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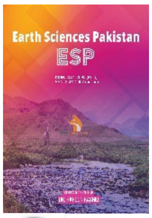

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RESEARCH ARTICLE

MULTI ELEMENT ANALYSIS FOR GOLD MINERALIZATION AT ABODUABO CHIRANO GOLD MINES LIMITED

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ABSTRACT

The main aim of this work was to identify pathfinder elements associated with gold mineralization at Aboduabo and identify the different elements associated with mineralization within the Aboduabo prospect. The geochemical data was obtained from 107 soil samples which were analyzed for 50 elements. The 50 elements were evaluated using multivariate statistical methods. Principal Components and Factor Analyses were used to reduce the data into ten groups and Cluster Analysis conducted to find elements associated with gold hence serving as pathfinders for gold. In order to identify the pathfinders for gold, descriptive statistics, scatterplot diagrams, component matrix, and a dendrogram was made. Principal Components, Factor and Cluster Analyses were conducted using the SPSS software. The ten Components extracted 85.656% of the explained variance in the variables. The first principal component extracted 34.040% of variability with large positive loadings from titanium, tin, germanium, and manganese which have their sources from the Birimian metasediments such as phyllite, schist and greywacke. The third loading although it has Au as the dominant factor, also has some positive associations with As, Na, Co, Ni, Sr, Rb, Ce, Mn, and Te which explained 8.856% of the total variance, Ni, Co, Mn, and Sr which are linked to the underlying mafic rocks such as basalts, dolerites, and diorites. Cluster Analysis on the elements reduced the whole data to four clusters. The first cluster consisted of Ga, Sc, Fe, Zr, Pb, La, Sr, Y, Li, Al, Th, As, Au, Cr, V, Cu, Zn, Ni, Ce, Ba, and Co. In the study area, As, Cu, Ni, Pb, Zn, Ba, Ce, Co, Cr, La, Sr, Y, and Li were shown to be gold pathfinders. These findings suggest that both primary and secondary processes contributed to the occurrence of gold and the elements it is associated with. Copper, nickel, lead, zinc, barium, cerium, cobalt, chromium, lanthanum, strontium, yttrium, lithium can be used as pathfinders for gold in the area whiles arsenic can be used as the main pathfinder for gold mineralization at Aboduabo.

KEYWORDS

Multi-element analysis, gold mineralization, Aboduabo Chirano gold mines, geochemistry, cluster analysis

1. INTRODUCTION

Because of its inherent qualities, gold has long enthralled people and is regarded as the most sensuous metal. Its rarity, beauty, and mysticism have made it a valuable resource from the beginning of humankind. Gold has long been used as a gauge of worth, and artifacts and jewelry made of gold from different historical periods have been found all over the world. With 48.8% of gross merchandise exports being accounted from gold mining, the mining industry in Ghana is the government's main source of income. In Africa, Ghana is the continent's largest gold producer, and it ranks sixth globally with 5 million ounces of gold production as of 2020 (Kwame, 2022). Over a million people work in the small sector, which accounts for about 28,000 of the sector's total employment in large-scale mining making the sector a significant part of the Ghanaian economy. Gold mineralization is the deposition of gold in the formation of ore bodies or "lodes" by various process. Gold mineralization in mineral deposits occur in shear zones located in orogenic belts, which were created during syn- to late metamorphic phases of orogeny and are found primarily in metamorphosed fore-arc and back-arc regions. The development of gold deposits is related to the structural evolution and structural geometry of the lithospheric crust as hydrothermal fluids pass through already existing and active discontinuities (faults, shear zones, and lithological boundaries) created by tectonic processes (McQueen, 2008). In addition to fluids conveying ore, these discontinuities also provide paths and channels for the passage of gases, melts, and metallic elements including silver, arsenic, mercury, and antimony. Gold-bearing fluids precipitate at an upper-crustal level between 3 and 15 km of depth (and maybe up to 20 km of depth) above the transition from greenschist to amphibolite metamorphic facies, creating vertically widespread quartz veins. Almost all of the lithologic units in the area include quartz veins (McQueen, 2008). On the contact zones of the boundaries between metavolcanic and metasedimentary rocks, as well as in the chemical sediments, gold-bearing quartz veins are seen, associated with shear and fault zones. As a gold source, the chemical sediments are of special significance. The gold quartz veins exhibit secondary mineral assemblages, such as chlorite, carbonate, muscovite, graphite, epidote, and sulphides, that are typical of hydrothermal alteration (McQueen, 2008). Anomalous concentration of metals or elements in soil samples can indicate presence of mineralization in a geochemical environment. A geochemical anomaly is a departure from the geochemical patterns that are normal for a given area of geochemical environment. An ore deposit being relatively rare or of abnormal phenomenon is itself a geochemical anomaly. Setting threshold values, which denote the upper and lower bounds of typical variation for a given population of data, is the most common method for identifying

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geochemical anomalies. The terms "background values" and "anomalies" are used to describe values that are above or below the threshold values. In mineral exploration, positive anomalies are typically of interest since it is assumed that ore deposits and their weathering have boosted element abundances above crustal levels (Ali, 2006). Geochemistry relies heavily on multi-element analyses of minerals to characterize rocks and minerals and to comprehend how they arise and change during geological processes (McQueen, 2008). It is frequently more fruitful to look at the spatial distribution of a group of elements rather than just one element when looking for a specific type of mineral deposit, like gold. Geochemical data analysis is typically used to identify mineralization in rocks that produce large amounts of gold. (Ali, 2006).

Multi-element analysis has to do with classical methods used to obtain the information about the various elemental composition of minerals and rocks to understand their formations. By examining the relationship between the gold and other geochemical elements, geochemical exploration serves as one of the many strategies used by scientists to find, characterize, and look for trends and anomalous haloes for gold (Umar et al, 2016). In this study, we would emphasis on the multi element analysis of gold mineralization at the Aboduabo prospect located at Chirano which is the area under study. The soil geochemical data which would be obtained from the soil sampling data would be used to map the anomalous zones using factor analysis and establish a relationship between the various elements and the gold using the Statistical package for social sciences (SPSS) and IOGAS software. The soil sampling would include picking of soil samples at areas within the Aboduabo prospect and using fire assay to analyze for the gold as well as induced coupled plasma mass spectrometry for the elements and derive the relationship between the elements and its association with the gold.

2. Regional Geology

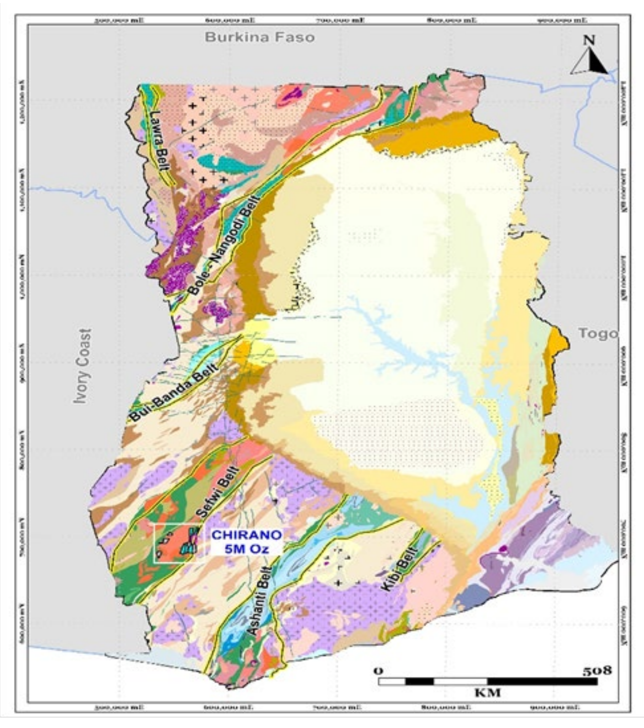

Figure 1: Regional geological setting within southwest Ghana and relation to Bibiani

The Chirano deposits are situated in the Paleoproterozoic Birimian rocks found in the southwestern region of Ghana, within the West Africa Craton. The West Africa Craton consists of two main parts: the Archean core, known as the Man Shield, and a Paleoproterozoic domain with remnants of Archean basement (Milési et al., 1989). The Man Shield, which dominates the southern part of the West African Craton, has a western section that dates back to the Archean era (~3.0-2.5 Ga), while the eastern part is composed of the early Proterozoic Birimian rocks (Leube et al., 1990). The Birimian rocks were formed during the Eburnean orogeny, a significant Paleoproterozoic crust-forming event (Davis et al., 1994). The Birimian terrains in Ghana consist of five northeast trending volcanic belts, spanning approximately 500 km in a NE-SW direction. These volcanic belts are separated by metasedimentary basins, which are around 200 km wide. Throughout West Africa, the Birimian geology contains notable gold deposits like Obuasi, Tarkwa, Bibiani, and Konongo. Figure 1 shows the regional geological setting within southwest Ghana and relation to Bibiani. The volcanic belts mainly comprise metamorphosed volcanic rocks with theolitic to calc-alkaline composition, while the metasedimentary basins contain metamorphosed volcaniclastics, wackes, and argillitic sedimentary rocks. The economic geology of Ghana is primarily influenced by the Precambrian Birimian and Tarkwaian sequences.

The contact between the Birimian and Tarkwaian rocks has undergone strong tectonism, leading to stratigraphic repetition, overturned bedding, and stretched lineation, indicating that the Birimian volcanic rocks were thrust obliquely onto the Tarkwaian rocks (Milesi et al., 1989). The Birimian can be broadly subdivided into metasediments consisting of phyllites, tuffs and greywackes (often referred to as the lower Birimian) and metavolcanics consisting of various basaltic to andesitic lavas and pyroclastic (often referred to as the Upper Birimian). These subdivisions are conformable and have been deformed and regionally metamorphosed to lower greenschist facies. The (tectonic) contacts between these two units have historically been the focus of economic attention, as this is the preferred position for the major shear zones and quartz veins that host the gold deposits of Obuasi, Prestea, Konongo, Bibiani and Chirano. Gold is invariably associated with arsenopyrite and subordinate pyrite. Three identifiable granitoid types have intruded the Birimian System, the two most extensive being the Cape Coast (or basin type) and the Dixcove (or belt type) suites. Gold is hosted by belt type (Chirano, Yamfo, Abore, Mpasatia).

2.1 Local Geology

The Chirano North Prospecting License is located along the southwestern margin of the northeast trending Sefwi-Bibiani Belt. The Prospecting License straddles the contact zone between the western mafic volcanic belt and the eastern Kumasi Basin sediments. The western part of the concession is dominated by mafic volcanic and intrusive rocks, including medium to coarse grained intrusive mafic bodies containing volcanic (basaltic) xenoliths. The middle portion of the concession is dominated by a wedge of Tarkwaian Group sediment outlier. The eastern portion is underlain by the Kumasi Basin sediments (CGML, 2019). The Tarkwaian unit is bounded by two fault zones; the major Bibiani Shear Zone (BSZ), to the east, and the Chirano Shear Zone (CSZ) to the west, which forms a splay from the BSZ. This is shown in Figure 2. A tonalite/porphyry body which has intruded along the western side of the Chirano Shear Zone has been the focus of exploration activities, with gold mineralization defined along a 10km strike. A change in orientation of the belt margin occurs within the Chirano North Prospecting License, from the regional north-easterly trend to a northsouth trend in the area where the Chirano Shear Zone splays off the Bibiani Shear Zone (CGML, 2019). The change in the regional trend and the location of the Tarkwaian inlier between the two shear zones is thought to have played an important role in localizing gold mineralization. The granitoid is affected by shearing, cataclasis, faulting and alteration. The sheared contact between the western mafic belt and the eastern Kumasi basin sediments is the single dominant structure within the concession. There are several other structures associated with the belt-basin sheared contact, with the most prominent one being the Chirano Shear Zone. The relationship between the regional scale sheared belt contact and the associated shear zones is not yet well understood (CGML, 2019). Previous exploration within the concession was focused on the Chirano Shear Zone, which forms a southwesterly splay fault off the regional Bibiani Shear Zone. The Chirano shear trends in a grid south direction from the Bibiani shear, for a distance of approximately fifteen kilometers, and then appears to trend in an arcuate, easterly direction back towards the Bibiani shear. The Chirano Shear Zone occurs along the contact region between the eastern edge of the mafic belt and the western edge of the Tarkwaian outlier. Exploration activities have also tested the Bibiani Shear Zone and Kumasi Basin sediments adjacent to the Chirano Shear Zone. This shear zone occurs along the eastern contact of the Tarkwaian outlier, forming the contact between this unit and the Kumasi Basin Sediments (CGML, 2019). The Bibiani Shear Zone is associated with the four million-ounce Bibiani gold mine, 15 km to the north of the Chirano Gold Mines Ltd. deposits. The Bibiani Shear Zone represents a major regional structure, extending for hundreds of kilometers. This shear forms the contact between the western mafic belt and the eastern sedimentary belt. A review of historical information including drill core suggest that the best grades along the BSZ are associated with quartz veins that are structurally interleaved with phyllite over several meters. These veins are developed in graphitic, brittle-ductile shear zones up to several meters wide that have caused significant folding and disruption of the mineralized quartz veins (CGML, 2019). Surface exposures suggest that the Birimian sedimentary units comprise interbedded shale and siltstone to fine-grained sandstone. Quartz veins appear to have preferentially developed in shale beds (now phyllite) between more competent siltstone-sandstone beds. Preferential development of the quartz veins in orientations sub-parallel to bedding and bedding-parallel cleavage suggests that flexural slip localized in shale units during folding may have assisted quartz vein emplacement, particularly in fold hinges. Distal from the mineralization the Birimian sedimentary rocks preserve bedding, strain is relatively low (even in the shale beds) and veining is only very weakly developed. A critical element in the development of the structural history is the presence of the Tarkwaian outlier. It is believed that these sediments have acted as a rheologically competent unit, and that the presence of the Tarkwaian unit has served to refract regional shear stresses around the margins of the outlier. This refraction has resulted in dilation and subsequent intrusion of the mineralized porphyries (CGML, 2019).

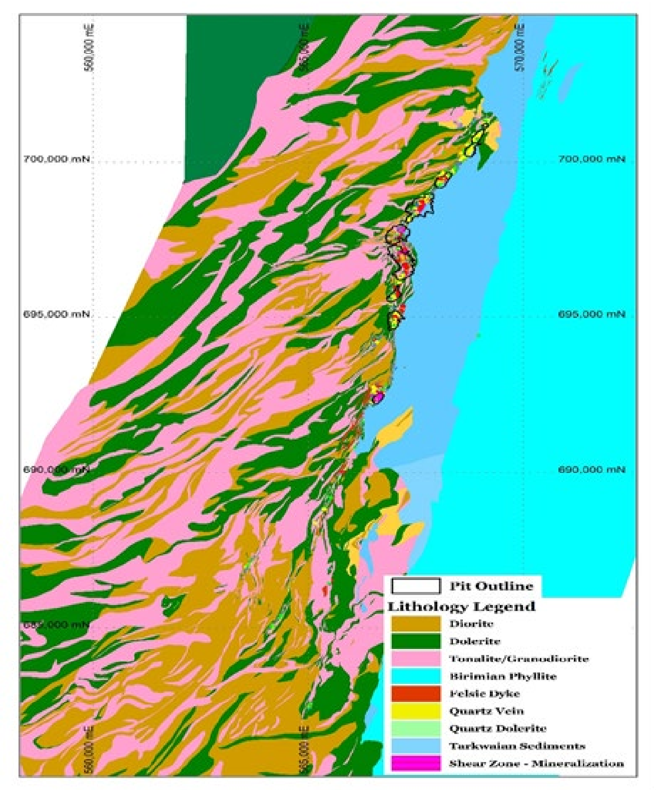

Figure 2: Local geology of Chirano

2.2 Multi Element Analysis Geochemistry

Mineral assemblages resulting from hydrothermal alterations reflect the composition of ore forming fluids. Geochemical variables, being multivariate and regionalized, are interesting candidates for numerical analysis using geostatistics and data analysis methods to identify geochemical anomalies. The availability of low-cost, rapid multi-element analytical techniques has led to the accumulation of extensive geochemical databases in exploration programs. Handling such vast data matrices, with thousands of samples, becomes burdensome when interpreting individual elements. However, employing multivariate statistical techniques can reveal underlying patterns related to geology, weathering, alteration, and mineralization, enhancing the interpretation of these patterns (Nude et al., 2012). Care must be taken when applying statistical methods to interpret geochemical datasets and define anomalies due to the specific characteristics of such data. Geochemical datasets often represent a single population or distribution, exhibit spatial dependence, and are influenced by various processes at each sampling site. Moreover, the data are imprecise due to inherent variability in sampling methods, media, and analytical precision. Consequently, there is no universally applicable statistical test for identifying anomalies. Hence, a range of techniques should be used to explore the nature of geochemical data before identifying anomalous values (Nude et al., 2012). In this study, Factor Analysis is applied to a multivariate geochemical dataset. Factor analysis is suitable for establishing element associations, as it allows obtaining several factors as linear 13 combinations of the original chemical elements. Some of these factors can provide insights into specific groups of variables, offering geochemically significant associations that go beyond the study of individual variables. The probabilistic and spatial behavior of geochemical variables is utilized by these techniques, aiding in the identification of potential anomalous areas for locating mineralization. Additionally, multivariate analysis helps study the inherent spatial structure of geochemical data and identify and refine significant anomalies related to Au-bearing mineral deposits. Factor analysis simplifies complex datasets by identifying underlying "factors" or processes that explain data variability dimensions. The "loading" of each factor, indicating the degree of association between variables and factors, allows the recognition of clusters (Nude et al., 2012). Hierarchical Cluster Analysis (HCA) is another commonly applied method for geological/hydrological analysis, aiming to group samples based on their similarities. HCA is a powerful tool for analyzing data sets, identifying expected or unexpected clusters, and detecting outliers. It starts with each point forming an initial cluster, and then the most similar points are grouped to form a cluster until all points belong to one cluster. The multivariate statistical analysis conducted on the dataset is produced using SPSS, which gives descriptive statistics like the arithmetic mean, median, standard deviation, minimum value, kurtosis, and skewness. Histograms and data plots are generated, and curve fitting is applied to check the normal distribution and stationarity of the data.

3. Methodology

3.1 Introduction to Methodology

For the purpose of this project, data from multielement soil geochemical survey conducted in the study area were used. The soil geochemical soil survey is a systematic and detailed process of collecting and analyzing unconsolidated soil sediments with the objective of locating geochemical anomalies in the underlying rock and to use these to find ore bodies. The samples are then prepared and analyzed using fire assay techniques. The fire assay process is a highly precise and accurate method for the total determination of Au and other precious metals in (ore grade) samples. For this project, the samples collected were analyzed using 50g low grade fire assay with aqua regia digest and extraction with AAS finish at detection limit of 10ppb.

3.2 Soil Sampling

Soil samples were collected at the sampling points defined by the geologists in local grid or UTM using Germain handheld GPS with accuracy within 4m. Samples are not collected if the sampling point is located on an alluvial channel and if sampling point is located on indurate material (duricrust, ferricrete). If sampling point is located on an outcrop of fresh or even weathered rock (saprolite and sap-rock) samples are not to be taken there. If no sample can be collected due to the above reason, then sampling point can be moved up to one tenth of the sampling spacing backward or forward along the line. If no sample can be collected even after moving, then the sampling point is discarded, and the 'No Sample' is entered in the sample ID field in the sample sheet (No sample number allocated). All sample preparation was done at Bibiani laboratory by pulverizing to 90% passing 75 microns. Samples were analyzed using 50g low grade fire assay with aqua regia digest and extraction with AAS finish at detection limit of 10ppb. Duplicates and standards reported within acceptable limits.

3.3 Descriptive Statistics

The dataset, consisting of 50 elements as variables, underwent multivariate statistical analysis using SPSS software. The analysis involved summarizing descriptive statistics, such as arithmetic mean, median, standard deviation, minimum value, maximum value, kurtosis, and skewness. Histograms were produced and fitted with normal curves to assess the normal distribution and stationarity of the data. To ensure the data were suitable for statistical analysis, they were log-transformed. Subsequently, histograms were plotted to evaluate the normality of the transformed data.

3.4 Hierarchical Cluster Analysis

The dendrogram gives a graphical representation of the correlation among the entire datasets. Individual elements are arranged along the vertical axis of the dendrogram, and clusters are formed by linking individual elements or existing element clusters, with the joining point referred to as a node. Each dendrogram node consists of an upper and lower sub-branch of clustered elements. The horizontal axis is labeled as "distance," representing the distance measure between elements clusters. The length of the node indicates the distance value between the upper and lower subbranch clusters. Highly correlated clusters appear nearer the labeled vertical axis on the left side of the dendrogram, while elements clusters with zero correlation values, indicating no correlation, have a corresponding distance value of 1. On the other hand, elements showing negative correlation, i.e., exhibiting opposite expression behavior, will have a correlation value of -1, and the distance will be greater than one.

3.5 Factor Analysis

Factor analysis is a statistical technique used to examine the relationships among numerous variables and uncover the underlying common factors that explain these variables. This method condenses the data into a smaller set while retaining essential information from the original dataset. To conduct factor analysis, the raw data is standardized, allowing variables with small variance to have a greater influence, and reducing the impact of variables with large variance. Next, correlation coefficients are calculated, aiding in understanding the structure of the underlying system that generated the data. Eigenvalues and factor loadings are determined for the correlation matrix, and a scree plot is created (Figure 5) to assess the significance of the factors. Principal Component Analysis (PCA) is used to extract factors based on variances and covariances of the variables. The eigenvalues and eigenvectors are then assessed, reflecting the amount of variance explained by each factor. Factors with eigenvalues greater than one indicate more variation in the data than individual variables. Lastly, the process of rotation is applied, maximizing the loading of each variable on one of the extracted factors while minimizing the loadings on all other factors. This step helps to simplify and clarify the relationships between variables and factors.

4. Results and Discussion

4.1 The Geochemical Data and Descriptive Statistics

The minor multi-elements include Au, As, Ni, Zn, Ba, Ce, Co, Cr, Ga, La, Nb, Rb, Sc, Sr, V, W, and Y. All the elements were factored into the analysis. Descriptive analysis was done for the elements. The summary of the descriptive analysis for the elements as presented in Table 1 shows an obvious disparity with the mean. Au has a total sample frequency of 107 having a range of 252.9 since the maximum value was 253.0 with the minimum value of 0.1, the mean was 11.078 and the standard deviation of 30.1632. The gold showed a skewness of 6.562. This shows an extreme variability of geochemical data. Most of the elements also departed from the mean and are neither normally distributed nor stationary (Table 1). This makes it difficult to be used in a multivariate analysis since the data is non-normal.

Table 1: Summary of Descriptive Statistics for The Data Set Before Log Transformation

Variable	Observations	Range	Minimum	Maximum	Mean	Standard Deviation	Skewness
Au_ppb	107	252.9	0.1	253.0	0.6508	30.1632	6.562
As_ppm	107	205.4	0.6	206.0	1.0333	30.9415	3.240
Cu_ppm	107	112.0	2.5	114.5	1.4446	17.9274	1.323

Histograms were generated for the dataset, but only two elements (Au and As) are presented in Figure 3. This observation further supports the notion that the dataset is not normally distributed and lacks stationarity. The histograms exhibit high kurtosis and strong positive skewness (Figure 3). The high kurtosis suggests that the concentrations of these elements are concentrated in specific areas of the study region, as represented by certain samples. Additionally, the dataset displays positive skewness, indicating that the concentrations of elements in the study area are not uniform. Most samples exhibit relatively similar concentrations, while a few others have exceptionally high concentrations, potentially representing point anomalies for these elements. The background concentrations, in turn, represent the prevailing values of these elements within the study area.

The fundamental assumption when applying multivariate methods such as Factor Analysis and Hierarchical Cluster Analysis is that the data should follow a normal distribution. However, geochemical data, due to their spatial dependence, are inherently non-normal. To address this issue, a logarithmic transformation was applied to the dataset, and the summary of descriptive statistics is presented in Table 2. The difference between Table 1 and Table 2 is evident. For instance, considering the gold raw data, the range is now 3.40, with a minimum value of -1.00 and a maximum value of 2.40, whereas before the transformation, the mean was 11.078, and the standard deviation was 30.1632. The skewness and kurtosis values have also changed to -0.111 and 2.335, respectively, from their previous values of 6.562 and 46.77. The data has now been transformed to be close to normal since the skewness and kurtosis of a normal distribution are 0 and 3, respectively. It is important to note that no dataset is exactly normally distributed; instead, it is sufficient for the data to be approximately normal (Figure 4 illustrates the histogram plots for the elements after the log transformation). This transformation effectively prepares the values for a more suitable multivariate statistical analysis.

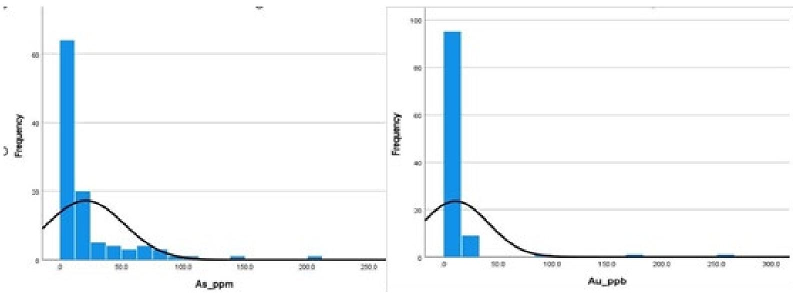

Figure 3: Histogram plots for Au and as elements before log transformation

Table 2: Summary of Descriptive Statistics for The Data Set After Log_Transformation

Variable	Observations	Range	Minimum	Maximum	Standard Deviation	Skewness
Log_Au	107	3.40	-1.00	2.40	0.5401	-0.111
Log_As	107	2.54	-0.22	2.31	0.4916	0.294
Log_Cu	107	1.66	0.40	2.06	0.2578	-0.770

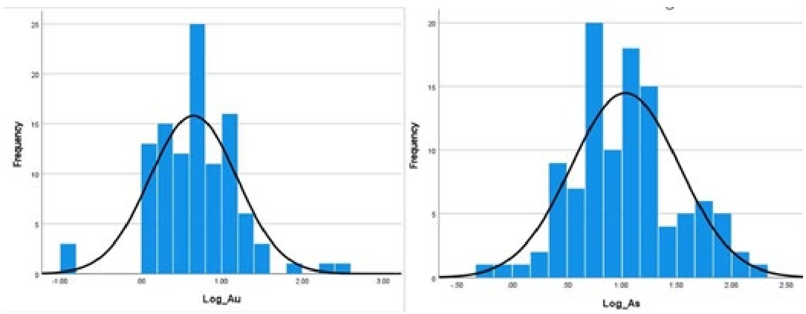

Figure 4: Histogram plots for Au and As elements before log transformation

4.2 Factor Analysis

The method used for extraction was the principal components. The analysis indicated ten factors in the data accounting for 85.656% of the total variability. Table 4 shows the variance explained for each of the factors extracted. From Table 3, we can tell that the first factor which accounts for 34.040% of total variance is dominated by titanium, tin, germanium, and manganese associated with some contribution of chromium, gallium, aluminum, and cesium, Ti and Sn which have their sources from the Birimian metasediments such as phyllite, schist and greywacke, the second is the Te factor with some positive loadings with antimony, which explained 15.877% of the total variance, the third is having Au as the dominant factor, also has some positive associations with As, Na, Co, Ni, Sr, Rb, Ce, Mn, and Te which explained 8.856% of the total variance, Ni, Co, Mn, and Sr which are linked to the underlying mafic rocks such as basalts, dolerites and diorites. The fourth is the Na factor with positive loadings with gold which explained 7.005% of the total variance, the fifth is dominated by antimony, magnesium, phosphorus, tungsten, gold, calcium, and cadmium associated with zinc, scandium, titanium, germanium, and silver which explained 5.029% of the total variance. The sixth is the Sb factor with some positive loadings with cobalt which explained 3.965% of the total variance. The seventh is the Au factor with some positive loadings with rubidium and titanium which explained 3.293% of the total variance. The eight is the S factor with positive loadings with potassium which explained 2.929% of the total variance. The nineth is the Na factor with some positive loadings with zinc which explained 2.397% of the total variance. The tenth is the Mn factor with some positive loadings with zinc which explained 2.263% of the total variance. Fig 5 shows the ten components extracted corresponds to all the factors with the eigenvalues The geology of the area taking into consideration the rock formation is present in the study area can be associated with. Factor 3 being the Au factor associated with As, Na, Co, Ni, Sr, Rb, Ce, Mn, and Te can be attributed to the hydrothermal process responsible for their emplacement. This process is chiefly responsible for Au mineralization in the area. However, the main aim of this work is to predict for the pathfinder elements for the gold within the study area, Table 3 indicates that, the highest loading value for gold is 0.358, obviously associating with component 3. From component 3, As, Cu, Ni, Pb, Zn, Ba, Ce, Co, Cr, La, Sr, Y, and Li indicated a linear trend with the gold. As, Cu, Ni, Pb, Zn, Ba, Ce, Co, Cr, La, Sr, Y, and Li may therefore be the pathfinders for gold within the study area.

Table 3: Component Matrix

Variable	Component									
	1	2	3	4	5	6	7	8	9	10
Log_Au	-0.050	0.138	0.358	0.209	0.157	-0.032	0.205	-0.005	-0.061	-0.014
Log_As	0.124	0.272	0.307	0.080	-0.025	0.079	-0.099	0.034	-0.037	-0.082
Log_Cu	0.194	0.034	0.059	0.004	0.032	0.058	-0.064	-0.032	0.001	0.010

Table 4: Total variance explained

Variables	Total	% of Variance	Cumulative %
1	2.055	34.040	34.040
2	0.958	15.877	49.917
3	0.535	8.856	58.773

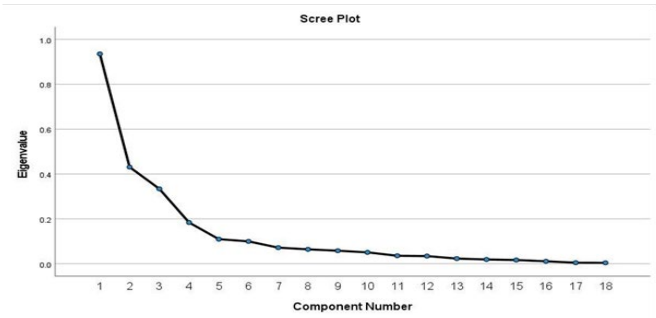

Figure 5: Scree plot showing the component numbers

4.3 Scatter Plot

Results from the scatter plots of Au against all the measured elements showed that As, has high positive correlation with Au. Bi, Zn, P, Sb, and Te have slight, almost negligible positive correlations with Au. However, Cd, Re, and B have no linear correlation with Au. Figures 6, 7 and 8 show scatterplots for Au against Cu, As, Ni, Ba, B, and Re.

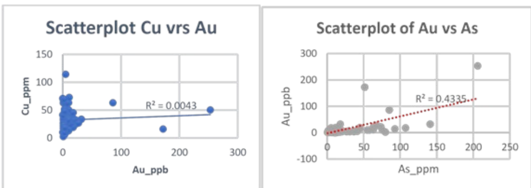

Figure 6: Scatter plots for Au against Cu and As

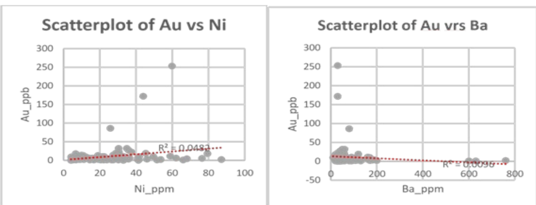

Figure 7: Scatter plots for Au against Ni and Ba

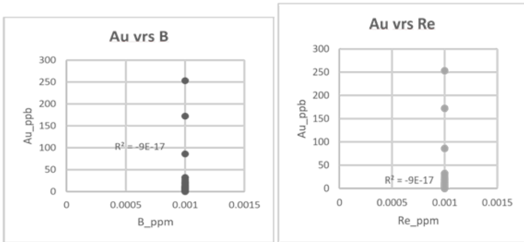

Figure 8: Scatter plots for Au against B and Re

4.4 Hierarchical Cluster Analysis and the Dendrogram

The dendrogram (Figure 9) had 4 clusters, cluster 1, cluster 2, cluster 3 and cluster 4. Cluster 1 consist of Ga, Sc, Fe, Zr, Pb, La, Sr, Y, Li, Al, Th, As, Au, Cr, V, Cu, Zn, Ni, Ce, Ba, and Co. Cluster 2 consist of the elements Mn and P. Cluster 3 consisted of Be, Sn, Mo, U, Se, Cs, Nb, and Sb. Cluster 4 consists of S, Na, Mg, Ca, Ti, Cd, Ag, Ln, Tl, Hg, K, Bi, Te, Hf, W, and Ge. The first cluster tallies with As, Cu, Ni, Pb, Zn, Ba, Ce, Co, Cr, La, Sr, Y, and Li of component 3 of Table. As, Cu, Ni, Pb, Zn, Ba, Ce, Co, Cr, La, Sr, Y, and Li can therefore be used as pathfinders for gold within the study area.

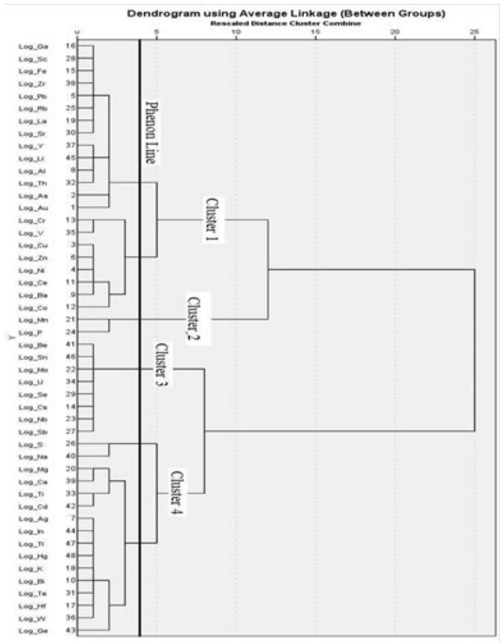

Figure 9: Dendogram using average linkage between group

5. Conclusion

The application of both factor analysis and hierarchical cluster analysis to the multi-element soil geochemical data from the study area Aboduabo in Sefwi-Bibiani belt of Ghana showed that, gold was associated with arsenic, nickel, cobalt, rubidium, cerium, copper, zinc, barium, chromium, lanthanum, yttrium, strontium, lithium, and lead. Factor analysis also showed that gold and these element associations are evident in Aboduabo, which can be explained via the same underlying geological factors. The results of factor analysis made it possible for the initial fifty variables and 107 samples to be reduced to ten factors representing 85.656% of the total variance explained. From hierarchical clustering, gold was also observed to be clustering with gallium, strontium, iron, zircon, Lead, Rubidium, Lithium, strontium, Aluminum, Thorium, arsenic, chromium, lanthanum, yttrium, copper, zinc, nickel, cobalt, cerium, and barium. The dendrogram also depicted that gold is closely related to arsenic if the phenom line is reduced to obtain more clusters. Scatter plots of the elements that were closely associated with gold were done and their correlation coefficients also depicted that the elements nickel, cobalt, lead, rubidium, cerium, and lead were near zero as such were not strongly correlated with gold. Arsenic positively correlated with the gold from the scatter plot. It can be inferred from these results that; the occurrence of gold and its associated elements was due to both primary dispersion from underlying rocks and secondary processes. Copper, nickel, lead, zinc, barium, cerium, cobalt, chromium, lanthanum, strontium, yttrium, lithium can be used as pathfinders for gold in the area whiles arsenic can be used as the main pathfinder for gold mineralization at Aboduabo.

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