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Statistical Dissection of Lithogeochemical Data from Parts of the Igarra Schist Belt, Southwestern Nigeria

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Abstract

Statistical analysis of the lithogeochemical data from parts of igarra schist belt was carried out with a view to testing the rocks for their mineralization potential. Univariate and multivariate statistical analyses of dispersion box plot and factor analysis, respectively, were employed on the concentrations of Ag, As, Au, Bi, Cu, Mo, Pb, Th, U and Zn in 45 rock samples. The dispersion box plots showed that the trace elements are log-normally distributed in these rocks and granted the threshold values for the elements but Zn as 240 and 5.2 ppb for Ag and Au, along with 3.1, 0.93, 77.63, 2.22, 18.68, 21, and 2.2 ppm for As, Bi, Cu, Mo, Pb, Th, and U, respectively. Factor analysis gave four models as Mo-Cu-Th-Bi-Ag; U; Zn-Th; and as factors. The interpretation of these data suspected two types of mineralization and also inferred two types. The two suspected mineralization include Au-bearing marble and Ag-Cu bearing silicified sheared rock both along the shear zone in the district; while the two inferred mineralization are U mineralization in the pegmatite veins and Pb-Zn mineralization in the metaconglomerate.

Keywords: Lithogeochemical data; Dispersion box plot; Factor analysis; Anomaly; element association; Mineral prospecting

Introduction

Igarra schist belt is one of the twelve schist belts discovered in Nigeria (Figure 1). The strati-volcanic successions in these schist belts are similar to those elsewhere that host important economic mineral deposits [1-12]. This, coupled with the historical assertion that alluvial gold was mined around Dagbala in Igarra area during the colonial days [13,14], led to Adepoju starting mineral prospecting study around Igarra schist belt *via* reconnaissance stream sediment geochemical survey of Orle drainage system [15]. The region drained by the Orle drainage system was selected for mineral prospecting study based on the existence of structural guide to mineralization within it, as River Orle is characterized by trellis drainage pattern, notably at its origin. This reconnaissance geochemical stream sediment survey allowed the identification of Dagbala and Atte areas of the Igarra Schist Belt as more prospective to host important economic metallic mineral deposits [16,17]. The Dagbala-Atte district of the region was consequently recommended for a follow-up investigation. Adepoju accomplished the follow-up investigation through geochemical soil survey of the Dagbala-Atte district [18], which permitted the recognition of areas possibly underlain by potential mineralized rocks in the district [19-21]. Therefore, the areas envisioned to be possibly underlain by the potential mineralized rocks were suggested for detailed study comprising lineament analysis using remote sensing, detailed geologic mapping and lithogeochemical survey. Adepoju and Adepoju et al. have reported the results of the detailed study involving lineament analysis using remote sensing method and detailed geologic mapping in the study area [22].

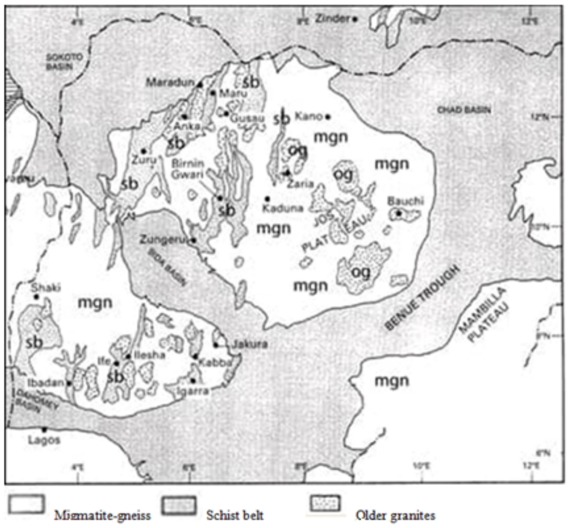

Figure 1: Generalized geological map of Nigeria showing the basement complex comprising migmatite-gneiss (Mgn), Schist belts (Sb) and Older granites (Og) (Modified after Turner, 1983). Note the location of Igarra Schist Belt in the southeastern margin of western Nigeria basement.

Lithogeochemical data is otherwise known as rock geochemical data. The data comprises both major oxides and trace elements that are frequently used in geological mapping, tectonic studies and mineral exploration studies by supplying chemical information on alteration and mineralization patterns [23]. The basic aim of the statistical analysis of lithogeochemical data for mineral exploration is the recognition of areas of high concentrations (e.g., geochemical anomalies) of trace elements that may be speculative of mineral deposits. Host of statistical/geostatistical techniques have been applied to highlight the enhance trends or patterns called anomalies in lithogeochemical data. These anomalous populations oftentimes exhibit particular geologic processes such as fractionation, regional alteration, hydrothermal alteration and metasomatism. The techniques employed to recognize anomalous trends or populations in lithogeochemical data can be classified into univariate, bivariate, trivariate, multivariate and geostatistical methods. Techniques utilized for univariate data (histograms, box plots etc.) are relatively easy to calculate and simple to use in lithogeochemical samples. They involve identifying anomalous populations based on thresholds defined by changes in slope or groups of outliers on plots of cumulative frequency distributions (e.g., QQ plots, normal probability graphs) or dispersion box plots. Multivariate methods have the benefit of analyzing three or more elements at once, thereby give information on the association and structure among multiple elements. Correlation Matrix (CM), Factor Analysis (FA) and Principal Component Analysis (PCA), correspondence analysis and N-dimensional clustering are example of multivariate techniques [24-26]. A major disadvantage of most univariate and multivariate techniques is that spatial information is not used. This paper presents the results of the application of statistical examination to the lithogeochemical data obtain from analysis of rocks that underlain the areas of anomalous metal concentrations in follow up pedogeochemical surveys.

Igarra schist belt

The Igarra schist belt is part of the western block of the Nigerian basement complex usually considered to be of Precambrian age. The basement complex rests east of the West African Craton and Northwest of the Congo-Kasai Craton in the Pan-African mobile belt (Figure 2). The area is considered to have developed as a result of modern plate tectonics processes [27,28].

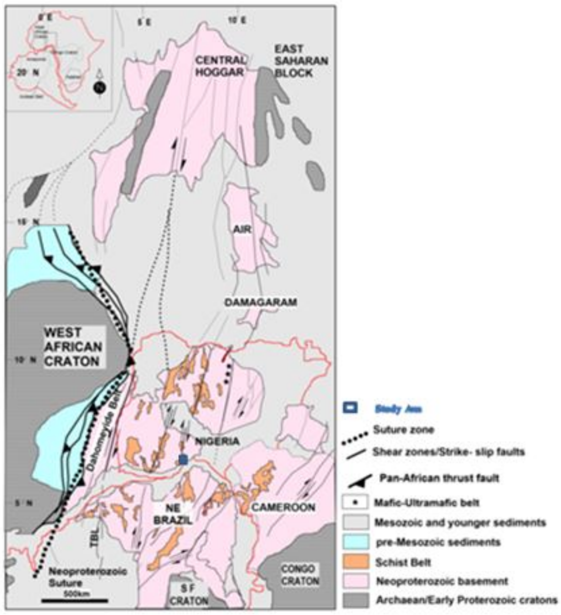

Figure 2: Location of igarra schist belt in the context of the Trans-Saharan mobile belt, the West African craton and the Congo craton.

A four-fold tectono-stratigraphic division [29,30], which explains best the field associations and age relationships among the lithologic units of the basement complex is as follows:

- The migmatite-gneiss-quartzite complex conventionally regarded as the basement sensu stricto;
- The Schist Belts which are supracrustal low to medium grade meta-sedimentary and meta-igneous rocks;
- The Pan African granitoids (Older Granites) and associated rocks such as charnockitic rocks and syenites; and
- The minor felsic and mafic intrusives.

Igarra schist belt is underlain mainly by metaclastic rocks but has prominent carbonate and metaconglomerate units (Figure 3).

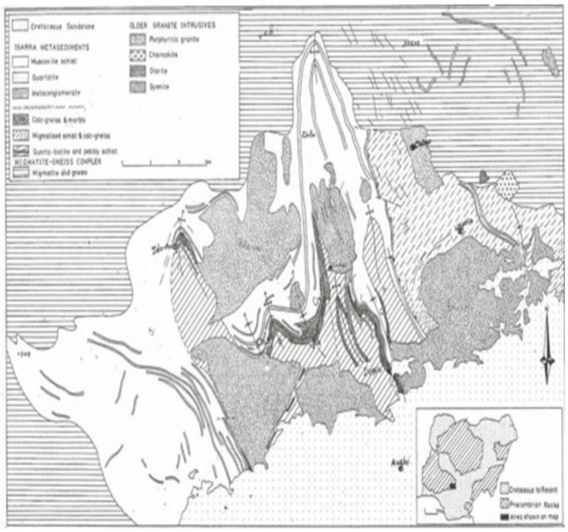

Figure 3: Geological map of igarra schist belt (after Odeyemi, 1988).

Geology of Dagbala-Atte District

Dagbala-Atte district in the igarra schist belt lies between latitude 7º 10ʹ to 7º 21ʹ N and longitude 6º 09ʹ to 6º 17ʹ E (Figure 4).

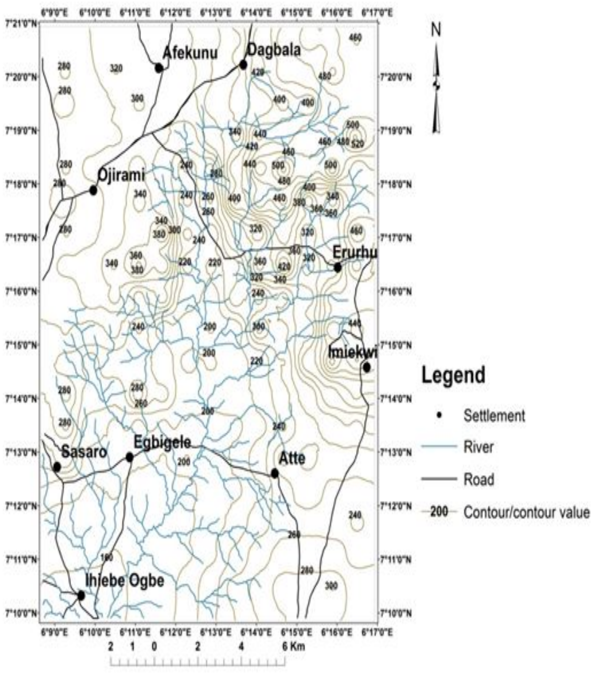

Figure 4: Topographic map of Dagbala-Atte district.

It comprises the rocks of migmatite-gneiss-quartzite complex dominated by granitic gneisses to the east while the western part is composed mainly of metasediments (Figure 5).

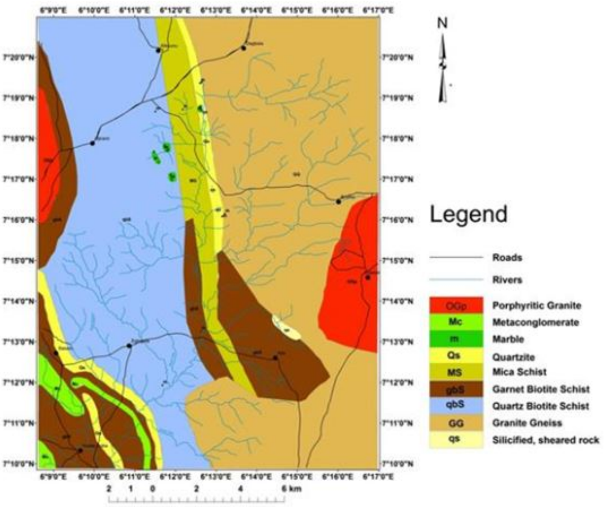

Figure 5: Geologic map of dagbala-Atte District (after Adepoju, 2017).

A shear zone: Ojirami Shear Zone (OSZ)-occurs almost at the boundary between these two contrasting lithologies that appear to be separated by the silicified, sheared rock in places. The metasedimentary assemblage consists of quartz-biotite, garnet-biotite and mica schists with minor metaconglomerate, quartzites and marble. Both the metasediments and the granitic gneisses are intruded by porphyritic Pan African granite. The Pan African granite and the two earlier rock groups are intruded by minor felsic and mafic intrusives that include pegmatite, aplite, microgranite and lamprophyre.

Materials and Methods

Sample collection and geochemical analysis

The forty-five rock samples, employed for the present study comprise 10, 10, 13, 7 and 5 samples of Biotite Schist (BS), Granitic Gneiss (GG), Silicified Sheared Rock (SSR), Marble (MB), and Garnet Schist (GS), respectively, were collected and treated for geochemical analysis. Sample treatment entailed subjecting about 1 kg each of the rock samples to crushing in a jaw crusher which reduced the rock sample to millimeter size. The crushed sample was subjected to Ball Swing pulverization in order to obtain about 200 mesh particle size. Communition of the rock samples was carried out at the Department of Geology, University of Ilorin, Ilorin, Kwara State, Nigeria. The powdered rock sample was subjected to conning and quartering to collect representative samples of about eight gram each of the 45 samples that were packaged and sent to ACME analytical laboratories, Vancouver, Canada [31]. In the laboratory, the samples were oven dried at 600^{o}C and half a gram of each sample was digested with modified aqua regia (*i.e.* 1:1:1 mixture of $HCl:HNO_3:H_2O$). After mixing with the modified aqua regia, the samples were heated in the oven at a regular temperature of 65oC for twelve hours to extract metals from them. Later the contents were cooled and diluted to 20 ml with ultra-distilled water. The samples were thereafter allowed to stay for a period of about 12 hours for settling of the suspended matter. Aqua regia digestion method is employed because it can digest oxide and sulphide-minerals that most ore minerals exists [32]. Consequently, the supernatant liquid was transferred on to fresh test tubes and used for the analysis of thirty-seven elements namely, Ag, Al, As, Au, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Se, Sr, Te, Th, Ti, Tl, U, V, W and Zn using the ultra-trace "Inductively-Coupled Plasma Mass Spectrophotometer" (ICP-MS). However, the results of ten trace elements, namely Ag, As, Au, Bi, Cu, Mo, Pb, Th, U, Zn were employed for the present study (Table 1).

Sample No	Rock Type	Ag	As	Au	Bi	Cu	Mo	Pb	Th	U	Zn
DPR01	BS	60	35.4	3.1	0.28	32.13	1.07	11.11	10.8	1.1	115
DPR02	BS	46	21	2.4	0.33	22.45	0.69	9.81	10.2	0.9	122.2
DPR03	BS	93	1	1.1	0.17	63.49	1.53	5.12	8.5	0.9	53.8
DPR04	BS	381	0.6	2.2	0.29	183.55	0.93	3.23	9.4	0.8	43.9
DPR05	BS	35	0.7	<0.2	0.21	12.01	0.96	4.26	11.4	1.4	40.9
DPR06	BS	55	0.3	0.3	0.13	8.91	0.91	3.37	8.9	1	60.8
DPR07	BS	59	10.9	1.3	0.41	36.26	0.36	4.01	10.9	1.1	116.2
DPR08	BS	20	<0.1	<0.2	0.08	8.61	0.32	4.1	7.3	0.3	45.2
DPR09	BS	22	0.8	3.8	0.25	13.92	1.02	4.22	11.9	1.4	41.1
DPR10	BS	45	0.6	0.8	0.21	30.51	0.27	5.54	8.5	0.7	60.5
DPR11	GG	20	1.2	<0.2	0.1	19.17	1.02	5.13	20	3.5	46.9

DPR12	GG	56	0.1	<0.2	<0.02	77.63	4.55	10.21	115.3	8.5	49.8
DPR13	GG	29	0.4	1.2	0.05	21.42	1.67	5.46	17.3	1.8	33.4
DPR14	GG	30	0.2	0.3	0.08	13.53	1.28	5.21	19.1	1.8	43.8
DPR15	GG	10	0.9	0.3	<0.02	11.91	1.58	3.27	1.4	0.4	34.9
DPR16	GG	70	0.5	0.2	0.26	17.17	0.86	5.26	15.3	2.2	76.9
DPR17	GG	15	0.3	<0.2	0.04	10.93	1.03	2.05	2.1	1.4	56.2
DPR18	GG	20	0.7	0.5	0.07	9.38	0.84	4.25	3.3	1.1	51.7
DPR19	GG	33	1.4	<0.2	0.11	24.05	1.1	4.8	18	3.3	46.5
DPR20	GG	30	0.6	0.8	0.09	24.78	1.37	9.35	21	1.6	30.7
DPR21	SR	61	0.8	0.8	0.14	38.13	1.23	3.78	1	0.4	1.8
DPR22	SR	114	0.9	2.1	0.78	46.86	1.35	16.75	1.7	0.5	1.5
DPR23	SR	21	0.9	1.5	9.07	16.62	1.13	9.79	5.1	11.7	4.4
DPR24	SR	205	0.6	1.4	0.48	142.91	2.22	16.14	4.3	0.5	4.9
DPR25	SR	223	1.6	2.8	0.35	157.98	3.59	16.07	5.8	0.8	8.2
DPR26	SR	231	0.5	5.1	0.37	126.34	1.47	16.79	4.4	0.5	4.7
DPR27	SR	240	1.6	1.5	1.56	159.37	1.48	23.78	0.7	0.3	7.2
DPR28	SR	180	6.1	1.2	1.38	68.74	1.19	11.71	2.6	1.6	21.5
DPR29	SR	119	1	1.5	0.63	17.4	1.31	16.17	0.7	0.1	1.7
DPR30	SR	72	9.2	0.5	0.87	12.81	0.9	10.34	2.1	0.5	3.4
DPR31	SR	77	8	0.4	0.93	10.52	0.41	9.97	1.9	0.3	2.9
DPR32	SR	182	1.7	1.6	0.8	48.47	0.92	7.01	3.9	0.7	18.2
DPR33	SR	197	1.7	0.5	0.8	48.35	0.8	7.27	3.9	0.6	19.7
DPR34	MB	20	0.7	0.5	<0.02	3.29	0.12	1.64	0.3	1.3	1.4
DPR35	MB	10	0.6	<0.2	<0.02	3.01	0.11	1.5	0.2	1	1.3
DPR36	MB	154	1.1	5.2	<0.02	8.59	0.21	129.73	0.3	<0.1	54.7
DPR37	MB	209	1.6	8.8	<0.02	2.1	0.19	18.68	0.1	<0.1	1.7
DPR38	MB	3	0.7	2.7	1	1.98	0.23	4.33	1	1.6	2.9
DPR39	MB	6	3.1	<0.2	<0.02	1.08	0.47	5.77	0.1	1.5	3.1
DPR40	MB	8	2.8	<0.2	<0.02	1.19	0.18	1.19	0.3	1.5	1.9
DPR41	GS	13	0.2	4.8	0.09	34.53	0.58	4.74	9.3	1.3	95
DPR42	GS	96	<0.1	2.3	0.52	275	0.6	4.24	4	0.7	101.7
DPR43	GS	21	<0.1	1.8	0.3	14.22	0.57	5.06	2.8	0.5	95.1
DPR44	GS	50	0.4	<0.2	0.23	33.82	0.57	5.11	9.6	1.3	94.3
DPR45	GS	13	0.2	<0.2	0.36	15.87	0.63	5.51	3.4	0.7	103.3

Table 1: Concentrations of the elements for the present study in rocks of the district- Ag and Au in ppb, other elements in ppm.

Statistical analysis

Univariate and multivariate statistical analyses were carried out employing the graphical method of box plots and factor analysis, respectively. The statistical data analyses were executed using software package, Minitab-16, in a DELL Inspiron 5521 Laptop computer.

A dispersion box plot allows different characteristics to be put on the same graphs. These characteristics include 1st Quartile (Q1), 2nd Quartile (Q2 or median), 3rd Quartile (Q3), Interquartile Range(IQR) (*i.e.* the difference between the 3rd Quartile and the first Quartile, Q3–Q1), range (the scale of the graph), upper threshold (Q3+1.5 IQR), lower threshold (Q1-1.5 IQR) and outliers, *i.e.* the points above the upper threshold (anomalies) and below the lower threshold (negative anomalies) if exist among the data sets. Thus the box plot is the only graph capable of synthesizing different statistical characteristics [33].

Available literature on FA suggests that the technique is useful in evaluating multivariable geochemical data of various types [34,35]. Commonly, it is possible to interpret the resulting multivariables (factors) in geological terms such as processes or types.

Thus one can investigate the extent to which individual samples reflect a particular process or end member rock type. FA is a mathematical method for determining interrelation of variables (trace elements in this case) using R-mode technique or Q-mode technique in a set of apparently complex data.

R-mode technique is the most commonly used in geochemical exploration and was consequently adopted for this study. R-mode FA examines the relationship among variables by analyzing a matrix of simple correlation coefficients for all pairs of variables considered.

Results

Figure 6 shows the box plots constructed using the raw data of the ten trace elements employed for this study. These raw data box plots show that there is a very large disparity between the median values and maximum values, with an even lower means for the elements.

The result is a longer whisker above the mean and a shorter one below it, which implies that the elements' values greatly depart from the mean. This is also an indication of the extreme variability of geochemical data. This trend in any data set indicates the data is obviously non-normal.

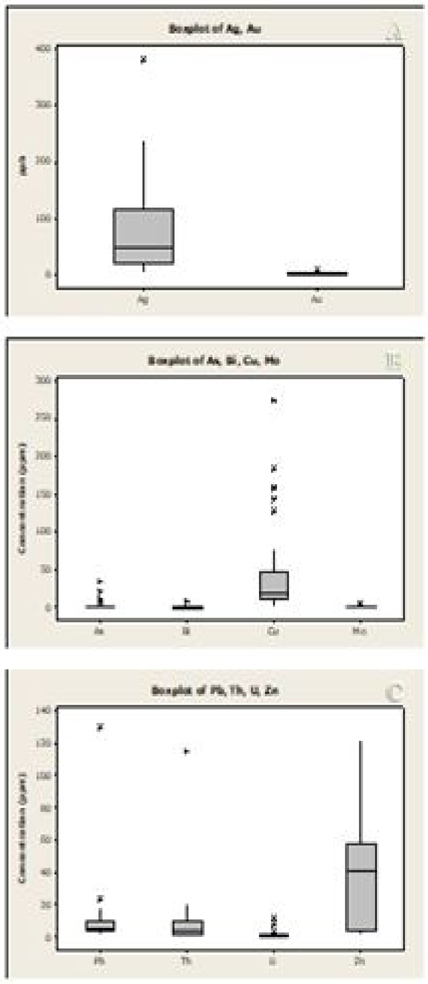

Figure 6: Raw data dispersion box plots of (A) Ag, Au, (B) As, Bi, Cu, Mo, (C) Pb, Th, U and Zn in the rocks of Dagbala-Atte district.

A log transformation gives a more refined dataset with both the maximum and minimum values evenly distributed about the mean values (Figure 7).

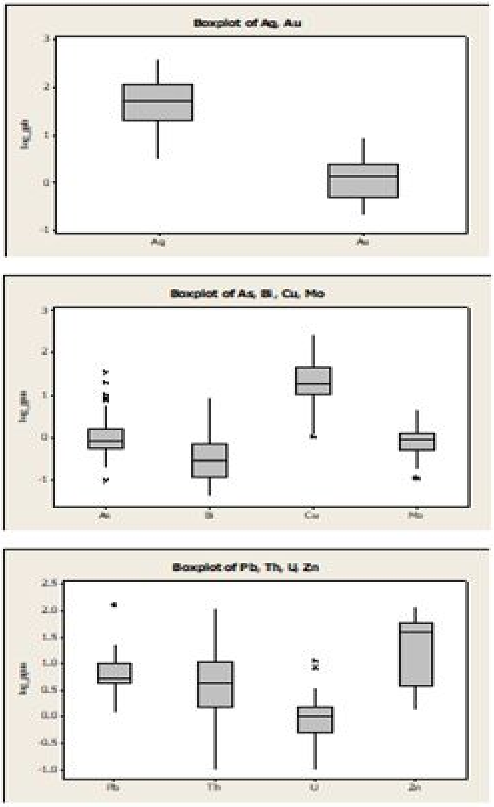

Figure 7: Logarithmically transformed-data dispersion box plots of Ag, As, Au, Cu, Mo, Pb, U and Zn in the rocks of Dagbala-Atte district.

Figure 6 also reveal the presence of positive anomalies for all the ten elements for this study but Zn, while no negative anomalies exists for any elements in the study area. There exists anomalies at 1, 5, 1, 2, 6, 2, 2, 1 and 3 number of site(s) for Ag, As, Au, Bi, Cu, Mo, Pb, Th and U, respectively (Table 2).

Element	Threshold	AS	Value in anomalous site	Rock type
Ag	240	1	381	BS
As	3.1	5	6.1, 9.2, 10.9, 21,35.2	SSR, SSR, BS, BS, BS
Au	5.2	1	8.8	MB
Bi	0.93	2	1.56, 9.07	SSR, SSR
Cu	77.63	6	126.34, 142.91, 157.98, 159.27, 183.55, 275.0	SSR,SSR, SSR, SSR, BS, GS
Mo	2.22	2	3.59, 4.55	SSR, GG
Pb	18.68	2	23.78, 129.73	SSR, MB
Th	21	1	115.3	GG
U	2.2	3	3.5, 8.5, 11.7	GG, GG, SSR

For the FA, all the ten elements were used because none contains censored data (*i.e.* values below or above analytical detection limit, DL) in greater than 30 % of the sampling sites. Ag, Cu, Mo, Pb, Th, U and Zn have no censored value. As, Au, Bi and U have in 3, 11, 8 and 2, respectively of their sites where they have values below their lower DLs all of which are less than 30 % of the 45 sampling sites employed for this study. For these elements with censored data in less than 30 % of their sampling sites, values equal to 66 % of their lower DLs are substituted at those sites. Another important requirement for multivariate analyses is that normal data is employed and in the case of Dagbala-Atte district [36], the logarithmically transformed data are normal (Figure 6), while the raw data are non-normal (Figure 5). Therefore, logarithmically transformed data are used for computation of the FA (Table 3a).

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Ag	0.479	-0.742	0.058	-0.001	0.783
As	-0.076	-0.19	0.095	-0.899	0.858
Au	0.085	-0.752	-0.05	-0.206	0.618
Bi	0.63	-0.204	0.105	-0.429	0.634
Cu	0.815	-0.375	-0.209	0.124	0.863
Mo	0.859	-0.026	-0.056	0.115	0.754
Pb	0.219	-0.78	0.032	-0.114	0.671
Th	0.656	0.251	-0.639	0.042	0.904
U	0.378	0.791	-0.191	-0.17	0.835
Zn	0.163	0.072	-0.953	0.102	0.95
Variance	2.6895	2.6383	1.4266	1.117	7.8713
% Var	26.9	26.4	14.3	11.2	78.8

Table 3a: Rotated factor loadings and communalities, Orthomax Rotation with Gamma= 0.00.

The table displays the four-factors Orthomax R-mode Factor Analysis of the log data for the study area. The total explained variance of the four-factor model is 78.8 % (Table 3a). Factor 1 is Mo-Cu-Th-Bi-Ag factor (Table 3b).

Factor	Element	Eigen Value
F-1	Mo-Cu-Th-Bi-Ag	26.9
F-2	U	26.4
F-3	Zn-Th	14.3
F-4	As-Bi-Au	11.2

Table 3b: Element association of the four-factor model.

It accounts for 26.9% of the four factor model in the studied rock of the area. It probably connotes association of these elements in a rock of the study area, with possible mineralization of some of them in the rock. Factor 2 is U factor that is antipathetically related with Pb, Au and Ag, accounting for 26.4% of the four-factor model in the rocks of the area. It may signify that U mineralization if exist in the study area may not associate with Pb, Au and Ag in the same rock. Factor 3 is Zn-Th factor with limited association with Cu and U, which account for 14.3% of the four-factor model in the considered rocks for the present study. It may imply that Zn and Th are associated in some lithological units in the study area whereas; they associate with Cu and U in less number of rock still. Factor 4 is as factor that is antipathetically related with most of the elements in the rocks of the study area. It might imply that as can serve as a pathfinder element for mineralization in highly restricted lithological units, such as the MB and SR rock in the study area.

Discussion

In this section the ten elements employed for the present study are statistically discussed, bearing on their average abundance in the earth crust and All Rocks (AR) employed for the present study as well as ranges and average abundance of the element in each of these rocks in Dagbala-Atte district (Table 4).

El	EC	Dagbala-Atte District										
		DA (n =45)	BS (n=10)		Granite gneiss	Sheared rock	Marble	Garnet schist				
					(n=10)	(n=13)	(n=7)	(n=5)				
	Aver	Aver	Ran	Aver	Ran	Aver	Ran	Aver	Ran	Aver	Ran	Aver

Ag	70	81.2	20-381	81.6	Oct-70	31.3	21-240	147.8	3-209	58.6		38.6
As	1.8	1.44359	0.3-35.4	0.67	0.1-1.4	0.63	0.5-9.2	2.662	0.6-3.1	1.514		0.2667
Au	4	1.92059	0.3-3.8	1.88	0.2-1.2	0.55	0.4-5.1	1.608	0.5-8.8	4.3		2.967
Bi	0.17	0.63389	0.08-0.41	0.24	0.04-0.26	0.1	0.14-9.07	1.397		0.02		0.3
Cu	55	42.9109	8.61-183.55	41.2	9.38-77.63	23	10.52-159.37	68.8	1.08-8.59	3.034		74.7
Mo	1.5	1.01822	0.32-1.53	0.81	0.84-4.55	1.53	0.41-3.59	1.385	0.11-0.47	0.216		0.59
Pb	12.5	10.2851	3.23-11.11	5.48	2.05-10.21	5.499	3.78-23.78	12.74	1.19-129.73	23.3		4.92
Th	10	8.89111	7.3-11.9	9.78	1.4-115.3	23.3	0.7-5.8	2.931	0.1-1	0.329		5.82
U	2.7	1.51395	0.3-1.1	0.96	0.4-8.5	2.56	0.1-11.7	1.423	1-1.6	1.38		0.9
Zn	70	40.5978	40.9-122.2	70	30.7-76.9	47.08	1.5-21.5	7.7	1.3-54.7	9.57		97.88

Table 4: Average Abundance of Elements in Earth Crust (EC), after and All the Rocks of Dagbala-Atte District Employed (DA), as well as Ranges and Average Abundance of Element in Each Rock Types of Dagbala-Atte District (all elements in ppm except, Au and Ag in ppb) [37].

Ag (Silver): Ag was detected in all the 45 rock samples employed for the present study. The contents of the elements range from 3 ppb to 381 ppb with a mean of 81.2 ppb. The selected threshold for Ag is 240 ppb which throws up only one anomalous sample with label DPR04 (381 ppb). Other samples with relatively high concentrations of Ag are DPR25 (223 ppb), DPR26 (231 ppb), DPR27 (240 ppb) and DPR36 (209 ppb). These anomalous- and high-value samples are those of BS (DPR04), SR (DPR25, DPR26 and DPR27) and MB (DPR37). However, when compared with the average crustal abundance, the Ag values in the study District is high, which might indicate a possible occurrence of Ag mineralization. A comparison of the average contents of Ag among the different lithologies, *i.e.* BS, GG, SR, MB and GS, that underlie the district (Table 4, Figure 8) revealed that the anomalous value recorded for BS be spurious and the SR could be the number-one suspect for Ag mineralization in the study area. The association of Mo-Cu-Th-Bi-Ag in Factor 1 (Table 3) might suggest that Mo, Cu, Th and Bi occur together in the suspected Ag mineralization in the silicified sheared rock [38].

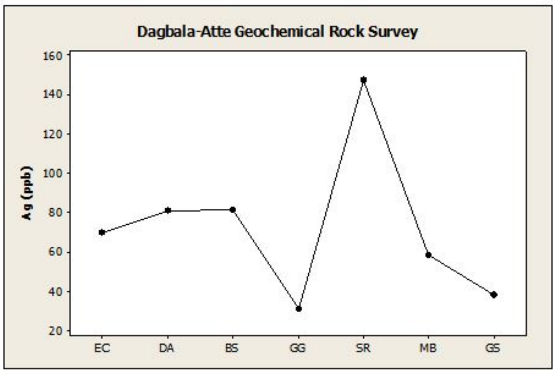

Figure 8: Line Plots of Average Abundance of Ag in the Earth Crust (EC), Its Averages in All the Rocks (DA) and Individual Rock (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

As (Arsenic): As was detected in 43 samples; it was present in amount less than the instrument's lower detection limit of 0.1 ppm in only 3 samples. Where it was detected its values ranged from 0.1 to 35.4 ppm with a mean of 2.94 ppm. The threshold value for as in this District is 3.1 ppm, which revealed six anomalous values in samples DPR01 (35.4 ppm), DPR02 (21 ppm), DPR07 (10.9 ppm), DPR28 (6.1 ppm), DPR30 (9.2 ppm) and DPR31 (8 ppm). These anomalous samples are those of BS (DPR01, DPR02 and DPR07) and SR (DPR28, DPR30 and DPR31). When the mean value of As in DA is compared with its average abundance in the EC (Table 4), the as concentration in the district is low except for the SR (Figure 9).

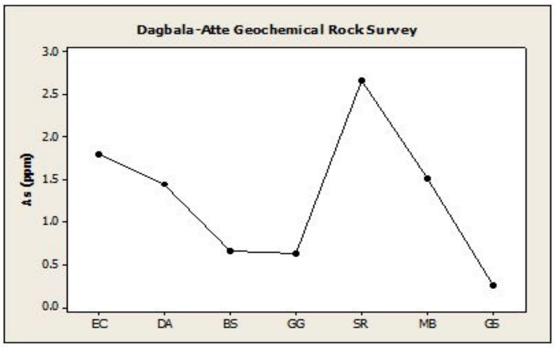

Figure 9: Line plots of average abundance of As in the Earth Crust (EC), its means in all the rocks (DA) and individual rocks (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

Thus, the anomalous values of as recorded in this particular rock probably suggest that it is the host rock for some epigenetic sulfide deposits in which as occurs possibly in association with Mo, Cu, Th, Bi, and Ag, as suggested by Factor 1. It can possibly be used as a pathfinder element for the exploration for the possible sulphide mineralization in the silicified sheared rock. The strong negative factor displayed by as and Bi in Factor 4 (Figure 3) buttresses this point. The weak negative factor between us and Au in the same factor also points to the fact that as has limited association with the possible gold-bearing rock in the study area.

Au (Gold): Au was detected in thirty-four of the forty-five rock samples studied. It occurred below the detection limit of 0.2 ppb in other 11 samples. Where it is detected, it ranges in concentration from 0.2 to 8.8 ppb with a mean of 1.9 ppb. With the threshold value of 5.6 ppb selected for Au, one anomalous value occurs in sample DPR36 (8.8 ppb). Other samples with high Au contents include DPR35 (5.2 ppb), DPR26 (5.1 ppb), DPR40 (4.8 ppb) and DPR09 (3.8 ppb) in the District. These samples are those of BS (DPR09), SR (DPR26), MB (DPR35 and DPR36) and GS (DPR40). Compared with the average abundance of Au in the crust (Table 4), its concentration in the rocks of the district is generally on the low side (Figure 10).

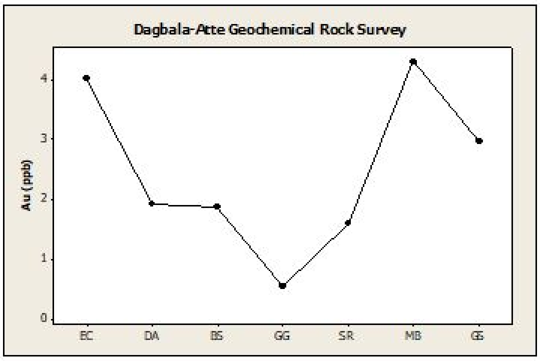

Figure 10: Line Plots of Average Abundance of Au in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rock (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

However, the ubiquity and high contents of Au in all the samples of the silicified sheared rock might indicate its possible limited association with the suspected sulphide mineralization in this particular rock. Also, the higher Au concentration in some MB samples could result from the alkaline nature of marble environment that could precipitate gold and other metals from hydrothermal fluids. Therefore, the prime suspect for Au mineralization in the study area is the MB deposit along the shear zone where sample DPR36 was taken. The negative As-Bi-Au Factor 4 suggests that as and Bi has application as pathfinder elements for Au in the area.

Bi (Bismuth): Bi has a fairly wide distribution in the study area and is present below the lower limit of detection in nine of the rock samples. The detected values range from 0.04 to 0.285 ppm with a mean of 0.63 ppm. Above the threshold value of 0.93 ppm three anomalous values exist in samples DPR23 (9.07 ppm), DPR27 (1.58 ppm) and DPR28 (1.38 ppm). Two other fairly high-value sample are DPR31 (0.93 ppm) and DPR30 (0.87 ppm). All the three anomalous values and the two high values of Bi are recorded from the samples of SR. The average Bi value for the DA of the study area (Table 4) is much higher than its average crustal abundance (Figure 11).

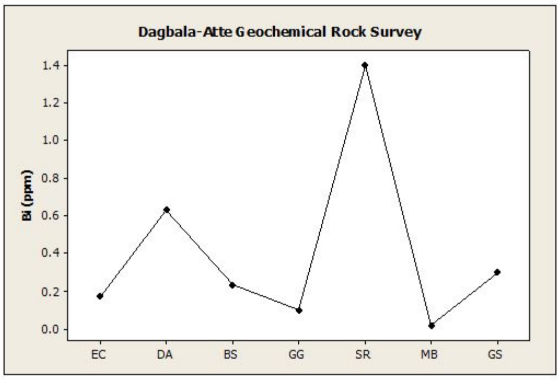

Figure 11: Line Plots of Average Abundance of Bi in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rock (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

Bi belongs in Factor 1 is Mo-Cu-Th-Bi-Ag factor, which is interpreted as indicating potential occurrence of Bi minerals associated with ores of Mo, Cu, and Ag in the study area. Bi is useful as a pathfinder for sulphide ore. There are high contents of Bi in the SR, as reflected by its much higher average than those of other rock types. This observation, therefore buttresses the earlier opinion that the rock could be the possible host for the sulphide ore, and Factor 1 is indeed indicative of mineralization in the SR in the district.

Cu (Copper): Cu is widely distributed in the District as it is detected in all the samples in concentrations ranging from 1.08 to 275 ppm with a mean of 42.9 ppm. With the threshold value of 77.63 ppm, five anomalous values of Cu exist in the rock samples DPR04 (183.55 ppm), DPR24 (142.91 ppm), DPR26 (126.34), DPR27 (159.88) and DPR41 (275 ppm) in the area. These anomalous samples are essentially those of SR. Compared with the average abundance of Cu in the EC (Table 4), its concentration in the rocks of the study area is generally lower except in the SR, where it is slightly higher (Figure 12).

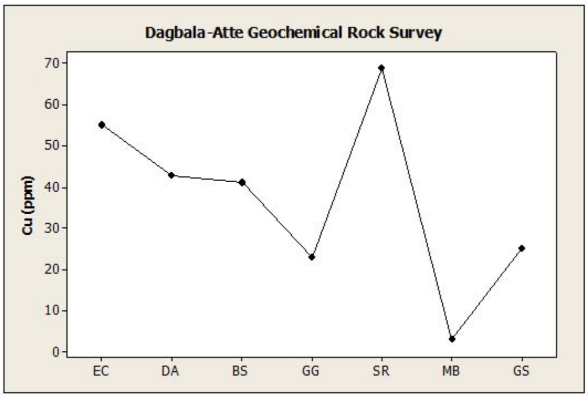

Figure 12: Line Plots of Average Abundance of Cu in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rock (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

Therefore, the anomalous Cu values in the SR and its association with Factor 1 could be due to its mineralization, albeit slightly, in the silicified rock.

Mo (Molybdenum): Mo is present in detectable amounts in all the forty-five rock samples. It ranges in concentration from 0.11 to 4.55 ppm with a mean of 1.02 ppm. Above the selected threshold value of 2.22 ppm, two anomalous values exist in samples DPR12 (4.55 ppm) and DPR25 (3.59 ppm). Other high Mo value samples include DPR13 (1.67 ppm), DPR15 (1.58 ppm) and DPR24 (2.22 ppm). These anomalous and high Mo value samples are those of GG (DPR12, DPR13 and DPR15) and SR (DPR24 and DPR25). A comparison of the average abundance of Mo in EC with its average concentrations in DA (Figure 13) shows that the concentration of Mo in the latter is generally low.

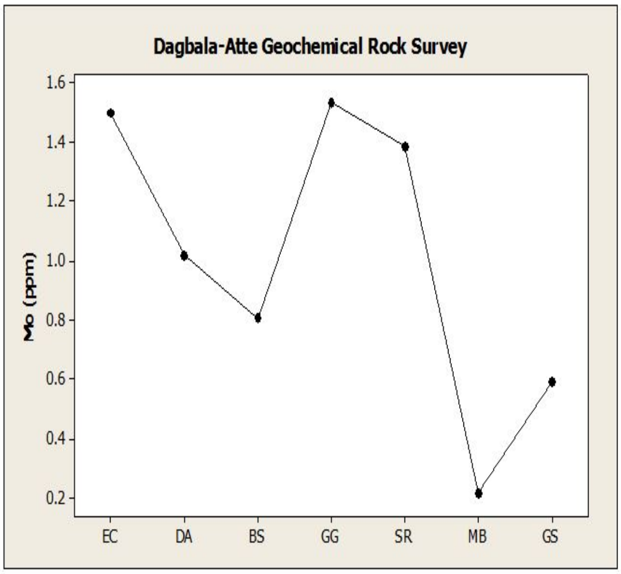

Figure 13: Line plots of average abundance of Mo in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rock (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

This is possibly an indication that Mo-mineralization is lacking in the district, however its association in Factor 1 might indicate that it could serve as a pathfinder element for the suspected Ag-Cu mineralization in the SR of the study area.

Pb (lead): The distribution of lead in the rocks of the district is wide because all the samples analyzed contain Pb in contents that range from 1.19 to 129.73 ppm with a mean of 10.29. With the selected threshold of 18.68 ppm, two anomalous values occur at samples DPR27 (23.78 ppm) and DPR35 (129.73 ppm). Other relatively high Pb values occur in samples DPR22 (16.75 ppm), DPR26 (16.79 ppm) and DPR36 (18.68 ppm). These samples of high and anomalous values are of silicified sheared rock (DPR22, DPR26 and DPR27) and marble (DPR35 and DPR36). Compared with the average abundance of Pb in EC (Table 4), the mean Pb concentration of the rocks is low, except that of the silicified sheared rock that is comparable (Figure 14).

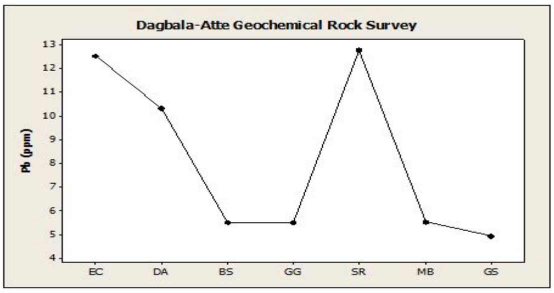

Figure 14: Line Plots of Average Abundance of Pb in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rock (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

This indicates that there might not be Pb mineralization in any of the rock units employed for this particular study in the district but the element might possibly be associated with the suspected complex sulphide mineralization in the SR. Also the Pb anomalous concentration detected in the residual soils in the southwestern part of Dagbala-Atte district that is underlain by the BS-MC intercalation, might be due to either anomalous concentration or mineralization of Pb in MC rather than BS in that part of the study area.

Th (Thorium): Th concentrations range from 0.1 to 115.3 ppm with a mean of 8.9 ppm in the rocks of the district. In the study area, one anomalous value exists above the threshold value of 21 ppm in sample DPR12 (115.3 ppm). Other rock samples, which show fairly high Th values include DPS11 (20 ppm), DPS14 (19.1 ppm), DPS19 (18 ppm) and DPS20 (21 ppm). These sample sites are spread within the granitic gneiss. A comparison of the average value of Th in DA with its average crustal abundance (Table 4) shows that the element is moderately distributed in the study area. Nevertheless, a much higher Th average in the granitic gneiss than its average crustal abundance exists in the district (Figure 15). These could indicate enrichment of Th in the GG of the district.

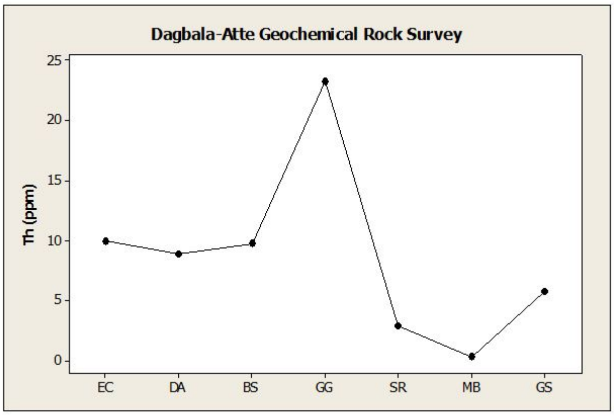

Figure 15: Line plots of average abundance of Th in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rocks (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

U (uranium): U is fairly widely distributed in the rocks of the district. It is detected in appreciable amounts in forty-two samples and its values in only three samples are less than 0.1 ppm, the lower limit of detection of the analytical instrument. Where it is detected U contents range from 0.1 ppm to a peak value of 11.7 ppm with a mean of 1.5 ppm. With the selected threshold of 2.2 ppm, four anomalous values occur in samples DPR11 (3.5 ppm), DPR12 (8.5 ppm), DPR19 (3.3 ppm) and DPR23 (11.7 ppm). Another fairly high U content sample is DPR16 (2.2 ppm). These anomalous and fairly high U containing rock samples are obtained from the GG, except DPR23, which is from the SR of the district. The average U values obtained for the rocks in this district, as compared with its average abundance in the EC (Table 4), shows that U content is lower in the study area. This might indicate lack of U mineralization in all the main rocks units employed for the present study. However, GG shows a much higher U average than other rocks, which may be a pointer to the expected U enrichment in this rock (Figure 16).

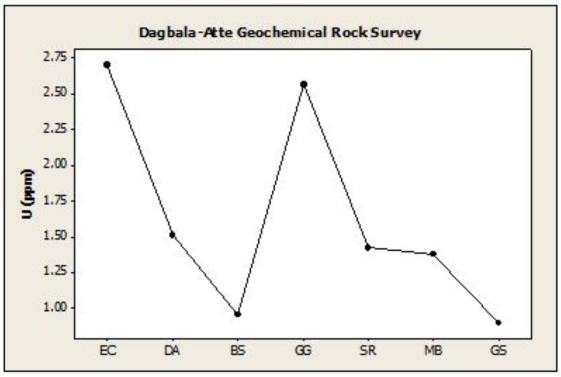

Figure 16: Line plots of average abundance of U in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rocks (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

The pedogeochemical survey for U mineralization carried out in the district that indicated possible occurrence of a U mineralization in this part could be drawing an inference to the tiny pegmatite veins associated with this rock.

Zn (zinc): Zn shows appreciable contents in all the 45 rock samples employed for this geochemical survey. The concentrations of Zn in the rocks of this district range from 1.3 to 122.2 ppm with a mean of 40.6 ppm. The selected threshold of 122.2 ppm revealed no anomalous values in all the samples. However, relatively high Zn values occur in samples DPR01 (115 ppm), DPR02 (122.2 ppm), DPR07 (116.2 ppm), DPR41 (101.7 ppm) and DPR45 (103.3 ppm). These samples are those of biotite schist and garnet schist, indicating that there is enrichment of zinc in the schist of the schist belt. However, the zinc values in the rocks of the district are generally low in comparison with the average crustal abundance of zinc (Figure 17).

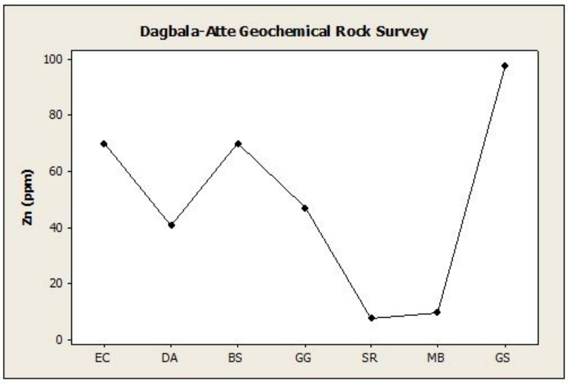

Figure 17: Line Plots of Average Abundance of Zn in the Earth Crust (EC) with Its Averages in All the Rocks (DA) and Individual Rocks (BS-biotite schist, GG-granitic gneiss, SR-sheared rock, MB-marble, GS-garnet schist) of Dagbala-Atte district.

It seems that the low Zn content could be due to a combination of serious depletion of Zn in the SR and MB, only a fair enrichment of Zn in the BS and fair depletion of Zn in the GG. Nevertheless, the Zn anomalous concentration detected in the residual soils in the southwestern part of Dagbala-Atte district that is underlain by the BS-MC intercalation, might be due to either anomalous concentration or mineralization of Zn in MC rather than BS in that part of the study area.

Conclusion

From the study, two types of mineralization are suspected and two inferred. The two suspected mineralization include Au mineralization in the marble deposit near Dagbala, and Ag-Cu mineralization in the silicified sheared rock near Dagbala, Ojirami, Erurhu and Atte both along the shear zone in the district. The two inferred mineralization include U mineralization in the pegmatite veins near Dagbala, and Pb-Zn mineralization in the metaconglomerate near Ojirami. Comprehensive exploration of the metal bearing rocks and detailed study of the potential mineralized rocks are recommended.

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