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A multivariate statistical assessment of Vein-type U-Th enrichment in Arıklı İgnimbrites

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Abstract

Various geological issues can be resolved using multivariate statistical methods. Mineralization zones have recently been investigated based on geochemical research findings. In this study, enriched U-Th anomalies in the fault zones of Arıklı ignimbrites were statistically evaluated. Magnesite and barite breccias are found in the fault zones of Arıklı ignimbrites. These fault zones also have the highest U-Th enrichment sequences. As a result, among the elements, MnO had the lowest average abundance and Ba had the highest average abundance. Pearson correlation coefficients were calculated to see the level of relationship between the elements; it was determined that there was a high level of positive correlation between Nb and Th, U and Y. Then a factor analysis was performed. The research yielded seven identified factors. Factor 1 includes many chemical concentrations (SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O, TiO_2, MnO, LOI, As, Cu, Ga, Rb, and Zr). Factor 2 includes P_2O_5, Nb, Sr, Th, and Y, as well as U-Th elements. As a result, other manganese oxide and trace element contents collaborated to enrich radioactive material.

1. Introduction

Multivariate statistical methods are used to identify important insights in geological research and many other professional disciplines [1]. Many scientists have looked for analytical and statistical explanations for properly implementing geochemical analysis results [2]. These explanations consider the use of both classical [3-4] and modern (such as fractal/multifractal analysis) mathematical techniques [5-6]. Studies based on statistical parameters, mineralization, correlation, and anomalies are presented to highlight geological relationships [7-8].

Major and strategic radioactive elements comprise uranium and thorium. Applications are made to search for these elements because they are abundant in many geological regions. The main sources of rocks for uranium enrichment are granite and volcanic rocks [9-10]. U deposits are categorized into four classes based on the lithology of the host rock [11]. They are, in order, carbonaceous-silica-pelitic rock type (CSP-type), sandstone type, volcanic rock type (V-type), and granite rock type (G-type). According to reports [12], Turkey's major uranium enrichment facilities are located in western Anatolia.

MTA initiated uranium prospecting activities in Turkey in 1953, and exploration studies have already continued [13-14]. Miocene carbonate rocks in the Ayvack-Küçükkuyu field near Anakkale province had a U_3O_8 value of 0.08% [15-16]. The volcanic tuffs between Küçükkuyu and Ayvack include phosphate nodules and natural radiation sources [17]. Taurite and uraninite, minerals found in the sands along the nearby Geyikli coast, contain heavy metals, uranium, and thorium [18]. Granitic rocks that are exposed near Geyikli are the source of these radioactive materials [18]. In and around Arıklı, bayleite and ningyoite have a U enrichment in chemical composition, according to Günaydın's [14] explanation.

High levels of natural radiation were also detected in the fault zones surrounding Örencik and Feyzullah Tepe, northwest of Arıklı. Magnesite breccias in the northwest of Arıklı are formed by the action of hydrothermal waters, and this fault zone contains U up to 700 ppm and Th greater than 1000 ppm [14]. According to Günaydın's [14] explanation, bayleite and ningyoite have a U enrichment in chemical composition in and around Arıklı.

Öztürk et al., [19] examined microthermometric measurements from magnesite observed in these fault zones and revealed that homogenization temperature (Th, ^{o}C) ranged from 282-348 ^{o}C and % NaCl salinity equivalents ranged from 4.2-8.0. They also state that the solution system of liquid inclusions is H_2O-$MgCl_2$-$CaCl_2$, and the density of liquids ranges between 0.58 and 0.74 g/cm^3. Yalçın et al. [20-21] used GIS applications and thematic maps to illustrate this region's geochemical distribution of U and Th enrichment.

This study employed a multivariate statistical analysis of the geochemical contents of 30 samples collected northwest of Arıklı, where Öztürk et al. [19] discovered the highest radioactive results.

2. Material and Method

Multivariate statistical approaches include correlation analysis (CA), factor analysis (FA), discriminant analysis (DA), and principal component analysis. Using IBM SPSS Statistics 23 program, the results of major oxide (%) and trace element (ppm) analysis of Öztürk et al. [19].

Pearson correlation coefficients were recalculated before factor analysis. Major oxide and trace element results were correlated with each other. Factor analysis was then performed to determine the differences between the samples. Subsequently, classifications belonging to the factors were revealed.

2.1. Geological framework

The field of application is in Western Anatolia, south of the Biga peninsula in the Sakarya Zone and is located in the Ayvacık district of Çanakkale (Figure 1a). Okay et al. [22] classified the units in the Çanakkale province as pre-Tertiary and post-Tertiary. It was divided into three pre-Tertiary tectonic zones observed in the NE-SW direction in subsequent studies [23-24]. These zones are the Ezine Zone, the Ayvack-Karabiga Zone, and the Sakarya Zone, in that order. In the north of the Gulf of Edremit, many metamorphic facies, as well as magmatic, ophiolite, sedimentary, and volcanic rock groups, have been established (Figure 1b) [25-26]. Miocene Pliocene continental sediments and Cretaceous Çetmi melange are outcropping in the vicinity of Arıklı (Figure 1b).

The study area comprises Cretaceous-aged Çetmi Ophiolitic Melange, Küçükkuyu Formation, and Quaternary-aged alluvial deposits. The Küçükkuyu formation was divided into a shale-sandstone member and an Arıklı tuff member, and diabases that cut these units were mapped on the Örencik Tepe (Figure 2).

2.2. Arıklı Tuff Member

Arıklı iginmbrites are widely outcropped in the study area around Arıklı (Figure 2). This unit, which is observed topographically at higher levels, spreads in Örencik Tepe, Feyzullah Tepe, west of Nusratlı, around Kale Tepe and Hasanoba region. Arıklı ignimbirites, consists of andesite-dacite lava and tuffs. In the northwest of Arıklı, there are hydrothermal magnesite breccias in dip-slip fault contacts [14]. The contact relationship of this unit, which has a lateral vertical transition with the shale-sandstone member, is tectonic in some regions. This unit is located side by side with Çetmi ophiolitic melange by dip-slipfault in the north of Hasanoba. In the north of Örencik Tepe, diabase dyke cuts this unit with an E-W trending (Figure 2).

2.3. Mineralization

In the field, Öztürk et al. [19] collected 48 samples. Geochemical analyzes were carried out at the Istanbul Technical University Geochemistry Research Laboratory (ITU-JAL). Major oxides were determined by XRF (X-Ray Floresance) method in BRUKER S8 TIGER device, and trace elements were determined by ICP-MS (Inductively Coupled Plasma Mass Spectroscopy) method in Perkin Elmer ELAN 6000 DRC-e device.

According to the analysis results, U and Th anomalies are observed in the dip-slip fault zones. U is between 64-1640 ppm and Th is between 302-11813 ppm in these fault zones. As a result of these issues, U and Th mineralizations in the location are associated with fault zones observed in Arıklı ignimbrites.

It is stated that the mineralization is vein type since it is observed only in fault zones and is associated with magnesite breccias. The direction of this mineralization observed in a very narrow and limited area is the same with the direction of the fault.

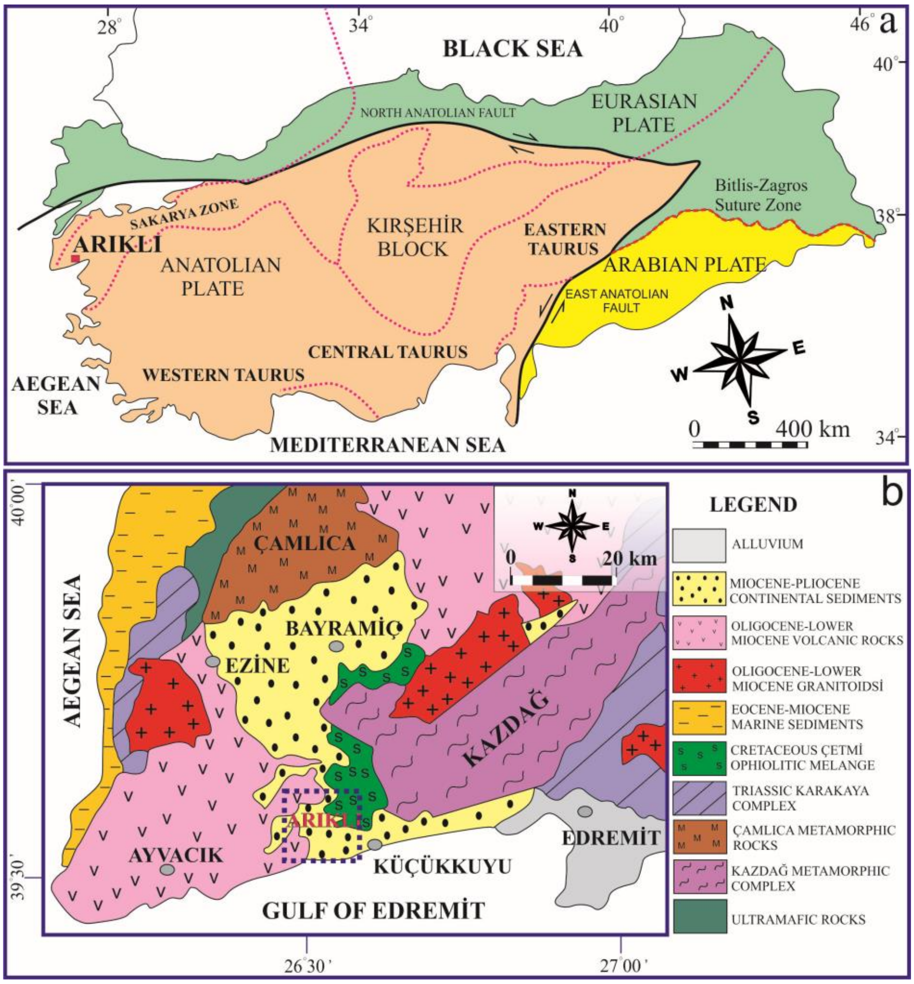

Figure 1. a. Tectonic location of the study area (modified from Işık [27]), b. Generalized geology map of the Biga region and location of the study area (modified from Okay and Satır [25]; Şengün et al. [26])

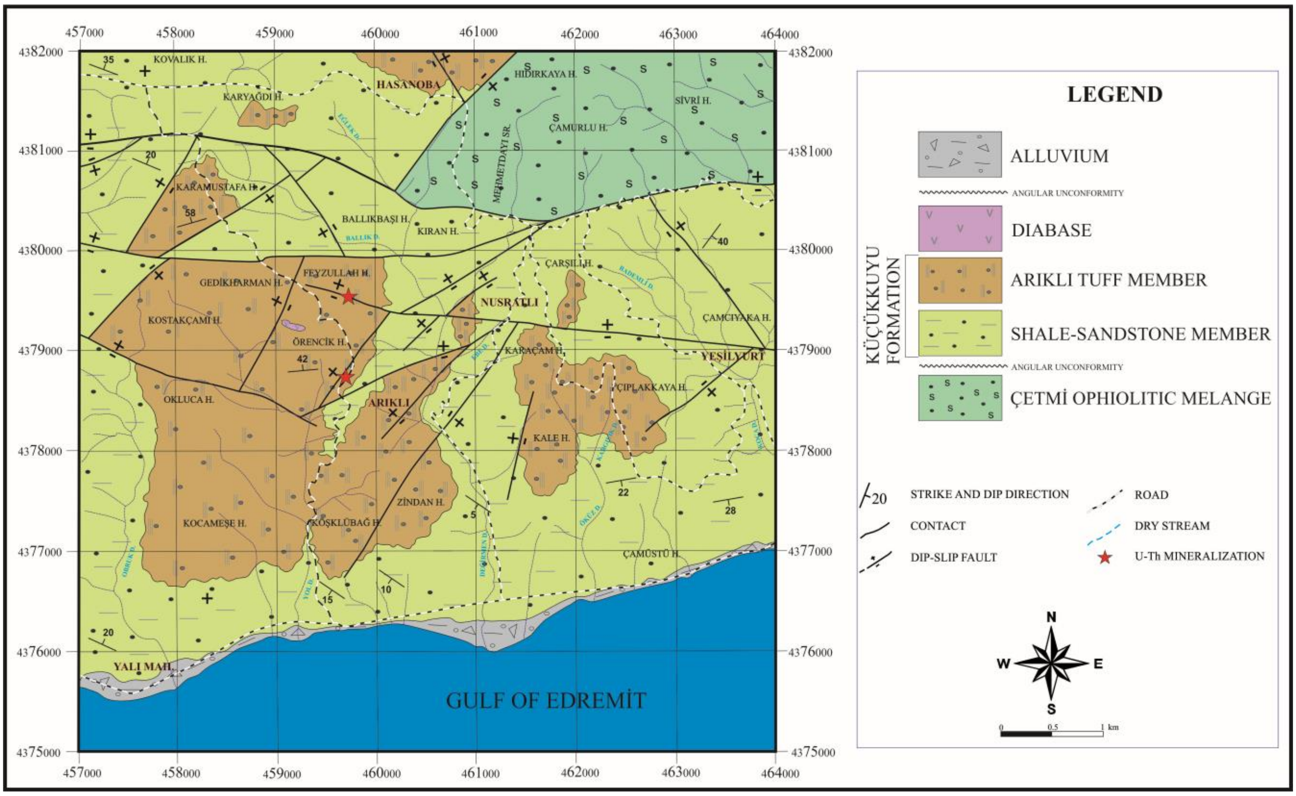

Figure 2. Geological map of the study area [19]

3. Multivariate Statistical Analysis

Multivariate analysis refers to a variety of statistical techniques/methods that are using primarily multivariate data to investigate the mathematical relation or relationships between variables of curiosity. Factor analysis is a statistical technique that utilizes a low amount of non-observed variables known as factors to explain variation among linked variables. Many geological studies have been using this technique to propose approaches based on data sets. In general, spatial and statistical approaches are used to identify patterns from geochemical analysis data. The chemical composition of 30 samples was investigated using multivariate statistical analysis techniques in the study. The descriptive statistics for chemical data are shown in Table 1. As a result, among the elements, MnO had the lowest average abundance and Ba had the highest average abundance.

Table 1. Descriptive statistics of geochemical data

Variant	**min**	**mean**	**max**	**sd**	**skewness**	**kurtosis**
SiO_2	2.00	46.69	95.70	25.77	-0.56	2.12
Al_2O_3	0.11	10.50	19.96	6.20	-0.52	1.88
Fe_2O_3	0.22	3.38	11.27	2.59	0.74	3.42
MgO	0.00	10.21	40.10	13.78	1.17	2.79
CaO	0.00	5.13	30.57	7.24	2.35	8.37
Na_2O	0.00	0.48	3.91	0.76	2.91	12.95
K_2O	0.00	5.25	15.40	4.55	0.55	2.39
TiO_2	0.01	0.45	1.28	0.34	0.33	2.16
P_2O_5	0.00	0.18	0.93	0.22	2.29	7.93
MnO	0.01	0.07	0.18	0.05	0.80	2.83
Cr_2O_3	0.00	0.08	0.45	0.13	1.69	4.52
SO_3	0.00	0.11	0.60	0.17	1.72	4.62
LOI	0.00	17.20	49.02	18.60	0.82	1.87
As	0.00	184.25	727.00	170.02	1.62	5.74
Ba	0.00	643.44	5039.00	837.44	4.11	22.40
Ce	0.00	94.72	1491.00	269.25	4.14	21.40
Cl	0.00	187.94	2874.00	474.27	5.26	30.26
Co	0.00	4.28	68.00	12.43	4.15	20.86
Cu	0.00	31.94	91.00	17.86	0.55	5.03
Ga	0.00	8.03	40.00	12.50	1.24	3.27
Nb	0.00	6.22	62.00	11.34	3.45	17.37
Ni	0.00	93.72	409.00	106.01	1.14	3.38
Pb	0.00	11.81	75.00	23.22	1.56	3.74
Rb	0.00	125.11	395.00	104.78	0.59	2.65
Sr	19.00	364.11	2977.00	544.29	3.38	16.05
Th	0.00	376.39	11813.00	1962.99	5.72	33.86
U	0.00	47.64	1640.00	273.19	5.73	33.92
V	0.00	22.61	458.00	82.30	4.48	23.35
Y	0.00	25.67	864.00	143.80	5.74	33.95
Zn	0.00	17.64	88.00	25.68	1.27	3.44
Zr	0.00	151.92	523.00	119.74	0.78	3.81

Pearson correlation coefficients were calculated to see the correlation levels between the elements. The results of the correlation analysis are presented in Table 2. Between SiO_2 and Al_2O_3; Between Al_2O_3 and K_2O, TiO_2 and Rb; Between Fe_2O_3 and Na_2O, TiO_2 and Cu; Between Mg and LOI; Between CaO and Sr; between Na_2O and V; Between K_2O and As and Rb; between As and Ba and Rb; between Rb and Z; between Nb and Th, U and Y; It was observed that there was a high level of positive correlation between Th and U and Y, and finally between U and Y. Besides, between MgO and SiO_2 and Al_2O_3; between K_2O and MgO; Between LOI and SiO_2, Al_2O_3, K_2O and TiO_2; There is a high level of negative correlation between Rb and MgO and LOI. Factor Analysis was performed to determine the differences between the samples. As a result of this analysis, 7 factors were obtained. The variance explanation ratios including the eigenvalues of the factors obtained are presented in Table 2.

Table 2. Eigenvalues of the Factors obtained

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor 1	10.079	4.809	0.328	0.328
Factor 2	5.269	1.842	0.172	0.500
Factor 3	3.428	1.294	0.112	0.611
Factor 4	2.134	0.195	0.070	0.681
Factor 5	1.939	0.232	0.063	0.744
Factor 6	1.707	0.378	0.056	0.800
Factor 7	1.329	0.378	0.043	0.843

Table 3 lists the factor loading values for the elements connected to the determined factors. The elements' inclusion in the factors is shown by the values in bold. SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O, TiO_2, MnO, LOI, As, Cu, Ga, Rb, and Zr elements are classified under factor 1; P_2O_5, Nb, Sr, Th, U, and Y elements are classified under factor 2; Na_2O, Pb, and V elements are classified under factor 3; SO_3, Ba, and Ce elements are classified under factor 4; Co element is classified under factor 5. Ni and Zn elements are the last to be included under factor 6; factor 7 also includes Cr_2O_3 and Cl elements.

Table 3. Factor load values

Variant	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
SiO_2	**0.7973**	-0.064	-0.078	-0.1065	-0.5452	-0.0558	-0.0865
Al_2O_3	**0.8952**	0.0285	-0.0643	0.1049	-0.1049	0.0478	-0.161
Fe_2O_3	**0.8023**	0.2191	0.4695	0.092	0.1077	-0.0863	0.0132
MgO	**-0.8327**	-0.2273	0.055	0.0241	0.3759	0.0771	0.1187
CaO	**-0.6118**	0.4963	0.083	0.1631	0.2257	-0.1084	-0.0387
Na_2O	0.4242	0.1166	**0.7402**	0.2023	0.1919	0.3059	-0.0888
K_2O	**0.8316**	0.1592	-0.3625	-0.2295	0.0696	-0.022	0.0364
TiO_2	**0.85**	0.2139	0.3096	0.0424	0.1139	-0.1339	0.0551
P_2O_5	0.1846	**0.7755**	0.419	-0.1987	0.0464	0.021	0.2323
MnO	**0.5672**	0.2724	0.2737	-0.015	0.2968	-0.3685	0.1336
Cr_2O_3	0.2613	-0.0428	-0.2266	0.3566	-0.3436	0.0695	**0.6752**
SO_3	0.4136	0.1232	-0.0875	**0.752**	0.0628	0.117	-0.1894
LOI	**-0.9019**	-0.0519	0.0422	0.0562	0.3829	0.0517	0.087
As	**0.559**	0.306	-0.3948	-0.3787	0.4203	0.0672	0.0442
Ba	0.3929	0.2145	0.0745	**0.5817**	0.0859	-0.0242	-0.3412
Ce	0.3941	0.1616	-0.4148	**-0.45**	0.3784	-0.1187	0.1348
Cl	0.1594	0.0117	-0.3897	0.3344	-0.0098	0.4423	**0.4664**
Co	-0.165	0.2727	0.0355	-0.3189	**-0.6059**	-0.0591	-0.1297
Cu	**0.6962**	0.038	0.4286	0.0541	0.0423	0.1394	0.2289
Ga	**0.4571**	0.1195	-0.2868	0.0799	0.2938	-0.3812	-0.2936
Nb	-0.0545	**0.905**	-0.2036	0.0937	-0.169	0.0555	0.0294
Ni	0.4793	0.11	0.2352	0.0055	-0.1074	**-0.6309**	0.2811
Pb	0.2694	0.4514	**-0.5777**	-0.1204	0.2525	0.3768	-0.0193
Rb	**0.8187**	0.2221	-0.3469	-0.0777	0.0276	0.1028	-0.0555
Sr	-0.6516	**0.6768**	0.0886	0.1532	0.1105	-0.0094	0.0029
Th	-0.4371	**0.8717**	-0.0168	-0.0145	-0.1441	0.0122	-0.0354
U	-0.4234	**0.8742**	-0.0136	-0.0126	-0.1549	0.004	-0.036
V	0.3029	0.1325	**0.7324**	-0.2403	0.1541	0.3257	0.1445
Y	-0.406	**0.8834**	-0.0112	0.0017	-0.161	-0.0006	-0.0363
Zn	0.2345	-0.071	0.3727	-0.4316	-0.1364	**0.5551**	-0.2605
Zr	**0.6908**	0.1154	-0.3371	0.2021	0.0353	0.2368	-0.1066

4. Conclusion

The geochemical behavior of the geochemically prospected U-Th enrichment with other main oxides and trace elements was also explained in this work using statistical methods.

The data obtained in geochemical prospecting studies can also be interpreted by mathematical analysis. Statistical approach can also provide important information in ore exploration studies in many occupational groups.

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Author contributions

Cihan Yalçın: Writing-Reviewing and Editing, Geology, Methodology, Geochemistry**. Önder Belgin:** SPSS, Statistical analysis, Writing-Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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