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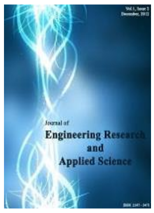

The Geostatistical Evaluation of the Genetic Relationship of Rocks: A Case Study of the Derinoba-Kayadibi Granites

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Abstract

This study aims to investigate the genetic relationship between different rock types by evaluating existing geochemical data using geostatistical approaches. For this purpose, all whole-rock analysis results of the Derinoba and Kayadibi granites (GB Trabzon, Türkiye), which outcrop in the northern zone of the Eastern Pontides, were evaluated using different statistical approaches. For the study, 15 whole-rock analyses belonging to the Derinoba granite and 5 whole-rock analyses belonging to the Kayadibi granite were processed. Non-parametric statistical methods were preferred in the analyses due to the limited number of elements in the data set under investigation (especially the Kayadibi granite). Within the scope of the study, the descriptive statistical parameters of the two granite masses were calculated. Thus, the central distribution parameters of the geochemical data were determined and the general character of the data set was tried to be understood. Subsequently, the Mann Whitney U test was applied to the relevant data sets and the genetic relationships between these two granite masses were investigated. As a result of the study, it was observed that the Derinoba and Kayadibi granites represent the same genetic source at the sig. %1 and/or %1-3 level by SiO_2, Gd, Tm, Er, Rb/Sr, La_{CN}/Lu_{CN}, La_{CN}/Yb_{CN}, ASI parameters, and by the other major oxides except SiO_2 and the elements Sr, Ta, Nb, Hf, Zr, U, Ga, La, Ce, Pr, Nd, Sm, Eu, Tb, Dy, and Ho at the %95 (1-sig.) confidence interval. The obtained results confirmed the results of conventional studies on the origin of these granites.

Keywords: *Eastern Pontides, Descriptive Statistics, Mann Whitney U test, Derinoba granite, Kayadibi granite, Trabzon, Türkiye*

1. Introduction

Statistical approaches have begun to play an important role in geosciences, particularly in geochemical studies aimed at mineral exploration, since the early 1900s [1, 2]. Along with the prevalence of these studies, the concept of geostatistics has found a significant place in the literature. Today, many geoscientists, especially in the fields of ore deposits and geochemistry, are conducting original research by utilizing statistical principles [3–7]. As in many scientific studies, a significant amount of data is obtained in geological studies. For the researcher, evaluating this large volume of data is as important as obtaining it. Statistics provides a significant convenience in the collective evaluation and interpretation of this substantial numerical data. Statistical knowledge and depth enable new approaches in the field. In these studies, the most commonly used methods include descriptive statistics (e.g., minimum, maximum, mean, median, skewness, kurtosis), t-tests (independent one-sample t-test, independent two-sample t-test, paired two-sample t-test), variation analyses (ANOVA, MANOVA), and factor analyses. Particularly, t-tests and ANOVA tests, as well as their nonparametric equivalents depending on the situation, are geostatistical methods suitable for comparing the genetic similarities of rocks in petrological studies.

The Pontid tectonic unit contains numerous magmatic rocks on a regional scale [8] (Figure 1A). Most of these rocks are associated with the converging/colliding boundaries of the Eurasia-Gondwana continents. The region's rich geological features and associated mineral deposit potential have drawn the attention of researchers, leading to many studies in the context of geosciences from past to present [9–19]. The magmatic rocks in the region cover a wide age range [20–26], and studies have identified numerous large and small magmatic bodies

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of similar age and origin in different locations [27–30]. The composition of the region's rocks ranges from low-K, high-K calc-alkaline metaluminous-peraluminous granitoids to alkaline syenites [31]. Most of the Paleozoic basement rocks in the region are granitoids. Recent studies have increasingly focused on their genetic and age relationships. Various geological-geochemical and isotopic (stable-radiogenic) studies have been conducted to elucidate these relationships. However, the geostatistical analysis of the numerical data for these relationships has generally been limited in the studies conducted. This study aims to evaluate geochemical data using a geostatistical approach, thereby providing a geostatistical assessment of the genetic relationships of the rocks. As a case study, the geochemical parameters of the Derinoba and Kayadibi granites, studied by Kaygusuz et al. [27], were used. The general evaluation of the data was carried out using descriptive statistical parameters (minimum, maximum, mean, median, skewness, kurtosis etc.), and considering the limited amount of data, the Mann-Whitney U test was used as a geostatistical method to attempt a genetic evaluation.

2. Regional geology

The Eastern Pontides are generally divided into two zones, north and south, taking into account their structural and lithological characteristics [32, 33].

In the southern zone, there are mainly volcanic, plutonic, sedimentary and metamorphic rocks ranging from Paleozoic to Neogene, while in the northern zone, volcanic (with occasional sedimentary intercalations) and plutonic rocks from Carboniferous to Neogene are dominant (Figure 1A) [18, 34–40].

The basement rocks of the Eastern Pontides consist of pre-Variscan schists and gneisses [41], which are intruded by Silurian-Devonian metagranites and Middle-Late Carboniferous plutons [21, 27, 42–47]. These basement rocks are unconformably overlain by an Early-Middle Jurassic volcano-sedimentary sequence [48–50] and are intruded by Early-Late Jurassic intrusions [51–54]. A thick carbonate deposition occurred during the Late Jurassic-Early Cretaceous period (Berdiga Formation, [55]). These units are conformably overlain by Late Cretaceous volcanic rocks [28, 30, 56] and are intruded by Late Cretaceous plutonic rocks [25, 57–61]. High-K magmatism persisted in the region from the Late Campanian to the Maastrichtian [62]. The Anatolid-Torid block collision occurred during the Late Paleocene to Early Eocene [63, 64]. The presence of Early Eocene adakitic rocks in the region [65–70] marks the final stage of the arc-continent collision.

The Eocene units in the Eastern Pontides consist of volcanic, volcanoclastic, pyroclastic, lava flows, and dikes [71–75] and are intruded by calc-alkaline plutons of the same age [37, 76–84]. Late Miocene-Pleistocene volcanic and clastic rocks, as well as Neogene alkaline volcanic rocks, are widely observed in the region [17, 33, 72, 85]. The youngest units in the region are Quaternary scree, travertine, and alluvium [86, 87].

3. Material and method

3.1. Geostatistical methods

In this study, geochemical data from a total of 20 samples were evaluated. 15 of the samples belong to the Derinoba granite, and 5 belong to the Kayadibi granite. Detailed information about the data is given in Kaygusuz et al. [27]. Descriptive statistical approaches are widely used to overcome the difficulties in evaluating data in bulk in scientific research. For example, the means of the data, the distribution characteristics around the mean, and the deviations from the mean make the evaluation of the data meaningful. Parameters such as mean, median, mode values, standard deviation and variance are included in the category of descriptive statistics. Another important concept when evaluating all this data is the concept of statistical significance, significance level or probability. This concept is generally represented by P. Information about significance levels is provided with expressions such as $P \leq 0.05$ or $P > 0.05$. The P value represents the 95% confidence interval and is generally expressed as "sig." in statistical evaluations. In this study, evaluation was made mainly by considering parameters such as mean, median, standard deviation (Std.Deviation), standard error of the mean (Std. Error Mean), minimum, maximum, skewness, kurtosis, etc.

The Mann-Whitney U test is a nonparametric alternative to the independent two-sample t-test. Unlike the independent two-sample t-test, this method is based on comparing the median values of the groups instead of their mean values. In this study, nonparametric tests were preferred instead of parametric tests due to the statistically small number of data we used [89].

4. Results

4.1. Field observations and petrographic properties of rocks

Considering the entire field, there are four separate granite masses in the field (Derinoba, Kayadibi, Şahmelik, and Kızılağaç). In this study, the genetic relationship between Derinoba and Kayadibi granites was evaluated. The intrusions in question are approximately NW-SE trending masses and represent high peaks in the region. These rocks are generally bounded by pre-Jurassic volcanics and pyroclastics [27]. The Derinoba granite is located 65 km southwest of Trabzon. The Derinoba granite has been subjected to intense alteration and weathering. The Kayadibi granite, on the other hand, is a smaller, ellipsoid-shaped mass that outcrops in an area of 1 km² and outcrops southwest of the Derinoba granite (Figure 2).

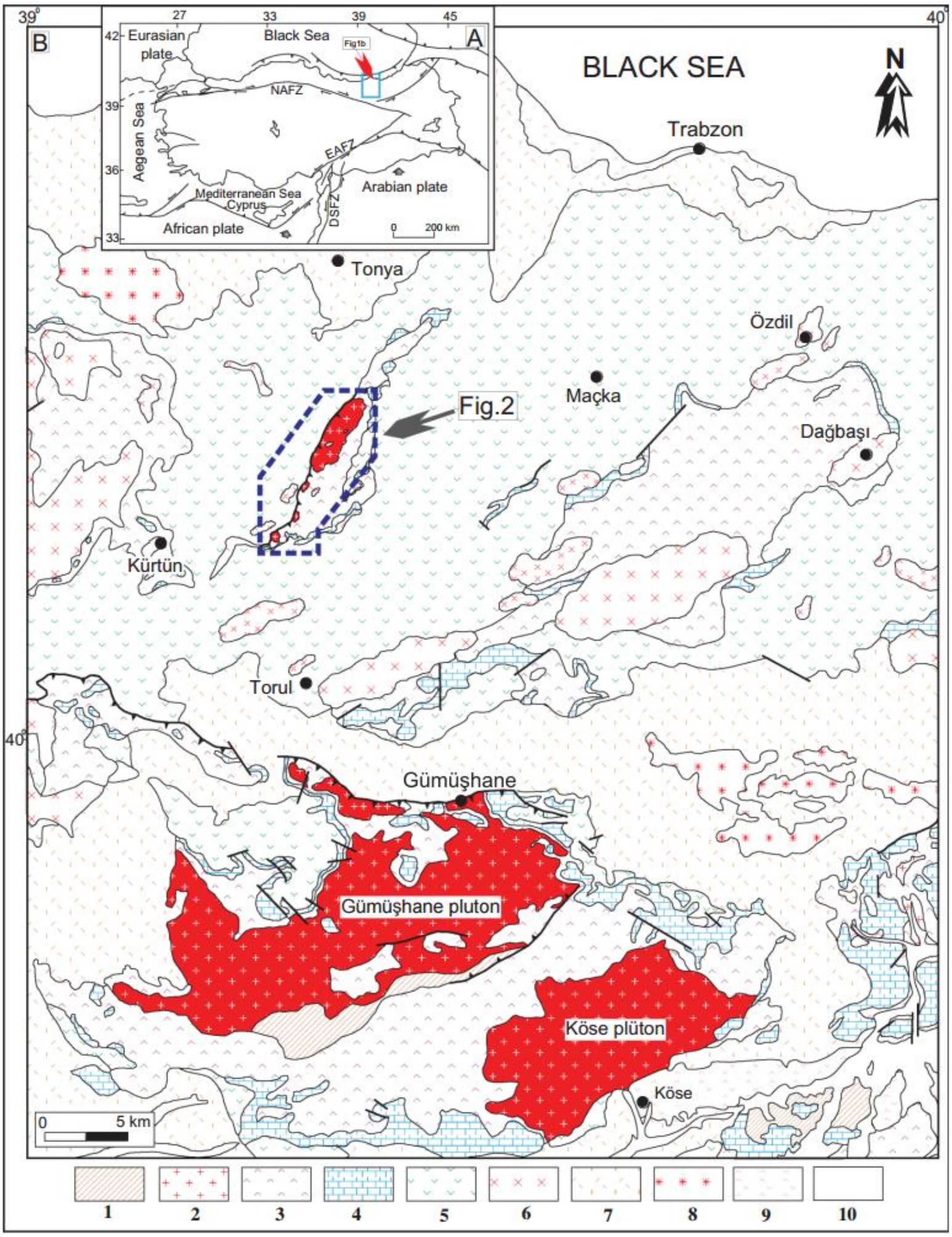


Figure 1. A. Tectonic map of Türkiye and surrounding areas (modified from [88]). B. Distribution of plutonic and volcanic rocks. (1) Paleozoic metamorphic rocks (2) Paleozoic plutons (3) Liassic-Dogger volcanic rocks (4) Malm-Lower Cretaceous sedimentary rocks (5) Upper Cretaceous volcanic rocks (6) Upper Cretaceous plutons (7) Paleogene-Neogene calc-alkaline volcanic rocks (8) Paleogene-Neogene alkaline volcanic rocks (9) Eocene plutons (10) Alluvium NAFZ: North Anatolian Fault Zone EAFZ: East Anatolian Fault Zone [See 27].

The general character of the granites is that of medium- to coarse-grained monzogranite. Mineralogically, they are composed of equal-grained K-feldspar, quartz, plagioclase, and biotite. Accessory minerals reported are zircon, apatite, allanite, and magnetite. Alteration products are sericite, chlorite, epidote, clay minerals, carbonates, and white mica [27].

4.2. Geostatistical findings and evaluations

Descriptive statistics for the Derinoba and Kayadibi granites are given in Tables 1 and 2.

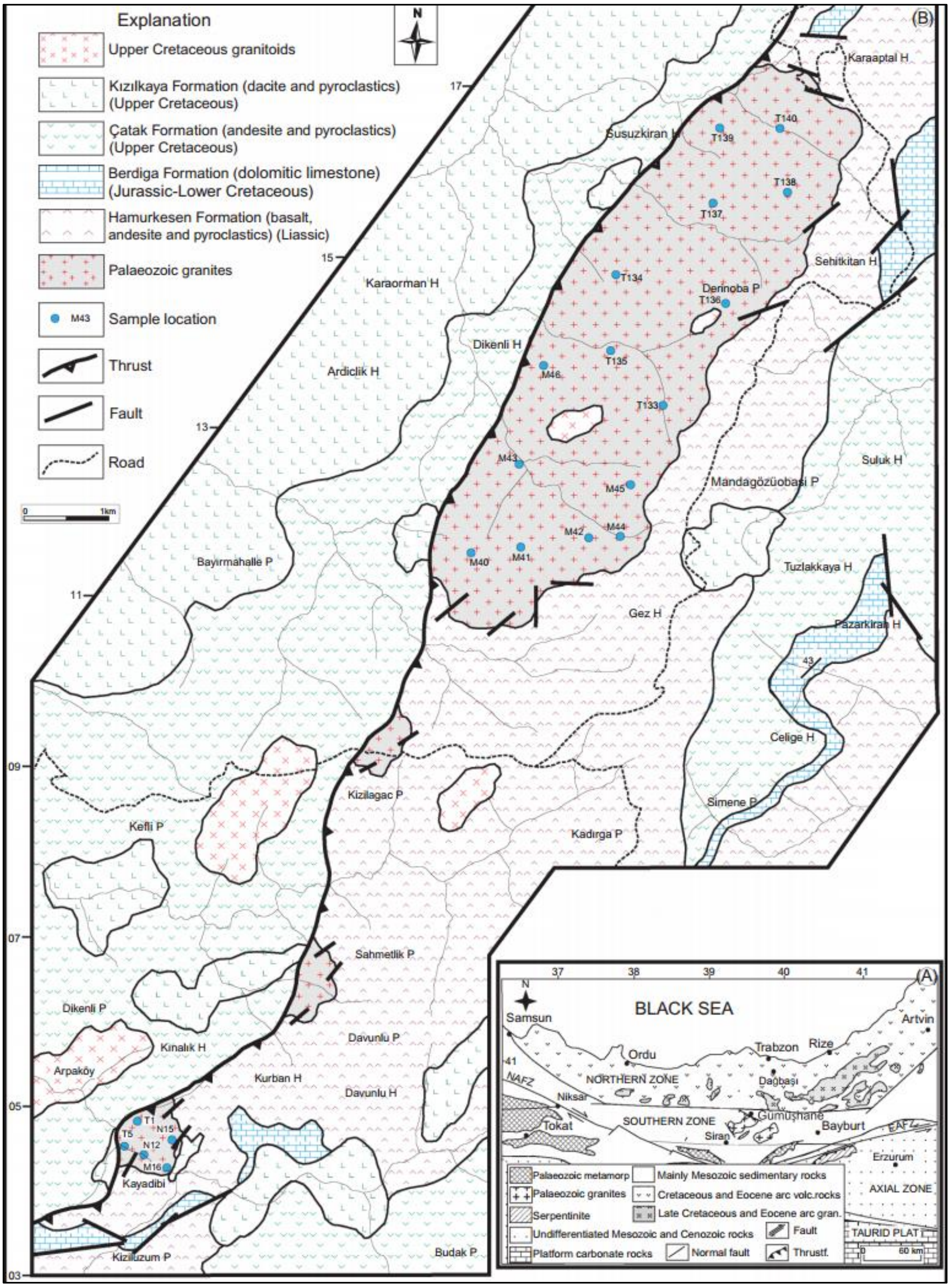


Figure 2. Geologic map of the study area and sample collection sites [modified from 27].

Upon examination of the descriptive statistics values, the closeness of the average values of the major oxides is striking. The low standard deviation values indicate the normal distribution of the data. However, the smallness of these values makes it difficult to decide on the closeness of the data in the %5 significant (Sig.0.05) range without statistical evaluation. Therefore, the closeness of the genetic relationship between the two different granitic masses can be revealed by detailed statistical tests. The skewness and kurtosis values of the data of both rock groups also indicate the normal distribution of the data. The median values calculated for the examined parameters are also found to be very close to the average values, which can be considered as an indication of the normal distribution of the data. However, the small sample size of the Kayadibi granitic mass (5) is a disadvantage for the evaluation of the normal distribution of the data.

Table 1. Descriptive geostatistical parameters for some geochemical parameters of the Derinoba granite (mean+standard error values should be considered when determining means for rocks, otherwise standard deviations relevant sections in the table are marked in bold)

	Mean	Median	Std. Deviation	Std. Error of Mean	Minimum	Maximum	Kurtosis	Skewness
SiO_2	**75.56**	75.66	0.59	**0.18**	74.66	76.53	-0.54	0.03
TiO_2	**0.10**	0.10	0.02	**0.01**	0.06	0.13	-0.48	-0.56
Al_2O_3	**12.73**	12.77	0.44	**0.13**	11.89	13.39	0.56	-0.74
Fe_2O_{3T}	**1.40**	1.42	0.26	**0.08**	1.08	1.72	-1.85	0.06
MnO	**0.03**	0.03	0.01	**0.00**	0.01	0.05	-1.12	0.09
MgO	**0.37**	0.42	0.13	**0.04**	0.15	0.53	-0.74	-0.76
CaO	**0.65**	0.45	0.52	**0.16**	0.11	1.45	-1.58	0.62
Na_2O	**3.28**	3.24	0.19	**0.06**	3.02	3.69	0.60	0.87
K_2O	**3.95**	3.90	0.40	**0.12**	3.24	4.75	0.92	0.33
P_2O_5	**0.03**	0.03	0.01	**0.00**	0.02	0.05	-0.13	0.73
Ni	**1.01**	0.90	0.23	**0.07**	0.80	1.50	0.89	1.20
V	**9.00**	8.00	1.41	**0.43**	8.00	12.00	0.60	1.30
Cu	**2.45**	2.50	0.79	**0.24**	0.90	3.40	-0.01	-0.59
Pb	**5.36**	5.10	3.12	**0.94**	2.20	12.70	2.09	1.31
Zn	**20.45**	24.00	10.96	**3.30**	2.00	31.00	-0.57	-1.07
W	**0.89**	0.80	0.38	**0.11**	0.50	1.60	0.73	1.24
Rb	**128.07**	117.50	30.30	**9.14**	104.10	187.70	1.37	1.66
Ba	**504.27**	530.00	105.85	**31.91**	320.00	677.00	-0.25	-0.38
Sr	**45.90**	43.20	10.01	**3.02**	36.20	67.10	0.53	1.15
Ta	**1.18**	1.00	0.42	**0.13**	0.90	2.10	1.80	1.73
Nb	**13.01**	13.50	1.41	**0.43**	9.80	14.60	1.39	-1.17
Hf	**4.51**	5.20	1.56	**0.47**	2.00	6.40	-1.14	-0.64
Zr	**134.11**	130.30	36.22	**10.92**	73.60	200.00	0.14	0.31
Y	**27.63**	28.50	4.52	**1.36**	20.70	32.90	-1.18	-0.68
Th	**13.89**	15.20	4.07	**1.23**	7.20	18.90	-0.73	-0.90
U	**3.05**	3.00	0.69	**0.21**	1.30	4.00	4.33	-1.57
Ga	**16.61**	17.20	1.25	**0.38**	14.10	18.10	0.39	-1.16
La	**32.83**	32.00	4.21	**1.27**	26.40	40.40	-0.50	0.22
Ce	**64.64**	62.30	10.51	**3.17**	54.60	85.40	-0.25	1.01
Pr	**7.38**	7.10	1.02	**0.31**	6.07	9.10	-1.12	0.31
Nd	**29.45**	30.70	4.79	**1.44**	23.10	37.80	-0.93	0.25
Sm	**5.29**	5.15	0.54	**0.16**	4.75	6.66	3.93	1.83
Eu	**0.64**	0.74	0.32	**0.10**	0.14	1.01	-1.02	-0.67
Gd	**4.80**	4.86	1.67	**0.50**	2.40	7.40	-0.98	-0.18
Tb	**0.99**	0.96	0.36	**0.11**	0.53	1.55	-1.31	0.18
Dy	**5.01**	4.97	1.34	**0.40**	3.25	6.85	-1.68	-0.06
Ho	**1.25**	1.26	0.41	**0.12**	0.74	1.75	-1.75	-0.03
Er	**3.27**	3.10	0.88	**0.27**	2.24	4.76	-0.43	0.73
Tm	**0.49**	0.49	0.11	**0.03**	0.36	0.71	-0.13	0.68
Yb	**3.30**	3.10	0.68	**0.20**	2.54	4.33	-1.50	0.40
Lu	**0.46**	0.46	0.07	**0.02**	0.36	0.58	-0.95	0.22
La_{CN}/Lu_{CN}	**7.53**	7.55	1.59	**0.48**	4.88	9.88	-0.91	-0.16
La_{CN}/Sm_{CN}	**3.92**	3.89	0.47	**0.14**	3.42	4.93	0.94	1.07
Gd_{CN}/Lu_{CN}	**1.26**	1.37	0.30	**0.09**	0.79	1.64	-1.28	-0.43
La_{CN}/Yb_{CN}	**7.01**	7.37	1.78	**0.54**	4.57	9.71	-1.46	-0.02

Tb_{CN}/Yb_{CN}	**1.24**	1.32	0.25	**0.08**	0.89	1.70	-0.62	0.06
Eu_{CN}/Eu^*	**0.37**	0.41	0.16	**0.05**	0.11	0.59	-0.41	-0.65
Mg#	**20.98**	22.58	7.38	**2.23**	9.32	32.52	-0.59	-0.29
ASI	**1.18**	1.18	0.11	**0.03**	0.98	1.35	-0.18	-0.24
K_2O/Na_2O	**1.21**	1.19	0.16	**0.05**	0.98	1.45	-1.31	0.00
Rb/Sr	**2.97**	2.47	1.18	**0.35**	1.75	5.19	0.28	1.16
Sr/Y	**1.72**	1.58	0.58	**0.18**	1.20	3.24	4.55	2.01
Nb/Ta	**12.05**	12.91	3.58	**1.08**	5.67	15.89	-0.66	-0.86
Zr/Hf	**31.83**	28.07	9.31	**2.81**	24.33	51.41	1.16	1.51
Th/U	**4.66**	4.73	1.25	**0.38**	2.48	6.77	0.45	-0.53

Table 2. Descriptive geostatistical parameters for some geochemical parameters of the Kayadibi granite (mean+standard error values should be considered when determining means for rocks, otherwise standard deviations relevant sections in the table are marked in bold)

	Mean	Median	Std. Deviation	Std. Error of Mean	Minimum	Maximum	Kurtosis	Skewness
SiO_2	**74.46**	74.33	0.54	**0.24**	73.95	75.29	0.20	0.98
TiO_2	**0.13**	0.12	0.04	**0.02**	0.09	0.18	-1.81	0.38
Al_2O_3	**12.94**	12.99	0.43	**0.19**	12.29	13.49	2.05	-0.59
$Fe_2O_3^T$	**1.90**	2.07	0.58	**0.26**	1.25	2.46	-3.02	-0.35
MnO	**0.03**	0.03	0.01	**0.01**	0.02	0.05	-0.18	0.40
MgO	**0.51**	0.46	0.16	**0.07**	0.31	0.72	-1.20	0.25
CaO	**1.14**	1.27	0.40	**0.18**	0.51	1.46	0.51	-1.15
Na_2O	**3.40**	3.35	0.36	**0.16**	2.91	3.83	-0.93	-0.20
K_2O	**4.28**	4.56	0.53	**0.24**	3.51	4.74	-1.03	-0.94
P_2O_5	**0.04**	0.04	0.02	**0.01**	0.02	0.06	-1.20	0.00
Ni	**1.12**	1.10	0.24	**0.11**	0.80	1.40	-1.12	-0.21
V	**8.40**	8.00	0.55	**0.24**	8.00	9.00	-3.33	0.61
Cu	**2.66**	1.30	3.21	**1.44**	1.00	8.40	4.96	2.22
Pb	**10.48**	10.40	1.49	**0.66**	8.40	12.50	1.10	-0.09
Zn	**13.80**	14.00	3.49	**1.56**	9.00	18.00	-0.64	-0.31
W	**0.56**	0.60	0.05	**0.02**	0.50	0.60	-3.33	-0.61
Rb	**104.56**	116.20	30.80	**13.77**	62.20	140.60	-0.91	-0.46
Ba	**646.80**	630.00	104.98	**46.95**	519.00	807.00	1.55	0.71
Sr	**81.28**	80.30	23.96	**10.71**	58.80	120.40	2.11	1.34
Ta	**0.88**	1.00	0.37	**0.17**	0.40	1.30	-1.81	-0.38
Nb	**11.42**	10.40	3.57	**1.60**	8.20	16.50	-1.25	0.73
Hf	**5.32**	5.20	0.84	**0.38**	4.30	6.40	-1.42	0.18
Zr	**146.70**	148.90	19.99	**8.94**	117.60	169.30	-0.09	-0.61
Y	**39.20**	40.50	3.84	**1.72**	32.50	42.10	4.09	-1.97
Th	**20.96**	20.70	2.11	**0.95**	18.20	24.10	1.72	0.43
U	**3.76**	3.50	2.04	**0.91**	1.50	6.90	1.01	0.88
Ga	**15.72**	15.30	2.52	**1.13**	13.00	19.70	1.58	1.06
La	**30.24**	36.30	8.99	**4.02**	19.10	37.30	-3.03	-0.65
Ce	**69.90**	78.40	17.84	**7.98**	41.10	84.40	1.32	-1.39
Pr	**7.76**	8.46	1.94	**0.87**	4.89	9.42	-0.70	-0.91
Nd	**29.96**	30.10	6.89	**3.08**	20.00	36.50	-0.63	-0.63
Sm	**5.98**	6.09	0.56	**0.25**	5.20	6.50	-1.38	-0.61
Eu	**0.75**	0.72	0.09	**0.04**	0.65	0.84	-2.67	0.23
Gd	**7.52**	7.30	0.92	**0.41**	6.32	8.65	-1.07	-0.03
Tb	**1.30**	1.28	0.08	**0.04**	1.22	1.43	1.42	1.20
Dy	**6.41**	6.06	0.54	**0.24**	6.02	7.21	-0.88	1.04
Ho	**1.48**	1.46	0.11	**0.05**	1.35	1.64	0.94	0.48
Er	**4.51**	4.54	0.28	**0.12**	4.20	4.86	-2.00	0.08
Tm	**0.67**	0.65	0.08	**0.04**	0.57	0.78	-0.55	0.45
Yb	**4.63**	4.62	0.13	**0.06**	4.49	4.83	1.66	0.97
Lu	**0.62**	0.62	0.06	**0.02**	0.53	0.68	1.78	-0.90
La_{CN}/Lu_{CN}	**5.17**	6.03	1.78	**0.79**	2.91	7.09	-2.25	-0.46
La_{CN}/Sm_{CN}	**3.19**	3.61	0.91	**0.41**	1.86	4.05	-0.99	-0.87
Gd_{CN}/Lu_{CN}	**1.52**	1.58	0.17	**0.08**	1.27	1.67	-1.03	-0.82
La_{CN}/Yb_{CN}	**4.43**	5.37	1.39	**0.62**	2.67	5.52	-2.86	-0.68
Tb_{CN}/Yb_{CN}	**1.20**	1.22	0.05	**0.02**	1.14	1.27	-1.75	0.05
Eu_{CN}/Eu^*	**0.34**	0.34	0.02	**0.01**	0.31	0.37	2.00	0.00
Mg#	**21.19**	20.67	2.48	**1.11**	18.18	24.57	-0.72	0.33

ASI	**1.06**	1.07	0.08	**0.03**	0.95	1.15	0.03	-0.36
K_2O/Na_2O	**1.26**	1.24	0.10	**0.04**	1.18	1.43	3.85	1.87
Rb/Sr	**1.42**	1.72	0.62	**0.28**	0.52	2.02	-0.83	-0.87
Sr/Y	**2.14**	1.91	0.90	**0.40**	1.48	3.70	3.83	1.90
Nb/Ta	**13.99**	12.69	3.86	**1.73**	10.40	20.50	3.10	1.62
Zr/Hf	**27.68**	28.63	1.65	**0.74**	24.92	28.79	2.33	-1.64
Th/U	**7.02**	5.86	4.00	**1.79**	3.49	13.80	3.15	1.67

The distribution characteristics of the data were also tested using the Kolmogorov-Smirnov and Shapiro-Wilks tests (Table 3). Since the Sig. values are mostly greater than 5%, it can be said that the vast majority of the parameters exhibit a normal distribution (Kolmogorov-Smirnov test values were considered for the Derinoba granite, and Shapiro-Wilk test values were considered for the Kayadibi granite).

Table 3. Nonparametric normality test results for the Derinoba and Kayadibi granites

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
SiO_2	Derinoba granite	0.14	11	.200*	0.957	11	0.73
	Kayadibi granite	0.19	5	.200*	0.919	5	0.53
TiO_2	Derinoba granite	0.18	11	.200*	0.917	11	0.29
	Kayadibi granite	0.23	5	.200*	0.943	5	0.69
Al_2O_3	Derinoba granite	0.22	11	0.13	0.919	11	0.31
	Kayadibi granite	0.28	5	.200*	0.920	5	0.53
$Fe_2O_3^T$	Derinoba granite	0.19	11	.200*	0.879	11	0.10
	Kayadibi granite	0.24	5	.200*	0.844	5	0.18
MnO	Derinoba granite	0.19	11	.200*	0.927	11	0.38
	Kayadibi granite	0.24	5	.200*	0.961	5	0.81
MgO	Derinoba granite	0.19	11	.200*	0.891	11	0.14
	Kayadibi granite	0.22	5	.200*	0.965	5	0.84
CaO	Derinoba granite	0.29	11	0.01	0.831	11	0.02
	Kayadibi granite	0.23	5	.200*	0.867	5	0.25
Na_2O	Derinoba granite	0.13	11	.200*	0.951	11	0.66
	Kayadibi granite	0.17	5	.200*	0.973	5	0.89
K_2O	Derinoba granite	0.13	11	.200*	0.974	11	0.93
	Kayadibi granite	0.30	5	0.15	0.866	5	0.25
P_2O_5	Derinoba granite	0.23	11	0.12	0.863	11	0.06
	Kayadibi granite	0.14	5	.200*	0.987	5	0.97
Ni	Derinoba granite	0.23	11	0.10	0.859	11	0.06
	Kayadibi granite	0.17	5	.200*	0.974	5	0.90
V	Derinoba granite	0.31	11	0.00	0.760	11	0.00
	Kayadibi granite	0.37	5	0.03	0.684	5	0.01
Cu	Derinoba granite	0.16	11	.200*	0.931	11	0.42
	Kayadibi granite	0.45	5	0.00	0.598	5	0.00
Pb	Derinoba granite	0.17	11	.200*	0.883	11	0.11
	Kayadibi granite	0.20	5	.200*	0.981	5	0.94
Zn	Derinoba granite	0.32	11	0.00	0.788	11	0.01
	Kayadibi granite	0.14	5	.200*	0.989	5	0.98
W	Derinoba granite	0.31	11	0.00	0.811	11	0.01
	Kayadibi granite	0.37	5	0.03	0.684	5	0.01
Rb	Derinoba granite	0.36	11	0.00	0.690	11	0.00
	Kayadibi granite	0.25	5	.200*	0.953	5	0.76
Ba	Derinoba granite	0.23	11	0.11	0.926	11	0.37
	Kayadibi granite	0.22	5	.200*	0.957	5	0.79
Sr	Derinoba granite	0.20	11	.200*	0.874	11	0.09
	Kayadibi granite	0.29	5	0.19	0.879	5	0.31
Ta	Derinoba granite	0.30	11	0.01	0.698	11	0.00
	Kayadibi granite	0.23	5	.200*	0.943	5	0.69
Nb	Derinoba granite	0.18	11	.200*	0.902	11	0.19
	Kayadibi granite	0.21	5	.200*	0.898	5	0.40
Hf	Derinoba granite	0.22	11	0.16	0.892	11	0.15
	Kayadibi granite	0.16	5	.200*	0.976	5	0.91
Zr	Derinoba granite	0.17	11	.200*	0.967	11	0.86
	Kayadibi granite	0.14	5	.200*	0.976	5	0.91
Y	Derinoba granite	0.20	11	.200*	0.859	11	0.06

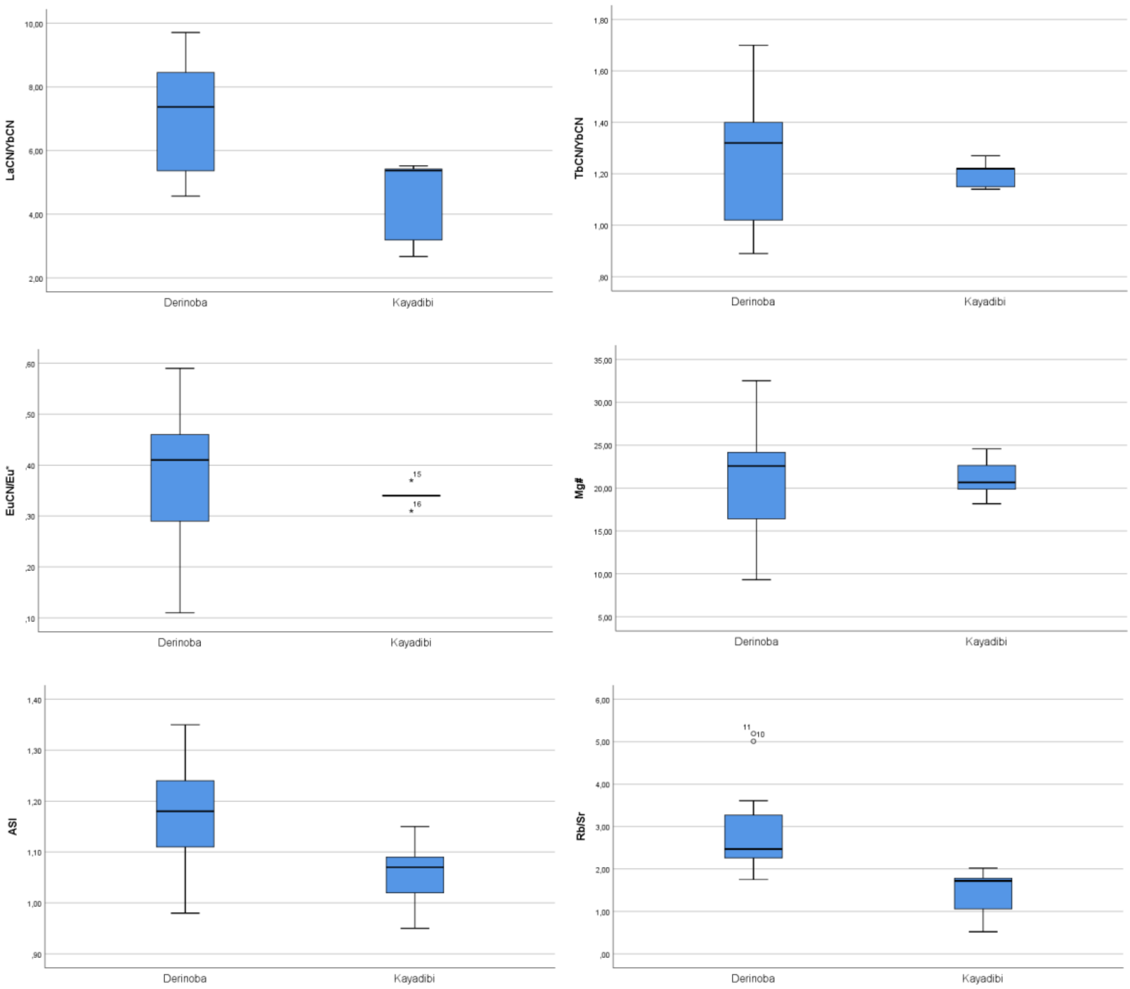
	Kayadibi granite	0.36	5	0.03	0.760	5	0.04
Th	Derinoba granite	0.29	11	0.01	0.827	11	0.02
	Kayadibi granite	0.24	5	.200*	0.947	5	0.72
U	Derinoba granite	0.27	11	0.02	0.843	11	0.03
	Kayadibi granite	0.20	5	.200*	0.959	5	0.80
Ga	Derinoba granite	0.26	11	0.04	0.852	11	0.04
	Kayadibi granite	0.22	5	.200*	0.941	5	0.67
La	Derinoba granite	0.12	11	.200*	0.979	11	0.96
	Kayadibi granite	0.35	5	0.04	0.761	5	0.04
Ce	Derinoba granite	0.20	11	.200*	0.849	11	0.04
	Kayadibi granite	0.28	5	.200*	0.849	5	0.19
Pr	Derinoba granite	0.15	11	.200*	0.949	11	0.63
	Kayadibi granite	0.24	5	.200*	0.881	5	0.31
Nd	Derinoba granite	0.15	11	.200*	0.942	11	0.55
	Kayadibi granite	0.22	5	.200*	0.917	5	0.51
Sm	Derinoba granite	0.22	11	0.16	0.825	11	0.02
	Kayadibi granite	0.21	5	.200*	0.909	5	0.46
Eu	Derinoba granite	0.19	11	.200*	0.888	11	0.13
	Kayadibi granite	0.24	5	.200*	0.886	5	0.34
Gd	Derinoba granite	0.15	11	.200*	0.943	11	0.56
	Kayadibi granite	0.20	5	.200*	0.966	5	0.85
Tb	Derinoba granite	0.14	11	.200*	0.934	11	0.45
	Kayadibi granite	0.20	5	.200*	0.920	5	0.53
Dy	Derinoba granite	0.18	11	.200*	0.906	11	0.22
	Kayadibi granite	0.34	5	0.05	0.794	5	0.07
Ho	Derinoba granite	0.20	11	.200*	0.874	11	0.09
	Kayadibi granite	0.19	5	.200*	0.970	5	0.87
Er	Derinoba granite	0.25	11	0.05	0.879	11	0.10
	Kayadibi granite	0.21	5	.200*	0.938	5	0.65
Tm	Derinoba granite	0.13	11	.200*	0.947	11	0.60
	Kayadibi granite	0.18	5	.200*	0.981	5	0.94
Yb	Derinoba granite	0.22	11	0.13	0.880	11	0.10
	Kayadibi granite	0.24	5	.200*	0.945	5	0.70
Lu	Derinoba granite	0.12	11	.200*	0.964	11	0.82
	Kayadibi granite	0.26	5	.200*	0.944	5	0.69
La_{CN}/Lu_{CN}	Derinoba granite	0.14	11	.200*	0.968	11	0.87
	Kayadibi granite	0.29	5	.200*	0.897	5	0.40
La_{CN}/Sm_{CN}	Derinoba granite	0.18	11	.200*	0.902	11	0.19
	Kayadibi granite	0.28	5	.200*	0.897	5	0.40
Gd_{CN}/Lu_{CN}	Derinoba granite	0.19	11	.200*	0.917	11	0.29
	Kayadibi granite	0.23	5	.200*	0.879	5	0.30
La_{CN}/Yb_{CN}	Derinoba granite	0.16	11	.200*	0.936	11	0.48
	Kayadibi granite	0.35	5	0.04	0.770	5	0.04
Tb_{CN}/Yb_{CN}	Derinoba granite	0.16	11	.200*	0.932	11	0.43
	Kayadibi granite	0.24	5	.200*	0.904	5	0.43
Eu_{CN}/Eu^*	Derinoba granite	0.17	11	.200*	0.922	11	0.33
	Kayadibi granite	0.30	5	0.16	0.883	5	0.33
Mg#	Derinoba granite	0.20	11	.200*	0.934	11	0.45
	Kayadibi granite	0.18	5	.200*	0.982	5	0.95
ASI	Derinoba granite	0.10	11	.200*	0.989	11	1.00
	Kayadibi granite	0.17	5	.200*	0.988	5	0.97
K_2O/Na_2O	Derinoba granite	0.17	11	.200*	0.942	11	0.54
	Kayadibi granite	0.38	5	0.02	0.779	5	0.05
Rb/Sr	Derinoba granite	0.24	11	0.08	0.844	11	0.04
	Kayadibi granite	0.29	5	.200*	0.902	5	0.42
Sr/Y	Derinoba granite	0.24	11	0.08	0.785	11	0.01
	Kayadibi granite	0.35	5	0.04	0.770	5	0.05
Nb/Ta	Derinoba granite	0.25	11	0.05	0.867	11	0.07
	Kayadibi granite	0.30	5	0.16	0.848	5	0.19
Zr/Hf	Derinoba granite	0.25	11	0.05	0.771	11	0.00
	Kayadibi granite	0.32	5	0.11	0.771	5	0.05
Th/U	Derinoba granite	0.22	11	0.16	0.913	11	0.27
	Kayadibi granite	0.30	5	0.15	0.843	5	0.17

*. This is a lower bound of the true significance
a. Lilliefors Significance Correction

Additionally, box-plot diagrams were created for some of the important parameters in determining the origin relationships of the rocks (Figure 3). In terms of Tb_{CN}/Yb_{CN}, Eu_{CN}/Eu^*, Mg#, Sr/Y, Nb/Ta, and Zr/Hf values, Kayadibi granite is observed to fall within the range of Derinoba granite. On the other hand, it is observed that ASI, Rb/Sr, and Th/U values are partially within similar ranges, while La_{CN}/Lu_{CN} and Rb/Sr parameters have slightly wider ranges relative to each other (Figure 3).

To determine the similarity of the parameters considered in the origin evaluation, the Mann Whitney U Test was used (Table 4). Low rank values for the data indicate that the results obtained for the corresponding parameter are also low. For example, it is stated that the value of Kayadibi granite is low for SiO_2, while the value of Derinoba granite is low for TiO_2. The other parameters are interpreted in the same way.

For the Mann Whitney U test statistics, the Asymp. Sig value is considered. If the sig. value is <0.05, it is stated that there is a 5% significant difference between the granitic rocks for the relevant parameters. If this value is greater than 5%, it is indicated that there is no significant difference between the two rock groups for the relevant parameters (with 95% probability). For a sig. value of 0.01, the same situation is interpreted as a difference between the rock groups studied at the 1% significance level for the relevant parameter, depending on the smallness of this value. If it is in the 1%-5% range, it is stated that the rocks are likely to have a similar origin for the relevant parameters with 99% probability.



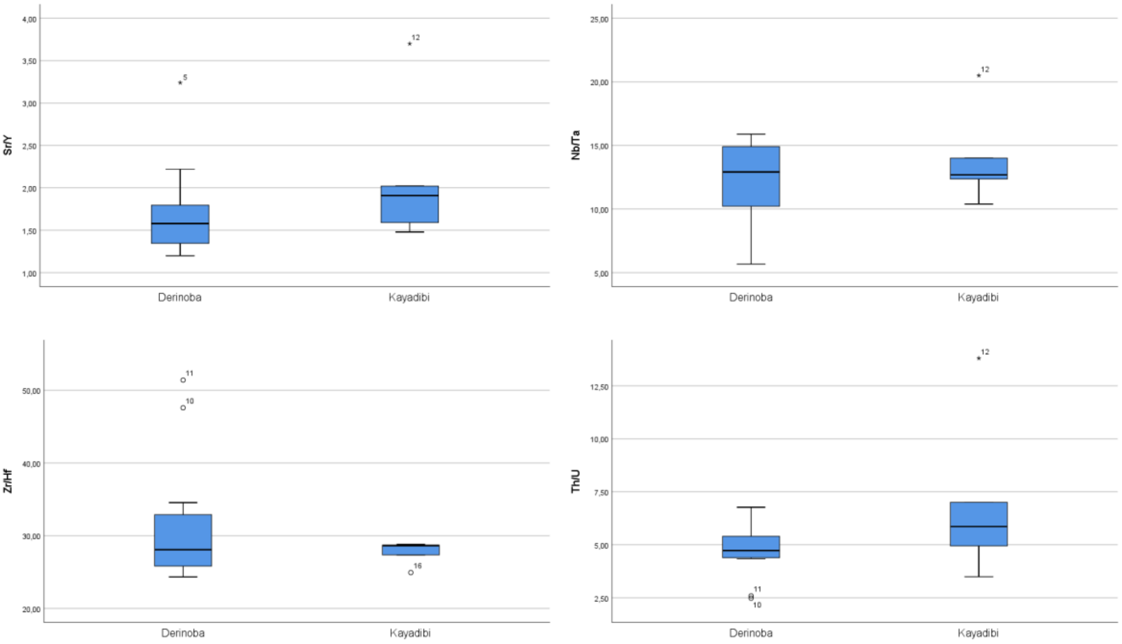


Figure 3. Comparative boxplot of some parameters for the Derinoba and Kayadibi granitic rocks.

Table 4. Mann Whitney U Test Rank Values (Left Region) and Mann Whitney U Test Test Statistics (Right Shaded Region)

Parameters	**Rocks**	**Mean Rank**	**Sum of Ranks**	**Parameters**	**Mann-Whitney U**	**Z**	**Asymp. Sig. (2-tailed)**	**Exact Sig. [2*(1-tailed Sig.)]**
SiO_2	Derinoba granite	10.64	117.00	**SiO_2**	4.000	-2.662	0.008	.005[b]
	Kayadibi granite	3.80	19.00	**TiO_2**	13.500	-1.609	0.108	.115[b]
TiO_2	Derinoba granite	7.23	79.50	**Al_2O_3**	17.000	-1.190	0.234	.267[b]
	Kayadibi granite	11.30	56.50	**$Fe_2O_3^T$**	13.000	-1.643	0.100	.115[b]
Al_2O_3	Derinoba granite	7.55	83.00	**MnO**	20.500	-0.812	0.417	.441[b]
	Kayadibi granite	10.60	53.00	**MgO**	16.500	-1.248	0.212	.221[b]
$Fe_2O_3^T$	Derinoba granite	7.18	79.00	**CaO**	11.000	-1.872	0.061	.069[b]
	Kayadibi granite	11.40	57.00	**Na_2O**	20.500	-0.794	0.427	.441[b]
MnO	Derinoba granite	7.86	86.50	**K_2O**	17.500	-1.134	0.257	.267[b]
	Kayadibi granite	9.90	49.50	**P_2O_5**	16.500	-1.290	0.197	.221[b]
MgO	Derinoba granite	7.50	82.50	**Ni**	19.500	-0.920	0.358	.377[b]
	Kayadibi granite	10.70	53.50	**V**	23.000	-0.567	0.571	.661[b]
CaO	Derinoba granite	7.00	77.00	**Cu**	15.000	-1.418	0.156	.180[b]
	Kayadibi granite	11.80	59.00	**Pb**	5.000	-2.551	0.011	.009[b]
Na_2O	Derinoba granite	7.86	86.50	**Zn**	15.000	-1.418	0.156	.180[b]
	Kayadibi granite	9.90	49.50	**W**	9.500	-2.079	0.038	.038[b]
K_2O	Derinoba granite	7.59	83.50	**Rb**	22.000	-0.624	0.533	.583[b]
	Kayadibi granite	10.50	52.50	**Ba**	10.500	-1.927	0.054	.052[b]
P_2O_5	Derinoba granite	7.50	82.50	**Sr**	3.000	-2.776	0.006	.003[b]
	Kayadibi granite	10.70	53.50	**Ta**	21.000	-0.746	0.455	.510[b]
Ni	Derinoba granite	7.77	85.50	**Nb**	18.000	-1.077	0.281	.320[b]
	Kayadibi granite	10.10	50.50	**Hf**	21.000	-0.737	0.461	.510[b]
V	Derinoba granite	8.91	98.00	**Zr**	20.000	-0.850	0.396	.441[b]
	Kayadibi granite	7.60	38.00	**Y**	1.000	-3.002	0.003	.001[b]
Cu	Derinoba granite	9.64	106.00	**Th**	1.000	-3.002	0.003	.001[b]
	Kayadibi granite	6.00	30.00	**U**	22.500	-0.568	0.570	.583[b]
Pb	Derinoba granite	6.45	71.00	**Ga**	17.000	-1.191	0.234	.267[b]
	Kayadibi granite	13.00	65.00	**La**	27.500	0.000	1.000	1.000[b]
Zn	Derinoba granite	9.64	106.00	**Ce**	18.000	-1.076	0.282	.320[b]
	Kayadibi granite	6.00	30.00	**Pr**	20.000	-0.850	0.396	.441[b]
W	Derinoba granite	10.14	111.50	**Nd**	26.000	-0.170	0.865	.913[b]
	Kayadibi granite	4.90	24.50	**Sm**	10.000	-1.984	0.047	.052[b]
Rb	Derinoba granite	9.00	99.00	**Eu**	27.000	-0.057	0.955	1.000[b]
	Kayadibi granite	7.40	37.00	**Gd**	5.000	-2.549	0.011	.009[b]

Ba	Derinoba granite	6.95	76.50	**Tb**	13.500	-1.587	0.112	.115[b]
	Kayadibi granite	11.90	59.50	**Dy**	13.000	-1.643	0.100	.115[b]
Sr	Derinoba granite	6.27	69.00	**Ho**	20.000	-0.850	0.396	.441[b]
	Kayadibi granite	13.40	67.00	**Er**	8.000	-2.211	0.027	.027[b]
Ta	Derinoba granite	9.09	100.00	**Tm**	6.000	-2.439	0.015	.013[b]
	Kayadibi granite	7.20	36.00	**Yb**	0.000	-3.118	0.002	.000[b]
Nb	Derinoba granite	9.36	103.00	**Lu**	2.000	-2.889	0.004	.002[b]
	Kayadibi granite	6.60	33.00	**La_{CN}/Lu_{CN}**	8.000	-2.209	0.027	.027[b]
Hf	Derinoba granite	7.91	87.00	**La_{CN}/Sm_{CN}**	16.000	-1.303	0.193	.221[b]
	Kayadibi granite	9.80	49.00	**Gd_{CN}/Lu_{CN}**	11.000	-1.872	0.061	.069[b]
Zr	Derinoba granite	7.82	86.00	**La_{CN}/Yb_{CN}**	9.000	-2.096	0.036	.038[b]
	Kayadibi granite	10.00	50.00	**Tb_{CN}/Yb_{CN}**	21.000	-0.738	0.461	.510[b]
Y	Derinoba granite	6.09	67.00	**Eu_{CN}/Eu^***	17.500	-1.142	0.253	.267[b]
	Kayadibi granite	13.80	69.00	**Mg#**	25.000	-0.283	0.777	.827[b]
Th	Derinoba granite	6.09	67.00	**ASI**	8.500	-2.156	0.031	.027[b]
	Kayadibi granite	13.80	69.00	**K_2O/Na_2O**	22.000	-0.624	0.533	.583[b]
U	Derinoba granite	8.05	88.50	**Rb/Sr**	3.000	-2.776	0.006	.003[b]
	Kayadibi granite	9.50	47.50	**Sr/Y**	15.000	-1.416	0.157	.180[b]
Ga	Derinoba granite	9.45	104.00	**Nb/Ta**	25.000	-0.283	0.777	.827[b]
	Kayadibi granite	6.40	32.00	**Zr/Hf**	25.000	-0.283	0.777	.827[b]
La	Derinoba granite	8.50	93.50	**Th/U**	15.000	-1.416	0.157	.180[b]
	Kayadibi granite	8.50	42.50					
Ce	Derinoba granite	7.64	84.00					
	Kayadibi granite	10.40	52.00					
Pr	Derinoba granite	7.82	86.00					
	Kayadibi granite	10.00	50.00					
Nd	Derinoba granite	8.36	92.00					
	Kayadibi granite	8.80	44.00					
Sm	Derinoba granite	6.91	76.00					
	Kayadibi granite	12.00	60.00					
Eu	Derinoba granite	8.45	93.00					
	Kayadibi granite	8.60	43.00					
Gd	Derinoba granite	6.45	71.00					
	Kayadibi granite	13.00	65.00					
Tb	Derinoba granite	7.23	79.50					
	Kayadibi granite	11.30	56.50					
Dy	Derinoba granite	7.18	79.00					
	Kayadibi granite	11.40	57.00					
Ho	Derinoba granite	7.82	86.00					
	Kayadibi granite	10.00	50.00					
Er	Derinoba granite	6.73	74.00					
	Kayadibi granite	12.40	62.00					
Tm	Derinoba granite	6.55	72.00					
	Kayadibi granite	12.80	64.00					
Yb	Derinoba granite	6.00	66.00					
	Kayadibi granite	14.00	70.00					
Lu	Derinoba granite	6.18	68.00					
	Kayadibi granite	13.60	68.00					
La_{CN}/Lu_{CN}	Derinoba granite	10.27	113.00					
	Kayadibi granite	4.60	23.00					
La_{CN}/Sm_{CN}	Derinoba granite	9.55	105.00					
	Kayadibi granite	6.20	31.00					
Gd_{CN}/Lu_{CN}	Derinoba granite	7.00	77.00					
	Kayadibi granite	11.80	59.00					
La_{CN}/Yb_{CN}	Derinoba granite	10.18	112.00					
	Kayadibi granite	4.80	24.00					
Tb_{CN}/Yb_{CN}	Derinoba granite	9.09	100.00					
	Kayadibi granite	7.20	36.00					
Eu_{CN}/Eu^*	Derinoba granite	9.41	103.50					
	Kayadibi granite	6.50	32.50					
Mg#	Derinoba granite	8.73	96.00					
	Kayadibi granite	8.00	40.00					
ASI	Derinoba granite	10.23	112.50					
	Kayadibi granite	4.70	23.50					

K_2O/Na_2O	Derinoba granite	8.00	88.00					
	Kayadibi granite	9.60	48.00					
Rb/Sr	Derinoba granite	10.73	118.00					
	Kayadibi granite	3.60	18.00					
Sr/Y	Derinoba granite	7.36	81.00					
	Kayadibi granite	11.00	55.00					
Nb/Ta	Derinoba granite	8.27	91.00					
	Kayadibi granite	9.00	45.00					
Zr/Hf	Derinoba granite	8.73	96.00					
	Kayadibi granite	8.00	40.00					
Th/U	Derinoba granite	7.36	81.00					
	Kayadibi granite	11.00	55.00					

In light of these explanations, when evaluating the Derinoba and Kayadibi granites; it was observed that the granites differ in terms of the elements Y, Th, Yb, and Lu (Sig. <0.01). It was determined that the Derinoba and Kayadibi granites have a similar origin at the 1% significance level (99% confidence interval) based on the parameters SiO_2, Gd, Tm, and Rb/Sr. Similar findings are also valid for the parameters Er, La_{CN}/Lu_{CN}, La_{CN}/Yb_{CN}, and ASI, indicating a common source. The other parameters studied also indicate a common source for the Derinoba and Kayadibi granites at the 95% confidence interval. Therefore, the common origin of the rocks has also been determined geoistically, and the findings of Kaygusuz et al. [27] have also been confirmed geoistically.

5. Conclusions

In this study, the main geochemical parameters of the Derinoba and Kayadibi granites located in the northern zone of the Eastern Pontides, were investigated using geostatistical approaches and methods to determine their genetic relationship. The granites studied are adjacent to each other, with the Derinoba granite located 65 km southwest of Trabzon, and the Kayadibi granite surfacing in the same direction and continuation. In this study, the general characteristics and ranges of the main geochemical parameters of the granites were determined using descriptive statistical parameters. Subsequently, the genetic similarity of the Derinoba and Kayadibi granites was statistically examined using the Mann Whitney U test. As a result of the study, it was determined that the SiO_2 contents of the Derinoba and Kayadibi granites are >%70, the TiO_2 contents are >%0.1, the Al_2O_3 contents are >%12, the $Fe_2O_3^T$ contents are >%1.40, and the total alkali contents are >%6. It was also determined that the values of La_{CN}/Lu_{CN}, La_{CN}/Sm_{CN}, Gd_{CN}/Lu_{CN}, La_{CN}/Yb_{CN}, Eu_{CN}/Eu^*, Mg# and ASI are, respectively, >5, >3, >1, >4, >1, >0.3, >20, and >1. When the genetic relationship between the Derinoba and Kayadibi granites was investigated using the Mann Whitney U Test, it could not be determined whether the granites share the same genetic source based on the elements Y, Th, Yb, and Lu. Based on the parameters SiO_2, Gd, Tm, Rb/Sr, Er, La_{CN}/Lu_{CN}, La_{CN}/Yb_{CN}, and ASI, it can be stated that the Derinoba and Kayadibi granites share the same genetic origin (with a significance level of 1% and/or within the 1%-5% significance level range). It was determined that the Derinoba and Kayadibi rocks share the same genetic origin within the 95% confidence interval for the other analyzed parameters besides SiO_2, Gd, Tm, Rb/Sr, Er, La_{CN}/Lu_{CN}, La_{CN}/Yb_{CN}, and ASI.

These geostatistical results have confirmed the findings of [27].

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