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Geostatistical Analysis of Gold Multi-Element Associations using Soil Geochemical Data from Julie Belt, Northwest Ghana

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Abstract: **Geochemical Exploration for gold often times fail to produce favourable results because pathfinders for the gold were not properly identified, in others the pathfinders could not be linked to the host geology and so high potential deposits have remained unexploited. The aim of the study is to identify pathfinder elements for gold and provide a link between inter-elemental associations and the hosting geology using multi-element soil geochemical data from Julie belt of Ghana, this was achieved by geostatistical tools. The dendrogram identified 3 clusters; Cluster 1 is dominated with V, Zn, Cu, Zr, Sr, Cr and Rb, cluster 2 with Au, Pb, W, As, Th, Co, Cl and cluster 3 having Ti, Mn, Ca, K and Fe. The gold was associated with the second cluster. The PCA identified 6 components contributing for 70.08% of the total variability, component 1 elements (Ti, Mn, Fe, Cu and Zn) gives the elemental composition of the mafic rock which has undergone least alteration. The gold shows an apparent association with component 3 which was dominated with Ti, V, As, Pb, Zr, and W, component 3 along with cluster 2 and 3 therefore represents the geology of the sheared granitoid that primarily composed of quartz, plagioclase, hornblende and biotite with accessory minerals of titanite, zircon and magnetite. Pb, W, and Ar were therefore identified as the pathfinder elements for the gold.**

Keywords: **Pathfinder Elements, Gold, Geochemical Exploration, Geology, Geostatistics, Julie Belt, Ghana.**

1. INTRODUCTION

Coveted for its beauty, gold (Au) has long captivated the human psyche and is considered the most sensuous metal, no precious metal is as legendary and beautiful as gold [1]. Its rarity, beauty, and enigma have provided it with status as a valuable commodity throughout the history of humanity. Gold has always been used as a monetary standard, and ancient gold jewellery and ornaments dating back centuries have been found throughout the world.

In Ghana, the mining sector is the most important source of revenue for government, with gold accounting for over 90% from the sector. Ghana is the second largest gold producer in Africa and the 9th largest producer in the world. The sector directly contributed 38.3% of Ghana's total corporate tax earnings, 27.6% of government revenue and 6% GDP in 2011 [2]. The sector employs about 28,000 people in the large-scale mining industry whilst over a million people are engaged in the artisanal sector. In 2011, Ghana produced 3.6 million ounces of gold, the highest ever in the history of the country. This resulted in export revenues of over US$5billion. It is significant to note that small scale miners contributed some 28% of the total gold production in 2011. Total Direct Investment (TDI) into the minerals and mining sector from 1983 to 2011 amounted to US$ 11.5billion [2].

Geochemical exploration is one of the many tools utilized by science, to search, identify and define trends and anomalous haloes for gold by analysing the manner to which the gold is been associated with other geochemical elements.

A. Problem Statement, Scope and Objectives:

Most gold exploration projects fail not because the geologic environment is inadequately gold mineralized but because the pathfinder elements were not scientifically identified. Failure to identify pathfinder elements with regard to its host geology within a concession, results to waste of resources and time, after which the exploration project fails. The objective of this work is to test the effectiveness of multivariate statistical techniques in identifying pathfinder elements and to understand the manner and degree of inter-elemental associations and or dependency which could be linked to the hosting geology using soil geochemical data from Julie belt North-western Ghana (Fig. 1.).

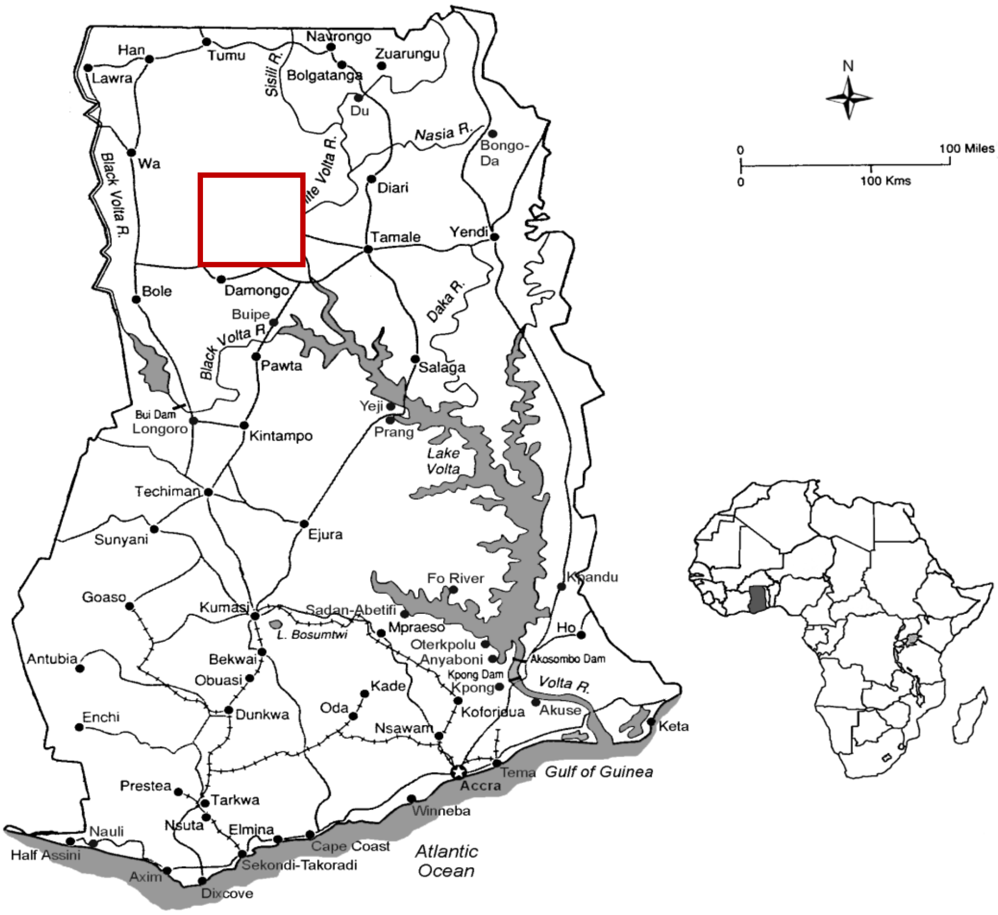

Fig.1: Physical Map of Ghana; insert is the location of the study area (not to scale (Modified [3])).

2. LITERATURE REVIEW

A. The Summary of Julie Deposit Geology:

The Julie gold deposit is currently the highest-grade in NW Ghana [4]. It is located in the Wa-East gold district, which lies within the Julie belt south of the Koudougou-Tumu granitoid domain (Fig. 2). The Wa-East gold district also includes gold camps of Collette, Kjersti, Kandia, Julie west, Baayiri and Danyawu. The Julie deposit is hosted in strongly sheared granitoids of the Julie belt. The rocks are pink in color on both fresh and weathered surfaces in the altered zone and greenish in the least-altered zone. They are medium to coarse grained, weakly magnetic in altered zones and strongly magnetic in the least-altered zones. It's not surprize because mineral deposits are well known to be associated with hydrothermal alterations [5]. They are primarily composed of quartz, plagioclase, hornblende and biotite with accessory minerals consisting of titanite, zircon and magnetite, which are overprinted by greenschist-facies metamorphic assemblages of epidote, calcite, fine grained biotite and rutile [4]. To the north of the Julie shear zone are basalts and sediments, consisting mainly of intercalated metamorphosed greywacke, shale and volcanosediments. The sediments are fine to medium grained, black to gray in color and composed of quartz, muscovites, chlorite biotite and graphite. The basalts are strongly magnetic and composed of plagioclase, green amphibole, calcite, chlorite with minor titanite and magnetite [4], [6], [7].

3. METHODOLOGY

A. Sampling and Sample Analysis:

The sampling was carried out by geologists and field technicians from the Exploration Department of AZUMAH Resources limited. A total of 1088 soil samples were taken from the research area which was achieved by soil Auger drilling to an average depth of 3 m.

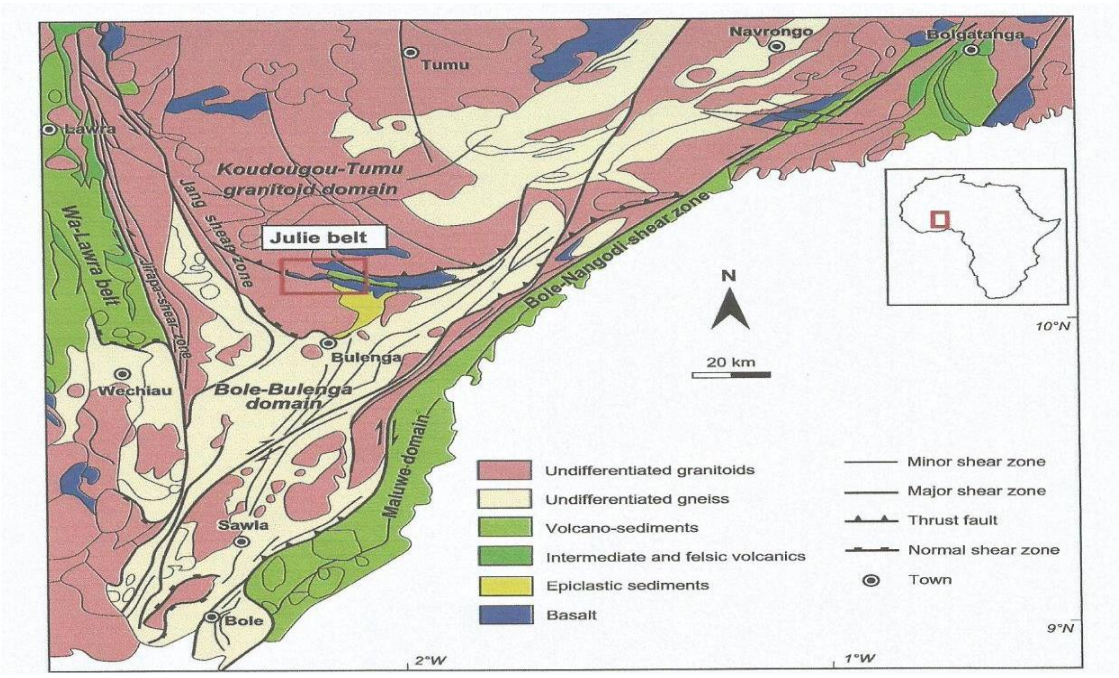

Fig.2: Regional litho-structural map of NW Ghana, insert is the study area. (Adopted [4], [7])

The samples were analyzed for gold only, at the SGS laboratory Australia, methods used were the bottle roll cyanidation test, 20% of the tails of the samples were re-assayed using fire assay to prevent preg-robbing duration to the graphic shaly material which was evidenced at the northern edge of the Julie belt. The multi element distribution was determined using x-ray method. Sample identification, quality control measurements for grinding, weighing, pulp and bulk storage, sample retrieval and disposal were performed by scanning the bar codes for easy identification and location of samples within the laboratory.

B. Descriptive Statistics:

Multivariate statistical analysis was carried out on the data (19 elements as the variables). Table 1 and Table 2 were generated using SPSS software which summarizes the descriptive statistics including the arithmetic mean, median, standard deviation, minimum value, maximum value, kurtosis and skewness. Histograms (Fig. 3) was generated, fitted with normal curve, so as to check whether the data were normally distributed, stationary, or not. The data were therefore log transformed to make them valid for the statistical analysis, histograms (Fig.4) were plotted to see how normal the data had transformed.

C. Hierarchical Cluster Analysis (HCA)

The dendrogram (Fig. 5) is a visual representation of the correlation of the entire datasets. The individual elements were arranged along the vertical axis of the dendrogram. The clusters were formed by joining individual elements or existing element clusters with the join point referred to as a node. At each dendrogram node have an upper and lower sub-branch of clustered elements. The horizontal axis is labelled distance and refers to a distance measure between elements clusters. The length of the node can be thought of as the distance value between the upper and lower sub-branch clusters. Highly correlated clusters are nearer the labelled vertical axis at the left side of the dendrogram, elements clusters that are not correlated have a correlation value of zero and a corresponding distance value of 1, elements that are negatively correlated, i.e. showing opposite expression behaviour, will have a correlation value of -1 and distance will be greater than one.

D. Factor Analysis:

Factor analysis is a statistical approach that can be used to analyze interrelationships among a large number of variables and to explain these variables in terms of their common underlying factors [8]. This approach reduced the data into a small set without losing the key information from the original data. In order to carry out the factor analysis, the raw data was standardized. This step helps in increasing the influence of variables having small variance and reducing the influence of the variables having large variance. Then the correlation coefficients were evaluated which will be helpful in explaining the structure of the underlying system which produced the data [9]

The eigen values (Fig. 6) and factor loadings (Table 3) for the correlation matrix are determined and scree - plot was drawn in Fig 6. One of the most important steps in factor analysis is the extraction of factors, in this case the method used was the Principal Component Analysis (PCA) based on the variances and co-variances of the variables. The eigen values and eigen vectors are evaluated which represent the amount of variance explained by each factor. The factors with eigen values greater than one, depict more variation in data than individual variable. Finally, by the process of rotation, the loading of each variable on one of the extracted factors is maximized and the loadings on all the other factors are minimized, This is presented in Table 4. .

4. RESULTS AND DISCUSSION

A. The Geochemical Data and Descriptive Statistics:

The multi-elements distributions include Au, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Zr, Mo, Ag, Cd, Se, Rb, Sr, Sn, Sb, W, Pb, Bi, Hg, Th, and U. The full geochemical data generated is too large to be placed here but can be accessed directly from the author upon request. However, not all the 29 elements were factored into the analysis since some were below detection limit, only 19 elements were retained. The Summary of the descriptive statistics for the dataset as presented in Table 1 shows obvious disparity with the mean, example the Au, its total sample frequency was 1088 having a range of 2096 since the maximum value was 2094 with the minimum value of -2, the mean was 9.81 and the standard deviation was 71.640. The gold also shows a skewness value of 23.732 and a kurtosis of 66.540. Not only the gold, most of the elements have departed from the mean and are neither normally distributed nor stationary. This is an indication of the extreme variability of geochemical data [10]

Histograms were plotted for the dataset but only two (Au and Cu) are presented (Fig. 3), this further indicated that the dataset were not normally distributed and are not near stationary, exception for Zn and V which were only near normal. The histograms have high kurtosis and were highly positively skewed (Fig. 3), the high kurtosis means that the concentrations of those respective elements were restricted to a particular portion of the study area which were represented by some particular samples. The dataset has shown positive skewness also, and this means the concentrations of the elements in the study area is never uniform, majority of the samples will have averagely similar concentrations while some other few samples will have exceptionally high concentrations. Those samples may therefore represent point anomalies for the respective elements and the background concentrations may represent the background values for the respective element within the study area.

The prime assumption underlying the application of the multivariate methods of Factor Analysis and Hierarchical Cluster Analysis is for the data to follow normal distribution [10]. The very nature of geochemical data makes them rather spatially dependent and as such inherently non-normal. Thus, logarithmic transformation was applied to the same dataset and the summary of the descriptive statistics is shown in Table 2. The difference between Table 1 and Table 2 is undisputable, looking at the gold raw data for example, the number of observations have reduced down to 587 and this was because about 501 values were below detection limit, the range here is 3.32 since the minimum value is 0.00 with the maximum value of 3.32. After the log transformation, the mean is now 0.7962 instead of 9.81 before transformation. The standard deviation is now 0.5033 instead of 71.640 prior to transformation. The skewness and the kurtosis are now 1.187 and 2.094 respectively instead of 23.732 and 66.540 for both. Indeed, the data has been transformed to near normal since the skewness and kurtosis of a normal distribution is 0 and 3 respectively. In fact, no dataset is exactly normally distributed, instead, it is only necessary for the data to be near normal [11]. Fig. 4. shows the histogram plots for the elements after the log_transformation, it further demonstrates how drastic the values had been justifiably transformed to better suit the multi-variate statistical analysis.

B. Hierarchical Cluster Analysis and the Dendrogram:

The dendrogram (Fig. 5) had 3 clusters, cluster 1 (upper), cluster 2 (middle) and cluster 3 (bottom); Cluster 1 consist of V, Zn, Cu, Zr, Sr, Cr and Rb, cluster 2 consist of the elements Au, Pb, W, As, Th, Co and Cl and cluster 3 consisted of Ti, Mn, Ca, K and Fe. It was known that the geology of the study area was dominated by two major rock types; the granitoids and the basalt, this therefore means that cluster 1 is a typical of the basalts which have undergone least alteration. Claster 2 can be said to represent the granitoid, the HCA also indicated that the gold is associated with this cluster indicating conformity with the chemistry of the granitoids, this is understandable because according to [4] Alteration (1), consisting of sericite + quartz + ankerite + calcite + tourmaline + pyrite, is restricted to the mineralized network of quartz veins. Cluster 3 also conforms to the geology because it has been reported that away from the mineralized zone, a metamorphic assemblage of chlorite–epidote–biotite characterizes the rocks and is considered to represent a greenschist-facies metamorphic gradational contacts as one moves laterally away from the veins [4], [7].

C. Principal Component Analysis:

The datasets were factored according to how closely correlated they were, elements with a high correlation value (i.e. close to 1) show similar expression values while elements with a high negative correlation value (i.e. close to -1) show opposing expression values. The method of extraction used in the Factor analysis was the Principal Component Analysis (PCA) and the scree plot in Fig. 6 indicated 6 components. Table 3 predicted the total variance explained for each of the six factors extracted and the factor model showing the loadings of the various variables under each of the respective factors is presented in Table 4.

TABLE 1: SUMMARY OF DESCRIPTIVE STATISTICS FOR THE DATA SET BEFORE LOG_TRANSFORMATION.

	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Au_ppb	1088	2096	-2	2094	10671	9.81	2.172	71.640	5.132E3	23.732	.074	666.540	.148
Cl_ppm	1035	982	0	982	101668	98.23	4.453	143.258	2.052E4	1.388	.076	1.942	.152
K_ppm	1086	12136	0	12136	3585859	3301.90	73.959	2437.277	5.940E6	.752	.074	.216	.148
Ca_ppm	1086	29018	0	29018	5584862	5142.60	138.810	4574.428	2.093E7	1.823	.074	3.916	.148
Ti_ppm	1085	7625	327	7952	2471264	2277.66	33.960	1118.625	1.251E6	1.407	.074	2.241	.148
V_ppm	1088	314	11	325	76349	70.17	.631	20.814	433.222	2.289	.074	21.972	.148
Cr_ppm	1088	2465	0	2465	112404	103.31	4.515	148.923	2.218E4	10.584	.074	134.238	.148
Mn_ppm	1088	2705	189	2894	847188	778.67	11.340	374.047	1.399E5	1.522	.074	4.072	.148
Fe_ppm	1088	138285	9990	148275	6.E7	5.31E4	898.192	29626.711	8.777E8	.932	.074	-.352	.148
Co_ppm	1088	253	0	253	23311	21.43	.667	21.986	483.391	1.964	.074	12.125	.148
Cu_ppm	1088	346	0	346	44292	40.71	.809	26.690	712.334	2.731	.074	18.357	.148
Zn_ppm	1088	152	8	160	67893	62.40	.740	24.406	595.663	.354	.074	-.230	.148
Ars_ppm	1063	1698	0	1698	17501	16.46	2.274	74.151	5.498E3	14.199	.075	275.567	.150
Zr_ppm	1088	527	21	548	162480	149.34	1.849	60.994	3.720E3	1.911	.074	6.945	.148
Rb_ppm	1086	151	0	151	30248	27.85	.624	20.547	422.199	1.302	.074	2.961	.148
Sr_ppm	1088	866	15	881	220248	202.43	3.618	119.333	1.424E4	1.094	.074	1.829	.148
W_ppm	1066	497	0	497	4272	4.01	.545	17.799	316.802	20.789	.075	556.454	.150
Pb_ppm	1087	88	0	88	7011	6.45	.130	4.275	18.279	7.179	.074	123.753	.148
log_Th	352	.87	1.11	1.98	510.09	1.4491	.00847	.15895	.025	.621	.130	.142	.259
Valid N (listwise)	315												

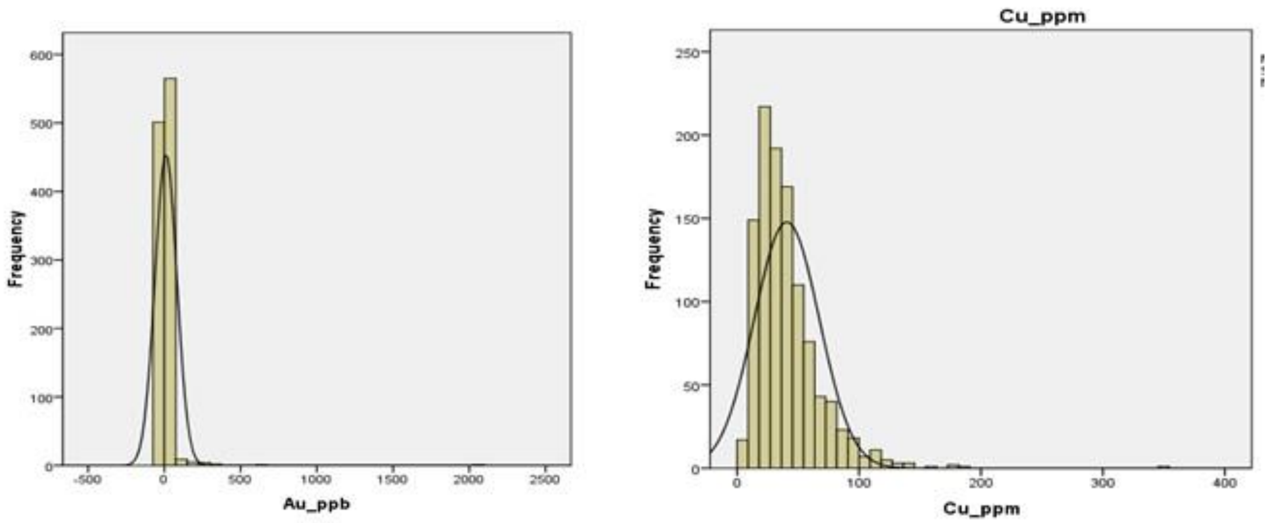

Fig.3: Histogram plots for Au and Cu elements (before log_transformation)

TABLE 2: SUMMARY OF DESCRIPTIVE STATISTICS FOR THE DATA SET AFTER LOG_TRANSFORMATION.

	N	Range	Minimum	Maximum	Sum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
log_Au	587	3.32	.00	3.32	467.36	.7962	.02077	.50333	.253	1.187	.101	2.094	.201
log_Cl	387	.96	2.03	2.99	924.41	2.3886	.00814	.16006	.026	.383	.124	.071	.247
log_K	1013	1.98	2.10	4.08	3470.26	3.4257	.01155	.36776	.135	-.854	.077	.423	.154
log_Ca	1083	2.66	1.81	4.46	3831.46	3.5378	.01311	.43131	.186	-.722	.074	.739	.149
log_Ti	1085	1.39	2.51	3.90	3592.60	3.3112	.00605	.19940	.040	.080	.074	.218	.148
log_V	1088	1.47	1.04	2.51	1989.10	1.8282	.00387	.12757	.016	-.689	.074	4.185	.148
log_Cr	1025	2.22	1.18	3.39	1993.08	1.9445	.00792	.25368	.064	.359	.076	5.037	.153
log_Mn	1088	1.19	2.28	3.46	3096.64	2.8462	.00600	.19807	.039	.022	.074	-.168	.148
log_Fe	1088	1.17	4.00	5.17	5072.15	4.6619	.00705	.23239	.054	.212	.074	-.777	.148
log_Co	751	1.65	.75	2.40	1064.86	1.4179	.00913	.25012	.063	.231	.089	-.514	.178
log_Cu	1086	1.84	.70	2.54	1666.34	1.5344	.00783	.25804	.067	-.044	.074	.036	.148
log_Zn	1088	1.30	.90	2.20	1911.97	1.7573	.00581	.19168	.037	-.796	.074	.902	.148
log_Ars	633	3.23	.00	3.23	570.37	.9011	.02303	.57946	.336	.978	.097	.559	.194
log_Zr	1088	1.42	1.31	2.74	2329.73	2.1413	.00524	.17275	.030	-.558	.074	2.652	.148
log_Rb	1048	2.18	.00	2.18	1394.95	1.3311	.01173	.37964	.144	-.921	.076	.521	.151
log_Sr	1088	1.78	1.16	2.94	2420.93	2.2251	.00854	.28168	.079	-.552	.074	.183	.148
log_W	254	1.92	.78	2.70	276.74	1.0895	.01624	.25885	.067	2.271	.153	7.217	.304
log_Pb	1022	1.64	.30	1.94	810.58	.7931	.00578	.18471	.034	.429	.077	1.727	.153
log_Th	352	.87	1.11	1.98	510.09	1.4491	.00847	.15895	.025	.621	.130	.142	.259
Valid N (listwise)	0												

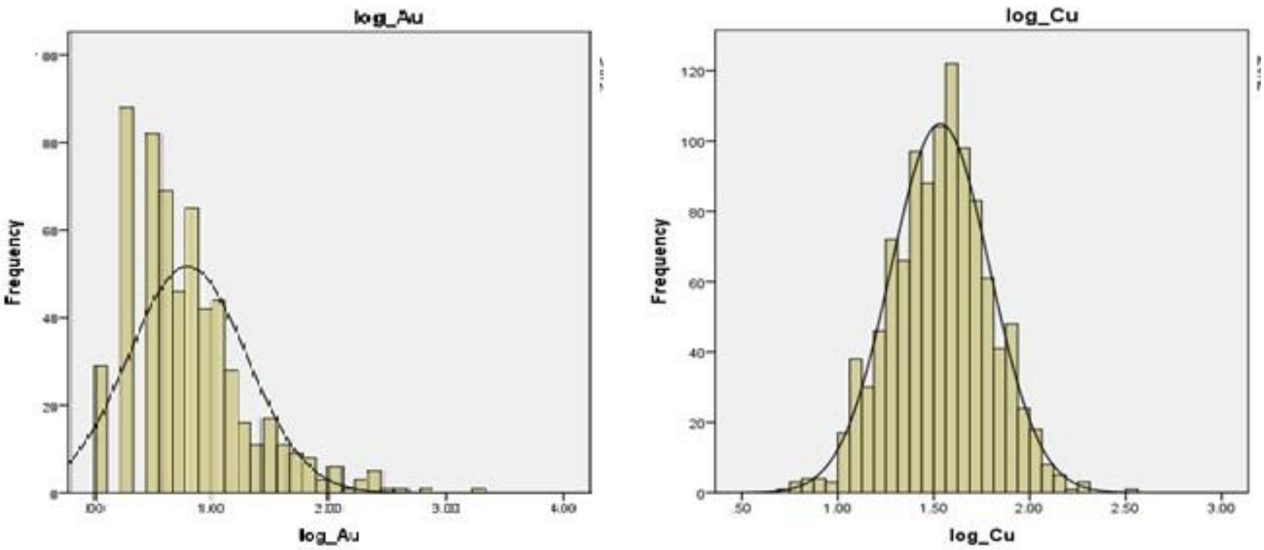

Fig.4: Histogram plots for Au and Cu elements (after log _transformation)

Rescaled Distance Cluster Combine

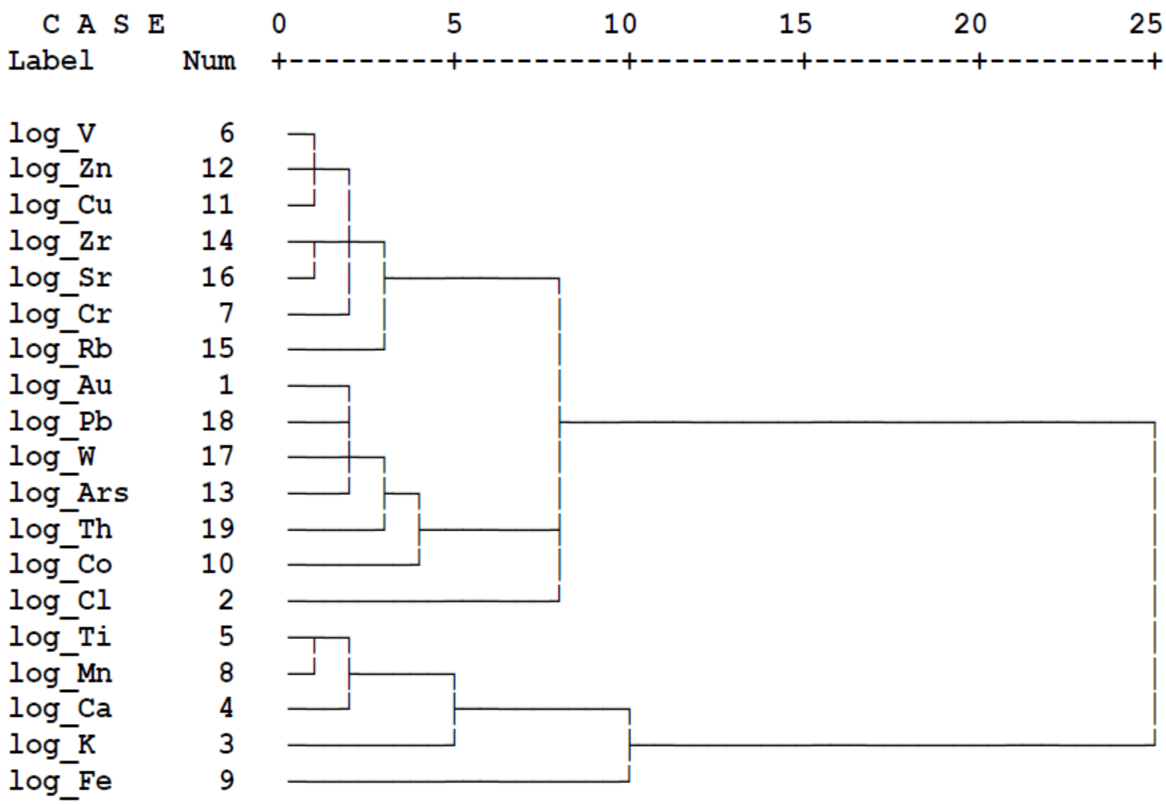

Fig.5: Dendrogram using Average Linkage (Between Groups)

Since the strength of correlation ranges from 0 (no correlation) to either +1 (strongly positively correlated) or -1 (strongly negative correlated), a value of 0.5 was used as the cut-off for reading the correlated variables; Thus, the 6 factors as indicated in Table 3 contributed for 70.08% of the total variability, the first factor accounts for 25.06% and Table 4 which represents the first factor as component 1indicated a positive correlation with Ti, Mn, Fe, Cu and Zn, factor 2 contributed for 15.26% with component 2 positively correlating with K, Co, Zn, Pb and Th, factor 3 contributed for 10.27% of the total variability and its component is dominated with Ti, V, Zr, and Au, in the same vein, factor 4 contributed for 7.39% dominated with only Sr, factor 5 which contributed 6.45% is associated with Cr and W, lastly component 6 contributing 5.66% is associated with only As.

TABLE 3: TOTAL VARIANCE EXPLAINED

Component	Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	4.761	25.058	25.058
2	2.899	15.256	40.315
3	1.950	10.266	50.580
4	1.404	7.391	57.971
5	1.225	6.449	64.420
6	1.076	5.661	70.081

The correlations of component 1 gives the elemental composition of the mafic rock which has undergone least alteration, since the north of the Julie shear zone are basalts and sediments, the basalts are strongly magnetic and composed of plagioclase, green amphibole, calcite, chlorite with minor titanite and magnetite [4]

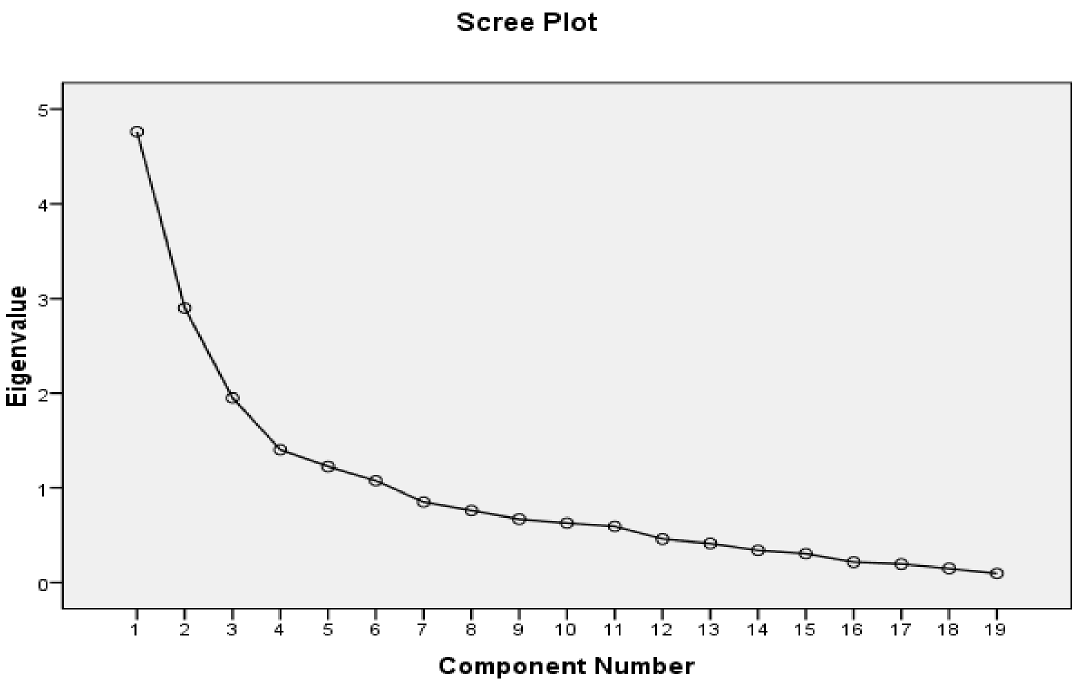

Fig.6: Scree plot showing the component numbers

However, the main objective of this work is to predict for the pathfinder elements for the gold within the study area, Table 4 indicated that the highest loading value for gold is 0.425, obviously associating with component 3, since only Pb, W, As, and Cl indicated a linear trend with the gold in Table 4, and also tally with the second cluster of the dendrogram (Fig. 5) to which the gold also belongs, Pb, As, W and Cl may therefore be the pathfinders for gold within Julie belt.

Pb and W, are probably the best pathfinder elements because pyrite is the principal ore mineral within the mineralized zones, either in the veins or in the altered host rocks [4] [6] [7] Taken into consideration As, since no arsenopyrite has been reported from Julie area, the correlation may be connected with a probable arsenide pyrite (pyrite with arsenic formed within the pyrite structure) present in the area. The presence of chloride as a pathfinder element is a big questionable since chloride in the area is mostly associated with chloride alteration within the hydrothermal mineralized system in Julie.

TABLE 4: COMPONENT MATRIX

	Component					
	1	2	3	4	5	6
log_Au	-.032	-.071	.425	-.469	.363	-.136
log_Cl	-.243	-.775	.232	.118	.024	.122
log_K	-.550	.508	.028	-.189	-.192	-.300
log_Ca	.441	.236	-.423	.273	.327	.391
log_Ti	.520	.264	.557	.331	-.047	.215
log_V	.410	.089	.749	.318	-.018	-.136
log_Cr	-.442	-.347	-.251	.137	.573	.016
log_Mn	.607	-.152	.106	.111	.204	-.240
log_Fe	.942	.024	.104	.001	.042	.024
log_Co	.413	.724	-.267	-.300	-.131	-.101
log_Cu	.618	.069	.051	.157	.267	-.291
log_Zn	.659	.517	-.112	-.173	.032	.160
log_Ars	.057	-.157	.272	-.536	.115	.611
log_Zr	-.543	.331	.467	.117	-.144	.266
log_Rb	-.764	.297	.296	.052	.042	-.097
log_Sr	-.431	.336	-.151	.522	.175	.013
log_W	-.152	.253	.199	-.280	.577	-.216
log_Pb	-.270	.532	.204	.043	.241	.109
log_Th	-.404	.527	-.099	.132	.167	.207

Extraction Method: Principal Component Analysis. 6components extracted

5. CONCLUSION

The factor analysis indicated that the gold within the study area has correlated with component 3 which matched cluster 2 of the dendrogram, while cluster 1 was deemed to represent the basaltic rocks, cluster 2 and 3 are typical of the granitoid, since the Julie deposit is hosted in strongly sheared granitoid that primarily composed of quartz, plagioclase, hornblende and biotite with accessory minerals of titanite, zircon and magnetite, which are overprinted by greenschist-facies metamorphic assemblages of epidote, calcite, fine-grained biotite and rutile. The veins carrying the gold have significant amount of calcite and ankerite, mineralization is associated with xenotime, so, these rocks have enough Heavy Rear Earth Elements (HREEs) it was not therefore unexpected that gold is associated with cluster 2 and component 3 from the HCA and PCA respectively. More still, within the mineralization zone itself, systems of alterations were reported [4], [6] and [7], and so original constituent of the tonalitic rock has been altered. Therefore, Lead (Pb), Tungsten (W), and Arsenic (As) are identified as the pathfinders for gold within the Julie belt. Apart from As, which this study is the first to report, Pb and W have also been identified as pathfinder elements within Julie belt [4], using ICPMS method and hard rock petrography, Pb has also been reported among others, as a pathfinder element for Au [10] from an adjacent deposit of Julie belt.

It is therefore concluded that, the multivariate statistical techniques utilized by this study have proven effective in identifying pathfinder elements, and effective in the study of inter-elemental associations using multi-element geochemical data.

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