PROSPECT OF METALLIC MINERALIZATION IN GBONGAN AREA OF SOUTHWESTERN, NIGERIA*

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(*Recieved*: November 2007; *Accepted*: May 2008)

Abstract

Thirty-six stream sediment samples were collected from an area of approximately two hundred and seventy three square kilometers, around Gbongan, delineated by longitude 4°20² and 4°30² and latitude 7°22² and 7°30². The objective was to determine the distribution pattern of some heavy metals in the area, with a view to discovering any indication of metallic mineralization.

The samples were air-dried and the minus 80 mesh fraction analysed for Au, Ta, Co, Sn, Fe, Ni, Mn, Cr, Hg, Pb, and Cu, after hot $HClO_4/HNO_3$ (7:3) acids digestion, using the Atomic Absorption Spectrophotometer. Both simple and R - mode factor statistical techniques were employed in data interpretation. The distribution maps of the elements were also plotted.

The results of the simple statistical analysis showed that all the elements except Cr and Pb were log - normally distributed and revealed both background and anomalous populations, in varying proportions of between 10% and 90%. The Pearson correlation study shows positive correlation between Fe/Au, Pb/Au, Ni/Co, Mn/Co, Ni/Fe, Fe/Cu, Mn/Ni, Pb/Zn, Hg/Cu, and Pb/Hg for example, with 'r' values ranging between 0.33 and 0.92. All these positive correlations are significant at 95% and above confidence level. The R - mode factor analysis, of the elements, identified three factors, which accounted for 75% of data variability. The factors are Fe-Ni-Mn-Pb-Cu-Co-Zn-Cr-Au, Hg Vs Ta, and Sn.

From the result of the statistical analysis and the distribution maps, it is deduced that the dominant factor controlling metal dispersion in the surfacial environment of the study area is lithology. There are also subtle but notable contributions from environmental and mineralization factors.

1. Introduction

The study area lies SW of the Ife-Ilesha schist belt of southwestern Nigeria (Fig.1). This schist belt constitutes one of the Neo-Proterozoic schist belts in the Nigerian basement complex, which contain both alluvial and primary gold deposits. These deposits have been previously mined in the Ife-Ilesha region described as Ife-Ilesha gold field (Adekoya, 1978).
In spite of known deposits of gold in the Ife-Ilesha area, not much exploration work has been carried out in the adjacent study area. This study area has a fairly similar lithology with the Ife-Ilesha gold field except that it is intruded in places by late Proterozoic older granite pegmatites. Such pegmatites are known to host gemstones, tantalite, columbite and cassiterite in other parts of Nigeria. It is for these reasons that the study area was selected for a regional geochemical stream sediment survey.
Garba (2000) has noted that West African countries like Ghana, Burkina Faso and Mali has benefited from a recent incursion of foreign investment in gold exploration and mining, essentially due to the fact that they contain early Proterozoic gold bearing Birimain rocks (Ca.2000Ma). Unfortunately, Nigeria has not yet benefited from such foreign investment. However, Adekoya (1996) has suggested that the sedimentary progenitors of the Nigerian schist belts, which host both alluvial and primary gold deposits may be as old as the Birimian of the West African craton. Consequently, it is arguable that from a geologic point of view, there is no reason why Nigeria should not host large gold deposits such as those found in other West African countries. The apparent reason for lack of discovery of such deposits may simply be attributed to under exploration and non-application of modern exploration techniques. This further justifies the need for the present study and stream sediment survey has been found to be very useful for reconnaissance studies in drainage basins. If properly collected, the samples represent the best composite of materials from the catchments area upstream from the sampling site (Lesvinson, 1974). The underlying rationale behind stream sediment survey is the fact that in the weathering environment, many minerals and particularly sulfide minerals are

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* Presented in part at the First Faculty of Science Conference, Obafemi Awolowo University, Ile-Ife, July 3-5, 2007.

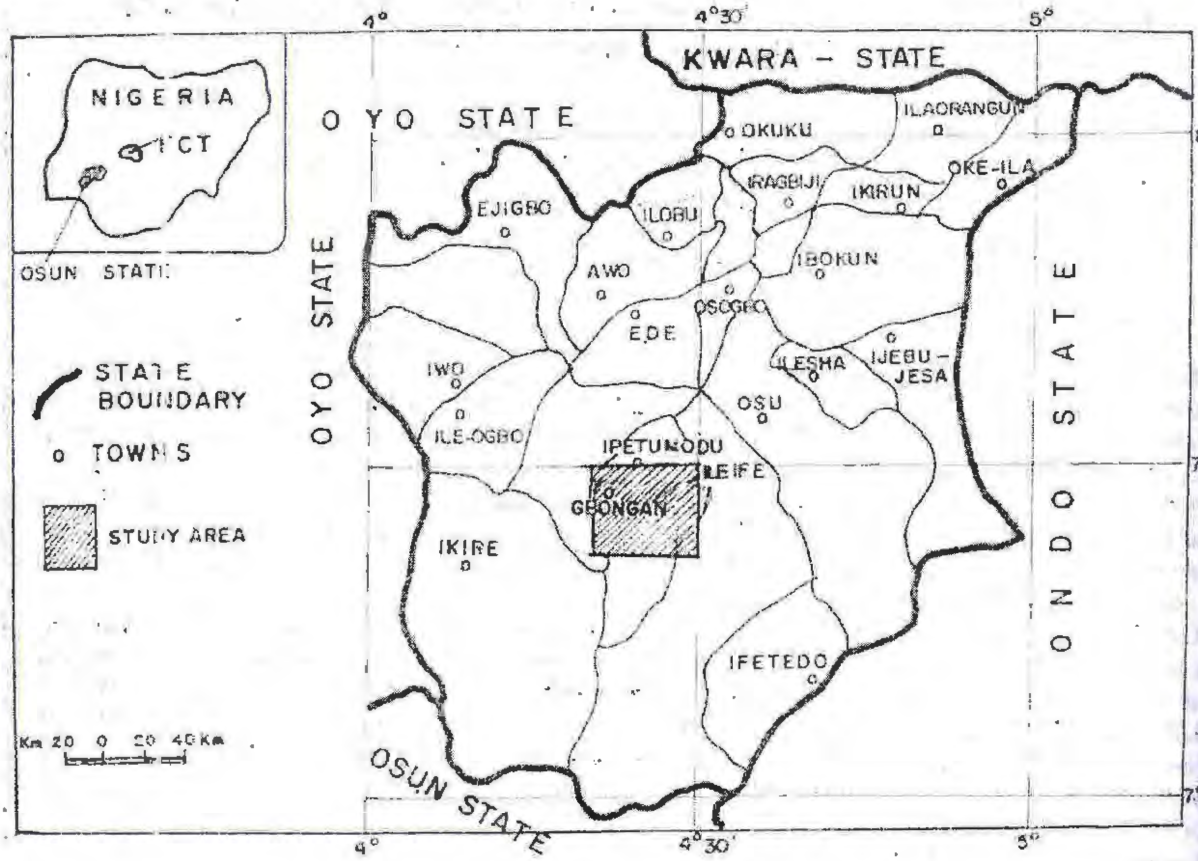


Fig. 1: Map of Osun state showing Gbongan and environs: The Study area

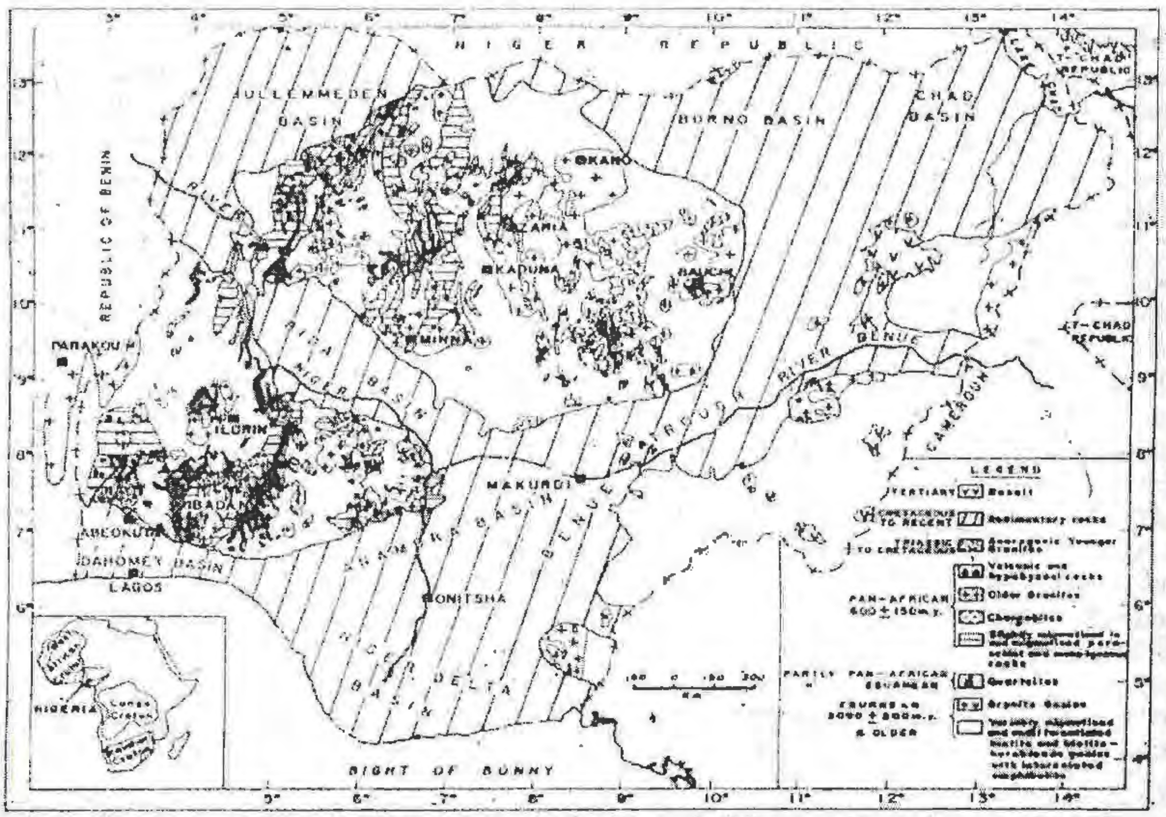


Fig. 2: Generalized Geological Map Of Crystalline Rocks Of Nigeria (after Rahaman, 1988)

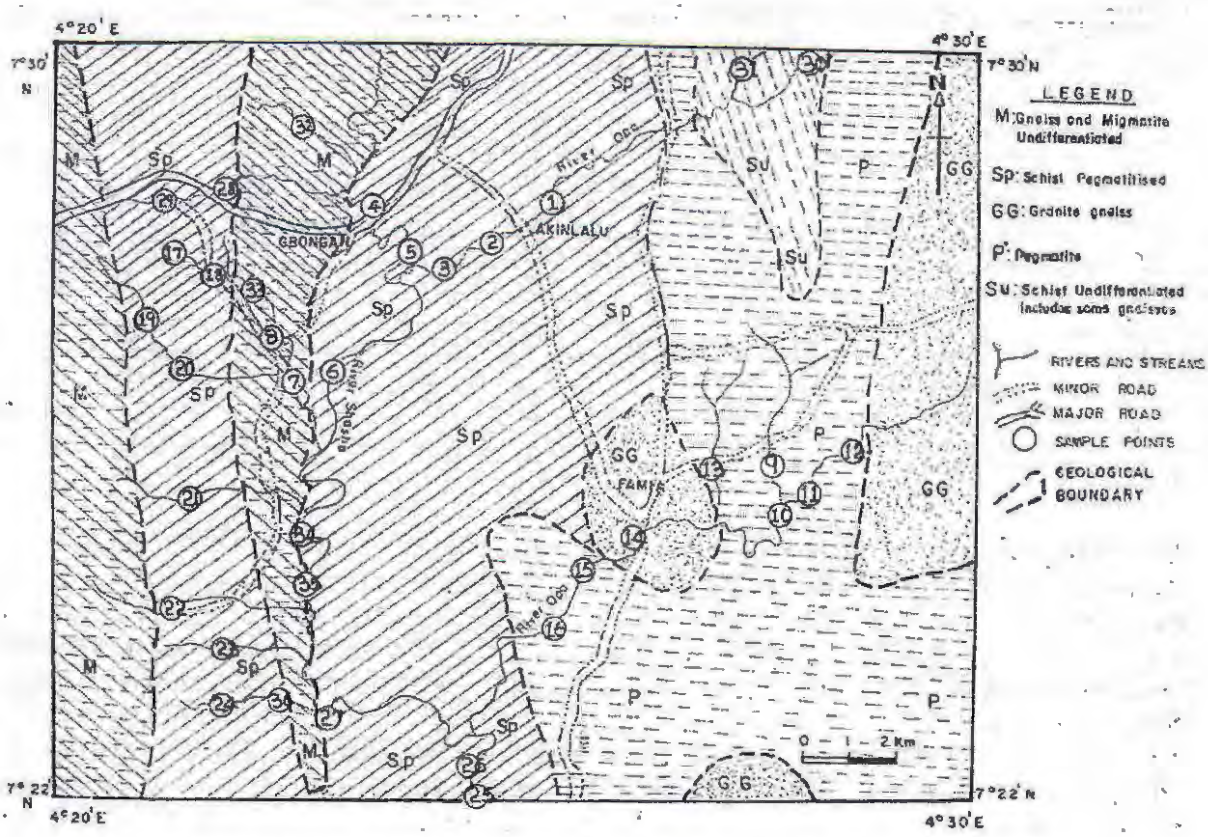


Fig. 3: Geological map of Gbongan and environs showing drainage and sample points.

unstable and will break down as a result of oxidation and other chemical reactions. This results in a dispersion of both ore and indicator elements in solution, in run-off and in ground water, sometimes for relatively long distance within the drainage basin (Levinson, 1974).

Geology of the Area:

The study area is underlain by rocks of the Nigerian Basement Complex, which according to de Swardt (1953) are Precambrian in age. Rahaman (1988) recognised six major rock groups within the Basement Complex (Fig.2). These are, migmatite-gneiss-quartzite complex, slightly migmatised to non-migmatite metasedimentary and metaigneous rocks also known as the schist belts, charnockitic, gabbroic and dioritic rocks, members of the older granite suite, metamorphosed to unmetamorphosed calc-alkaline volcanics and hypabyssal rocks and unmetamorphosed dolerite dykes, basic dykes, syenite dykes etc. The main features of these rocks have been discussed in details by Rahaman (1988). However, the Basement Complex rocks underlying the area (Fig.3) as shown on the 1:250,000 Geological Survey of Nigeria map, Iwo sheet 60 are: gneiss and migmatite undifferentiated, pegmatitised schists, granite gneiss, pegmatite and schists undifferentiated. Of these five rock groups, the schists (pegmatitised) cover the greater part of the study area trending from the north to the south. They cover part of the central and the western portions. Second to the schists in area extent is pegmatite, which occurs in the eastern part and also trends from the north to the south. The gneiss and migmatite occur at the western portion of the area and within the schists. They also extend from the north to the south. The undifferentiated schists occur within pegmatites around the northeastern part of the area; while the granite gneiss shares boundary with pegmatite at the eastern part and with pegmatite and schist towards the central portion of the area.

Detailed and systematic mapping of part of the study area was carried out by Ajayi *et al*., (1971) and they noted the following rocks; granite gneiss, migmatite, amphibolite, talc-tremolite schists and calc-gneiss. Babafemi (1993) did an independent mapping exercise in Akinlalu area which also falls within the study area. He reported that the rocks present in the area are biotite gneiss, granite gneiss, amphibolite, talc-tremolite-actinolite schists, pegmatite and dolerite, which occur as dykes.

The rocks in the study area have been subjected to marked tectonic deformation, which give rise to the various structures observable on the field. Such structures include foliation, schistosity, lineation, folds, veins, faults and joints. A major fracture that occurs in this area is observable in the pattern of movement of river Shasha.

Table 1: Summary of the basic statistics for raw stream sediment geochemical data from the study area

Element	Range of Metal Concentration (ppm)	Arithmetic Mean Value (ppm)	Median	Standard Deviation (S)	Threshold	Coefficient of variation
Au	3 - 23	9	8	5	19	56
Ta	0 -2587	595	590	497	1589	84
Co	3 - 58	20	19	14	48	70
Sn	0 - 653	114	21	165	444	145
*Fe	0.40 - 7.36	2.26	1.67	1.61	5.48	71
Ni	4 - 47	16	13	10	36	63
Zn	11 - 205	44	33	39	122	89
Mn	108 - 6514	555	539	321	1197	58
Cr	5 - 24	11	11	5	21	46
Hg	0 - 121	46	41	38	122	82
Pb	13 - 99	48	43	22	92	46
Cu	3 - 25	9	8	6	21	67

* Fe is given as wt%

The sampling exercise for this work was carried out during June and July 2002 when the main rivers and most of the streams in the area were flowing. Thirty-six stream sediment samples were collected by making the most use of the available stream-road/footpath intersections.

The samples were dried, disaggregated and sieved. One gram each of the minus 80 mesh fractions was treated with concentrated $HClO_4$ and HNO_3 in a ratio of 7:3 (Ajayi, 1981). After heating to dryness (which took between 12 and 15 hours), the residue was leached with 20 ml of 6 M HCl for ten minutes and filtered. The leached solution was then made up to mark inside a 50 ml volumetric flask with distilled water.

The resulting solutions were analysed for Au, Ta, Co, Sn, Fe, Ni, Zn, Mn, Cr, Hg, Pb and Cu, using the Alpha-4 model of Atomic Absorption Spectrophotometer of the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife. Standard analytical conditions for AAS were strictly adhered to while analytical precision and accuracy were determined by the analyses of duplicates and insertion of standard solutions as reslope standards at intervals of 12 samples. Both accuracy and precision were reasonable and satisfactory

2. Presentation of Data

The results of the analysis were used to prepare histograms showing the relative frequency distribution of the elements (Fig.4) and cumulative probability plots (Fig.5: A-J). Also, elements concentrations in parts per million (ppm) were plotted on their actual positions on the drainage maps of the study area, super-imposed on the geological maps in individual elemental forms (Fig.6: A-L) to show the distribution patterns of the elements analysed in the area.

Basic Statistical Parameters:

The basic statistical parameters of the data obtained from the analysis were computed and they include the arithmetic mean, the median, standard deviation and coefficient of variation. The computations were achieved with the use of the statistical package for social sciences (SPSS). The threshold value of each of the elements analysed was then determined using the formular mean plus two standard deviation. It should be noted that Ta and Mn data were screened for excessively high values. Table 1 shows a summary of the basic statistical parameters, the threshold values and the range of metal concentrations.

Interpretation of Data:

Interpretation of geochemical data has been described by Levinson (1974) as the most difficult part of any geochemical exploration. In order to minimize the difficulties of interpretation and prevent the possibility of arriving at a wrong conclusion, a multiple approach has been adopted in this study.

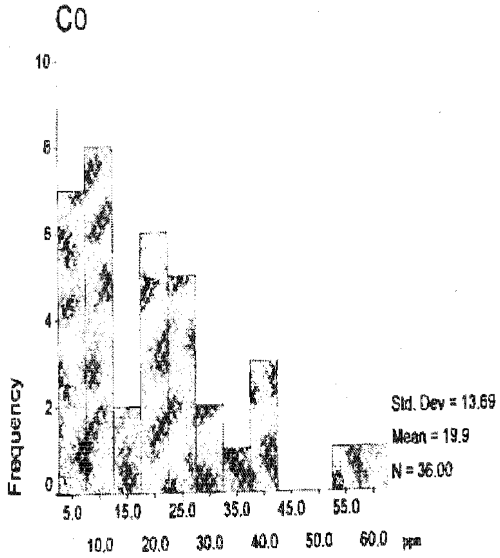
Frequency Distribution:

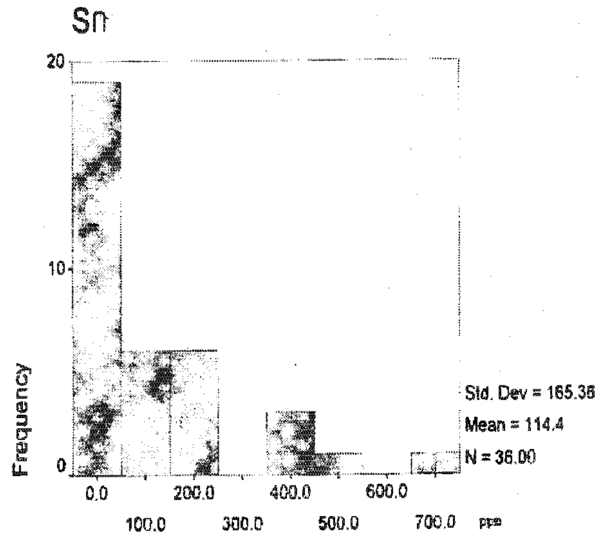
The frequency plots of ten of the elements, namely Au, Ta, Co, Sn, Fe, Ni, Zn, Mn, Hg and Cu exhibit lognormal distribution. Sn, Zn and Hg have strong positive skewness while Au, Ta, Co, Fe, Ni, Mn, and Cu are less skewed. On the other hand Cr and Pb exhibit almost normal distribution.

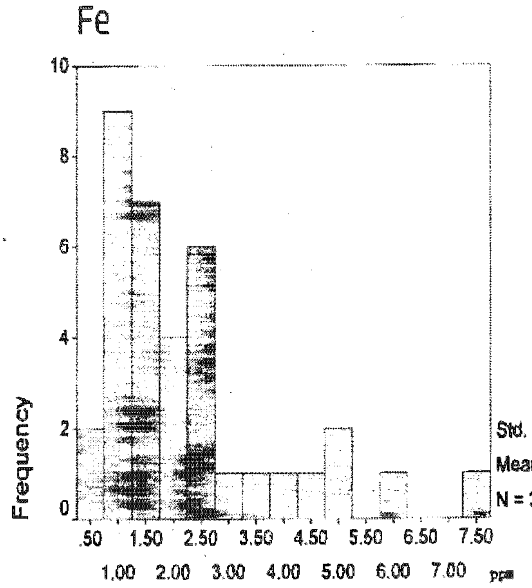
Most of the plots show a mixture of two populations (Fig.4). Breaks in the distribution occur for Au at 21 ppm, Ta at 1500 ppm, Co at 42.5 ppm, Sn at 250 ppm and 550 ppm and Fe at 5.25 wt % and 62.5 wt %. The breaks occur for Ni at 37.5 ppm, Zn at 110 ppm and 150 ppm, Mn at 650 ppm, 850 ppm and 1150 ppm, Cr at 1 ppm and 19 ppm, Hg at 5 ppm and 35 ppm and Cu at 19 ppm. Only Pb did not show any obvious break, but its two populations are very distinct.

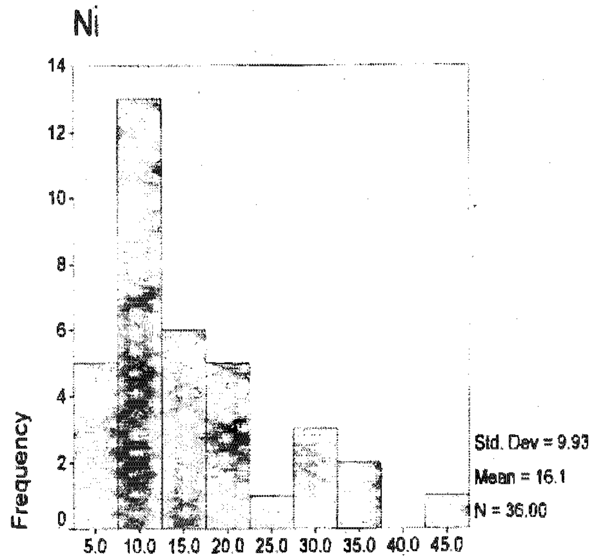
Cumulative Probability Plots:

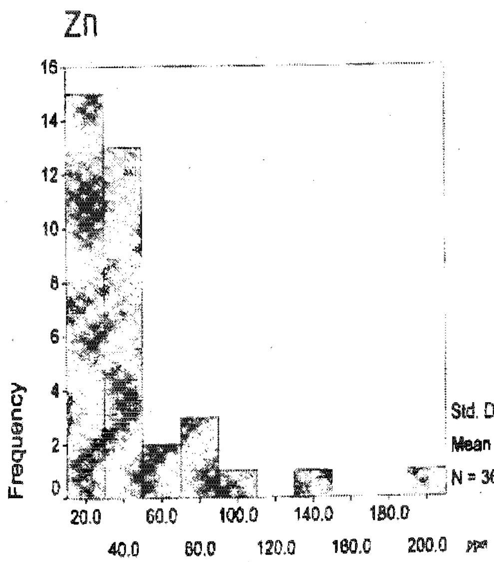
The cumulative probability plots of the elements were undertaken employing a software package,

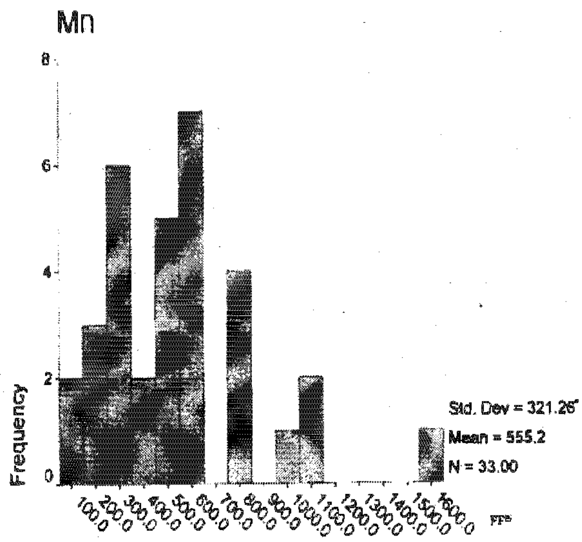

Co
Frequency
Std. Dev = 13.69
Mean = 19.9
N = 36.00
ppm


Sn
Frequency
Std. Dev = 165.36
Mean = 114.4
N = 36.00
ppm


Fe
Frequency
Std. Dev = 1.61
Mean = 2.26
N = 36.00
ppm


Ni
Frequency
Std. Dev = 9.93
Mean = 16.1
N = 36.00


Zn
Frequency
Std. Dev = 38.86
Mean = 44.2
N = 36.00
ppm


Mn
Frequency
Std. Dev = 321.26
Mean = 555.2
N = 33.00

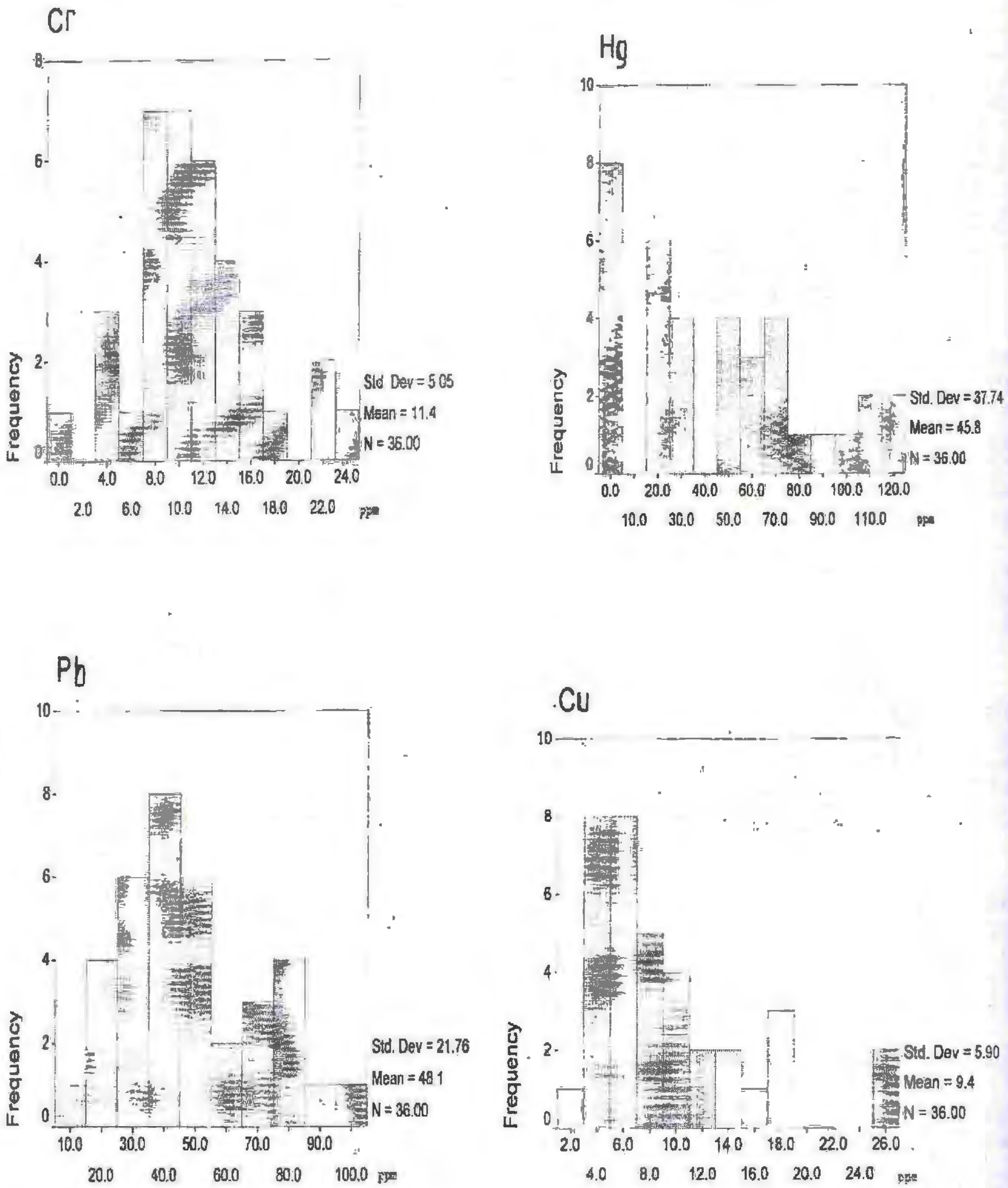


Fig.4: Frequency Distributions of Elements in Stream Sediments of Gbongan and Environs

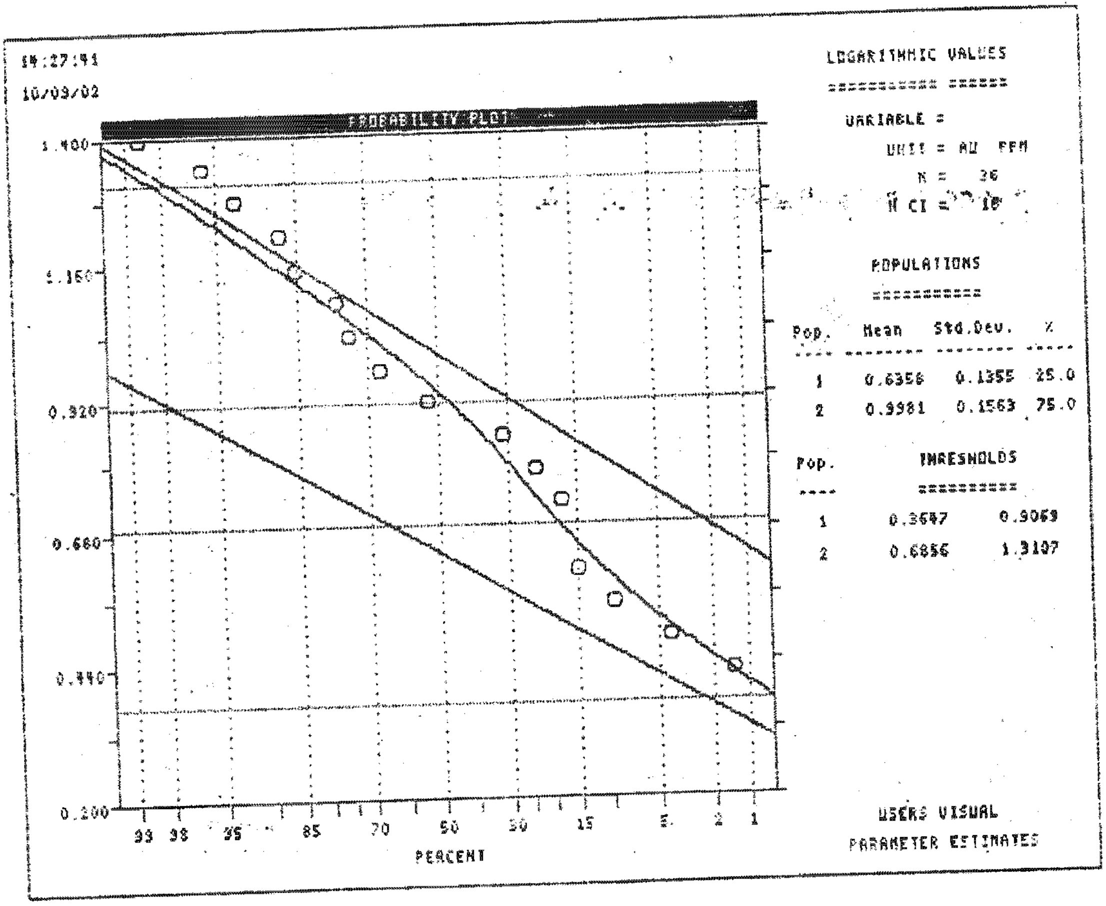

14:27:41
10/09/02
LOGARITHMIC VALUES
VARIABLE =
UNIT = AU PPM
N = 36
POPULATIONS
Pop. Mean Std.Dev. %
1 0.6356 0.1355 25.0
2 0.9981 0.1563 75.0
Pop. THRESHOLDS
1 0.3647 0.9069
2 0.6856 1.3107
1.400
1.160
0.920
0.680
0.440
0.200
PERCENT
USERS VISUAL
PARAMETER ESTIMATES

Fig. 5a

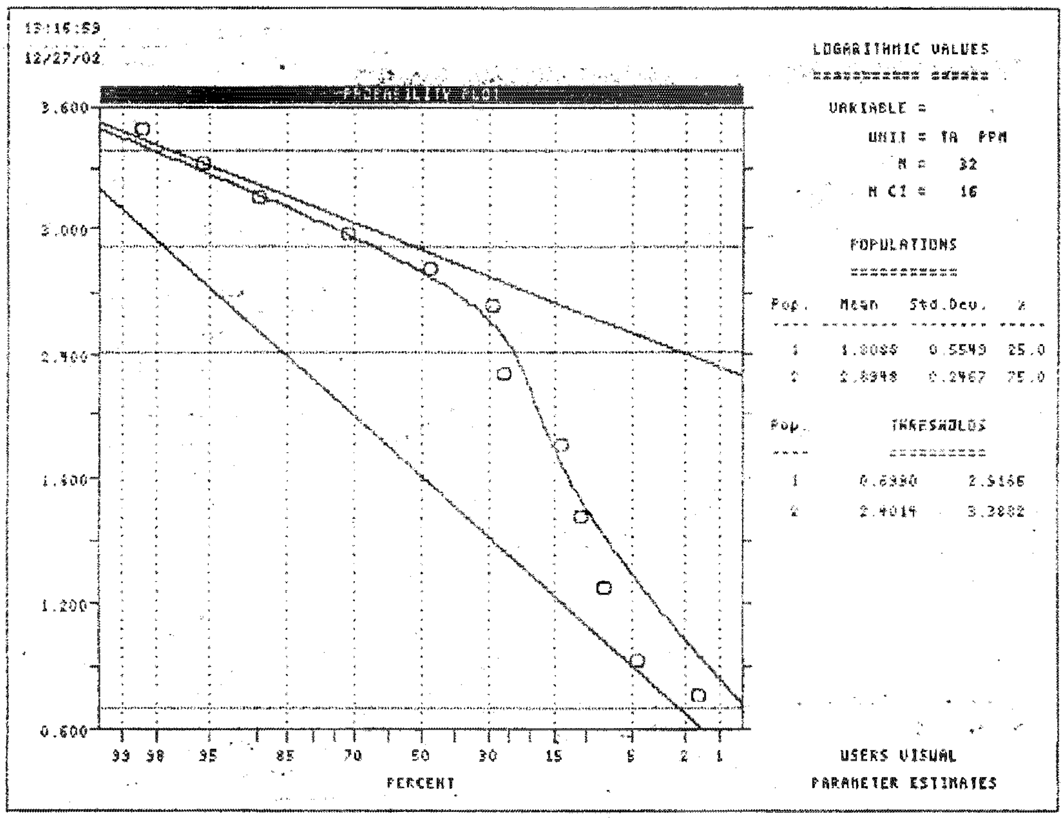

13:16:59
12/27/02
LOGARITHMIC VALUES
VARIABLE =
UNIT = TA PPM
N = 32
N CI = 16
POPULATIONS
Pop. Mean Std.Dev. %
1 1.8088 0.5549 25.0
2 2.8948 0.2967 75.0
Pop. THRESHOLDS
1 0.6980 2.9166
2 2.4014 3.2882
3.600
3.000
2.400
1.800
1.200
0.600
PERCENT
USERS VISUAL
PARAMETER ESTIMATES

Fig. 5b

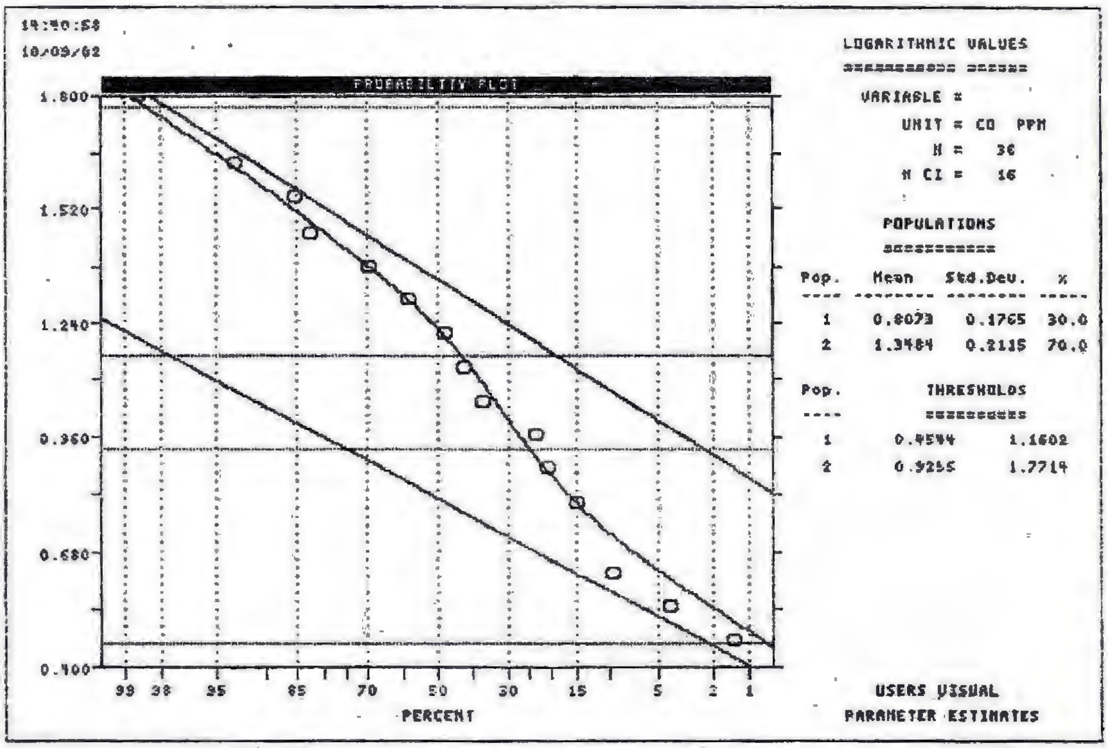

14:50:58
10/09/02
PROBABILITY PLOT
1.800
1.520
1.240
0.960
0.680
0.400
99 98 95 85 70 50 30 15 5 2 1
PERCENT
LOGARITHMIC VALUES
VARIABLE =
UNIT = CO PPM
N = 36
N CI = 16
POPULATIONS
Pop. Mean Std.Dev. %
1 0.8073 0.1765 30.0
2 1.3484 0.2115 70.0
Pop. THRESHOLDS
1 0.4544 1.1602
2 0.9255 1.7714
USERS VISUAL
PARAMETER ESTIMATES

Fig. 5c

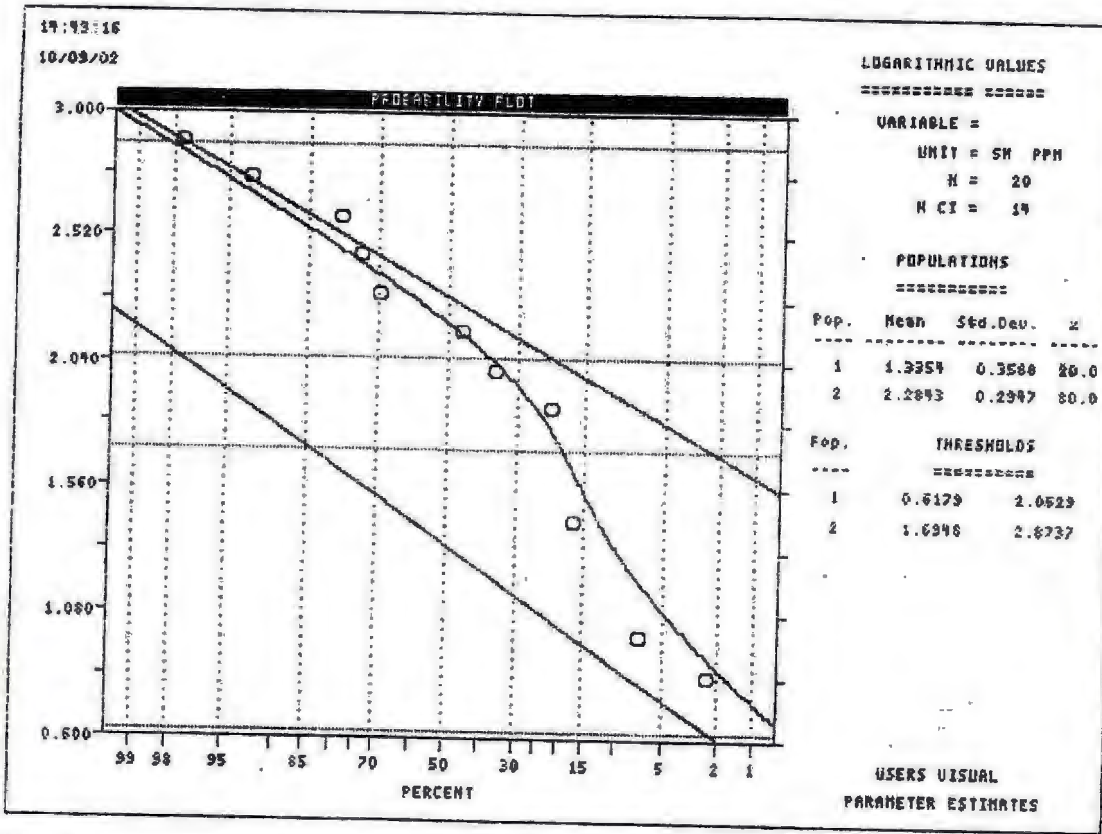

14:53:16
10/09/02
PROBABILITY PLOT
3.000
2.520
2.040
1.560
1.080
0.600
99 98 95 85 70 50 30 15 5 2 1
PERCENT
LOGARITHMIC VALUES
VARIABLE =
UNIT = SN PPM
N = 20
N CI = 14
POPULATIONS
Pop. Mean Std.Dev. %
1 1.3354 0.3588 20.0
2 2.2893 0.2947 80.0
Pop. THRESHOLDS
1 0.6179 2.0529
2 1.6948 2.8737
USERS VISUAL
PARAMETER ESTIMATES

Fig. 5d

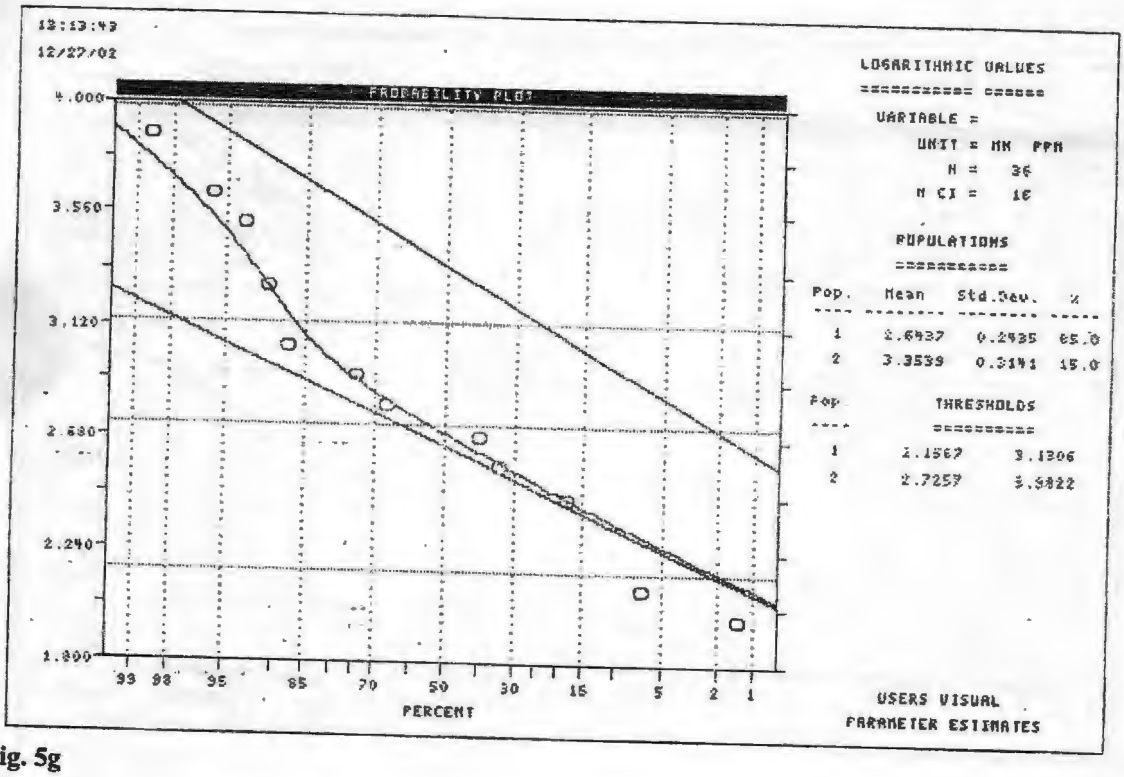
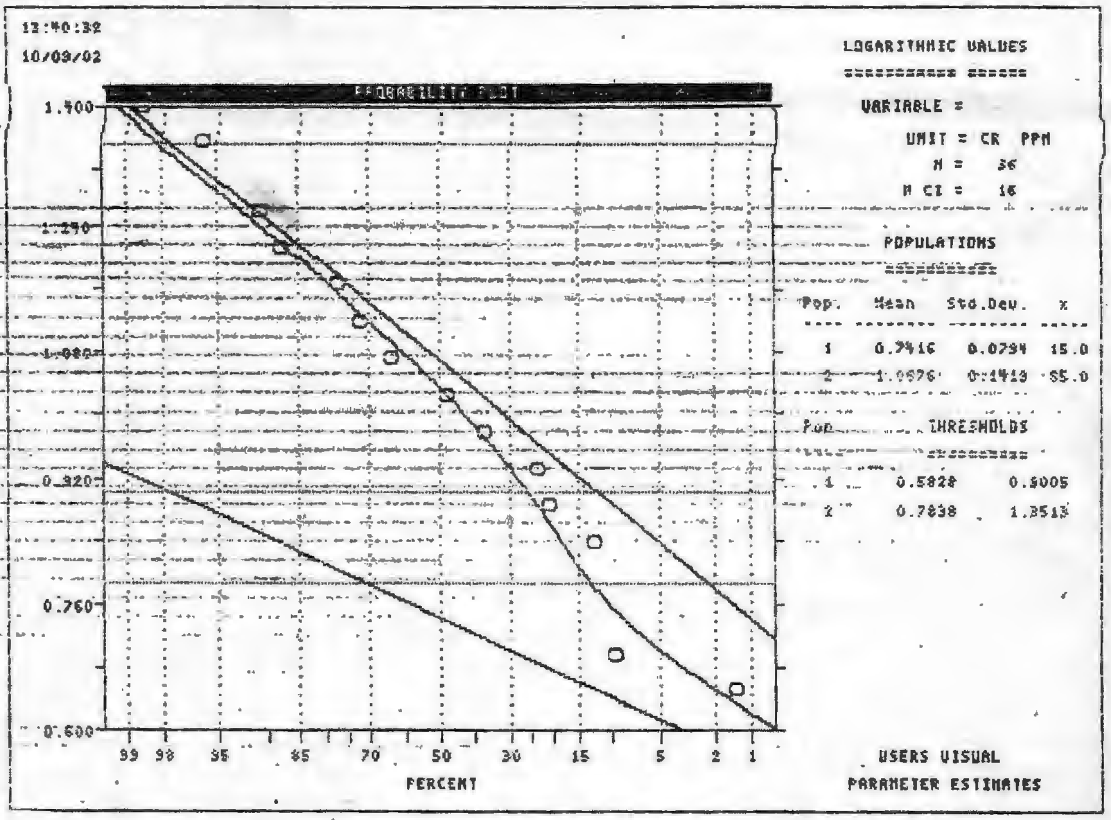

13:13:43
12/27/02
PROBABILITY PLOT
4.000
3.560
3.120
2.680
2.240
1.800
99 98 95 85 70 50 30 15 5 2 1
PERCENT
LOGARITHMIC VALUES
VARIABLE =
UNIT = MN PPM
N = 36
N CI = 16
POPULATIONS
Pop. Mean Std.Dev. %
1 2.6437 0.2435 65.0
2 3.3539 0.3141 15.0
Pop THRESHOLDS
1 2.1567 3.1306
2 2.7257 3.9822
USERS VISUAL
PARAMETER ESTIMATES

Fig. 5g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PROBABILITY PLOT
1.400
1.240
1.080
0.920
0.760
0.600
99 98 95 85 70 50 30 15 5 2 1
PERCENT
LOGARITHMIC VALUES
VARIABLE =
UNIT = CR PPM
N = 36
N CI = 16
POPULATIONS
Pop. Mean Std.Dev. %
1 0.7416 0.0794 15.0
2 1.0676 0.1419 85.0
Pop THRESHOLDS
1 0.5828 0.9005
2 0.7838 1.3513
USERS VISUAL
PARAMETER ESTIMATES

Fig. 5h

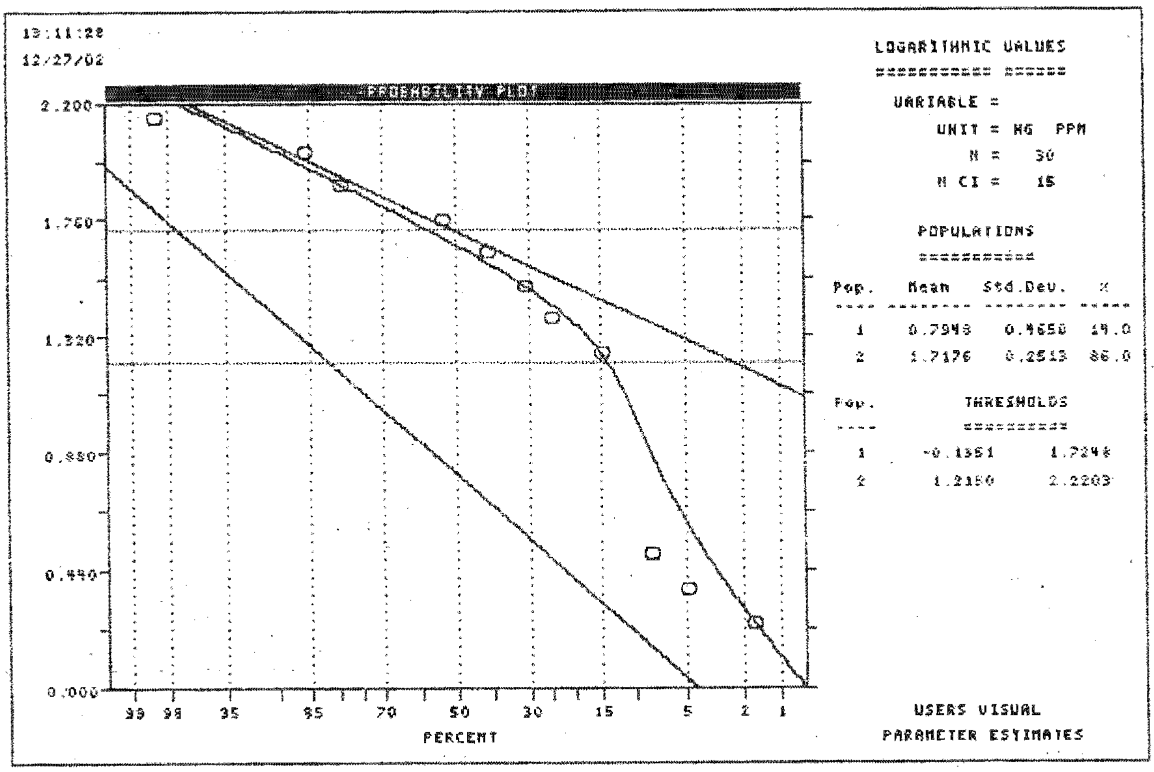
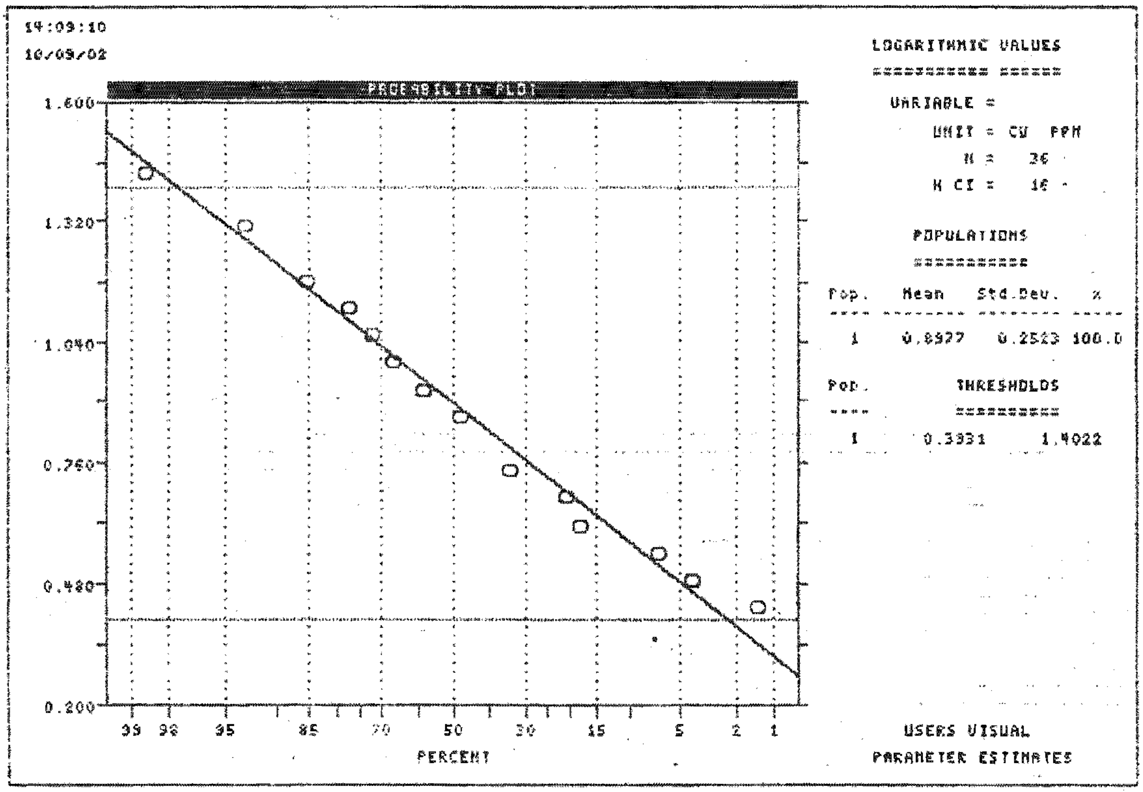

13:11:28
12/27/02
PROBABILITY PLOT
LOGARITHMIC VALUES
VARIABLE =
UNIT = HG PPM
N = 30
N CI = 15
POPULATIONS
Pop. Mean Std.Dev. %
1 0.7948 0.4650 14.0
2 1.7176 0.2513 86.0
Pop. THRESHOLDS
1 -0.1351 1.7248
2 1.2150 2.2203
PERCENT
USERS VISUAL PARAMETER ESTIMATES

Fig. 5i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10/09/02
PROBABILITY PLOT
LOGARITHMIC VALUES
VARIABLE =
UNIT = CU PPM
N = 36
N CI = 16
POPULATIONS
Pop. Mean Std.Dev. %
1 0.8927 0.2523 100.0
Pop. THRESHOLDS
1 0.3931 1.4022
PERCENT
USERS VISUAL PARAMETER ESTIMATES

Fig. 5j

Table 3: Pearson correlation matrix of stream sediment geochemical data from the study area

Element	Au	Ta	Co	Sn	Fe	Ni	Zn	Mn	Cr	Hg	Pb	Cu
Au	1.00											
Ta	-0.08	1.00										
Co	0.47	-0.08	1.00									
Sn	0.23	0.15	0.08	1.00								
Fe	0.61	-0.01	0.79	0.16	1.00							
Ni	0.54	-0.14	0.84	0.02	0.92	1.00						
Zn	0.48	-0.18	0.65	0.07	0.72	0.70	1.00					
Mn	0.50	-0.14	0.80	0.16	0.88	0.82	0.84	1.00				
Cr	0.34	-0.02	0.47	-0.14	0.62	0.52	0.48	0.48	1.00			
Hg	0.34	-0.27	0.45	0.03	0.41	0.48	0.28	0.40	0.12	1.00		
Pb	0.54	-0.08	0.58	0.11	0.84	0.72	0.70	0.75	0.62	0.33	1.00	
Cu	0.50	-0.17	0.79	-0.08	0.80	0.88	0.75	0.77	0.47	0.48	0.63	1.00

Table 4: R-Mode varimax rotated factor matrix for thirty-six stream sediments (with 12 variables) from the study area

Element	Factor 1	Factor 2	Factor 3	Communality
Au	0.597	0.153	0.385	0.528
Ta	-0.0001	-0.799	0.221	0.687
Co	0.827	0.217	0.009	0.739
Sn	0.004	-0.115	0.920	0.860
Fe	0.952	0.005	0.149	0.931
Ni	0.898	0.247	0.003	0.868
Zn	0.824	0.147	0.003	0.702
Mn	0.889	0.180	0.144	0.844
Cr	0.725	-0.222	-0.327	0.682
Hg	0.351	0.693	0.186	0.638
Pb	0.856	0.0006	0.007	0.738
Cu	0.850	0.307	-0.006	0.821
Eigen values	6.329	1.463	1.246	
Proportion of Total Variance (%)	52.742	12.195	10.385	
Cumulative (%)	52.742	64.938	75.323	

ELEMENT ASSOCIATION OF THE THREE FACTOR MODEL

Factors	Elements	Eigen values as %
1	Fe, Ni, Mn, Pb, Cu, Co, Zn, Cr, Au	52.74
2	Ta, Hg	12.20
3	Sn	10.39

Table 5: Average abundance of the elements analyzed in the earth's crust, ultramafic rocks, soil and granire (after Levision, 1974)

Element	Earth's crust	Ultramafic	Granite	Soil
Au	0.004	0.005	0.004	-
Ta	2.0	1.0	3.5	-
Co	25.0	150.0	1.0	1 – 40
Sn	2.0	0.5	3.0	10.0
*Fe	46,500	94,300	14200	21,000
Ni	75.0	2000.0	0.5	5 – 500
Zn	70.0	50.0	40.0	10 – 300
Mn	950.0	1300	500.0	850.0
Cr	100.0	2000	4.0	5 – 1000
*Hg	0.02	0.004	0.0	0.06
Pb	12.5	0.1	20.0	2 – 200
Cu	55.0	10.0	10.0	2 – 100

* After Rose, Hawkes and Webb, (1979).

"Probplot" by Stanley (1987) using the IBM 486 computer at the Department of Geology, Obafemi Awolowo University. The data were log-transformed prior to plotting and the frequencies were cumulated from the highest to the lowest values following Lepeltier's (1969) method in order to give maximum emphasis to the higher values.

The plots of all the elements show two distinct populations with the exception of Fe and Cu each of which shows only one population (Fig.4). The two populations of Au occur at relative proportion of 25% and 75%, while those of Ta occur at 30% and 70%. Similarly, the populations of Co, Sn, Ni, Zn, Mn, Cr, Hg and Pb occur at 30% and 70%, 20% and 80%, 10% and 90%, 60% and 40%, 20% and 80%, 15% and 85%, 10% and 90%, and 30% and 70% respectively. The two populations of all the affected elements can represent the background and anomalies or the heterogenous nature of the underlying rocks in the study area. They could also represent hydromorphic anomaly superimposed on normal dispersion halo. In the case of Fe and Cu, the single population can be interpreted as the background.

Table 2 shows a summary of the statistical parameters obtained from the cumulative probability plots of the elements. A comparison of the mean values shown on this table with the arithmetic means on Table 1 indicates that the latter corresponds to the means of the second populations, showing that the mean values are biased towards the high values in a single population.

Simple Pearson Correlation:

Certain groups of elements respond more or less similarly to a given set of environmental conditions. Consequently, mutual correlations between different elements serve to identify more clearly the variations present in the geochemical landscape (Levinson, 1974).

Pearson linear correlation of elements measures the linear relationship between different pairs of elements. The correlation matrix for the data obtained in this study (Table 4) was generated with the use of statistical package for Social Sciences. It shows both positive and negative correlation. The values range from "0.01 for Fe and Ta to 0.92 for Ni and Fe. Some of the elements pairs have fairly strong to strong positive correlation with one another but Sn and Ta have a weak positive correlation with each other and weak negative to positive correlations with some other elements. In some cases, Au and Hg also have a weak positive correlation with the other elements.

All the fairly strong to strong positive correlation coefficient (r) values are significant at 95% and above confidence level. The fairly strong to strong positive correlation between most of the elements (Table 4), may indicate the scavenging effect of Fe and Mn oxides and hydroxides on heavy metals in the study area. The higher value of 0.92 between Ni and Fe probably indicates that Fe has a strong scavenging effect than Mn in the area.

Moreover, the strong positive correlation between some of the elements, notably, Fe/Cu, Mn/Co, Pb/

Table 2: Graphically determined statistical parameters of stream sediments geochemical data of the study area

Element	Population	Mean	Standard deviation	Threshold (ppm)	Percentage (%)
Au	1	4	6	8	25
	2	10	14	21	75
Ta	1	248	399	643	30
	2	765	1026	1375	70
Co	1	6	10	15	30
	2	22	36	59	70
Sn	1	22	49	112	20
	2	192	379	748	80
*Fe	1	2	4	10	100
Ni	1	5	6	8	10
	2	15	25	41	90
Zn	1	23	33	48	60
	2	64	105	172	40
Mn	1	203	304	453	20
	2	575	894	1389	80
Cr	1	6	7	8	15
	2	12	16	23	85
Hg	1	5	13	38	10
	2	48	88	161	90
Pb	1	25	33	46	30
	2	54	74	102	70
Cu	1	8	14	25	100

*Fe is given wt%

Zn, Ni/Cu, Ni/Co etc may be indicative of underlying mafic/ultramafic rocks with sulphides. The fairly strong positive correlation of Au with some of these metals may also suggest the presence of gold-bearing quartz veins in the area. Woakes *et al.*, (1987) noted that the typical gold bearing quartz veins do carry some sulphides, galena and pyrite being the most common.

R-mode factor analysis:

The R-mode factor analytical technique is the most commonly used in geochemical exploration. It assists in grouping the multi-element geochemical data into metal associations, which characterize specific geological processes, thereby improving the interpretation of the data. In this study, the R-mode factor analysis using the varimax rotation method with Kaiser normalization was employed. The data were log-transformed before being analysed and the factor solutions provide information on loading, communality and eigen values.

In the analysis, the three factor model (Table 5) which account for 75% of the data variability is considered appropriate in view of known geology of the study area.

Factor 1: (Fe-Ni-Mn-Pb-Cu-Co-Zn-Cr-Au association) accounts for 52.7% of the model variance. It also has some contribution from Hg and the metal association defines mainly a mafic lithological control, which reflects probably the parent rock as the dominant influencing factor. It could also be interpreted as the presence of sulphide minerals with which gold is associated or gold quartz veins occurring within mafic rocks.

Furthermore, this association coupled with the strong positive correlation between most of the elements may indicate co-precipitation activities of Fe-oxide and Mn-hydroxide in the vicinity mafic suites.

Factor 2: (Hg Vs Ta association) accounts for 12.2% of the model variance. It probably represents the effect of felsic rocks on the composition of the stream sediments in question. The inverse relationship of Ta with Hg in the factor may suggest the presence of felsic rocks such as pegmatites and gneisses, with sulphides carrying veins. This is consistent with the lithology of the area where there are gneisses and pegmatitic intrusions.

Factor 3: (Sn) accounts for 10.4% of the model variance with some contribution from Au. This factor defines felsic lithological control and the association of Au here may suggest placer Au and Sn. The Sn is probably derived from the pegmatite.

Distribution of Elements:

To explain element's concentration in earth's sampled materials and thus consider the element's significance in a study area, a basis of comparison is required. The average abundance of elements in the earth's crust, ultramafic rocks, soil and granite (Table 5) serves that purpose in this study.

The distribution maps of all the elements analysed in this study are herein presented (Fig. 6, A-L). The maps are super-imposed on the geological map of the area to aid the description of elements distribution.

Gold:

Gold, a precious metal, which commonly occurs in the native form, was found in all the samples analysed. It values range between 3 ppm and 23 ppm with a mean value of 9 ± 5 ppm, coefficient of variation of 56% (Table 2) and a threshold value of 19 ppm. T' e mean value is relatively high when compared with the average abundance of gold in the earth's crust, ultramafic rocks and granites and there are two anomalous values of 20 ppm and 23 ppm at the northeastern part of the area (Fig. 6 A). This part is underlain by schist undifferentiated with some gneisses. Also, fairly high values of 16 ppm, 17 ppm and 18 ppm were recorded in the northwestern part where the underlying rock is pegmatitised schist.

It is pertinent to note that there is similarity in the patterns displayed by the geochemical maps of Au, Co, Fe, Ni, Mn, Hg, Pb and Cu, particularly in areas with high concentrations. This is suggestive of a close association between these elements, which may not be unconnected with co-precipitation activities of Fe and Mn with other elements.

However, with the high values recorded for gold, the possibility of occurrence of placer gold in the study area cannot be ruled out. This might have resulted from the erosion of disseminated gold in the schists and or gold bearing quartz veins within gneisses and pegmatite.

Tantalum:

Tantalum has a very low mobility in all the geochemical environments and this is responsible for its usual occurrence in form of placer deposit. It was detected in 32 samples of the 36 samples analysed (Fig. 6B), with a concentration range of 7 ppm to 1767 ppm and a mean value of 595497 ppm. The coefficient of variation is 84%.

Tantalum is evenly distributed in the study area. It has a threshold value of 1589 ppm and there are two anomalous values of 1745 ppm and 1767 ppm in the northeastern and western parts of the area respectively, when the 2587 ppm value obtained in the western part is not considered because it is thought to be an outlier. Below the threshold, there are other fairly high values, scattered all over the study area and these high values, the anomalous inclusive, are not restricted to areas underlain by particular rock type.

However, the source of tantalum in this area is thought to be the intrusive pegmatite. According to Woakes *et al.* (1987), mineralized pegmatites consist of quartz, potash feldspar, albite, muscovite and less commonly biotite, and a range of accessory minerals including tourmaline, and economically important cassiterite and columbotantalite.

The concentration of tantalum in the study area with the mean value of 595 ppm is high when compared with its average abundance in granitic rocks, which is 3.5 ppm. Consequently, tantalum mineralization is suspected in this area.

Cobalt:

The distribution of cobalt in the study area is fairly wide (Fig. 6C) but its abundance is generally low. It has a concentration range of 3 ppm and 58 ppm, with a mean value of 2014 ppm and a coefficient of variation of 78%.

The threshold value for cobalt in the area is 48 ppm and there are only two anomalous values of 55 ppm and 58 ppm at the northwestern part, where the underlying rock is pegmatitised schists. When compared with the average abundance of cobalt in ultramafic rocks (150 ppm) such as talc-schists, which may be the source of cobalt in the area, the anomalous values are insignificant. They are probably due to co precipitation of Co with Fe and or Mn, Fe and Mn values are also high where Co has anomalous values.

Tin:

Tin is one of the first metals used by man since ancient times both in its pure form and in alloys. The main and practically the only economic mineral for tin is cassiterite, SnO_2 (78.6% Sn), which usually occurs in both primary and placer deposits.

In Nigeria, it is estimated that more than 95% of over 650,000 tonnes of cassiterite produced has been from alluvial deposits derived from the Mesozoic Younger Granites. The remaining 5% has been derived from pegmatites, which form a well-defined trending zone from the central Jos to the Ife-Ilesha area (Woakes *et al.*, 1987).

The distribution of tin in the study area is not very wide. It was detected in 20 of the 36 sample collected (Fig. 6D). Its concentration ranges from 8 ppm to 653 ppm, with a mean value of 114165 ppm and coefficient of variation of 145%. The threshold value is 444 ppm. Consequently, only two anomalous values of 463 ppm and 653 ppm were observed in samples from the northeastern and north central parts respectively. These two areas are underlain by pegmatitised schists and schists undifferentiated respectively, although the source of Sn in the study area is thought to be the pegmatite. This assertion is supported by the known geology of the area and the fact that river Opa on which the two anomalous values are situated drains a pegmatite terrain before the sampled points. Also there are two fairly high values of 419 ppm and 443 ppm situated on streams directly on the pegmatite at the southeastern part of the area.

The mean value of tin in the study area is high when compared with its average abundance in granite rocks, which is 3 ppm. As a result, the anomalous values observed in the study may be connected with placer tin deposit.

Iron:

The distribution of Fe in the study area is very wide (Fig. 6E). It has a concentration range of 0.4 wt% to 7.4 wt% with a mean value of 2.31.6 wt% and a coefficient of variation of 71%. The threshold value for iron in this area is 5.5 wt%. There are thus only two anomalous values of 5.8 wt% and 7.4 wt% in the northwestern and southwestern part of the area respectively. These anomalous values and other fairly high values of 4.1 wt%, 4.8 wt% and 5.1 wt% are all situated on streams found in part of the area underlain by pegmatitised schists. Only the fairly high value of 4.7 wt% at the northeastern part is situated on a stream underlain by undifferentiated schists with some gneiss.

With its mean value of 2.3 wt%, the abundance of Fe in the study area is low when compared with its average abundance in the earth's crust, which is 4.65 wt%. Consequently, the anomalous values recorded are not likely to be associated with mineralization.

Nickel:

Generally, the deposits of nickel are of the complex ore type, copper-nickel with cobalt. To be workable, sulphide copper-nickel ores should average at least 0.3% nickel. In silicate ores, 0.6% nickel is the workable minimum (Doroklun *et al.*, 1969).

Nickel was detected in all the samples analysed in the study area (Fig. 6F). Its concentration range from 4 ppm to 47 ppm, with a mean value of 1610 ppm and a coefficient of variation of 63%. The threshold value of nickel is 36 ppm and this indicates only two anomalous values of 46.9 ppm at the southeastern part and 36.2 ppm at the northeastern part of the study area. Other fairly high values of 31.5 ppm and 33.8 ppm occur at the northwestern part of the area. These high nickel values are associated with pegmatitised schists and undifferentiated schists.

With its mean value of 16 ppm, the abundance of nickel is very low in the study area when compared with the average abundance of nickel in ultramatic rocks, which is 2000 ppm. The few fairly high values recorded are probably due to co precipitation of nickel with hydrated iron oxide, or hydrolysis. The anomalous values are thus non-significant and not related to mineralization. However, the similarity in patterns displayed by the distribution maps for nickel and copper is suggestive of a close association between the two elements and this is supported with the strong positive correlation of 0.88 between the two elements.

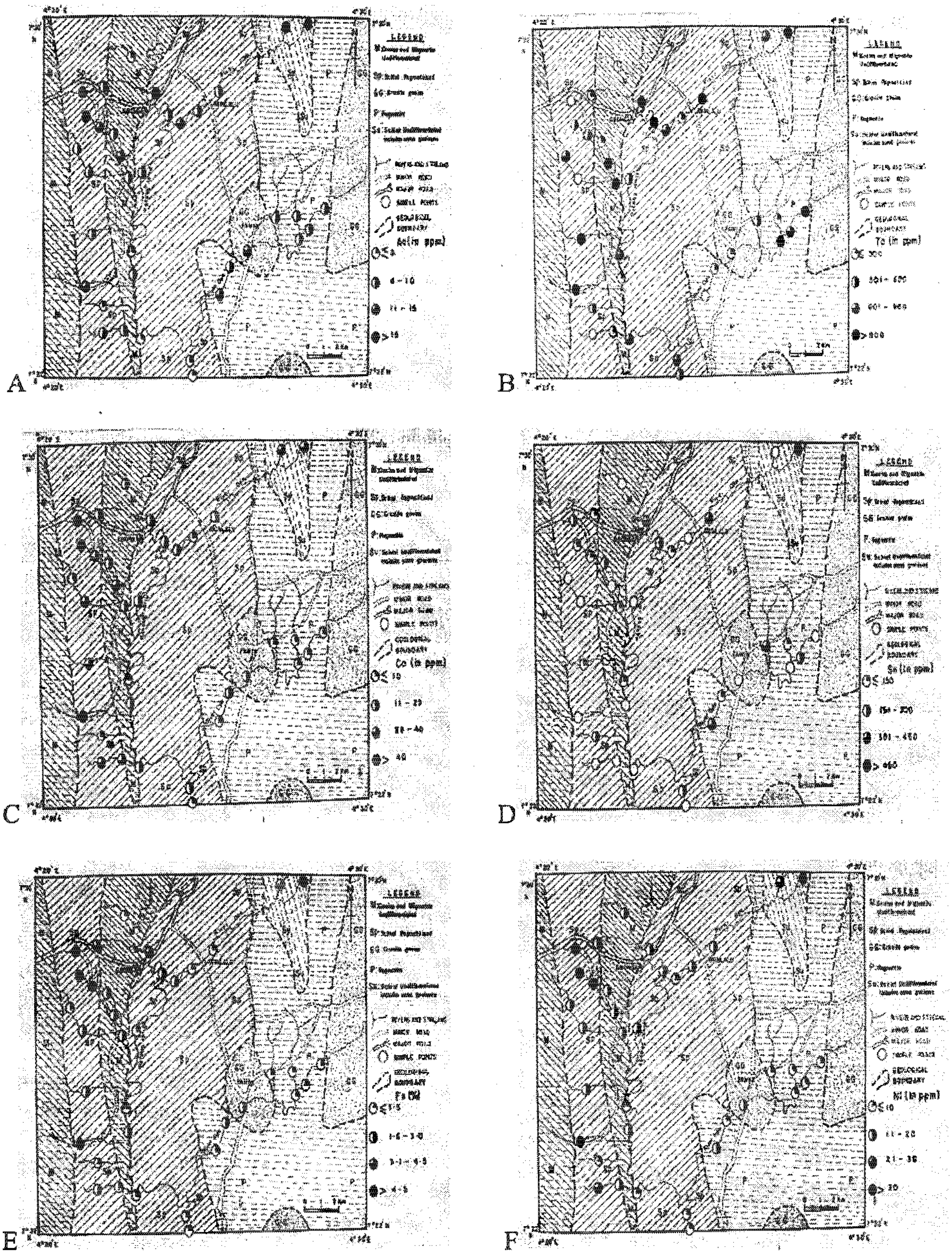

Fig. 6A-L

A – Distribution of Gold in Stream Sediments of Gbongan and Environs
B – Distribution of Tantalum in Stream Sediments of Gbongan and Environs
C – Distribution of Cobalt in Stream Sediments of Gbongan and Environs
D – Distribution of Tin in Stream Sediments of Gbongan and Environs
E – Distribution of Iron in Stream Sediments of Gbongan and Environs
F – Distribution of Nickel in Stream Sediments of Gbongan and Environs

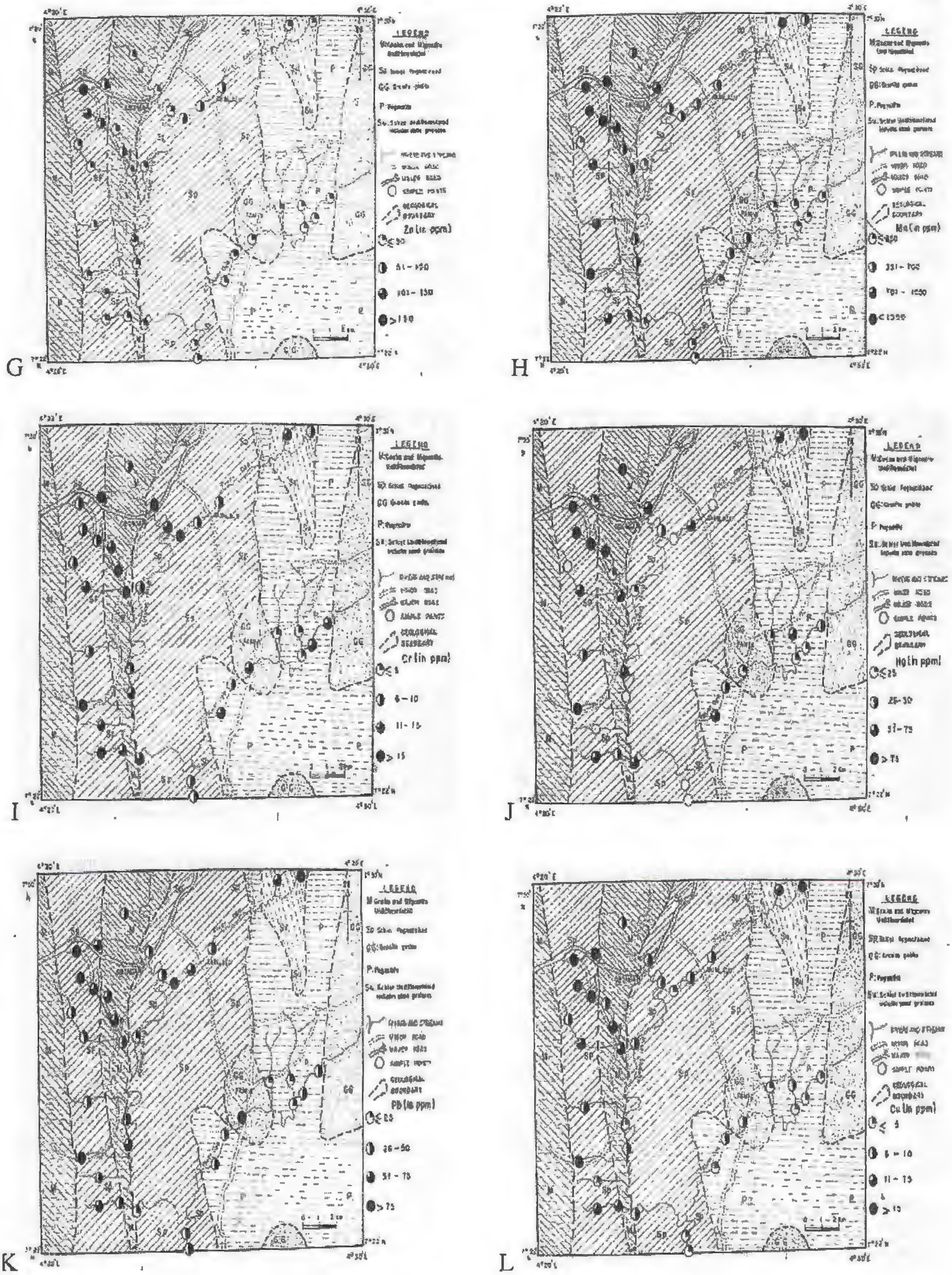

Fig. 6G-L
G – Distribution of Zinc in Stream Sediments of Gbongan and Environs
H – Distribution of Manganese in Stream Sediments of Gbongan and Environs
I – Distribution of Chromium in Stream Sediments of Gbongan and Environs
J – Distribution of Mercury in Stream Sediments of Gbongan and Environs
K – Distribution of Lead in Stream Sediments of Gbongan and Environs
L – Distribution of Copper in Stream Sediments of Gbongan and Environs

Zinc:

The concentration of zinc in the study area ranges between 11 ppm and 205 ppm. It has a mean value of 4439ppm and a coefficient of variation of 89%.

The element is widely distributed in this area, as it is detected in all the samples analysed (Fig. 6G) and its abundance is fairly high. With a threshold value of 122 ppm, there are two anomalous values of 144 ppm and 205 ppm and both values occurred on streams around the northwestern part of the study area, where the underlying rock is pegmatitised schists. In addition to these anomalous values, other fairly high values of between 74 ppm and 93 ppm were obtained around the northwestern part. These values, excluding one 74 ppm are in the area with schists as the underlying rocks. The 74 ppm was obtained on a stream in an area underlain by gneiss and migmatite undifferentiated.

With zinc's mean level of occurrence, its mineralization is unlikely in the study area. This is especially true when the mean is compared with the average abundance of zinc in soil, which is between 10 ppm and 300 ppm. The relatively high values obtained in some parts of this area may therefore be connected with cocoa plantation, which is characterized by high accumulation of leaves from which zinc can be derived (Goldsmith, 1958). Another possible source of the high zinc values may be the sulphides associated with the suspected primary gold mineralization in the area.

Manganese:

Manganese is associated mostly with basic igneous rocks. Chemically and geochemically, it stands closest to iron, and it forms more than a hundred minerals, only few of which are widespread and rich (Dorokhin *et al.*, 1969).

In the study area, the concentration of manganese range between 108 ppm and 1616 ppm, with a mean value of 555321 ppm and a coefficient of variation of 58%. This takes no cognizance of some values, which are considered to be erratically too high. These values are 3094 ppm, 3452 ppm and 6574 ppm. With this, the threshold value of Mn in the area is 1197 ppm and there is only one anomalous value of 1616 ppm. This anomalous value was obtained at the northwestern part where the erratically high values also occurred. Here the underlying rock is pegmatitised schist. Apart from these, there are some other fairly high values scattered all over the area in parts, which are underlain by the different rock types. The distribution of Mn in the study area is widespread (Fig. 6H). All the samples analysed reflects it and its distribution map is fairly similar to that of some other elements such as Co, Ni, Fe, Zn, and Cu. This suggests the scavenging effect of Mn hydroxide in the area. Although its mean level of occurrence in the area is higher than the average abundance of Mn in the earth's crust, which is 950 ppm, mineralization is not suspected. The anomalous values obtained are probably due to the scavenging action.

Chromium:

Chromium is characteristically associated with ultramafic and mafic rocks where its mean concentration reaches 2000 ppm as against 4 ppm for granites (Levinson, 1974). It is very immobile in secondary environment.

Chromium was detected in all the samples analysed in this study (Fig. 6I). Its concentration range is 5 ppm to 24 ppm and the mean value is 115 ppm, while the coefficient of variation is 46%. With a threshold value of 21 ppm, there are three anomalous values for chromium in this area. Two of these values, that is, 23 ppm and 24 ppm were obtained on streams around the northwestern part, underlain by pegmatitised schists and undifferentiated gneiss and migmatite respectively. The remaining one of 23 ppm was obtained on a stream to the southwestern part, also underlain by pegmatitised schist. Generally, low values of chromium in this area are associated with pegmatite. At its mean level of occurrence, mineralization of chromium is very unlikely in this area. The only anomalous value associated with the migmatite may be due to coprecipitation with Mn hydroxide and or Fe oxide.

Mercury:

Mercury as an individual element has close association with precious metals and elements of volcanogenic deposits. This makes it a useful pathfinder for Au, Ag, Sb and massive sulphides (Rose *et al.*, 1979).

In the study area, the abundance of mercury is relatively high, but it is not very widely distributed (Fig. 6J). It was detected in 20 out of the 36 samples analysed and it gave a concentration range of 2 to 121 ppm and a mean value of 4638 ppm. The coefficient of variation is 82%. With a threshold value of 121 ppm, there seems to be no anomaly for mercury in this area. However, a few fairly high values of between 75 ppm and 121 ppm occur in the northwestern, northeastern and southwestern parts of the area. Remarkably, some of these parts recorded the highest values of Au, Fe, Zn, Ni and Mn, suggesting a kind of close association between these elements, which may be connected with the suspected gold mineralization in the area.

Compared with the average abundance of Hg in all the rock types in the area, the concentration of this element seems to be high considering its mean level of occurrence. However, this is not thought to be due to Hg mineralization or contamination but rather the suspected gold mineralization and occurrence of sulphides in the area.

Lead:

Lead is more often found as Pb^{2+} and it has a relatively low mobility. This low rate of mobility according to Rose *et al.*, (1979) affords its use in geochemical prospecting where its concentration in stream sediments may be an indication of lead-rich deposits.

All the samples analysed in this study contained lead, the concentrations of which range between 12 and 99 ppm (Fig. 6k). The mean value is 4822 ppm and the coefficient of variation is 82%. With it threshold value as 92 ppm, there is apparently only one anomalous value of lead in this area and it is situated on river Opa at the north central part, which is underlain by pegmatitised schist. Apart from the anomalous value, there are other fairly high values of between 71 and 85 ppm. These are however, randomly distributed within the study area but restricted to the parts underlain by pegmatitised schists and granite gneiss.

At its mean level of occurrence, the concentration of lead in the study area is relatively high. This is particularly true when it is compared with its average abundance in granitie rocks, which is 20 ppm. However, this high concentration is difficult to attribute to mineralization, as the origin of lead in the area is not very clear. The high value may be due to the feldspar within pegmatites or the micas in the gneisses. Wedepohl (1970) reports the primary occurrence of lead in K-feldspar structure in which the element diadochically replaces the potassium. Cech *et al.*, (1971) has also observed the accumulation of lead in pegmatites in which it occurs in amazonite feldspars. To this end, further studies may have to be undertaken to ascertain the source of the lead and find out whether it is related to mineralization or not.

Copper:

Copper shows similar dispersion characteristics to those of cobalt and nickel in the secondary environment. It has intermediate mobility, which is affected by adsorption to Fe- and Mn- oxide and organic matter. It also precipitates by hydrolysis at pH greater than 5.0 (Rose *et al.*, 1979).

All the samples analysed in the study contained copper (Fig. 6L) with a concentration range of 3 ppm to 25 ppm and a mean value of 96 ppm. The coefficient of variation is 67%. With its threshold value being 21 ppm, the anomalous values of copper in this area are only two. Both of them are 25 ppm and one occurs at the northwestern part while the other is found at the southwestern part. Also, there are other fairly high values but all these together with the anomalous and even the low values exhibit a distribution pattern similar to those for cobalt and nickel.

With its mean value of 9 ppm, the abundance of copper in the study area is low when compared with the average abundance of copper in ultramafic and granitic rocks, which are 55 ppm and 10 ppm respectively. The anomalous values are therefore probably due to co-precipitation and or adsorption of Cu to Fe- and Mn oxides and organic matter. They may also be attributed to the presence of sulphides, which are associated with the suspected primary gold mineralization earlier mentioned. The positive correlation between copper and other elements such gold, cobalt lead etc supports this.

3. Discussion

The frequency plots show that the distribution of most of the elements analyzed from the study area is largely lognormal. However, the distribution plot of Cr and Pb are somewhat normal.

Zn, Sn and Hg have a strong positive skewness, while Au, Ta, Co, Fe, Ni, Mn and Cu are less skewed. All these elements show a mixture of two populations with the most distinct being the populations for Pb.

The cumulative probability plots (Fig. 5) show two distinct populations for all the elements, except for those of Fe and Cu with one population each. The first populations of the affected elements are predominantly background, while the second populations are mainly anomalous populations. These, most probably reflect the heterogenous nature of the underlying geology and co-precipitation and adsorption activities of Fe, Mn and clays on other elements in the study area. A few of the anomalous population may also be due to mineralization, as it is suspected in the case of gold, tantalum and tin.

Moreover, the fairly strong to strong positive correlations between most of the elements notably between iron and nickel, manganese and cobalt, lead and zinc, nickel and copper, nickel and cobalt etc., may indicate scavenging effects. This is possible in an area underlain by both mafic and ultramafic rocks. The scavengers are most probably Fe- and Mn-oxides and hydroxides. Also, the fairly strong positive correlations between gold and cobalt, gold and nickel, gold and zinc, gold and manganese, gold and lead, and gold and copper probably suggests the presence of gold-bearing quartz vein with sulphides within the underlying rocks of the area. However, the erosion of this vein, and the schists in the area might have resulted in the formation of alluvial gold deposit.

The results of the factor analysis (Table 4) shows that the distribution patterns of the elements studied depend largely on the lithology of the area. There are also evidences to support co-precipitation of certain elements like Ni, Pb, and Cu with Mn and or Fe in the vicinity of mafic suites, and gold, tantalum and tin mineralization.

From the geochemical maps (Fig. 6A-L) it was obvious that the distribution of the trace elements in the study area is largely lithologically controlled. However, abundant occurrences of most of these elements are restricted to areas underlain by rocks, which are their expected sources. Examples are the high concentration of gold, nickel, chromium, zinc and manganese recorded in areas underlain by the schists, which may include amphibolite and talc schists.

However, there are a few exceptions, such as where high concentrations of tantalum and tin are recorded in areas underlain by schists instead of pegmatite, which is their expected source rock. This situation confirms the heterogeneous nature of the underlying rocks in the study area, where a stream may drain two or more rock types.

4. Conclusion

Some rocks of the Precambrian Basement Complex of Nigeria underlie the study area. The results obtained from the geochemical studies indicate the heterogeneous nature of the underlying rocks. The geochemical maps provide a quick pictorial view of elements distribution in the area. It also facilitates comparison between the distribution pattern and the geology, as well as possible geochemical associations. Certain elements such as Au, Co, Fe, Ni, Mn, Hg, Pb and Cu, show similarity in their geochemical distribution maps. These suggest close associations between these elements. It is not unlikely that some of these elements e.g. Ni and Cu have primary association with the suspected Au deposit. The belief is buttressed with the strong positive correlation between most of these elements and the kinds of factor models obtained from factor analysis.

There are strong evidences to support the scavenging effects of iron and manganese oxides and hydroxides on the abundance of certain elements in the different parts of the study area. Mineralizations of gold, tantalum and tin in the forms of placer deposits are also suspected.

It may be concluded that stream sediments are useful tool in the geochemical mapping of the study area. It serves as a pointer to possible occurrence of mineralization. Also, the multiple approach to interpretation of the analytical data was found to be excellent.

ACKNOWLEDGEMENT

The authors are greatly indebted to Prof. T.R. Ajayi of the Department of Geology, Obafemi Awolowo University, Ile-Ife , for his immense contribution to the success of this work ,especially in the area of statistical analyses. We also thank the Management and staff of the Atomic Absorption Spectrophotometer laboratory of Centre for Energy Research and Development, O.A.U., Ile-Ife, where the chemical analysis was carried out.

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