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Research Article

Investigation of Intrusive Rocks in the Çambaşı Plateau and Bektaşyayla Region Located South of Ordu Using $^{40}Ar/^{39}Ar$ Petrology and Geothermochronology Methods

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Abstract

This research focuses on elucidating the tectonic processes in the Eastern Pontides by investigating the Çambaşı Quartz Syenite and Bektaş Yaylası Quartz Monzonite, situated south of Ordu province in northeastern Turkey. To achieve this, mineralogical and petrographic characteristics of the acidic granitoids were analyzed alongside $^{40}Ar/^{39}Ar$ biotite age dating and comprehensive whole-rock and mineral geochemical analyses. Samples collected from Bektaş Yaylası Quartz Monzodiorite and Çambaşı Quartz Syenite underwent crushing, grinding, sieving, and washing to prepare for age determination. The biotite minerals were embedded in epoxy, polished, and examined. After processing the rock sample, geochemical analyses, including trace and rare earth element studies, were carried out at Actlabs laboratory in Canada. The $^{40}Ar/^{39}Ar$ biotite dating yielded ages ranging from 44.50 ±0.35 million years to 81.12 ±0.25 million years, indicating that these intrusions formed during the Late Cretaceous and Late Paleocene periods. Geochemical data classify the acidic intrusive rocks as calc-alkaline, high-potassium calc-alkaline, and shoshonitic. Integrating geochronological and geochemical evidence, the study suggests that the Çambaşı Quartz Syenite and Bektaş Yaylası Quartz Monzonite originated from the partial melting of the mafic lower crust, driven by continental collision. These results highlight the crucial role of continental collision in the geodynamic evolution of the Eastern Pontides.. This study on the geochronology and geochemistry of the Çambaşı Quartz Syenite and Bektaş Yaylası Quartz Monzonite offers valuable insights into the tectonic processes of the Eastern Pontides. The results demonstrate that the region's geodynamic evolution is characterized by a complex and multi-phase history.

Keywords

Geochronology, Granitoids, Eastern Pontides

1. Introductıon

Turkey is situated on the Anatolian Plate, one of the youngest and most dynamic components of the Alpine-Himalayan orogenic belt. This region has a highly complex geological structure, consisting of remnants of the Paleo-Tethys and Neo-Tethys ocean basins [39]. It has particularly been shaped under the influence of north-south directed tectonic movements. The Eastern Pontides Orogenic Belt (EPOB) (Figure 1) is situated in the eastern part of the

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Sakarya Zone, and numerous studies have been conducted on the geodynamic evolution of this region [2-4, 49-53, 14, 42-44, 46, 19-21, 16].

The Anatolian Plate can be described as a continental block situated between the African-Arabian and Eurasian plates, moving westward during the Late Cenozoic. This mobility has been facilitated by major strike-slip faults such as the North Anatolian Fault (NAF) and the East Anatolian Fault (EAF), which have significantly shaped the tectonic evolution of the region [39, 11, 36, 15].

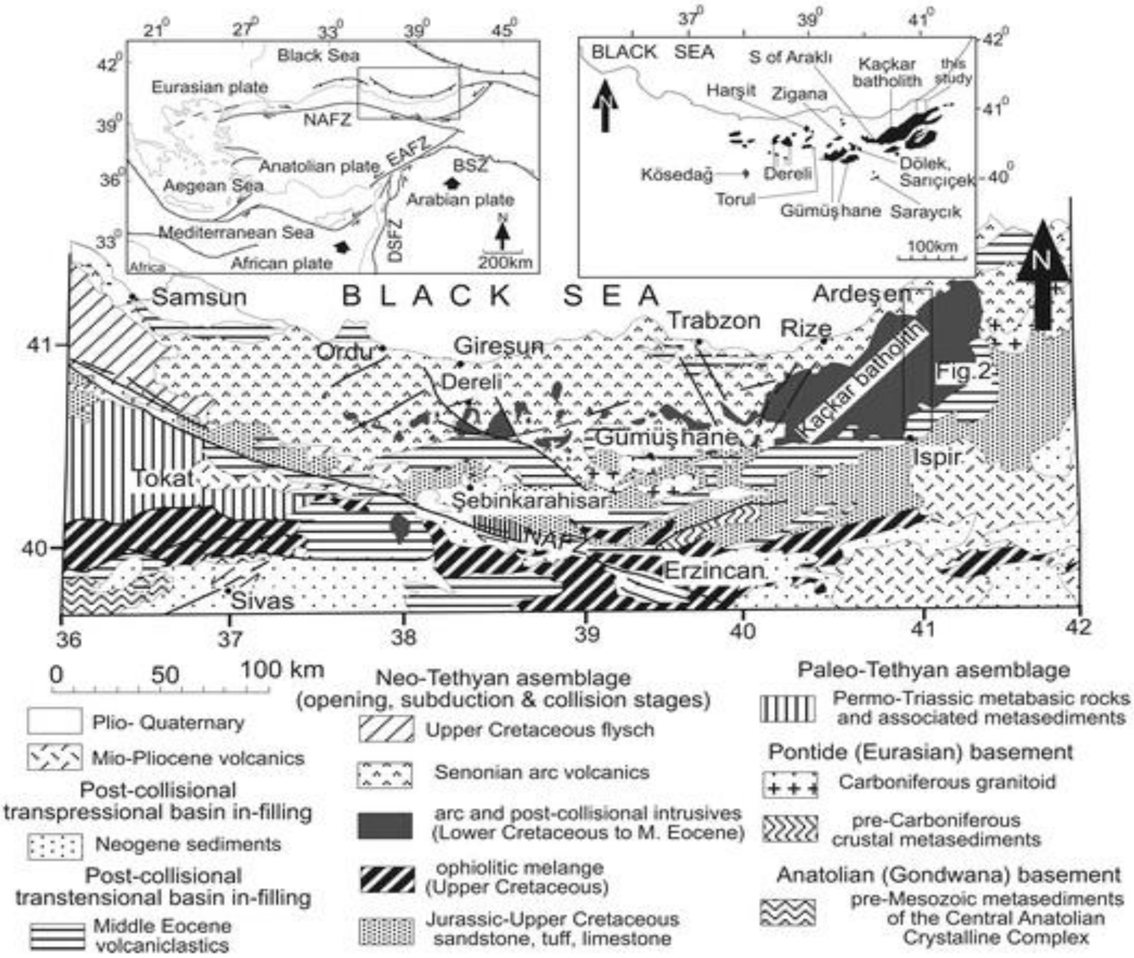

Figure 1. *The study locations of granitoid rocks in the Eastern Pontides. (Modified from [7, 9]).*

The major faults, which play a crucial role in understanding the tectonic evolution of Anatolia, have caused the displacement of rocks with varying ages and geological characteristics. Although the initiation age of the North Anatolian Fault remains a topic of debate, various studies suggest that this fault dates back to the Late Miocene to the Plio-Pleistocene periods [12, 40, 6, 8, 22, 23]. Furthermore, the geological structure of Anatolia comprises five major tectonic blocks, separated by distinct tectonic processes, each representing different evolutionary stages of the region [34].

The Eastern Pontides can be described as a Late Mesozoic ensialic arc located east of the Sakarya Block. This region was shaped predominantly by northward subduction processes beneath the Eurasian continent and is characterized by granitic intrusions and volcanic rocks [39, 33, 20, 21, 38, 30]. These processes are significant factors influencing the evolution of the rocks in the region, affecting their development from the depths of the crust to the surface. This tectonic evolution is particularly examined in connection with collisions between the Eurasian and Anatolide-Tauride blocks [37, 41].

The foundational rocks of the Eastern Pontide region include Devonian-aged metamorphic units, Late Carboniferous-Early Permian terrestrial and marine sedimentary rocks, and Permo-Triassic metabasalts and phyllites [39, 47, 14]. These units are overlain by pyroclastic and clastic sediments of Early-Middle Jurassic age and enriched with ophiolitic mélanges, particularly during the Late Cretaceous [47, 26, 35, 5, 24]. The granitoid rocks in the region are dated to the Late Mesozoic-Early Cenozoic periods, developed in diverse geodynamic settings, and exhibit intrusions of varying ages [48, 17].

In this study, petrographic, geochemical, and geochronological analyses conducted on regional rock samples from

Çambaşı Plateau and Bektaşyayla will be examined to better understand the tectonic evolution of the Eastern Pontide region, and a geological map of the area will be prepared. These rocks provide essential data for understanding the geological structure of the region and the timing of granitic intrusions. Çambaşı Plateau and Bektaşyayla are key areas offering critical insights into the cooling and exhumation processes of the Eastern Pontide granitoids, forming the primary focus of this study. In this context, the study aims to elucidate the geodynamic evolution of the granitic rocks in the Eastern Pontide region and provide new data on the timing and impact of significant tectonic events in the area.

2. Çambaşı Syenite and Bektaşyayla Quartz Monzonite

The Çambaşı Syenite and Bektaşyayla Quartz Monzonite are widespread rocks located east of the Çambaşı Plateau and west of Bektaşyayla in southern Ordu Province. These rocks are compositionally similar but distinguished by their quartz contents. They exhibit holocrystalline and porphyritic textures, typically displaying grayish and pinkish tones, while alteration zones show brownish colors. The main minerals include orthoclase, plagioclase, biotite, and hornblende, accompanied by accessory minerals such as apatite, zircon, and titanite. Large orthoclase and plagioclase laths and small, anhedral quartz grains are observed in the rocks. Mafic minerals include lath-shaped amphiboles, oval-shaped biotite, and small crystals of augite. Fe-Ti oxide minerals are also commonly found [13].

The Çambaşı Syenite generally contains large K-feldspar minerals, with poikilitic plagioclase inclusions within biotite and orthoclase, indicating disequilibrium textures. Plagioclase is found as rod-like prismatic and lath-shaped sericitized minerals. Orthoclase appears grayish-white and exhibits Karlsbad twinning. Hornblende occurs as lamellar prismatic crystals with hexagonal sections and variable extinction angles. Apatite is present as small needle-like crystals with grayish-black interference colors, while biotite exhibits lamellar shapes ranging from light brown to dark brown tones. Zircon is characterized by short prismatic shapes and vibrant interference colors, while titanite displays a brownish hue, rhombohedral shapes, and symmetrical extinction properties. Opaque minerals exhibit optically isotropic properties.

These minerals comprehensively reflect the mineralogical composition and petrographic features of the Çambaşı Syenite and Bektaşyayla Quartz Monzonite rocks (Figure 2). The study of these rocks provides detailed insights into the region's geological structure and the timing of granitic intrusions.

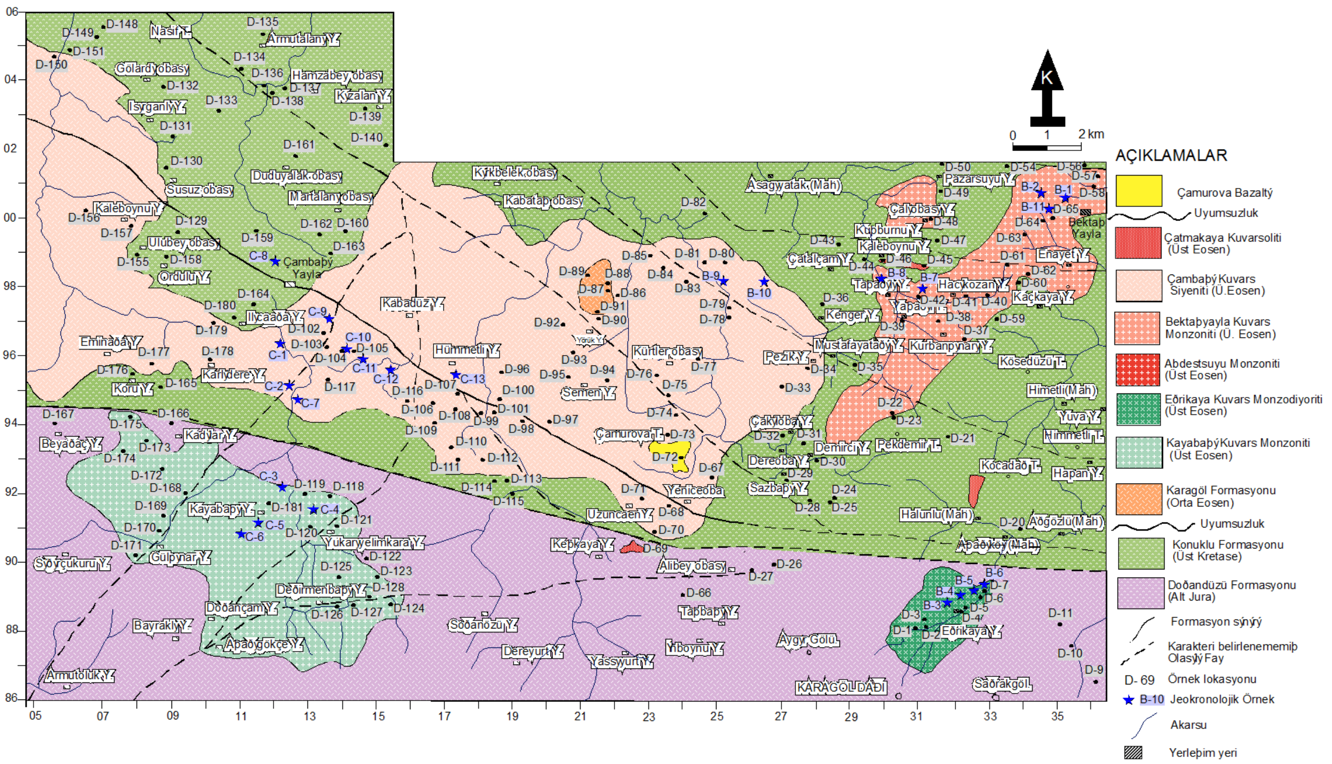

Figure 2. Geological map of the Bektaşyayla and Çambaşı region. (Modified from mta.gov.tr. and [13]).

3. Materıals and Methods

Rock samples were selected based on previous fundamental studies and the geological map of the study area. The aim of this selection was to collect samples from rocks with minimal alteration to improve the accuracy of the results obtained from chemical analyses and mineralogical examinations. In this context, ^{40}Ar-^{39}Ar dating was conducted on biotite minerals separated from rock samples collected from the region to determine the cooling ages of these rocks. This dating method provides valuable insights into the geodynamic evolution of the rocks by shedding light on the timing of magmatic events in the area.

Additionally, major element geochemical data were used to determine the origin of the magmatic rocks and to investigate processes affecting the evolution of magma composition, such as fractional crystallization. The minerals for analysis were separated as follows: heavy minerals (such as biotite and hornblende) with a density greater than 2.9 g/cm ^{3}settled at the bottom when treated with heavy liquid (bromoform), while lighter minerals (such as quartz and plagioclase) with a density less than 2.9 g/cm ^{3}remained suspended in the liquid. The biotite and hornblende minerals, separated from other minerals, were manually handpicked under a binocular microscope.

The selected samples were sent to the University of Nevada, Las Vegas, for, ^{40}Ar-^{39}Ar analysis. Trace and rare earth element analyses of all rock samples were conducted to determine the geochemical characteristics of the rocks. These analyses were performed by Actlabs in Canada.

4. Analytıcal Results

4.1. ^{40}Ar-^{39}Ar Petrology and Geothermochronolgy Method of the Intrusive Rocks in the Çambaşı Region

Age determinations were performed on the biotite fraction obtained through magnetic separation and heavy liquid methods from sample B9, collected from the Çambaşı Syenite.

Sample B9 provided an exceptionally ideal dataset (Table 1). The age spectrum is flat and concordant. The total gas age was determined to be 76.05 ± 0.53 million years. A plateau age of 76.20 ±0.54 million years was identified between steps 2 and 13, where approximately 98% of the ^{39}Ar gas was released. The same steps yielded a valid isochron age of 76.27 ± 0.25 million years. The isochron has an initial $^{40}Ar/^{39}Ar$ isotopic composition of 297 ± 2.4, which is indistinguishable from atmospheric argon.

The Ca/K ratios are low, consistent with gas release from homogeneous biotite minerals. Radiogenic products are abundant and show no significant alteration. The isochron age represents the most dependable age estimate for this sample.

Table 1. *Step-heating $^{40}Ar/^{39}Ar$ dating data for sample B9 from the Çambaşı Syenite [13].*

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40Ar*	%39Ar rlsd	Ca/K	40Ar*/39Ar K	Age (Ma)	1s.d.
1	650	12	6,371	0,288	2,314	11,382	1982,65	9,4	1,5	0,451151	16,516533	45,49	3,07
2	725	12	1,9	0,173	1,312	13,334	764,949	30,4	1,7	0,231315	17,438244	47,99	1,09
3	790	12	1,509	0,218	4,235	52,372	1279,45	67,5	6,8	0,074209	16,48675	45,41	0,5
4	850	12	1,393	0,328	9,593	123,493	2400,23	84,1	16	0,047350	16,423145	45,23	0,43
5	905	12	0,962	0,321	7,794	102,169	1923,99	96,5	13,2	0,056012	16,34668	45,03	0,42
6	960	12	0,862	0,231	6,02	80,669	1546,65	85,3	10,5	0,051050	16,306981	44,92	0,43
7	1015	12	0,914	0,24	5,543	74,484	1452,15	83,3	9,6	0,057444	16,182016	44,58	0,43
8	1050	12	0,766	0,196	3,973	52,667	1060,52	81,1	6,8	0,066346	16,176504	44,56	0,44
9	1080	12	0,669	0,164	3,157	41,24	850,789	79,7	5,3	0,07089	16,193777	44,61	0,44
10	1110	12	0,624	0,172	2,923	37,844	784,282	79,6	4,9	0,081027	16,211785	44,66	0,45
11	1140	12	0,65	0,221	3,139	40,404	829,772	79,9	5,2	0,097514	16,155924	44,51	0,44
12	1170	12	0,683	0,353	3,588	45,741	926,62	81	5,9	0,13758	16,204802	44,64	0,44
13	1400	12	1,182	1,492	7,481	96,1	1875,9	83,9	12,4	0,276803	16,202597	44,63	0,43
								Cumulative%39Ar rlsd =	100		Total gas age =	44,92	0,29

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40Ar*	%39Ar rlsd	Ca/K	40Ar*/39Ar K	Age (Ma)	1s.d.
											Plateau age =	44,79	0,29
											(steps 3-13)		
											Isochron age =	44,7	0,18
											(steps 1-13)		

4.2. Bektaşyayla Kuvars Monzodiyoriti ^{40}Ar/^{39}Ar Petrolojisi ve Jeotermokronoloji Yöntemi

Age determinations were performed on biotite fractions obtained from B1 and B2 samples taken from the Bektaşyayla quartz monzodiorite rock using magnetic separation and heavy liquids.

The biotite separation obtained from the B1 sample (Figure 3) generally produced a flat, concordant age spectrum. Excluding the first step, which yielded an age of 23 million years, all steps produced ages within the range of 75–81 million years. The total gas age, equivalent to the conventional K/Ar age, is 76.54 ± 0.49 million years (Table 1). Considering the obtained data, plateau and isochron ages could not be determined.

The Ca/K ratios are consistent with the gas release process typical for a common biotite mineral. While radiogenic products (40Ar*) are high, they do not indicate significant alteration effects. For such a sample, it is recommended to use the total gas age.

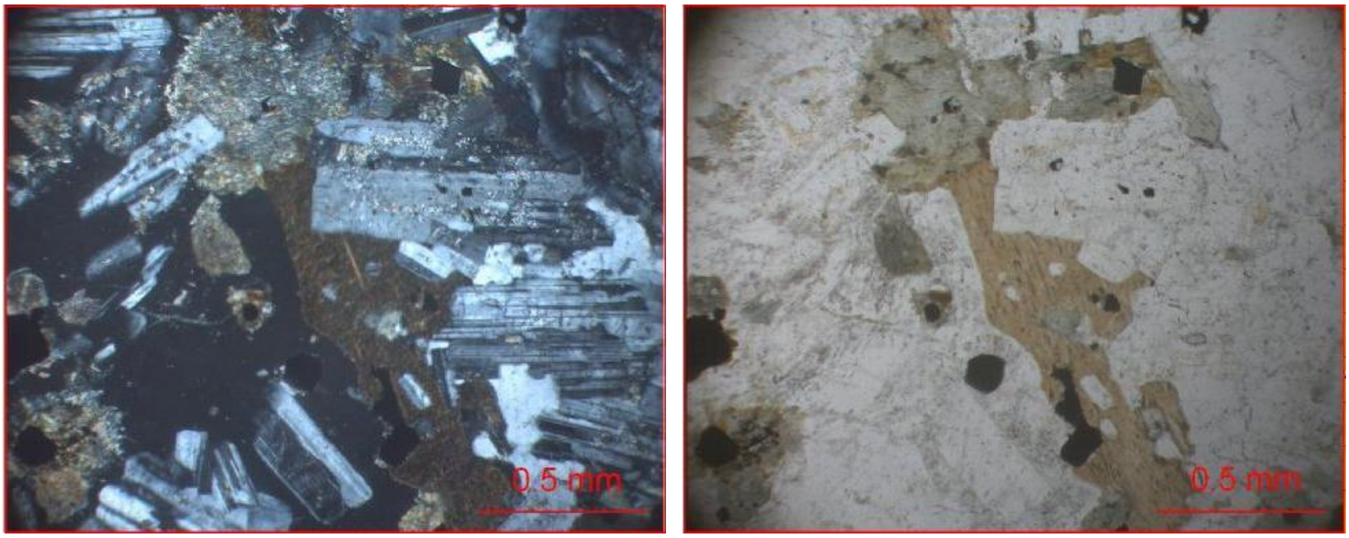

Figure 3. *Appearances of the biotite mineral under crossed and plane-polarized light.*

The biotite separation obtained from sample B2 presents an ideal, flat, and concordant spectrum. Excluding the first and last steps, which account for 2% of the 39Ar gas release, the age is approximately 43 million years. The total gas age is 42.66 ±0.29 million years. Steps 2 through 12, accounting for 98% of the 39Ar^{39}\text{Ar}39Ar gas release, provide an almost ideal plateau age of 42.89 ±0.30 million years. The same steps yield a valid isochron age of 42.93 ±0.14 million years (Table 2, Table 3). The isochron, with an initial ^{40}Ar/^{39}Ar isotopic composition of 295 ±2.9, is indistinguishable from the atmospheric value of 295.50 Excluding the first and last steps, the Ca/K ratios are consistent with gas release from homogeneous biotite. The absence of alteration effects is evidenced by the high levels of radiogenic products. The isochron age is considered highly reliable for this sample.

Table 2. *$^{40}Ar/^{39}Ar$ step-heating dating data for sample B1 of the Bektaşyayla Quartz Monzodiorite [13].*

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40 Ar*	%39Ar rlsd	Ca/K	40Ar*/ 39ArK	Age (Ma)	1s.d.
1	650	12	2,768	2,364	4,501	30,168	1027,38	24,5	2,8	1,1865031	8,335057	22,59	0,66
2	725	12	3,715	0,539	2,822	19,615	1630,91	36,1	1,8	0,4159756	30,124847	80,36	1,61
3	790	12	0,876	0,279	3,904	39,13	1380,89	82,8	3,6	0,1079249	29,309668	78,23	0,81
4	850	12	0,743	0,396	7,211	79,479	2518,92	92,1	7,4	0,075416	29,37437	78,4	0,76
5	905	12	0,398	0,395	8,242	93,651	2813,53	96,4	8,7	0,063842	29,156929	77,83	0,74
6	960	12	0,564	1,422	10,973	119,5	3637,28	95,9	11,1	0,1801227	29,424532	78,53	0,75
7	1015	12	0,839	2,353	15,246	149,616	4726,79	95,2	13,9	0,2380609	30,339911	80,92	0,77
8	1050	12	0,596	1,714	15,356	151,4	4596,13	96,6	14	0,1713643	29,564691	78,9	0,75
9	1085	12	0,424	1,801	14,391	147,421	4350,58	97,5	13,7	0,184923	29,01226	77,45	0,73
10	1125	12	0,38	2,394	11,369	125,141	3625,79	97,4	11,6	0,289585	28,42892	75,93	0,72
11	1175	12	0,289	4,212	7,614	89,62	2596,92	97,4	8,3	0,7115238	28,40024	75,85	0,72
12	1235	12	0,24	7,124	2,724	27,226	827,424	93,6	2,5	3,9652474	28,405593	75,87	0,73
13	1400	12	0,434	24,553	1,949	5,62	269,923	61,1	0,5	67,467772	28,000044	74,81	0,98
								Cu-mula-tive% 39Ar rlsd =	100		Total gas age =	76,54	0,49

Table 3. *$^{40}Ar/^{39}Ar$ step-heating dating data for sample B2 [13].*

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40 Ar*	%39 Ar rlsd	Ca/K	40Ar*/39Ar K	Age (Ma)	1s.d.
1	650	12	3,292	0,685	2,359	22,503	1192,24	22,3	1,5	0,463479	11,87317	31,66	1,01
2	725	12	3,732	0,667	4,11	51,072	1861,03	43,8	3,4	0,1988328	16,019896	42,59	0,73
3	790	12	1,236	0,82	9,285	136,638	2540,59	86,6	9	0,0913636	16,213291	43,09	0,44
4	850	12	0,976	0,791	8,225	123,081	2251	88,2	8,1	0,0978402	16,224332	43,12	0,44
5	905	12	0,652	0,655	5,932	90,385	1635,38	89,4	5,9	0,1103261	16,234613	43,15	0,43
6	960	12	0,87	0,939	6,135	93,037	1744,45	86,5	6,1	0,1536558	16,290207	43,3	0,44
7	1015	12	1,344	1,822	8,519	126,834	2423,1	84,8	8,3	0,2187058	16,293253	43,3	0,45
8	1050	12	0,843	0,861	9,245	143,891	2530,74	91	9,5	0,0910963	16,104785	42,81	0,42
9	1085	12	0,54	0,645	11,041	172,507	2879	95	11,3	0,0569219	15,971176	42,46	0,41
10	1125	12	0,426	0,88	17,338	261,447	4254,86	97,4	17,2	0,0512419	15,977266	42,47	0,4
11	1175	12	0,339	1,629	16,764	240,516	3908,03	97,8	15,8	0,103112	16,01647	42,58	0,41
12	1235	12	0,242	1,58	3,739	50,547	874,739	93,5	3,3	0,4759298	16,153135	42,94	0,42
13	1400	12	0,233	1,968	0,767	9,268	217,408	77,4	0,6	3,2357885	16,673392	44,3	0,5
								Cu-mula-	100		Total gas age =	42,66	0,29

step	T (C)	t (min.)	36Ar	37Ar	38Ar	39Ar	40Ar	%40 Ar*	%39 Ar rlsd	Ca/K	40Ar*/39Ar K	Age (Ma)	1s.d.
								tive% 39Ar rlsd =					
											Plateau age =	42,89	0,3
											(steps 2-12)		
											Isochron age =	42,93	0,14
											(steps 2-12)		

4.2.1. Major Element Geochemistry

The major element geochemistry data of the Çambaşı and Bektaşyayla units in the study area are evaluated to determine the source characteristics of the magma from which the magmatic rock originated and to identify the processes (fractional crystallization) that led to changes in the magma composition (Table 4, Table 5).

4.2.2. Trace Element Geochemistry

Bektaşyayla Quartz Monzonite is composed of rocks with monzonite, quartz monzonite, and syenite compositions. According to the classification based on SiO_2 and alkali content (Figure 4), the Çambaşı and Bektaşyayla granitoids are located in the syenite, monzonite, and quartz monzonite regions. The Bektaşyayla Quartz Monzonite rocks are generally intermediate in composition, with SiO_2 content ranging from 56.32 to 60.94, Mg# values between 0.47 and 0.58, and Al_2O_3 values ranging from 16.20 to 18.21. These rocks exhibit an I-type plutonic character with a metaluminous orientation. Çambaşı Syenite rocks also have intermediate composition, with SiO_2 content ranging from 56.32 to 66.55. The Mg# values range from 0.40 to 0.53, and Al_2O_3 values range from 16.23 to 18.49. Çambaşı Syenite exhibits I-type chemical characteristics and shows a trend from metaluminous to peraluminous charter (Figure 5). According to SiO_2 variation diagrams, the rocks of the Çambaşı Plateau are typically shoshonitic in character, showing a high potassium signature. Although both units have different chemical characteristics, they share a common geological structure, reflecting the evolution and chemical characteristics of plutonic rocks (Table 4, Table 5).

Table 4. *Trace and Rare Earth Element (REE) analysis results for Bektaşyayla Quartz Monzonite [13].*

ELEMENT	Rb	Sr	Ba	Zr	Th	Pb	Zn	Nb	Y	Co
D 22	138	398	875	181	14	31	83	11	30	21
D 37	117	421	919	116	11	20	66	10	25	23
D 38	126	414	805	144	12	18	64	9	26	24
D 40	153	380	795	183	19	22	79	12	35	19
D 41	109	409	1004	133	8	32	66	10	26	22
D 42	123	388	982	109	9	20	53	9	27	24
D 57	120	531	723	130	7	24	81	9	26	22
D 58	128	526	803	145	7	19	92	10	29	24
D 61	118	546	755	113	5	31	109	7	25	22
D 62	114	605	1041	136	3	26	106	7	27	22
D 65	112	539	713	126	10	15	81	8	25	24

Table 5. *Trace and Rare Earth Element (REE) contents of Çambaşı Quartz Syenite [13].*

ELEMENT	Rb	Sr	Ba	Zr	Th	Pb	Zn	Nb	Y	Co
D 67	224	488	919	262	32	43	81	24	48	15
D 71	332	228	350	401	109	96	99	38	67	12
D 74	221	483	1058	356	25	34	84	19	44	13
D 75	206	542	953	235	20	52	80	15	41	19
D 76	342	225	351	448	96	186	158	30	65	10
D 77	233	429	584	192	50	105	153	21	47	19
D 78	231	452	717	254	27	136	118	19	45	18
D 79	244	525	1131	206	32	61	94	16	45	11
D 80	235	542	1290	244	12	79	122	15	43	12
D 81	254	331	520	250	22	54	98	20	51	12
D 83	170	424	850	216	9	56	86	12	34	17
D 86	234	378	910	255	12	12	80	15	46	7
D 90	172	510	995	190	7	10	87	11	34	15
D 93	284	393	836	398	31	67	84	26	56	12
D 94	328	281	326	315	34	109	144	28	63	13
D 95	304	339	500	423	29	245	89	28	60	15
D 96	317	282	367	424	42	89	91	31	63	14
D 97	230	519	1170	311	20	48	74	19	43	12
D 104	228	564	1201	241	20	63	97	18	43	14
D 105	221	517	951	254	25	52	86	19	44	13
D 116	250	432	758	289	30	83	112	21	46	10
D 117	202	265	1014	266	22	57	95	18	39	14

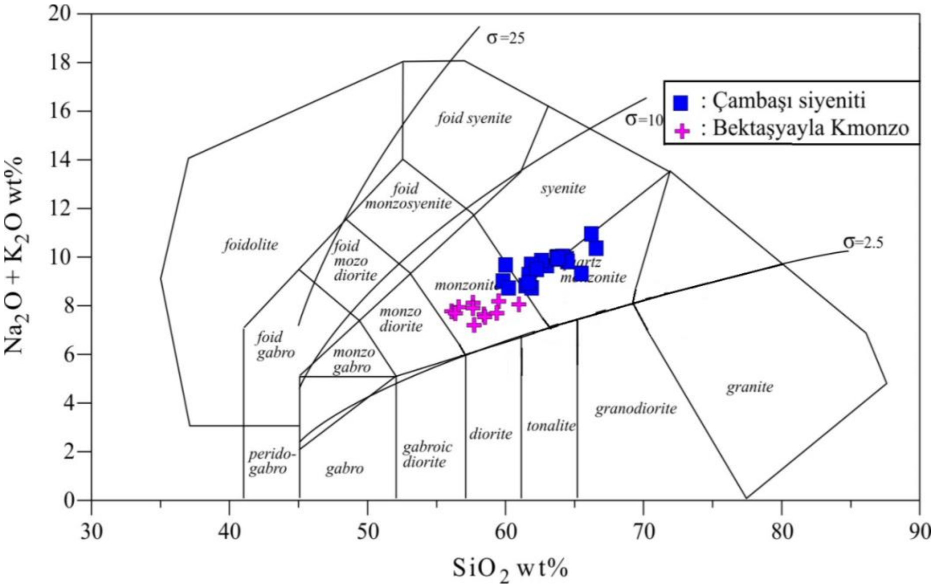

Figure 4. *(a) Classification of Bektaşyayla and Çambaşı granitoids on the SiO_2 diagram based on total alkali content [29].*

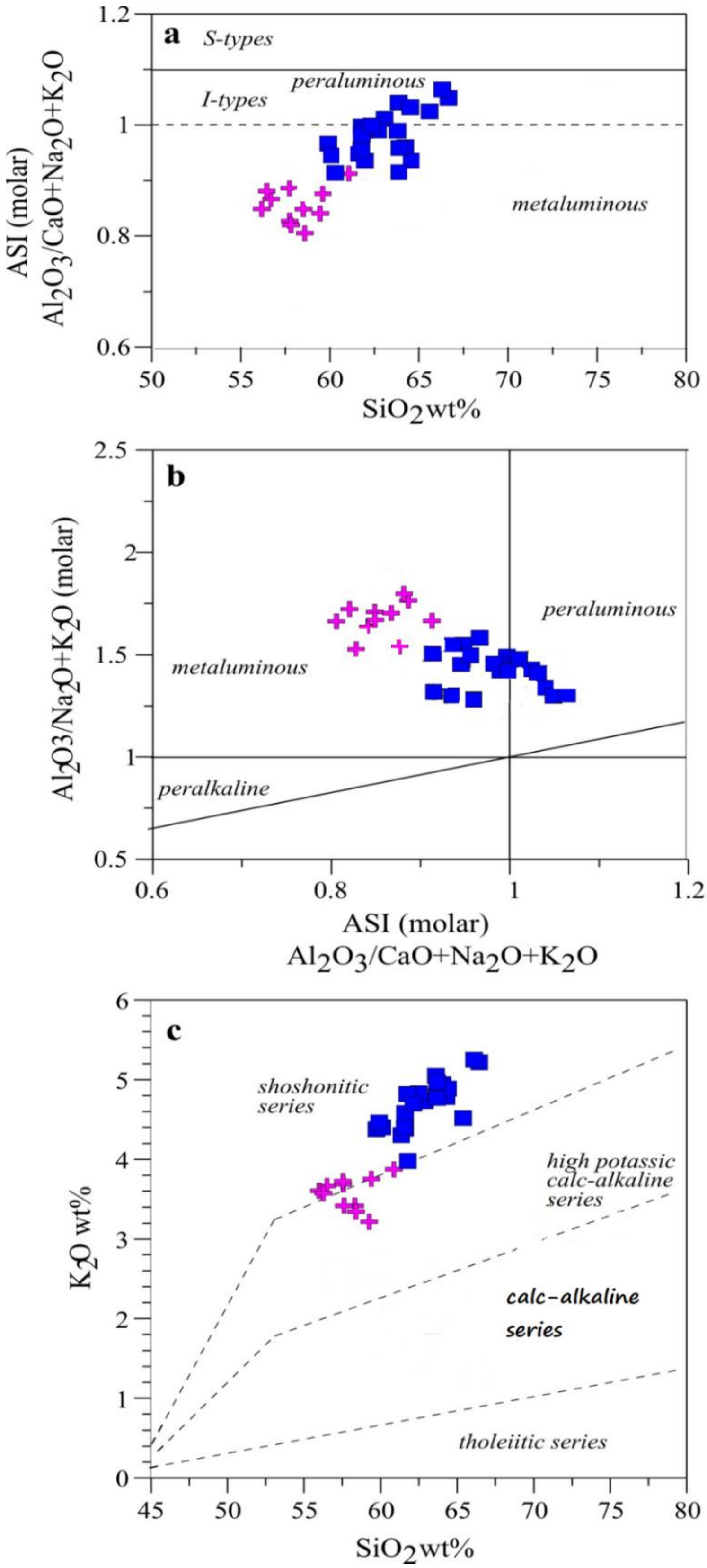

Figure 5. *(a) The distributions of the Bektaşyayla and Çambaşı granitoids in: the SiO_2 vs. alkali saturation index diagram, (b) the molar $Al_2O_3/(Na_2O + K_2O)$ vs. alkali saturation index diagram [28], and (c) the K_2O vs. SiO_2 variation diagram [32].*

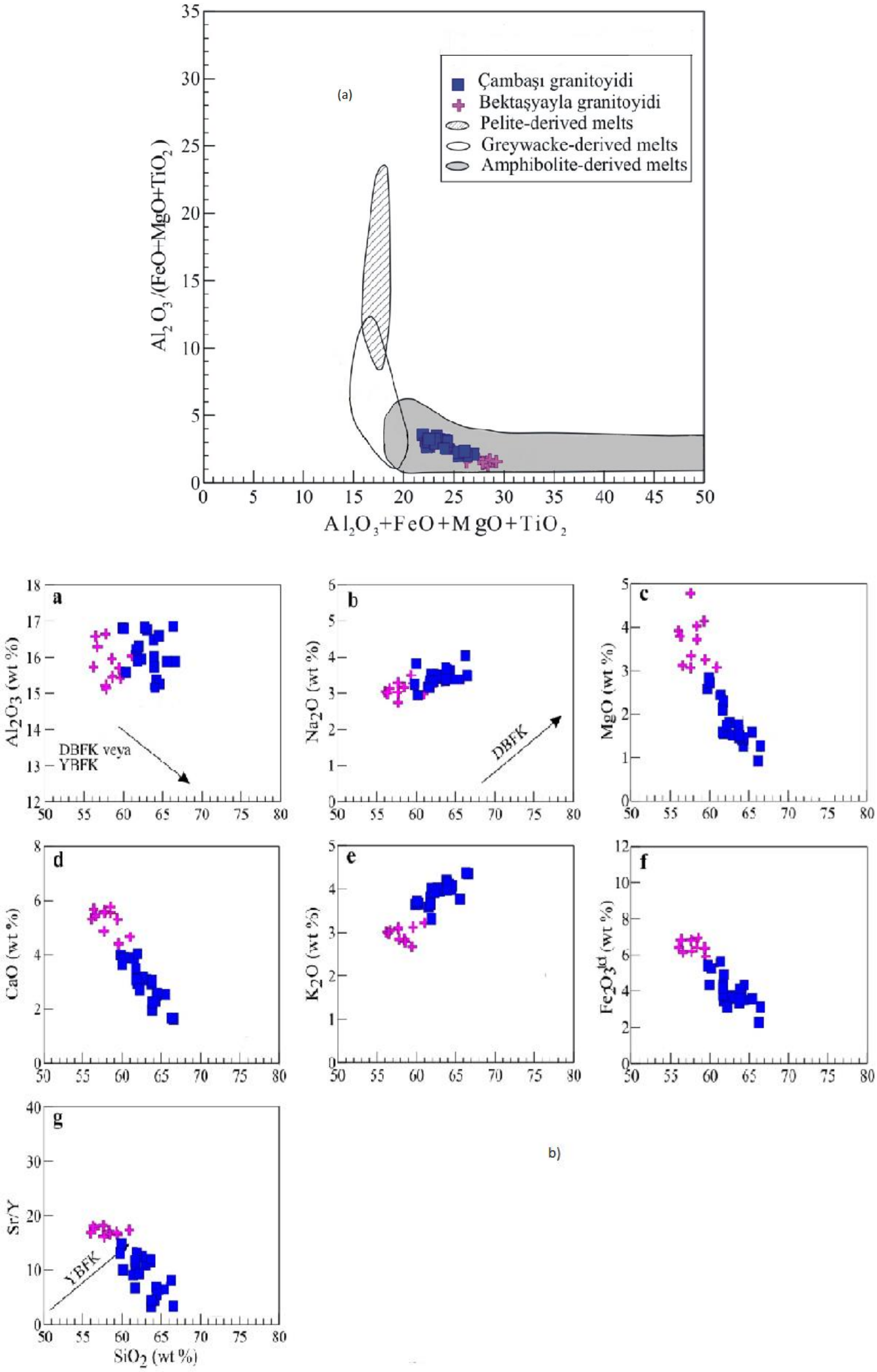

Figure 6. *(a) The Bektaşyayla and Çambaşı plutons in the northern part of the Eastern Pontides: a) Al_2O_3 contents versus SiO_2 contents, b) Na_2O contents versus SiO_2 contents, c) MgO contents versus SiO_2 contents, d) CaO contents versus SiO_2 contents, e) K_2O contents versus SiO_2 contents, f) total iron oxide contents versus SiO_2 contents, g) Sr/Y ratios versus SiO_2 contents. Low-pressure fractional crystallization (LPFC) trend containing olivine + clinopyroxene + plagioclase + hornblende + titanomagnetite is from Castillo et al. [10]. and high-pressure fractional crystallization (HPFC) trend containing garnet is from [27]. (b) The positions of Bektaşyayla and Çambaşı granitoids in the Al_2O_3/(FeO+MgO+TiO_2) versus Al_2O_3+FeO+MgO+TiO_2 variation diagram. The experimentally produced amphibolite melt fields are from [31].*

The Bektaşyayla and Çambaşı granitoids, located in the northern part of the Eastern Pontides, are considered as apophyses of the Kaçkar Batholith and present a wide spectrum of rock types. Fractional crystallization plays a significant role in the formation of these rocks. The chemical compositions of the Bektaşyayla and Çambaşı plutons are shown in the relationships between SiO_2 and various oxides (Al_2O_3, Na_2O, MgO, CaO, K_2O, Fe_2O_3, Sr/Y) (Figure 6). These relationships reveal the low-pressure fractional crystallization (LPFC) trend of the rocks, particularly with SiO2 inversely related to MgO, CaO, Fe_2O_3, and Sr/Y, while Al_2O_3, Na2O, and K2O show parallel increases. This indicates that the rocks have undergone more low-pressure fractional crystallization, with amphibole, plagioclase, and pyroxene fractionation being widespread.

The obtained data suggest that the Bektaşyayla and Çambaşı granitoids may have formed not from a single source rock but through the fractional crystallization of a hybrid magma generated by the partial melting of two different source rocks. Petrographic structures, textural characteristics, and mafic microgranular enclaves support the presence of this hybrid magma.

Additionally, analyses based on Al_2O_3/(FeO+MgO+TiO_2) and Al_2O_3+FeO+MgO+TiO_2 values show that these rocks exhibit amphibolite-derived melting characteristics, with a particular emphasis on amphibolite-derived magmatic features.

5. Results and Discussion

The 40Ar-39Ar geothermochronological analyses conducted on the rocks taken from the Bektaşyayla and Çambaşı plateaus in the Eastern Pontides have provided significant insights into the geodynamic processes of the region. This study has enabled a detailed examination of the geochemical, mineralogical, and geochronological characteristics of the rocks, providing new information about the Late Cretaceous and post-Late Cretaceous evolutionary processes of the region [45].

Geochemical analyses of trace and rare earth elements from the Bektaşyayla Quartz Monzodiorite and Çambaşı Syenite have provided important clues about the magmatic sources and geodynamic processes that contributed to the formation of these rocks. The geochemical characteristics of the rocks offer valuable information about the magmatic processes and environmental conditions in the region. In addition, rock samples underwent mineral enrichment at the TU Bergakademie Freiberg Geological Institute (Germany) for apatite fission-track and 40Ar-39Ar age dating studies. During this process, biotite and accessory minerals (apatite, zircon) were separated using heavy liquids, and the minerals were subsequently embedded in epoxy and polished. These separation and preparation procedures are critical for accurate age determinations.

The main aim of this study is to produce new findings regarding the geodynamic model of the Late Cretaceous and post-Late Cretaceous periods in the Eastern Pontides. In this context, plutonic rocks cutting through Middle-Late Cretaceous subduction-related volcanic rocks have been investigated, and the chemical characteristics of the rocks along with source rock interpretations have been made. Geochronological analyses reveal that these plutons were emplaced in the shallow depths of the continental crust in the Pontides between 44 million and 80 million years ago. This marks a key moment in understanding the magmatic evolution of the region.

The widely accepted view in the Eastern Pontides is the existence of northward subduction during the Late Cretaceous. According to the geochronological analyses, these rocks may have been emplaced in the shallow depths of the crust during the Late Cretaceous, associated with back-arc extension. This extension is linked to the initiation of the Black Sea formation and led to the formation of granitoids due to the steepening of oceanic crust.

The obtained data are consistent with the mineral paragenesis, mineral chemistry, and textural features indicating magma mixing in the studied rocks. These rocks have formed through the hybridization of mantle- and crust-derived magmas, and the evolutionary processes of these hybrid magmas reflect the geodynamic development of the region. Magma mixing and hybridization have played an important role in the magmatic evolution of the region.

Some of the studied rocks are dated to the Middle Eocene. The Middle Eocene period in the Eastern Pontides is interpreted as a time of continental thinning and extensional tectonic events [25], along with the onset of asthenospheric uplift. This uplift is directly related to partial melting in the mantle of the lithosphere, and this process led to the formation of the rocks under investigation. These findings, reflecting the late orogenic and post-collision dynamic phases, contribute significantly to our understanding of the geodynamic processes in the region.

The Late Cretaceous and Middle Eocene granites in the Eastern Pontides were formed by the hybridization of subcontinental lithospheric mantle and lower crust-derived melts in varying proportions [18]. It is believed that the back-arc extension started [1], at least 78 million years ago and represents the final stages of the closure of the Neo-Tethys Ocean. The Paleocene-Early Eocene processes signal collision tectonics and continental thinning events in the region. The beginning of these processes dates back to at least 44-45 million years ago.

In conclusion, the Late Cretaceous and Middle Eocene rocks in the Eastern Pontides evolved through the hybridization of subcontinental lithospheric mantle and lower crust-derived magmas, and were emplaced in shallow depths during the extensional phase. The obtained geochronological, petrographic, and geochemical data allow us to better understand the magmatic evolution and geodynamic processes in the region. These findings offer important contributions, particularly in interpreting the evolution of the Pontide orogeny and the geological developments in the region.

Future research should focus on additional geochemical and geochronological analyses to further refine the magmatic and tectonic evolution of the region. Investigating other isotopic systems such as Lu-Hf and Re-Os could provide deeper insights into the mantle-crust interactions and source characteristics of magmatic rocks. Moreover, high-resolution geophysical surveys and numerical modeling studies can help elucidate the dynamics of magma generation, migration, and emplacement. These advancements will significantly enhance our understanding of the geodynamic history of the Eastern Pontides and provide valuable data for broader regional tectonic models.

Abbreviations

EPOB	The Eastern Pontides Orogenic Belt
EAF	East Anatolian Fault
NAF	North Anatolian Fault
REE	Trace and Rare Earth Element
LPFC	Low-Pressure Fractional Crystallization
HPFC	High-Pressure Fractional Crystallization

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Author Contributions

Gülşah Levent: Data curation, Investigation, Project administration, Writing – review & editing.

Durmuş Boztuğ: Data curation, Funding acquisition, Supervision.

Conflicts of Interest

The authors declare no conflicts of interest.

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