Bull. Min. Res. Exp. (2019) 160: 163-175

Bulletin of the Mineral Research and Exploration

http://bulletin.mta.gov.tr

Statistical approach by factor and cluster analysis on origin of elements from the Hamit Plutonic (Turkey) rock samples

Fusun YALCIN[a*], Daniel G. NYAMSARI[b], Nurdane ILBEYLI[b] and Rifat BATTALOĞLU[c]

[a]*Akdeniz University, Department of Mathematics, 07058, Antalya, Turkey.*
[b]*Akdeniz University, Department of Geological Engineering, 07058, Antalya, Turkey.*
[c]*Niğde Ömer Halisdemir University, Department of Chemistry, 51200, Niğde, Turkey.*

Research Article

Keywords:
Plutonic Rocks' Data, Multivariate analysis, Cluster analysis, Factor analysis.

Received Date: 18.06.2018
Accepted Date: 05.11.2018

ABSTRACT

The Hamit pluton forms part of the Central Anatolian Crystalline Complex. It is located N-NE of Kaman (Kirsehir). It covers an area of about 120 km^2. The geochemical contents of 63 rock samples collected from this pluton were analyzed for their origin, homogeneity and relationship with crustal rocks. Their element contents were determined by using X-Ray Fluorescence spectroscopy. The samples were divided into 2 major groups based on their similarities: Group 1 contained 63.5% of the samples and indicated they were formed from melts whose contents might have evolved greatly due to crustal assimilation; while the 36.5% of samples belonged to Group 2, and show minimal evolution of the melt. According to the variation in K/Rb ratio versus SiO_2 and the Rb/Zr versus SiO_2 the initial melt had experience great evolution due to crustal assimilation. The initial melt is considered to have contained "most" of SiO_2, TiO_2, Fe_2O_3, MnO, MgO, CaO, P_2O_5, Sr, Zn, Cu, Ni, Co, Cr, Ba, Nd, Sc and V that formed the pluton, while "majority" of the Al_2O_3, Nb, Zr, U, Th, Pb, Ga, Rb, Ce and La are considered to have been derived from crustal contamination, and "almost all" of Na_2O, K_2O and Y are considered to have originated from crustal assimilation.

1. Introduction

Practically, the term "alkaline" is used to encompass a wide range of igneous rocks, all of which do not conform to this rigid definition. Carbonatites, for example, are certainly silica-deficient but are rarely alkali-rich (Fitton and Upton, 1987). Alkaline plutonic rocks are large scale intrusive igneous rocks containing an excess of alkali oxides (Na_2O + K_2O) over silica and/or alumina with respect to alkali. The excess alkali in these rocks cannot be accommodated in feldspar alone and so they appear in feldspathoids, sodic pyroxenes, sodic amphiboles and other alkali-rich phases (Fitton and Upton, 1987).

Alkaline rocks are usually important for their geochemical contents as they can host or be associated with most of the world's resources of niobium (Nb), tantalum (Ta), rare earth elements (REE) (Fitton and Upton, 1987) and mostly associated with economic deposits of apatite (Verplanck et al., 2014) and with diamonds (Mitchell, 1991).

The Central Anatolian Crystalline Complex is made up of metamorphic rocks overthrust by ophiolitic units and intruded by a number of calc-alkaline to alkaline plutons (Göncüoğlu et al., 1991) as shown in figure 1. One of the alkaline pluton in the complex is the Hamit pluton, which is surrounded by the Paleozoic Kaman metamorphics, the Mesozoic Karakaya ultramafics and the Cenozoic cover units. The Hamit pluton is

Citation info: Yalcin,F., Nyamsari, D. G., Ilbeyli,N., Battaloglu, R. 2019. Statistical approach by factor and cluster analysis on origin of elements from the Hamit Plutonic (Turkey) Rock Samples. Bulletin of the Mineral Research and Exploration, 160, 163-175. *http://dx.doi.org/10.19111/bulletinofmre.502074*
* *Corresponding author: Fusun Yalcin, fusunyalcin@akdeniz.edu.tr*

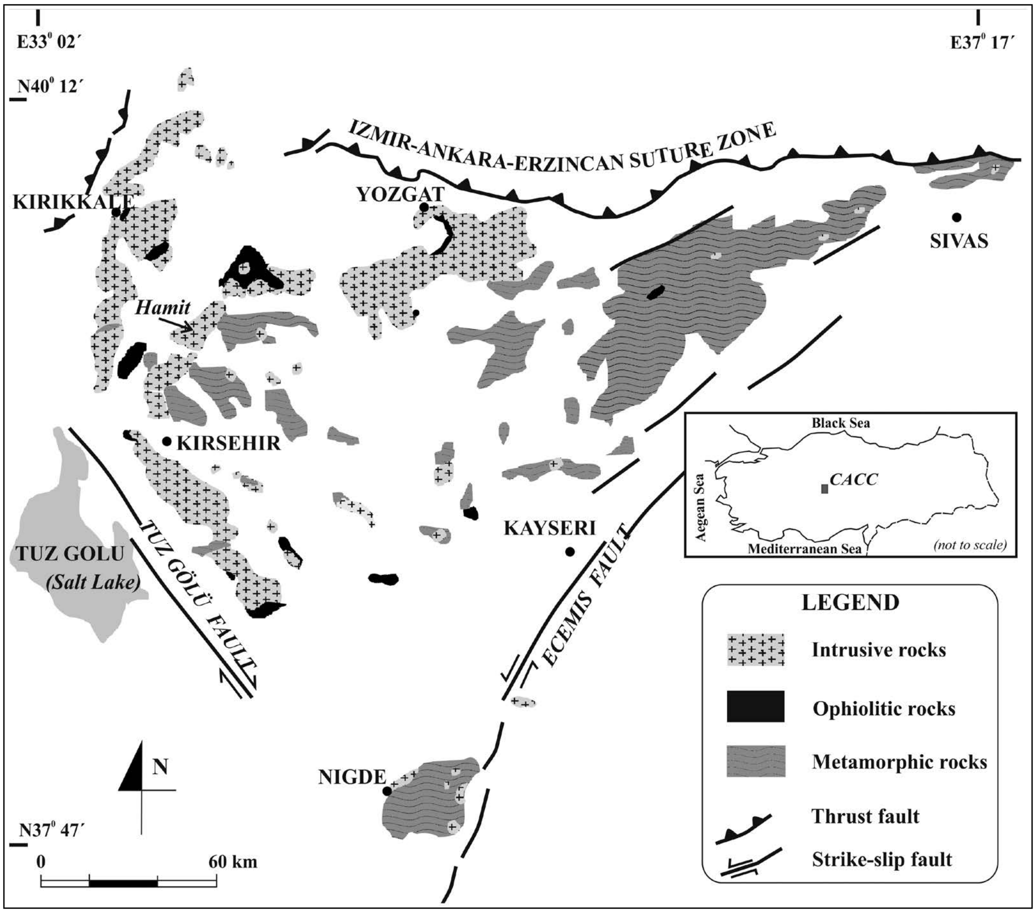

Figure 1- Geological setting of the Central Anatolian Crystalline Complex (after Bingöl, 1989).

situated in N-NE of Kaman and covers an area of about 120 km^2 containing nepheline syenite, pseudoleucite syenite, alkali feldspar syenite and quartz syenite. The alkaline-peralkaline Hamit intrusive rocks show comparable field to the petrographic and geochemical characteristics with A-type granites (Ilbeyli, 2004). The aim of this study is to use factor and cluster analysis to: examine the homogeneity of the samples' contents and study the origin and relationship of the elements in the parental magma that eventually lead to the formation of these plutonic rocks.

The use of factor analysis is this study is tied to the fact that it could show not only chemical changes during alteration but also chemical variation in the rocks (Gill, 1972). Meanwhile according to Yalcin et al. (2013) cluster analysis can be used to identify similarly or homogeneously combining samples. These methods have also been used in interpreting geochemical data by several different authors in their publications (Child, 1970; Lawley and Maxwell, 1971; Jöreskog et al., 1976; Facchinelli et al., 2001; Kumru and Bakac, 2003; Boruvka et al., 2005; Yalcin and İlhan, 2008; Akbarpour et al., 2013; Yalcin et al., 2013; Yalcin and Ilbeyli, 2014, 2015; Ilbeyli and Yalcin, 2015).

2. Materials and Method

Sixty-three (63) representative rock samples (Ilbeyli, 1999) were collected from along the Hamit pluton and store in plastic bags with the use of a hammer and a sledgehammer. The location of every sample was noted with the use of a GPS and transported to the University of Durham, United Kingdom where they were prepared for X-Ray Fluorescence to determine their element contents. In the laboratory, the samples were prepared one by one. Their sizes were first reduced with the use of a hammer and a jaw crusher, after which they were reduced to a homogenized powder form using an agate ball mill and then pressed into pellets. Before the preparation of each sample, the apparatus was washed with water and purified with washed with 10% HNO_3 acid to prevent contamination from other samples, and then dried with compressed air. The major and trace elements were then determined using pressed powder pellets by X-ray fluorescence spectrometry (XRF) at the University of Durham, United Kingdom using an automated Philips PW 1400 spectrometer with a Rh anode tube.

Major Elements: From the 63 samples analyzed, the main analytes for alkaline rocks are composed of averages as follows: SiO_2 (60.02%), Al_2O_3 (19.45%), CaO (2.87%), Na_2O (4.51%), K_2O (8.10%). SiO_2 and K_2O both have an approximately right symmetric distribution (skewness ranging between 0 and 0.5) implying most of their values are close to and lower than the mean value. CaO has a moderately skewed distribution with its skewness in the range of 0.5 and 1, while Al_2O_3 and Na_2O are highly and right skewed (skewness > 1). This indicates most of their values were lower than the mean value with extreme values higher than the mean value, as confirmed by the median values 18.98 (Al_2O_3) and 4.30 (Na_2O), which are lower than their respective mean values; as shown on table 1 below.

Trace Elements: 15 trace elements were analyzed. The averages of six of the significant trace element analytes are: Ba (599.37 ppm), Sr (550.74 ppm), Zr (351.92 ppm), Rb (303.15 ppm), Th (79.63 ppm) and Nb (39.97 ppm). Ba and Sr (with Skewness of 0.73 and 0.59 respectively) have a moderately right skewed distribution while Zr, Rb and Nb (with skewness 1.25, 1.16 and 1.52 respectively) show a highly right skewed distribution and Th shows an approximately symmetrical distribution. Out of the other nine trace elements, 7 of them (Pb, V, Ga, U, Cu, Ni, and Cr) show highly right skewed distribution while Zn shows approximately symmetric distribution and Co shows a moderately skewed distribution; as shown on table 1 below.

Rare Earth Elements – REE: 5 REE where analyzed. They have averages in ppm as follows Ce (171.56), La (105), Nd (51.49), Y (34.59) and Sc (3.64). According to their distribution patterns, La (-0.24) and Nd (-0.35) both have an approximately symmetric distribution, while Ce (-0.99), Y (0.87) and Sc (0.96) show moderately skewed distribution; as shown on table 1 below.

The box plot, figure 2, shows the anomalous concentration of an elements' distribution within

Table 1- Summary of statistical description of the various elements in the samples analyzed.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba	Sr	Zr	Rb	Th
N	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00
Minimum	52.52	0.04	14.50	0.42	0.00	0.02	0.15	1.78	5.86	0.00	22.30	57.70	20.20	173.80	2.30
Maximum	72.24	0.74	25.86	6.49	0.15	3.02	7.15	8.32	11.30	0.44	2082.10	1452.50	996.70	559.30	160.20
Mean	60.02	0.38	19.45	3.10	0.09	0.76	2.87	4.51	8.10	0.13	599.37	550.74	351.92	303.15	79.63
Median	60.96	0.31	18.98	2.21	0.11	0.31	1.93	4.30	8.01	0.04	168.80	198.60	332.10	283.80	67.00
Skewness	0.10	0.32	1.40	0.60	-0.35	1.47	0.79	1.18	0.35	0.93	0.73	0.59	1.25	1.16	0.36
Kurtosis	-1.32	-0.91	2.50	-0.96	-1.34	0.97	-0.86	3.06	-0.08	-0.74	-1.21	-1.56	1.37	1.87	-0.63
Std. Deviation	5.17	0.20	2.15	1.83	0.05	0.94	2.38	1.18	1.18	0.15	660.59	524.05	232.20	79.70	35.75
	Zn	Pb	V	Nb	Ga	U	Cu	Ni	Cr	Co	Ce	La	Nd	Y	Sc
N	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00	63.00
Minimum	8.40	40.80	0.60	8.20	12.20	0.00	0.00	0.00	0.00	0.00	6.30	14.60	3.60	2.00	0.00
Maximum	156.50	146.30	125.50	101.00	41.00	44.70	36.80	31.80	52.80	16.90	290.30	182.60	103.80	104.30	11.50
Mean	65.27	62.54	46.44	39.97	20.23	10.73	10.52	8.78	8.76	4.79	171.56	105.38	51.49	34.59	3.64
Median	59.50	59.20	32.80	37.20	19.60	9.10	5.00	6.40	3.40	3.00	178.40	103.10	53.50	36.80	2.70
Skewness	0.38	2.35	1.03	1.52	1.75	1.53	1.04	1.26	1.74	0.98	-0.99	-0.24	-0.35	0.87	0.96
Kurtosis	-0.51	6.17	-0.10	2.80	4.98	2.82	-0.41	1.41	3.39	-0.19	1.70	0.64	-0.02	2.87	0.22
Std. Deviation	34.34	19.57	34.96	19.33	5.20	9.77	11.19	7.10	11.12	4.86	58.78	37.97	21.96	18.09	2.97

the samples. In all the samples, SiO_2, TiO_2, Fe_2O_3, MnO, CaO, K_2O, P_2O_5, Sr, Th, Zn, Cu, Co, Ba, Nd and Sc, show no anomalous concentration and most of them also display an approximately symmetric to moderately skewed distribution. Al_2O_3 shows high anomaly concentrations in 3 samples (S15, S28 and S31) and low anomaly in 1 sample (S56); MgO shows high anomalies in 4 samples (S5, S6, S9 and S13); Na_2O shows high anomalous concentrations in 5 samples (S15, S16, S17, S20, and S41) and low anomalies in 2 samples (S29 and S30); Nb has high anomaly concentrations in 4 samples (S28, S29, S30 and S31) and low in 4 samples (S33, S35, S40 and S56); Zr shows very high anomalies in 8 of the samples (S15, S16, S17, S20, S28, S29, S30 and S31). Rb shows high anomalies in 2 samples (S29 and S30); Y shows high anomalies in 2 samples (S44 and S46); Ce shows high anomalies in 2 samples (S30 and S36) and low anomalies in 4 samples (S33, S34, S40 and S56); and La has high anomalies in 2 samples (S30 and S31) and low anomalies in 4 samples (S33, S39, S40 and S56).

Correlation: Considering the major determinant element of an alkaline rock (SiO_2, Al_2O_3, Na_2O and K_2O), the coefficient correlation matrix presented on table 2 reveals that SiO_2 shows no significant positive relationship with any of the elements; rather they show very strong negative/weak relationship (where $r < -0.7$) with TiO_2, Fe_2O_3, MnO, MgO, CaO, P_2O_5, Sr, Zn, Co, Ba, Nd, Sc and V. Meanwhile there exist “strong” positive relationship ($r > 0.7$) between Al_2O_3 and Nb and Zr; and between CaO and MnO, Sr, Cu, Ni, Ba, Nd and Sc. A moderately strong positive relationship (where $r > 0.5$) exists between Al_2O_3 and U, Ga, Zn, Ce and La; between CaO and Zn and Y; between Na_2O and Pb; between K_2O and Rb. Whereas there exists moderately negative (moderately weak) relationship (where $-0.7 < r < -0.5$) between SiO_2 and Cu, Ni and Ce; and between MgO and K_2O; and weak negative relationship (where $-0.5 < r < 0$) between CaO and Na_2O, K_2O, Th and Rb; between Na_2O and Fe_2O_3, MgO, P_2O_5, Cu, Co, Sc and V; between K_2O and P_2O_5, Sr, Cu, Ni, Co, Ba, Sc and V.

On the other hand, considering the rest of the elements constituted in the rock samples, we notice that a “very strong” positive correlational relationship ($r > 0.9$) is demonstrated among the following elements: between TiO_2 and Fe_2O_3, CaO, P_2O_5, Co and V; between Fe_2O_3 and MgO, CaO, P_2O_5, Co and V; between MgO and CaO, P_2O_5, Co; between CaO and

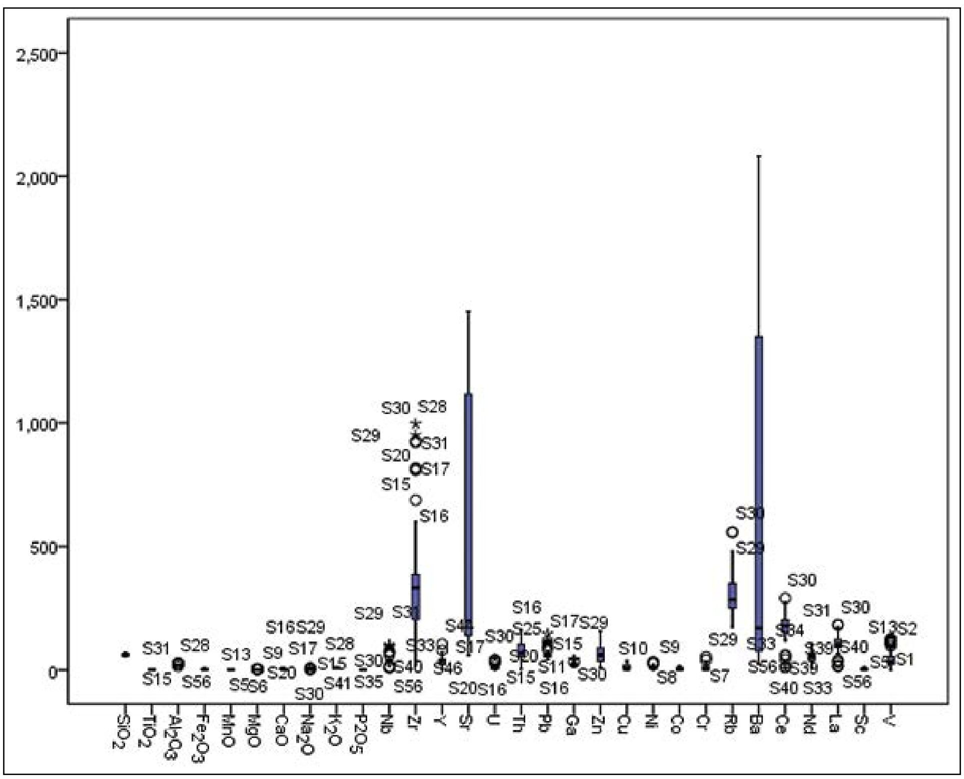

Figure 2- Distribution of the elements’ concentration within the various samples of the Hamit Pluton.

Table 2- Coefficient correlation between the elements in samples analyzed from of the Hamit Pluton.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Nb	Zr	Y	Sr	U	Th	Pb	Ga	Zn	Cu	Ni	Co	Cr	Rb	Ba	Ce	Nd	La	Sc	V
SiO_2	1																													
TiO_2	-.772**	1																												
Al_2O_3	-.380**	-.199	1																											
Fe_2O_3	-.858**	.969**	-.083	1																										
MnO	-.789**	.799**	-.055	.814**	1																									
MgO	-.728**	.886**	-.178	.928**	.650**	1																								
CaO	-.807**	.929**	-.193	.962**	.812**	.903**	1																							
Na_2O	.076	-.427**	.271*	-.361**	-.010	-.422**	-.301*	1																						
K_2O	.149	-.353**	.300*	-.404**	-.219	-.506**	-.451**	-.130	1																					
P_2O_5	-.782**	.933**	-.159	.965**	.700**	.962**	.940**	-.384**	-.465**	1																				
Nb	-.335**	-.068	.819**	-.023	.053	-.148	-.119	.070	.293*	-.159	1																			
Zr	-.480**	.031	.772**	.160	.186	.075	.102	.117	.024	.052	.865**	1																		
Y	-.342**	.495**	-.147	.413**	.645**	.244	.421**	-.212	.088	.282*	.105	.060	1																	
Sr	-.785**	.853**	-.044	.892**	.711**	.771**	.863**	-.231	-.362**	.884**	-.131	.082	.245	1																
U	-.297*	-.122	.578**	-.016	.204	-.056	-.040	.384**	.084	-.087	.598**	.674**	.015	-.096	1															
Th	.227	-.348**	.304*	-.387**	-.209	-.441**	-.441**	.160	.270*	-.474**	.589**	.456**	.063	-.490**	.405**	1														
Pb	-.309*	-.034	.464**	.033	.310*	-.095	.055	.541**	-.113	-.077	.510**	.590**	.101	.068	.531**	.312*	1													
Ga	-.380**	.027	.653**	.149	.032	.154	.039	-.078	.081	.099	.660**	.768**	-.137	.067	.572**	.352**	.350**	1												
Zn	-.846**	.521**	.569**	.621**	.586**	.491**	.540**	-.063	.009	.509**	.609**	.738**	.191	.553**	.563**	.114	.439**	.692**	1											
Cu	-.692**	.833**	-.119	.853**	.649**	.861**	.804**	-.345**	-.373**	.885**	-.143	.016	.302*	.754**	.102	-.441**	-.119	.106	.465**	1										
Ni	-.629**	.693**	.003	.725**	.540**	.801**	.711**	-.244	-.455**	.742**	.098	.260*	.281*	.529**	.076	-.199	.238	.242	.410**	.643**	1									
Co	-.743**	.905**	-.182	.941**	.685**	.953**	.915**	-.407**	-.477**	.959**	-.141	.070	.300*	.829**	-.062	-.434**	-.079	.115	.495**	.853**	.737**	1								
Cr	-.419**	.358**	.198	.410**	.227	.470**	.304*	-.223	-.106	.412**	.182	.311*	.107	.272*	.176	.070	-.008	.456**	.450**	.441**	.443**	.371**	1							
Rb	.237	-.425**	.362**	-.444**	-.367**	-.469**	-.478**	-.069	.564**	-.498**	.579**	.452**	-.026	-.476**	.283*	.712**	.163	.465**	.145	-.459**	-.271*	-.472**	.104	1						
Ba	-.738**	.819**	-.023	.858**	.642**	.779**	.813**	-.272*	-.374**	.875**	-.140	.074	.200	.960**	-.042	-.485**	.033	.117	(	.797**	.579**	.818**	.288*	-.468**	1					
Ce	-.643**	.413**	.533**	.421**	.515**	.227	.320*	-.017	.154	.260*	.760**	.695**	.397**	.293*	.453**	.526**	.504**	.530**	.784**	.224	.327**	.257*	.332**	.360**	.244	1				
Nd	-.803**	.768**	.153	.753**	.776**	.547**	.702**	-.197	.021	.612**	.337**	.338**	.532**	.638**	.098	.030	.221	.208	.732**	.508**	.409**	.591**	.297*	-.058	.520**	.775**	1			
La	-.472**	.235	.517**	.243	.358**	.072	.182	.097	.087	.089	.783**	.730**	.339**	.114	.423**	.649**	.542**	.506**	.653**	.004	.246	.091	.230	.438**	.054	.929**	.660**	1		
Sc	-.703**	.767**	-.095	.814**	.610**	.753**	.828**	-.314*	-.367**	.778**	-.043	.147	.170	.750**	-.126	-.365**	.004	.094	.541**	.574**	.495**	.779**	.204	-.407**	.659**	.307*	.674**	.195	1	
V	-.799**	.934**	-.147	.955**	.758**	.932**	.945**	-.378**	-.416**	.930**	-.040	.127	.442**	.781**	-.111	-.363**	.002	.096	.530**	.773**	.773**	.926**	.393**	-.434**	.727**	.379**	.732**	.251*	.824**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

P_2O_5, Co and V; between P_2O_5 and Co and V; between Sr and Ba; between Co and V; and between Ce and La.

In addition, there exist "strong" positive relationships (r > 0.7) between TiO_2 and MnO, MgO, Sr, Cu, Ba, Nd and Sc; between Fe_2O_3 and MnO, Sr, Cu, Ni, Ba, Nd, La and Sc; between MnO and P_2O_5, Sr, Nd and V; between MgO and Sr, Cu, Ni, Ba, Sc and V; between P_2O_5 and Sr, Cu, Ni, Ba and Sc; between Nb and Zr, Ce and La; between Zr and Ga, Zn and La; between Sr and Cu, Co, Sc and V; between Th and Rb; between Zn and Ce and Nd; between Cu and Co, Ba and V; between Ni and Co and V; between Co and Ba and Sc; between Ba and V; between Ce and Nd; between Nd and V; and between Sc and V.

There exist weak relationships between Fe_2O_3 and Th and Rb; between MnO and Rb; between MgO and Th and Rb; between P_2O_5 and Th and Rb; between Sr and Th and Rb; between Th and Cu, Co, Ba, Sc and V; between Cu and Rb; and between Co and Rb.

Regression: Regression analysis has been done to determine the relationship of SiO_2 with other elements (Table 3). According to the adjusted R^2 value, 99.7% of the total variability in SiO_2 is explained by the all the other elements, while the ANOVA (variant analysis) indicates model has a significant explanatory power. This therefore implies the Model SUMMARY has a very strong; explanatory power on SiO_2 and that the numbers of samples used in this analysis were sufficient.

Cluster Analysis: Hierarchical clustering analysis was done to group the samples according to their similarity or homogeneity. The most similarly or homogeneously combining samples are 17 and 20 followed by: 43-51, 19-21, 22-24, 5-10, 9-13, 3-5, 57-60, 43-53 and 46-47. The most dissimilar samples are 1 and 15, followed by: 1-12, 15-32, 1-3, 15-16, 3-4, 32-57, 3-6, 3-18, 27-30, 32-33 and 4-11. Samples 1, 2, 3 and 15 show the highest number of most dissimilar combination with other samples, occurring 4 times among the 15 highly most dissimilar combining cluster samples; followed by 32 (3 times), 4 (3 times) and 33 (2 times).

According to the dendrogram, the most similar combined samples are divided into 7 clusters. They include Cluster 1 (samples 17, 20, 15, 28, 31, 29, 30), which closely linked to Cluster 2 (only sample 16); Cluster 3 (samples 59, 61, 57, 60, 62, 63, 58, 34, 35, 50, 43, 51, 53, 37, 49, 54, 41, 42, 36, 46, 47, 44, 45, 32, 38, 48, 52, 55, 40, 56, 33 and 39); Cluster 4 (samples 1 and 2); Cluster 5 (samples 4, 14, 7 and 11); Cluster 6 (samples 6, 23, 22, 24, 25, 9, 13, 5, 10, 3, 8, 19, 21, 26, 27 and 18); and Cluster 7 (only sample 12); as shown on figure 3a below.

It can be observed from the dendrogram that the elements are divided in 4 different cluster groups, each of which contains elements showing relatively close correlational relationship. They include Cluster 1 (MnO, P_2O_5, TiO_2, MgO, Fe_2O_3, CaO, Sc, Na_2O, Co, K_2O, Cu, Ni, Cr, Al_2O_3, Ga, U, SiO_2, Pb, Nd, V, Nb, Y, Zn, Th and La), Cluster 2 (Rb and Ce), Cluster 3 (Zr), Cluster 4 (Sr and Ba). Cluster 1 and more closely related directly. This grouping shows some similarity among the elements, as shown on figure 3b.

Factor Analysis: Table 4 (a, b and c), shows the results of the Principal Component Analysis (PCA) of the elements. In the retained 3 components, all the elements are well represented with at least 63.3% of the elements having a proportion > 0.7, of their variance explained by the retention factor and 93.3% of the elements have proportion of their variances > 50% (> 0.5) explained by the retention factor; whereas just 6.7% (2/30) of the elements (Y and Cr) have > 0.5 of their variance that is not explained by the retention factor table 4a.

Table 3- Data Regression of samples content of the Hamit Pluton using Model SUMMARY (a) and ANOVA (b).

Model SUMMARY[a]	R	R Square	Adjusted (Adj.) R Square	Std. Error of the Estimate
1	.999[b]	.999	.997	.26691

ANOVA[a]		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1654.239	29	57.043	800.697	.000[b]
	Residual	2.351	33	.071		
	Total	1656.590	62			

a. Dependent Variable: SiO_2 ; b. Predictors: (Constant), V, Pb, Ga, K_2O, Th, Cr, Y, U, Al_2O_3, Ba, Na_2O, Ni, Rb, Sc, Cu, Nd, Zr, MnO, Co, Nb, La, Zn, CaO, Ce, Sr, P_2O_5, TiO_2, MgO, Fe_2O_3

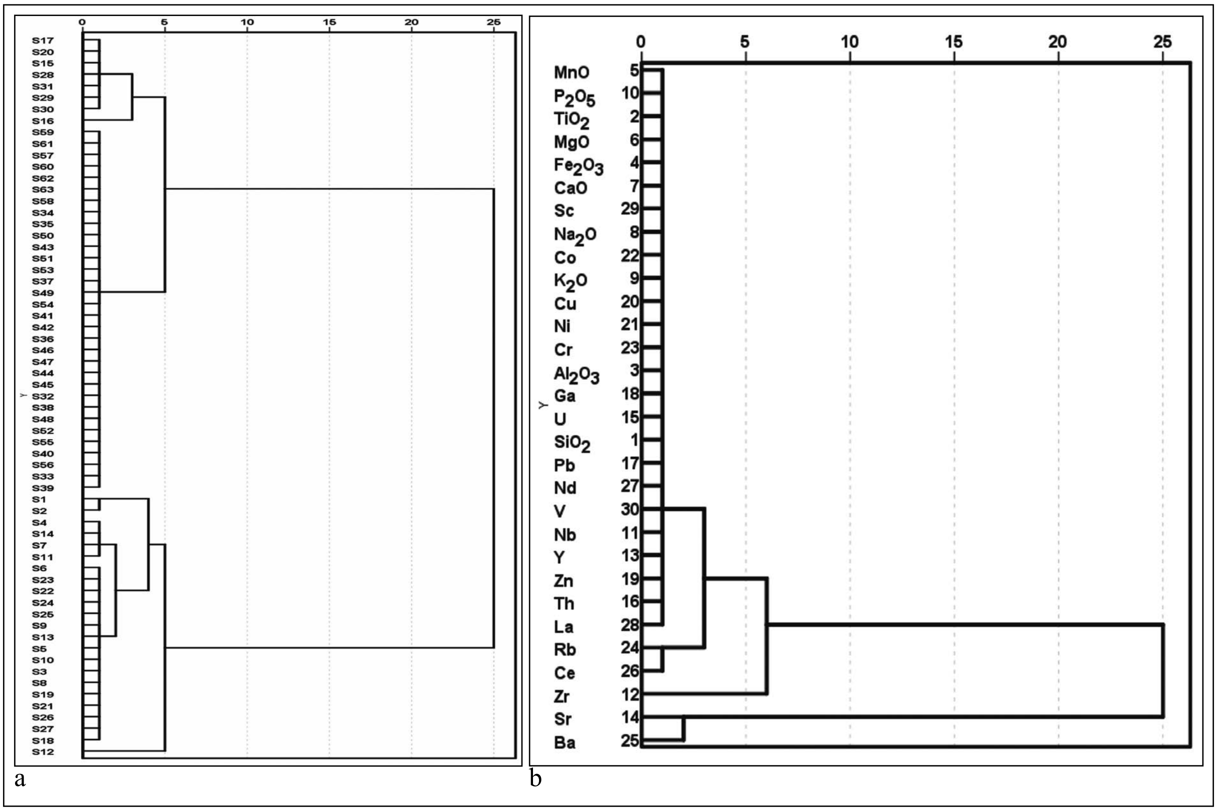

Figure 3- a) Dendrogram of Hierarchical Cluster analysis of samples of the Hamit Pluton. b) Elements dendrogram of the Hamit Pluton samples.

Table 4a- Proportion of elements' variance explained in the Hamit Pluton samples.

Communalities			Communalities		
	Initial	Extraction		Initial	Extraction
SiO_2	1.000	.907	Zr	1.000	.861
TiO_2	1.000	.967	Nd	1.000	.823
Al_2O_3	1.000	.721	La	1.000	.821
Fe_2O_3	1.000	.993	Sr	1.000	.818
MnO	1.000	.688	Ba	1.000	.783
MgO	1.000	.899	Cu	1.000	.763
CaO	1.000	.942	Rb	1.000	.744
Na_2O	1.000	.538	Th	1.000	.690
K_2O	1.000	.538	Sc	1.000	.675
P_2O_5	1.000	.962	U	1.000	.643
V	1.000	.931	Ga	1.000	.595
Co	1.000	.915	Ni	1.000	.587
Ce	1.000	.911	Pb	1.000	.573
Zn	1.000	.885	Y	1.000	.474
Nb	1.000	.873	Cr	1.000	.249

Extraction Method: Principal Component Analysis.

The 3 components retained contribute for 75.903% of the total variable's variance with the least total Eigenvalues > 2.0 (Table 4b). The Factor 1 with initial Eigenvalue 13.684, explains 45.613% of the total variable variance constituting the largest number of the strongest correlational relationships with 56.7% of the elements as presented on table 4c (TiO_2, Fe_2O_3, MgO, CaO, P_2O_5, Co, V – all with $r > 0.9$ –; MnO, Sr, Zn, Cu Ni, Ba, Nd, Sc – all with $r > 0.7$ –; Cr – with $r < 0.5$ –; and SiO_2 with $r < -0.89$); Factor 2 with Eigenvalue 7.077, explains 23.592% of the total variable's variance and constitutes the strongest

Table 4b- Proportion of elements' variance explained in the Hamit Pluton samples.

Total Variance Explained						
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.684	45.613	45.613	13.684	45.613	45.613
2	7.077	23.592	69.204	7.077	23.592	69.204
3	2.010	6.699	75.903	2.010	6.699	75.903
Extraction Method: Principal Component Analysis.						

Table 4c- Component matrix of elements in the Hamit Pluton samples.

Component Matrix[a]					**Component Matrix**[a]		
	Component				Component		
	1	2	3		1	2	3
SiO_2	-.893	-.312	.107	Th	-.344	.700	.287
TiO_2	.953	-.149	.191	Pb	.111	.625	-.412
Al_2O_3	-.007	.802	-.278	Ga	.211	.723	-.170
Fe_2O_3	.992	-.083	.036	Zn	.679	.646	-.086
MnO	.823	.085	.054	Cu	.849	-.194	-.064
MgO	.923	-.213	-.054	Ni	.754	.030	-.131
CaO	.957	-.164	.000	Co	.933	-.211	-.021
Na_2O	-.318	.239	-.616	Cr	.438	.236	.035
K_2O	-.392	.325	.528	Rb	-.402	.656	.390
P_2O_5	.955	-.222	-.041	Ba	.853	-.171	-.161
Nb	.049	.931	.059	Ce	.478	.787	.250
Zr	.239	.877	-.187	Nd	.773	.327	.345
Y	.411	.089	.545	La	.308	.823	.221
Sr	.884	-.157	-.108	Sc	.814	-.108	.007
U	.058	.707	-.373	V	.952	-.118	.102

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

correlational relationships with 33.3% of the elements (Nb with r > 0.9, Al_2O_3, Zr, U, Th, Pb, Ga, Rb, Ce and La – all with r > 0.7); and Factor 3 constituting strongest correlational relationship of 10% of the elements (Na_2O < -0.5, K_2O and Y – all with r > 0.5), has initial Eigenvalue 2.010 explaining 6.699% of the total variable variance.In summary, 56.7% of all the elements show their strongest positive relation in component 1, while 33.3% of them show their strongest positive relationship in component 2 and 10% in component 3. Scree plot diagram (Figure 4) also shows that there are three components for these elements.

3. Discussion

The boxplot, figure 2, actually reveals particular samples with elements that could possibly have affected the fairly normal distribution of the elements with the Hamit Pluton. 88.24% (15/17) of the elements (SiO_2, TiO_2, Fe_2O_3, MnO, CaO, K_2O, P_2O_5, Sr, Th, Zn, Cu, Co, Ba, Nd and Sc; with the exception of LREEs La and Ce) have skewness ranging from approximately symmetrical to moderately skew.

Comparing figure 2 and figure 3a, Cluster 1 contain samples with most of the anomalous concentration of elements – only in some or all of these samples that high anomalous concentration of Al_2O_3, Nb, Zr, Rb are observed. La and Na_2O show both high and low anomaly, except in S41; Cluster 3 contains majority of the samples, that is 50.8% (32/63); and in contrast to Cluster 1, some of its samples instead show low anomalous concentration of Al_2O_3, Nb, Ce and La, with exceptions of high anomalous concentrations of Na_2O (S41), Y (S44 - S46) and Ce (S36). Cluster 6 is the second largest cluster with 25.4% (16/63) of the samples. Here only few samples S5, S6, S9 and S13 do have anomalous concentrations (MgO, one of the abundant oxides in the earth crust). In Clusters 4, 5 and 7 no sample was identified with an anomalous concentration of any elements.

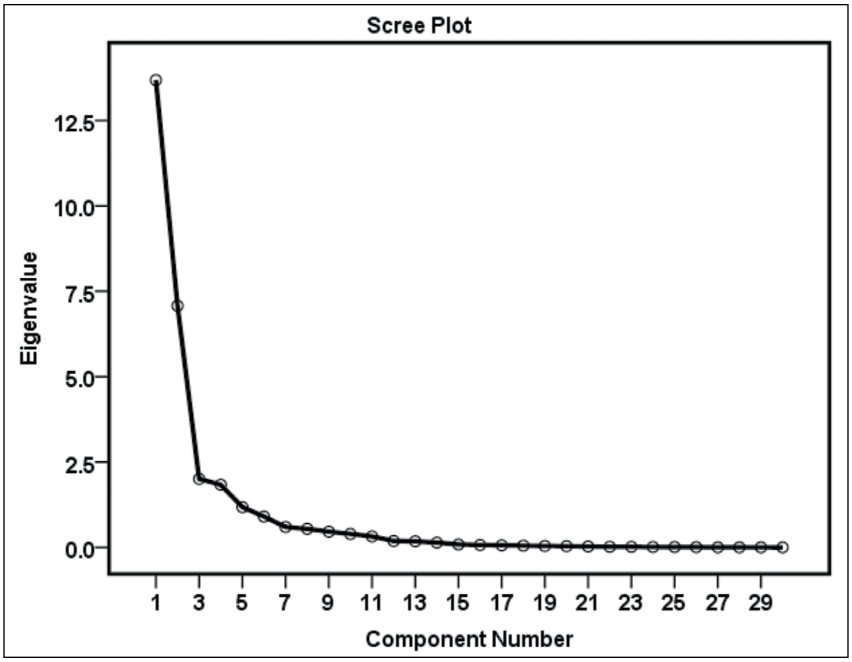

Figure 4- Scree plot showing a visual presentation of factor analysis.

It can be observed from the dendrogram (Figure 3a) that the 7 clusters can be grouped into two, with each group containing clusters with samples that show close correlation with each other. That is Group 1 (clusters 1, 2 and 3) and Group 2 (clusters 4, 5, 6 and 7). It is clear that the 2 groups of clusters of the samples show a great disparity in their similarity of element content. Group 1 contains all the samples showing most of the anomalous concentrations of major, trace and REEs (but for 4 samples in Group 2 indicating anomalous concentrations only in MgO). It is also observed that all the elements indicating anomalous concentration in Group 1 are well-loaded in the second component of the Principal Component Analysis (PCA) as shown on table 5, a probable indication that samples of Group 1 may have probably being originated from a different source and most likely crustal contamination.

According to correlation analysis of the samples, the fact that the samples show possibility in homogenous combination of elements, it means their elements could possibly be from the same source or origin. In addition, elements with the “very strong” and “strong” correlational relationships are also considered to be from the same “initial” source (Yalcin et al., 2015).

Majority of the elements demonstrating a “very strong” correlational relationship ($r > 0.8$) according to Pearson correlation coefficient are best-loaded on component 1 (Table 4c) are mostly heavy and/or high temperature elements and mostly mantle abundant elements.

Comparing the trace element averages (Figure 5) of the Hamit pluton to those of the mantle and earth crust, concentrations of Zr, Sr, Rb, Ba and Ce are distinctly higher than those of the earth crust, which in turn are also much higher than those of the mantle, whereas average values for Ni and Cr in the Hamit pluton is far much lower than those of the mantle and almost similar to those of the earth crust. It could generally be observed that the averages of trace element values of the Hamit pluton are much similar to those of the earth crust than to those of the mantle.

The pattern of the 3 component matrix extraction and Pearson coefficient correlation matrix do indicate some similarities. All the elements signifying strong to moderately positive correlation with Al_2O_3 are all located within the component 2, where the highest proportion of their variances are explained; all those indicating a strong negative correlational relationship with SiO_2 are loaded on the first component where a greater proportion of their variances are also explained.

Pearson coefficient correlation of variables explain majority of the elements with their strongest

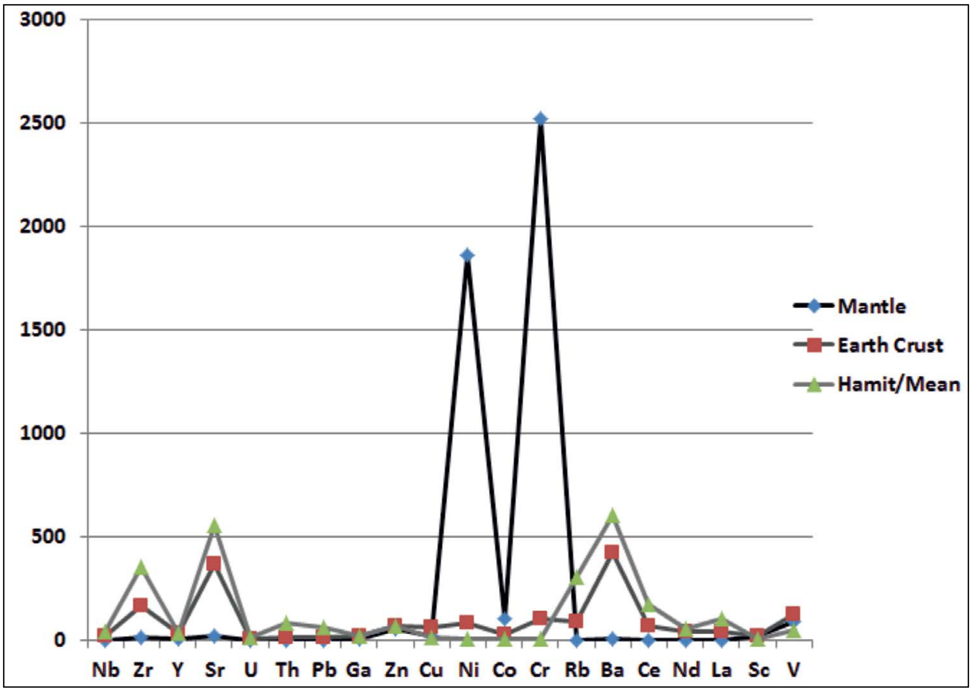

Figure 5- Comparing trace element averages in the Hamit Pluton to those of the mantle (Palme and O'Neill, 2005) and earth crust (Greenwood and Earnshaw, 1997; Lide, 2008).

correlation coefficient located in component 2, with the exception of Rb, Ce and Zr, are grouped alongside the elements of component 1, with the exception of Sr and Ba.

Ba and Sr are not being grouped with the other elements of component 1 by the Pearson variable correlation, rather grouped together separately. They are thought to have being of same source with the initial magma, which was probably and relatively very rich in Ba and Sr. The high concentration of Zr is thought to have resulted from a crustal contamination relatively rich in Zr.

Considering that most of the well-loaded elements in component 1 are mostly related to partial melting from the mantle, it was labeled to be the initial melt content of the plutonic rocks; component 2 as elements with much contribution from the crustal interaction; and component 3 as mostly crustal contamination; considering the abundance of Na_2O, K_2O and Y in the earth crust.

There was insignificant crustal contamination of MgO, Ni and Cr in some samples that might have resulted to their skewed distribution. La and Ce though are respectively left approximately symmetric to moderately skewed distribution; they are well-loaded on the second component with elements showing right skewed distribution. This could imply a significant and insignificant quantity of these elements might have come from a source different from the initial melt.

Crustal Contamination Test: LILE (e.g. Rb and K) and Zr are incompatible with respect to the major crystallizing mineral assemblage (plagioclase, augite, magnetite, and hornblende) and ratios like K/Rb and Rb/Zr do not significantly change by fractional crystallization of this assemblage (Davidson et al., 1987). Implying that variations in these ratios are preferably related to crustal contamination by assimilation and fractional crystallization processes (Davidson et al., 1987). The examination of the samples (Figure 6) illustrates wider range variance of K/Rb and Rb/Zr ratios with respect to SiO_2; indicating significant crustal assimilation is involved during the evolution of the entire plutonic suite.

4. Conclusion

The initial magma that resulted to the formation of the Hamit plutonic rock suite experienced some degree of evolution due to crustal assimilation.

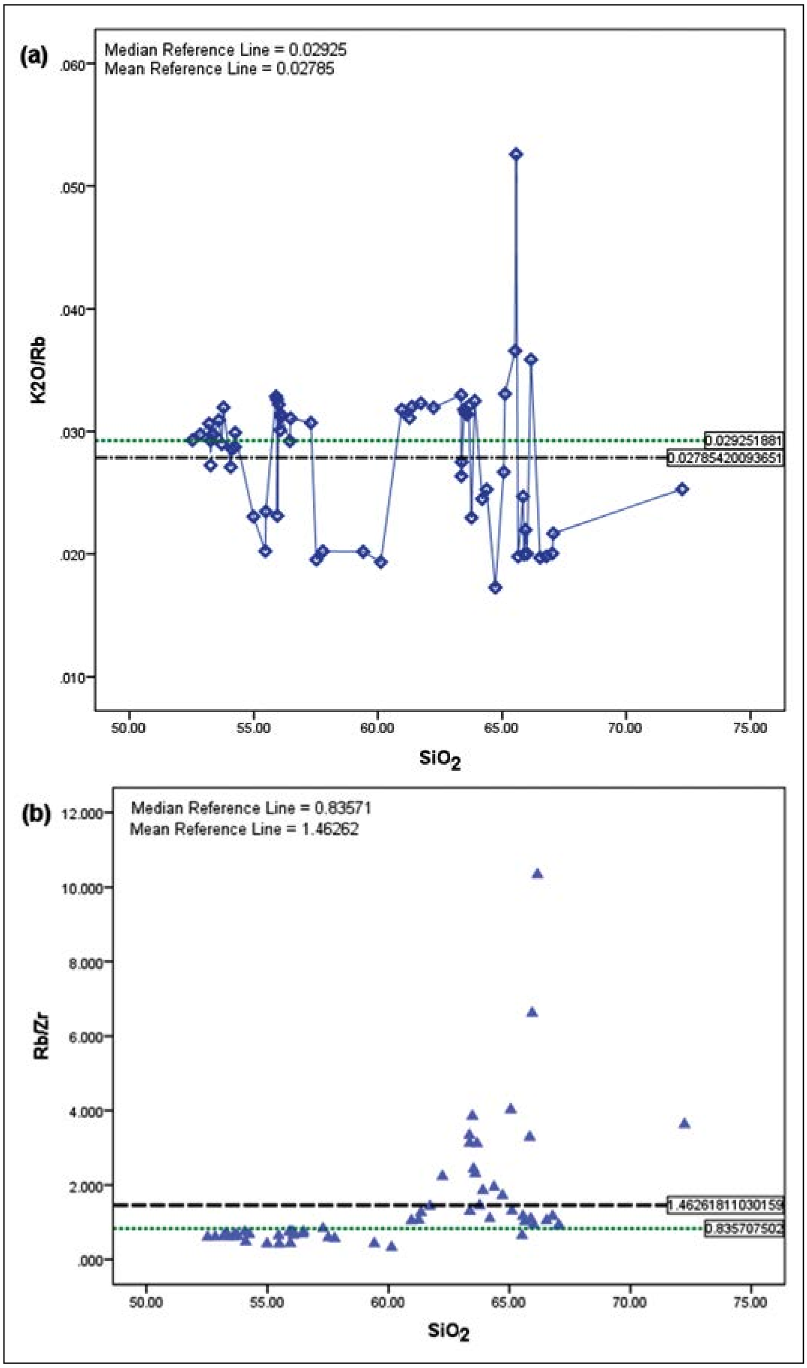

Figure 6- Variations of (a) K_2O/Rb vs. SiO_2 and (b) Rb/Zr vs. SiO_2.

The 63 samples studied could be divided into major 2 groups: 63.5% in Group 1 (samples 15, 16, 17, 20, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62 and 63) and 36.5% in Group 2 (samples 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 18, 19, 21, 22, 23, 24, 25, 26 and 27); with Group 1 containing mostly samples formed from melts whose contents might have evolved greatly due to crustal assimilation.

The initial melt is thought to have contained "most" of the SiO_2, TiO_2, Fe_2O_3, MnO, MgO, CaO, P_2O_5, Sr, Zn, Cu, Ni, Co, Cr, Ba, Nd, Sc and V that formed the pluton, while "majority" of the Al_2O_3, Nb, Zr, U, Th, Pb, Ga, Rb, Ce and La are thought to have been derived from the crustal contamination, and “almost all” of the Na_2O, K_2O and Y are thought to have originated from crustal assimilation

Generally, trace element values of the Hamit pluton are much similar to those of the crust than to those of the mantle, discrediting thoughts that the mantle could be a likely source for the magma. The initial magma is thought to have been very rich in Sr and Ba before subsequent contamination by the crust.

Acknowledgement

This study was supported by the Akdeniz University Research Fund.

References

Akbarpour, A., Gholami, N., Azizi, H., Torab, F.M. 2013. Cluster and R-mode factor analyses on soil geochemical data of Masjed-Daghi exploration area, northwestern Iran. Arabian Journal of Geosciences 6: 3397-3408.

Bingöl, E. 1989. Geological map of Turkey, 1:2 000 000. Mineral Research and Exploration Institute, Ankara.

Boruvka, L., Vacek, O., Jehlicka J. 2005. Principal component analysis as a tool to indicate the origin of potentially toxic elements in soils. Geoderma 128: 289-300.

Child, D. 1970. The essential of factor analysis. Hold Rinehart and Winston Ltd, London, 107 pp.

Davidson, J.P., Ferguson, K.M., Colucci, M.T., Dungan, M.A. 1987. The origin of magmas from the San Pedro-Pellado Volcanic Dokhan Volcanics complex, S. Chile: multicomponent sources and open system evolution. Contributions to Mineralogy and Petrology 100: 429-445.

Facchinelli, A., Sacchi, E., Mallen, L. 2001. Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. Environmental Pollution 114: 313-324.

Fitton, J.G., Upton, B.G.J. 1987. Alkaline Igneous Rocks. Geological Society Special Publication No. 30, pp. ix-xiv.

Gill, R.C.O. 1972. The geochemistry of the Grønnedal-Ika alkaline complex, South Greenland. PhD Thesis, University of Durham, UK (unpublished).

Göncüoğlu, M. C., Toprak, V., Kuşcu, İ., Erler, A., Olgun, E., 1991. Orta Anadolu Masifinin Batı Bölümünün Jeolojisi, Bölüm 1-Güney Kesim: TPAO Rapor No. 2909, Ankara (unpublished).

Greenwood, N.N., Earnshaw, A. 1997. Chemistry of the Elements 2nd edition. Oxford: Butterworth-Heinemann.

Ilbeyli, N. 1999. Petrogenesis of Collision-related Plutonic Rocks, Central Anatolia (Turkey). PhD Thesis, University of Durham, Durham, UK (unpublished).

Ilbeyli, N. 2004. Field, Petrographic and Geochemical Characteristics of the Hamit Alkaline Intrusion in the Central Anatolian Crystalline Complex, Turkey. Turkish Journal of Earth Sciences 13: 269-286.

Ilbeyli, N., Yalcin, F. 2015. Application of Factor Analysis Method to the Alkaline Geochemical Data from Central Anatolia (Turkey). Goldschmidt 2015 Abstracts, 3314.

Jöreskog, K.G., Klovan, J.E., Reyment, R.A. 1976. Geological Factor analysis. Elsevier, Amsterdam, 178 pp.

Kumru, M.N., Bakac, M. 2003. R-mode Factor Analysis Applied to the Distribution of Elements in Soils from the Aydın Basin, Turkey. Journal of Geochemical Exploration 77: 81-91.

Lawley, D.N., Maxwell, A.E. 1971. Factor analysis as a statistical method. 2nd edition Butterworth and Co., Ltd., London, 153 pp.

Lide, D.R. 2008. CRC Handbook of Chemistry and Physics, 88th edition. Boca Raton, Florida: Taylor, Francis Group.

Mitchell, R.H. 1991. Kimberlites and Lamproites: Primary Sources of Diamond. Geoscience Canada, Volume 18, Number 1, pp. 1-16.

Palme, H., O’Neill, H.St.C. 2005. Cosmochemical Estimates of Mantle Composition. pp. 1-38 in the Mantle and Core. Edited by Richard W. Carlson. Oxford: Elsevier Ltd.

Verplanck, P.L., Van Gosen, B.S., Seal, R.R., McCafferty, A.E. 2014. A deposit model for carbonatite and peralkaline intrusion-related rare earth element deposits. U.S. Geological Survey Scientific Investigations Report 2010-5070-J, 72 pp.

Yalcin, F., Ilbeyli, N. 2014. Multivariation Statistics Determination of the Hamit Alkaline Plutonic Rocks (Kirsehir-Turkey). 30th International Conference on Alkaline, Kimberlite and Carbonatite Magmatism Abstracts, 228.

Yalcin, F., Ilbeyli, N. 2015. Cluster Analysis Applied to Alkaline Geochemical Data (Hamit, Turkey). ICJMS’2015 - The 28th International Conference of the Jangjeon Mathematical Society, Antalya, Turkey, 128.

Yalcin, M.G., Ilhan, S. 2008. Major and Trace Element Geochemistry of Terra Rossa Soil in the Kucukkoras Region, Karaman, Turkey. Geochemistry International (Geokhimia) 46: 1038-1054.

Yalcin, M.G., Simsek, G., Ocak, S.B., Yalcin, F., Kalayci, Y., Karaman, M.E. 2013. Multivariate Statistics and Heavy Metals Contamination in Beach Sediments from the Sakarya Canyon, Turkey. Asian Journal of Chemistry 25: 2059-2066.