

Basaltic andesite-andesite

Oksidlər	Co	Cp	Opx	Cpx	Pl	TiMt	Amf	Cd
SiO_2	55,62	55,63	54,78	50,16	53,52	-	40,63	63,66
TiO_2	0,92	1,09	0,31	0,74	0,22	11,78	2,01	0,60
Al_2O_3	17,45	17,53	1,39	4,29	28,50	7,57	11,62	17,72
FeO	8,47	8,44	18,56	11,36	0,44	77,56	16,31	5,03
MnO	0,15	0,10	0,33	0,18	0,01	0,17	0,30	0,08
MgO	4,19	4,20	32,89	12,36	0,52	2,81	14,07	2,89
CaO	8,64	8,62	1,24	20,54	11,61	0,11	12,88	5,41
Na_2O	3,36	2,87	0,36	0,37	4,88	-	1,67	3,01
K_2O	1,20	1,01	0,12	-	0,30	-	0,50	1,60
			-	0,10	0,19	0,04	0,09	0,58
$\sum R^2=0,308$								
Andesite-dasite								
Oksidlər	Co	Cp	Opx	Cpx	Pl	TiMt	Q	Cd
SiO_2	63,66	63,66	52,26	49,84	57,15	-	99,70	67,63
TiO_2	0,60	0,19	0,45	0,66	0,22	3,58	-	0,04
Al_2O_3	17,72	17,65	1,45	5,17	26,02	0,33	0,30	18,02
FeO	5,03	5,05	20,94	10,16	0,95	95,65	-	4,40
MnO	0,08	0,06	0,50	0,28	-	0,44	-	0,03
MgO	2,89	2,88	21,80	13,16	0,68	-	-	1,51
CaO	5,41	5,42	2,09	19,08	9,11	-	-	2,19
Na_2O	3,01	3,40	0,36	1,13	5,62	-	-	3,11
K_2O	1,60	1,69	0,15	0,23	0,25	-	-	3,07
			0,04	0,08	0,30	0,01	0,06	0,57
$\sum R^2=0,340$								
Dasite-rhyolite								
Oksidlər	Co	Cp	Bi	Pl	TiMt	Q	Cd	
SiO_2	67,63	67,63	37,58	58,02	-	99,70	72,22	
TiO_2	0,04	0,32	1,51	0,11	1,16	-	0,24	
Al_2O_3	18,02	17,76	14,01	25,89	4,64	0,30	16,27	
FeO	4,40	4,42	26,17	0,96	90,73	-	2,24	
MnO	0,03	0,05	0,12	0,02	0,75	-	0,04	
MgO	1,51	1,17	9,38	0,52	2,61	-	0,40	
CaO	2,19	2,71	1,70	7,49	0,11	-	1,53	
Na_2O	3,11	3,52	1,49	6,24	-	-	3,07	
K_2O	3,07	3,61	8,05	0,75	-	-	4,00	
			0,08	0,20	0,01	0,02	0,70	
$\sum R^2=0,998$								

The olivine-clinopyroxene-plagioclase-titanium magnetite association is a characteristic mineral paragenesis for dolerites and basalts (Table 8). Olivine crystallized earlier and contains a lot of iron. Clinopyroxene, plagioclase and titanium magnetite form mutual associations. This also shows their co-crystallization (TºC=1100ºC, $fO_2=10^{-8-10}$).

The following mineral paragenesis consists of orthopyroxene-clinopyroxene-plagioclase-titanium magnetite-amphibole, orthopyroxene-clinopyroxene-plagioclase-titanium magnetite-quartz, biotite-plagioclase-titanium magnetite-quartz.

It can be seen from the above that the composition of the rocks of the Gazakh trough complexes shows a sequential alteration from picrodolerites to plagioclase basalts and from basaltic andesite to rhyolite (Table 8).

Conclusion:

The majority of rocks of the studied volcanic complexes are characterized by the impregnations of rock-forming minerals. They consist of olivine, rhombic and monoclinic pyroxenes, biotite, plagioclase, hornblende, quartz, titanium magnetite and sometimes sanidine, apatite and chromespinel.

The mineral parageneses distinguished in these complexes consist of olivine-chrome spinel-clinoproxene, olivine-clinopyroxene-plagioclase-titanium magnetite, orthopyroxene-clinopyroxene-plagioclase-titanium magnetite-amphibole, orthopyroxene-clinopyroxene-plagioclase-titanium magnetite-quartz, and biotite-plagioclase-titanium magnetite-quartz.

References:

[1] Abdullayev RN, Mustafayev GV, Mustafayev MA, Aliyev IA, Shafiyev HI, Hasanov RK. Mesozoic igneous formations of the Lesser Caucasus and associated endogenous mineralization. 1988. Baku: Elm, 158 p. (in Russian)

[2] Akhundov FA. Late Cretaceous volcanic formations of the Lesser Caucasus. 2003. Baku. 232 p. (in Russian)

[3] Babayeva GJ. Petrological-mineralogical evolutional transformation of Cretaceous teschenite-tephrite, syenite-trachyte, and essexite-trachybasalt primary meltings (Carpathian, Caucasian and North TransBaikal regions). *Journal of Geology, Geography and Geoecology.* 2023. 32 (3), 450-460. doi:10.15421/112340

[4] Karyakin YuV. Geodynamics of the formation of volcanic complexes of the Lesser Caucasus. 1989. M.: Nauka, 150 p. (in Russian)

[5] Imamverdiyev NA, Sarıyev FH, Babayeva GJ. Petrological characteristics of the formation of sub-alkaline picrits of the Khojavend subzone. *Proceedings of the second scientific and practical conference "Current problems of prospecting geology"*. 2025. Moscow: VIMS, 55-57.

[6] Mammadov MN, Babayeva GJ. Petrogenetic peculiarities of Fe-Ti oxide minerals in the processes of crystallization and evolution of late Cretaceous volcanic complexes of the Lesser Caucasus. *Journal of Geology, Geography and Geoecology*. 2021. 30 (4), 692-705. https://doi.org/10.15421/112164

[7] Мамедов МН, Бабаева ГДж, Гасангулиева МЯ, Сарыев ФГ. Петролого-геохимические условия формирования мезо-кайнозойских пикритов Малого Кавказа и Талыша, Институт геологии и геофизики НАНА. 2021. Baku: Pp 9-14.

[8] Mammadov MN, Babayeva GJ, Sariyev FH. (2024): Petrogenetıc role of pyroxenes in the formatıon of pıcrıtes of the Lesser Caucasus and Talysh zone. *ANAS Transactions, Earth Sciences.* 2024. 2, 3-16. doi:10.33677/ggianas2024020012

[9] Mammadov MN. Petrology and geochemistry of Late Cretaceous and Eocene igneous formations of the Lesser Caucasus and Talysh. Nafta-press. 1999, Baku. 400 p. (in Russian)

[10] Mammadov MN. Petrological and geochemical peculiarities of the formation of the trachybasalt formation of the Khojavend trough. *Proceedings of the Institute of Geology of the Academy of Sciences of Azerbaijan*, 2000, 28, pp. 86-99 (in Russian)

[11] Mammadov MN, Babayeva GJ, Sadigov NM. Clinopyroxenes of the trachybasalt-trachydolerite and tephrite-teschenite complexes of the Khojavend trough. *Otechestvennaya Geologiya,* 2012. No. 6, pp. 48-55 (in Russian)

[12] Mammadov MN, Babayeva GJ, Panahi KA, Sadigov NM, Kerimov VM. Indicator values of iron-titanium oxide minerals in the process of crystallization of rocks of the trachybasalt-trachydolerite and tephrite-teschenite complexes of the Khojavend trough of the Lesser Caucasus. *Bulletin of BSU, series of natural sciences*, 2015, 3, pp. 76-85 (in Russian)

[13] Mammadov MN, Babayeva GJ, Sadigov NM. Mineral parageneses of the trachybasalt-trachydolerite and tephrite-teschenite complexes of the Khojavend trough of the Lesser Caucasus. *Bulletin of the National Academy of Sciences of Azerbaijan*, series of Earth Sciences, 2013, 2, 26-36 (in Russian)

[14] Mustafayev MA. Petrology and geodynamic conditions of formation of Mesozoic igneous complexes of the Caucasian margin of Tethys (Azerbaijan). *Bulletin of Baku University*. Series of Natural sciences. 2007, No. 4, pp. 139-151 (in Russian)

[15] Ostroumova AS, Center IYa, Avdeyev AT, Bugrova EM. Late Cretaceous volcanic series of the Gochas trough (Lesser Caucasus). *Soviet Geology*, 1991, 7, pp. 65-72 (in Russian)

[16] Shikhalibeyli ESh. Geology and minerals of Nagorno-Karabakh of Azerbaijan. 1994, Baku, p. 281 (in Russian)

[17] Fabries J. Spinel-olivine geothermometry in peridotites form ultramafic complexes. *Cont. Minerology and Petrology*, 1979, 69, p. 329-336.

[18] Morimoto N. Nomenclature of pyroxenes. *Mineralogy and petrology*, 1988, 39.1., p.5.