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# Geochemical dispersion of gold in stream sediments in the Paleoproterozoic Nyong Series, southern Cameroon

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**Abstract:** Twenty-five stream sediment samples were collected in the Ngovayang area of southern Cameroon over a 1100 km<sup>2</sup> area for heavy mineral fraction geochemical survey. The heavy mineral fraction of the stream sediments was analyzed for 45 trace elements. The majority of samples showed high Au concentrations though the anomalies were erratic. The geochemical data were processed using statistical and spatial analytical methods. R-mode Factor analysis produced a four-factor model which accounted for 77.02 % of the total variance in the data with the following metal associations: U-Th-Pb-W, Nb-Ta-Co-V, Au-Hf and Cu. The Au-Hf association indicated gold mineralization while the others reflect lithologic control. Uranium, Pb, Co, Ni and Ag show an almost uniform distribution within the Nyong Series indicating essentially the lithology. Anomalous gold concentrations clustered mostly in the northeastern part of the study area defining a potential primary gold target.

**Keywords:** Stream Sediments, Gold Exploration, Nyong Series, Cameroon

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## 1. Introduction

Stream sediment geochemistry and heavy mineral surveys are routinely used in the early stages of gold (Au) exploration. However it is well known that results from such surveys are often extremely erratic and difficult to reproduce or confirm. Such problems are typical of geochemical patterns for elements that are principally transported in stream sediments as the constituents of rare grains of heavy minerals [1,2]. The mobility and redistribution of elements in the secondary environment has been widely used as a tool for exploration especially in areas where weathering is intense and outcrops are rare [3-8,2]. Also element distribution in stream sediments is best investigated by geochemical characteristics of the heavy mineral concentrates [9-12]. Widespread acceptance of sediments as a sample medium in exploration surveys is based on the promise that sediment composition is representative of the geochemistry of the catchment basin upstream of the sample site. In the guidelines for such surveys it is usually specified that active sediments (i.e., sediments in the process of being transported by the stream) should be sampled [1]. If an anomaly is followed upstream, the point of maximum metal values is

known as the cut-off. This is usually considered to be close to the source of the anomaly and thus the starting point for follow-up. It is apparent therefore that the sedimentological behavior of gold is relevant to the design and interpretation of stream sediment and heavy mineral surveys for gold. Selective accumulation of particles of free gold on the bed of a stream occurs if their motions (deposition) or starts (erosion) are under different conditions to that of the rest of the sediment.

Weathering is very prominent in the tropics. Southern Cameroon lies within the tropical zone; consequently, the weathering blanket is very thick and is a hindrance to exploration efforts using rock samples alone. This has significantly reduced the heavy mineral suite in sediments. As such, resistant minerals such as Au, tin (Sn) and uranium (U) can be sought for by using concentrates. Heavy mineral concentrates enhance the contrast between ore-related, anomalous values and background values. They are yielded from the panning of, most often recent sediments of different provenance that form the secondary aureoles of deposits [13]. Also a significant aspect of research is to find out if areas of high gold grades determined by panning and weighing methods correlated positively with areas of high gold

concentration determined by bulk geochemistry. Element association can also be unraveled when the spatial display of stream sediment geochemical data is combined with the statistical treatment of the data that are relevant to primary exploration in the region [14]. It therefore becomes more effective to analyze for the spatial distribution of a suite of elements than simply looking at gold alone when exploring for gold using stream sediments [6, 15].

Early alluvial gold exploitation in Cameroon started in the 1940s and continues to date although records of the output of such activities are lacking. Most of the alluvial gold workings in Cameroon are located in the Lom Basin (Betare-Oya District) and extending south of it to Batouri District. By 1951, a total of 2256 kg of gold in this area had been produced mainly from alluvial workings [15]. Production records after 1951 are not available because small scale-miners kept no records of output. Previous works on gold mineralization in Cameroon have focused on the alteration and gold grade variation in wall rocks in the Lom series [16], the morphology and geochemistry of gold grains [17], the

style of mineralization [15] and the geophysical delineation of favourable gold structures [18]. Stream sediments have received little attention with recent studies focused on the gold grade variation survey targeting the Vaimba-Lidi drainage system in the north of Cameroon [14]; and stream sediment reconnaissance survey for gold in the Upper Lom Basin in East Cameroon [19].

Gold is commonly found in association with iron (Fe) ore deposits. Most often, Banded Iron Formations (BIFs) host Au deposits [20,21]. Gold in BIFs may be found associated with sulfides as small inclusions, healing micro-fractures (occasionally) or occurs as free grains or as invisible gold [20,22,23,21]. This paper examines the geochemistry of heavy mineral fraction from active stream sediments draining a BIF-bearing region of southern Cameroon. The aim of this work was to determine the multi-element geochemistry of the heavy mineral concentrates, identify the potential pathfinder elements for gold and produce element distribution maps of the area as a contribution to gold exploration.

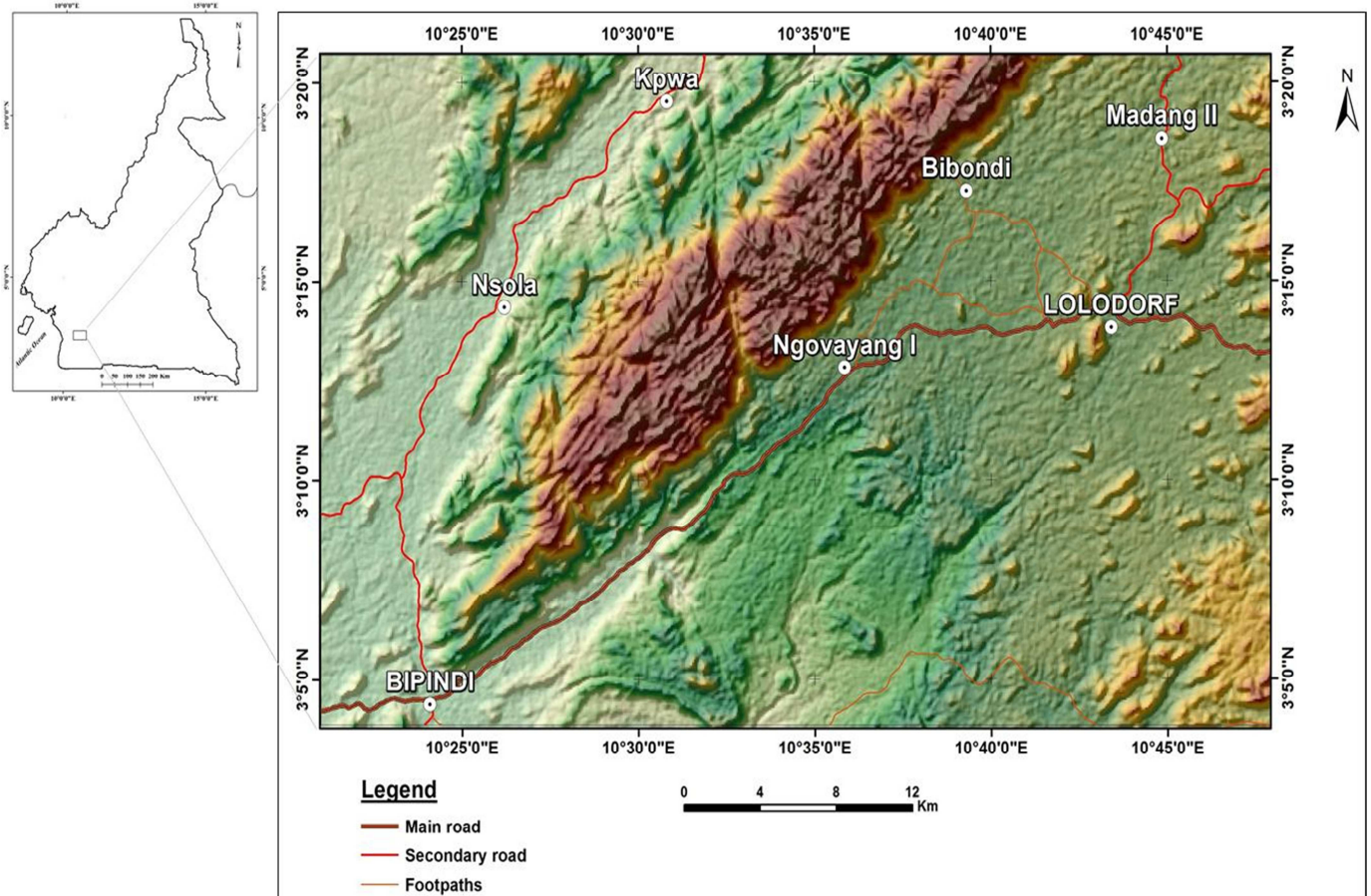


Figure 1. Location map of the Ngovayang area, southern Cameroon.

## 2. Location of the Study Area and Regional Geological Setting

The study area is found in the southwestern part of Cameroon

located between northern 340 kmN and 370 kmN and eastern 650 kmE and 700 kmE (Fig. 1). It trends from Eseka via Minlongo to Lolodorf and stretches down to Bipindi passing through Bikala, Ngovayang and Lambi. The vegetation of the area is the Tropical Rain or Wet Evergreen Forest type [24]. The forest is immense, luxuriant with a continuous canopy of leaves

that shade the underneath from sunlight. Such vegetation is supported by daily high temperatures, rainfall and humidity all year as well as less seasonal and diurnal fluctuation. The study area experiences four seasons: the long rainy season (September to December), short rainy season (March to April); long dry season (December to March) and short dry season (July to August). Sporadic rainfall is experienced during the period July to August [24]. The dendritic drainage system is controlled by two major rivers; the Nyong in the north and the Lokoundje in the south. These two rivers are supplied by small streams that flow within the valleys which in turn are fed by a network of runoffs.

The Nyong Series is characterized by various rock types. The most dominant include biotite-hornblende gneisses which appear as grey gneisses of TTG composition, orthopyroxene-garnet gneisses (charnockites), garnet-amphibole pyroxenites and Banded Iron Formation [25]. Plutonic rocks include augen-metadiorites, granodiorites and syenites. These syenites are represented by a SW-NE-trending group of small intrusions extending from Lolodorf to Olama [26]. Reference [27] noted the occurrence of Pan-African syenite around the Island of Rocher du Loup, 200 m from the beach south of Kribi. This was later confirmed by [28] describing it as part of a N-S discontinuous sheet, a few

hundred metres wide intrusive into the Nyong Series. According to [29], these metasyenites were crustally derived.

Previous dating of rocks of the Series defined it as Archaean. Reference [30] obtained a composite Rb-Sr whole rock isochron of  $2980 \pm 45$  Ma with an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  of 0.7010, defining this series as Archaean in age. U-Pb and Sm-Nd isotope data on zircon and garnet whole rock [31,32], yielded ages of ca. 3.0 Ga confirming the Archaean age. Nonetheless, younger  $T_{\text{DM}}$  of 2.5 Ga was reported around Edea suggesting the contribution of juvenile materials into the unit [31]. Similar ages (ca. 2.3 Ga) were obtained by [29] on zircons from metasyenites NE of Lolodorf. Recorded from SHRIMP U-Pb analysis [26] of zircon, ages of generally < ca. 2400 Ma confirming the Nyong Series as a Paleoproterozoic unit.

Structurally, the Nyong Series is characterized by the occurrence of N-S sinistral shear zones associated with the Pan-African orogeny [32]. The formation of these structures was accompanied by high grade metamorphism [26], and this event dated at 2050 Ma [31]. References [33,34,26] have discussed those fault systems in detail. Based on preserved ages of some metamorphic minerals like titanite and garnet, [35] concluded that these structures and the closely associated migmatization are Paleoproterozoic (ca. 2.05 Ga).

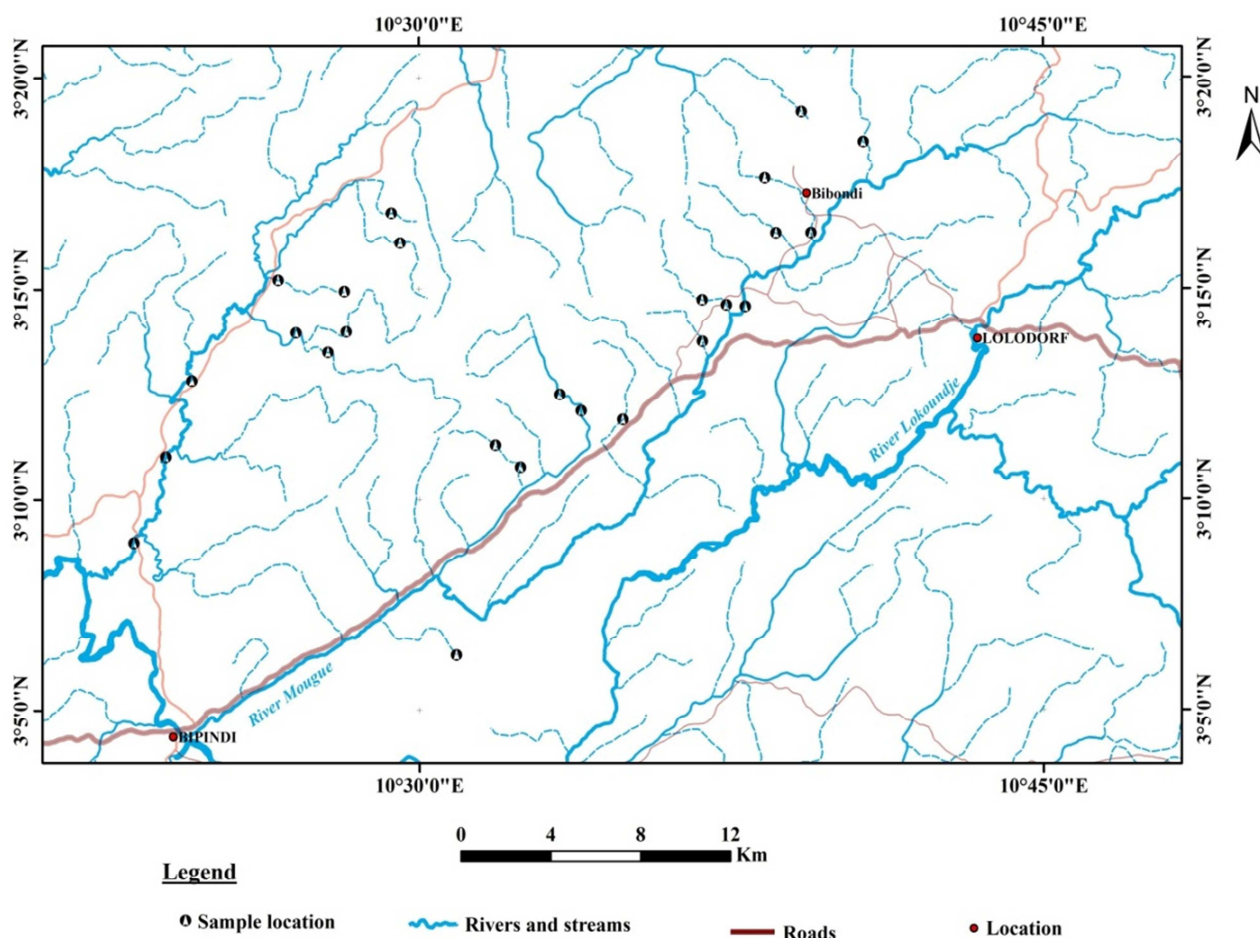


Figure 2. Stream sediment sampling sites within the Ngovayang area, southern Cameroon.

### 3. Methods

The stream sediment samples were collected randomly from the bottom of active stream channels using a spade onto a stainless steel, flat-bottom conical pan. A total of 25 samples were collected (Figure 2). Clay was carefully washed from each sample before panning. The heavy mineral concentrates were extracted from the placer by circular and pendulum motions of the pan under the water level. During repeated shaking cycles, the lighter particles were washed away whereas the heavier ones settled down the pan. This process was repeated until a residue of heavy minerals was obtained. These concentrates were then air dried before submitted for chemical analysis.

A 0.2 g of each sample pulp was analyzed for trace and rare earth elements by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) at ACME laboratories in Canada. To test for analytical precision, replicate samples chosen from the sample batch were randomly placed in each analysis. Blanks were introduced after every 4<sup>th</sup> as a test for quality analysis and control. The data set was transformed into a standard format in an Excel database and subjected to statistical treatment using SPSS®.

Geochemical data were represented spatially as element distribution maps, which plot the occurrence of geochemical elements superimposed on the drainage, for surface geochemical investigations. The maps were prepared using ArcGIS 10.0 software and the geochemical information

presented as bubble plots.

## 4. Results and Discussions

### 4.1. Geochemical Analysis

Gold concentrations in the heavy mineral fractions, range from <0.5 ppb to >100000 ppb with an average of  $15940 \pm 30202$ . The highest Au values were recorded at locations EN22, EN19, EN25 and EN20 (Fig. 3a) where artisanal Au workings are located. The geochemical data obtained were treated raw without logtransformation. The descriptive statistics of Au and associated elements are presented in Table 1. All the elements but Co, V, Zr and Se demonstrated positively skewed distribution.

To investigate the element relationship, Pearson's correlation matrix (Table 2) was computed for the elements. The correlation values (r) display a wide range from -0.04 between Au and Ta, Au and Th to 0.9 between U and Th. This suggests that different geochemical factors influenced their concentrations. Au shows a relatively high correlation value of 0.49 only with Hf. Other element pairs which had high positive r values include U-Th, Th-Pb and U-Pb. Furthermore, the multi-element geochemical data show a weak negative relationship between Au and elements such as Co and V that are commonly associated with heavy minerals in drainage sediments.

**Table 1.** Basic Statistics of trace elements of the heavy mineral fraction (N=25) of stream sediments within the Nyong Series, southern Cameroon.

Element	Range	Mean	Standard Deviation	Skewness
Ba	5-34	11.33	6	2.6
Be	*bd-2	0.72	0.47	2.24
Co	24.5-73.5	50.47	11.28	-0.27
Cs	bd-0.4	0.06	0.06	5.32
Ga	2-14.6	5.39	3.05	1.93
Hf	327.8-3118.8	1636	841.12	0.17
Nb	76.7-1085	414.72	155.16	2.53
Rb	0.1-2.5	0.48	0.44	3.68
Sn	3-85	20.33	13.85	3.67
Sr	1.3-13.8	3.88	2.83	1.87
Ta	6.2-163.7	37.64	30.61	2.85
Th	131-ad**	2283	2454.4	1.6
U	21.6-342.2	130.24	77.42	0.9
V	299-1148	793.1	173.41	-0.44
W	1.7-209.5	19.49	47.47	3.62
Zr	12285.3-ad	42700	12140	-1.36
Mo	02-1.8	0.68	0.37	0.82
Cu	3.2-183.7	12.1	32.54	5.41
Pb	10.2-873.8	207.69	213.1	1.73
Zn	12-59	27.63	10.96	1.23
Ni	1.5-80.3	9.72	19.43	3.42
As	bd-9.2	2.42	2.19	1.42
Cd	bd-0.2	0.06	0.03	4.78
Sb	bd-8	0.38	1.47	5.12
Bi	bd-0.3	0.08	0.05	3.6
Ag	bd-0.5	0.08	0.1	3.59
Au	ad-bd	15940	30202	1.99
Hg	bd-0.07	0.02	0.03	2.72
Tl	bd-0.1	0.05	0.01	3.66
Se	bd-0.7	0.25	0.03	-2.19

\*Below detection limit \*\* Above detection limit



**Table 2.** Matrix of Pearson's Correlation for trace elements in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.

	Co	Ga	Hf	Nb	Ta	Th	U	V	W	Cu	Pb	Au
Co	1	-0.44	-0.45	0.48	0.38	-0.31	-0.33	0.62	-0.3	-0.2	-0.25	-0.07
Ga		1	-0.41	-0.31	-0.05	0.04	-0.17	-0.13	0.15	-0.11	0.07	-0.35
Hf			1	-0.15	-0.21	0.21	0.52	-0.46	0.22	0.34	0.11	0.49
Nb				1	0.67	0.25	0.3	0.32	-0.08	-0.11	0.11	-0.21
Ta					1	0.27	0.29	0.21	0.16	-0.11	0.41	-0.04
Th						1	0.9	-0.09	0.51	-0.1	0.82	-0.04
U							1	-0.24	0.54	0.02	0.70	0.08
V								1	-0.24	-0.24	0.08	-0.25
W									1	-0.06	0.42	-0.14
Cu										1	-0.11	0.03
Pb											1	0.00
Au												1

**Table 3.** Varimax Rotated Factor Matrix (Four-Factor Model) for trace elements in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	**Communality
Co	-0.547	0.665	0.333	-0.046	0.855
Ga	0.005	-0.164	-0.88	0.057	0.805
Hf	0.546	-0.484	0.575	0.033	0.864
Nb	0.065	0.787	0.293	0.299	0.8
Ta	0.22	0.75	0.099	0.164	0.648
Th	0.875	0.307	-0.12	-0.074	0.879
U	0.936	0.193	0.151	0.028	0.937
V	-0.388	0.655	-0.019	-0.154	0.604
W	0.664	0.025	-0.282	0.036	0.522
Cu	0.069	-0.373	0.28	0.766	0.809
Pb	0.765	0.354	-0.164	-0.172	0.768
Au	0.133	-0.328	0.619	-0.494	0.752
*Eigen values	3.343	2.387	0.885	0.443	
Variance (%)	28.36	21.72	15.53	11.41	
Cumulative (%)	28.36	50.08	65.61	77.02	

\* The sum of scores for each factor.

\*\* The communality for each element expresses the proportion of the total variability of that element that is contained in the factors (that is, sum of squares of four factors).

R-mode factor analysis produced a four-factor model accounting for 77.02 % of the total data variance (Table 3). The factors generated from Table 3 are as follows:

Factor 1 is dominated by the high field strength elements (HFSE), U-Th-Pb-W-Hf, and accounts for 28.36 % of the total data variance. The presence of these elements in heavy mineral fraction of stream sediments indicates that the host minerals are exclusively heavy phases. These include garnet, apatite, monazite, ilmenite and zircon present in the metamorphic rocks [11,36]. This compares favorably with observation from this study as the HFSE have been seen to occur in the heavy mineral fractions. Furthermore, [37] proposed that the noticeable enrichment of any stream sediment in HFSE especially U, Th, Zr, and Hf is a strong indication of granitic source. This therefore implies that the protolith from which the sediments are derived have a granitic origin.

Factor 2 comprises Nb-Ta-Co-V and explains 21.72 % of the total data variance. Reference [38] showed that Fe can be substituted for by Co, Mn and Ni in magnetite reflecting the receptivity of the octahedral and tetrahedral sites in the spinel lattices. The presence of V in this factor is explained by its normal occurrence in small amounts in magnetite [39]. Furthermore, Fe being the most important host element for V

is a major component of magnetite, an oxide occurring in the Fe rich quartzites and gneisses of the study area. The high field strength element (HFSE) association in Factor 2 is related to Ta and Nb minerals (probably tantalite and columbite) in the host rocks. These are common trace minerals in granitic plutons. Reference [40] suggested that the most important material source of Ta and Nb are granites, rare-element granitic pegmatites and to a lesser extent alluvial placer deposits. Also, columbite-tantalite minerals often occur in association with Th, U, and REE [41], which are present in the heavy mineral concentrates. These minerals are thus probably produced by the weathering of the basement rock of the Ngovayang area. The variability of the elements in this factor appears to be controlled by the mixed rock types occurring in the area.

In the Ngovayang area, Au demonstrated very weak correlation with almost all the other elements (Table 2). Strange observation is seen for Factor 3 which is made up of Au-Hf association and accounts for 15.53 % of the total variance. This is a mineralization factor. The fact that Au is not found associated with the chalcophilic elements Zn-Cu-Pb, supports the idea of placer gold; whose source though unknown is not generally related to sulphides of these base metals [42]. This is supported by the observation of tiny

specks of Au suggesting Au is free. Also, Hf is associated with elements in Factor 1 which are common in resistant minerals and can thus concentrate in placers.

Factor 4: Cu. This explains 11.41 % of the total information. This single element factor can be attributed to the enrichment of some of the Fe-bearing quartzites and gneisses in sulphides. It can also be regarded as a single element mineralization factor. Reference [43] noted that Cu is mobile particularly at high temperatures. The possibility that Cu fractionated into a fluid phase during magmatism and subsequent hydrothermal activity can account for the segregation of Cu from the other base elements. Consequently Cu-bearing minerals will be devoid of other essential trace elements.

#### 4.2. Spatial Analysis

The concentrations of the elements Au, Ag, Pb, U, Co and Ni were presented as point symbol maps for the target area (Fig.3 a-f).

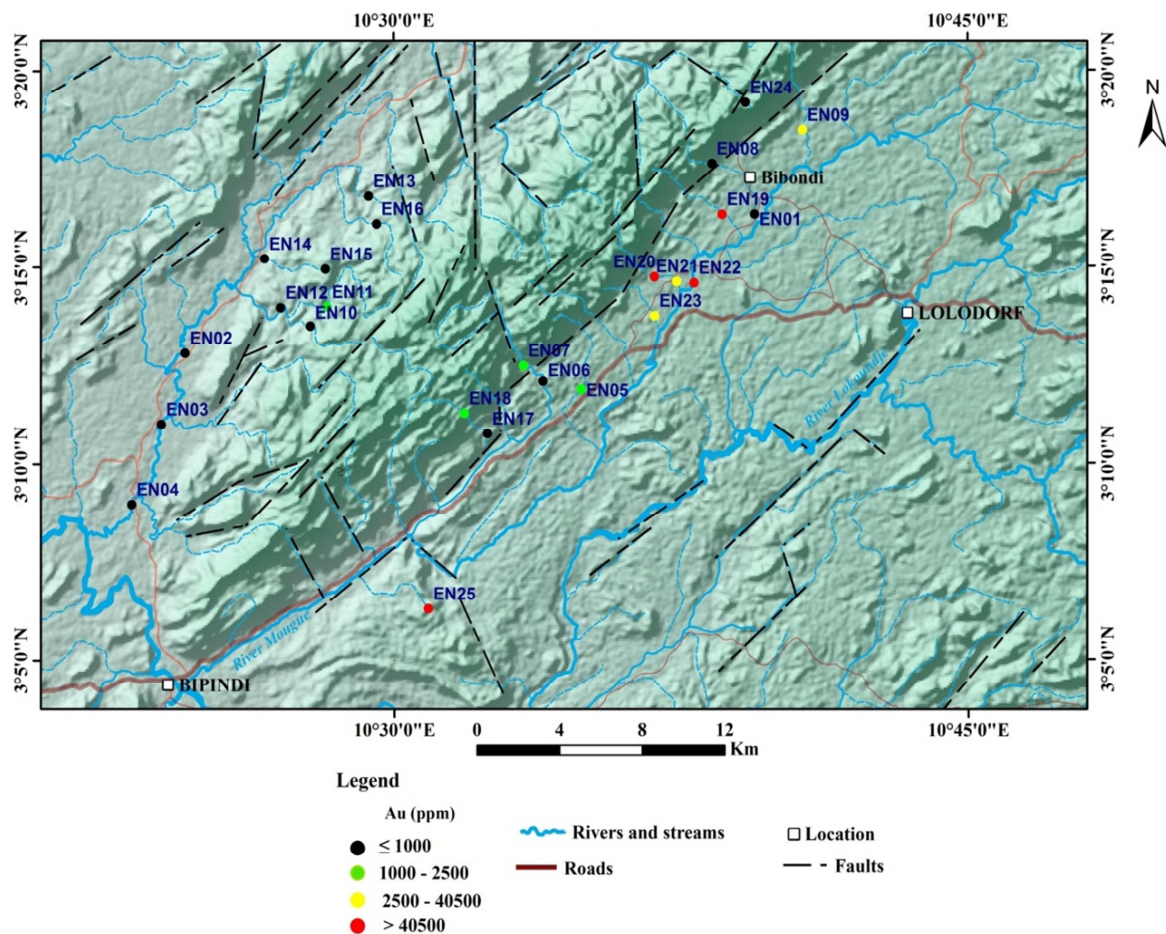
Gold occurrences in South Cameroon have not been known but for the current artisanal workings. In this study, promising Au exploration targets have been found and restricted mainly to the northeastern part (Fig.3a) of the study area. Furthermore, given that the Ngovayang massif is characterized by faults and fractures which are associated with folds suggests that the Au mineralization was probably

introduced within the shear zone. This is supported by anomalous concentrations (EN25, EN09, EN19, EN20, EN21 and EN22) within the structure, east of the massif.

Silver (Ag), a potential pathfinder element for Au, mimics the high Au values for samples EN22 and EN20 (Fig.3b). However, its values are very low (<0.1 to 0.5 ppm) (Table 1). A possible reason for this could be due to co-precipitation along with Fe and Mn oxides [44]. Further, intense weathering might also transport materials into the stream channels diluting Ag concentration.

Elevated levels of Pb and U are restricted to the southwestern part of the study area (Fig.3c-d). The uniform distribution of U and Pb within the study area basically reflects the bedrock geology.

The transition metals Co and Ni show similar distribution style within the study area (Fig.3e-f). However, most of the abundances of Ni and Co in the concentrates are lower than values necessary to define anomalies [45]. Ni and Co distribution displays a small spread (standard deviation 19.43 and 11.28 respectively). Such constancy in sediments of different streams within the study area indicates consistent environment of dispersion, uniform rock exposure, weathering pattern and climatic condition [44]. This leads to the nearly identical concentrations of Ni and Co in the stream sediments; thereby reflecting background dispersal.



**Figure 3a.** Distribution of Au concentrations in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.



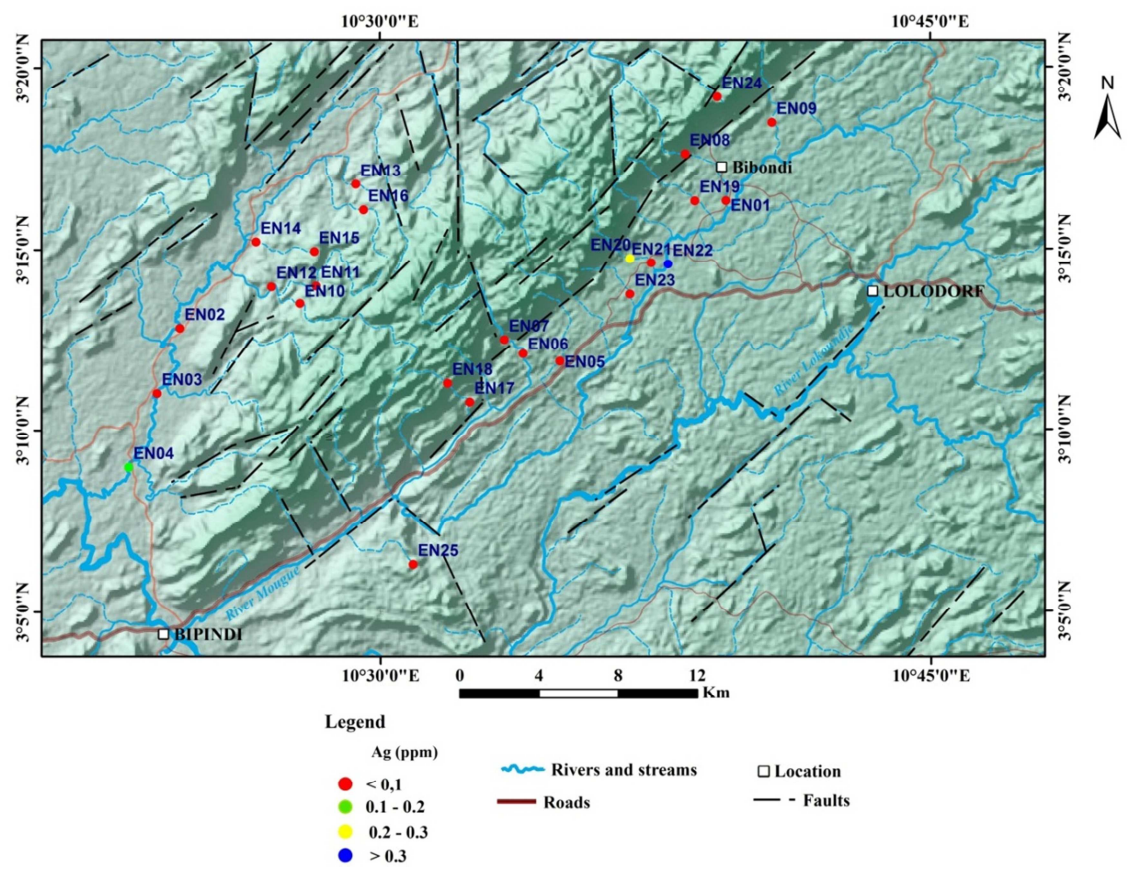


Figure 3b. Distribution of Ag concentrations in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.

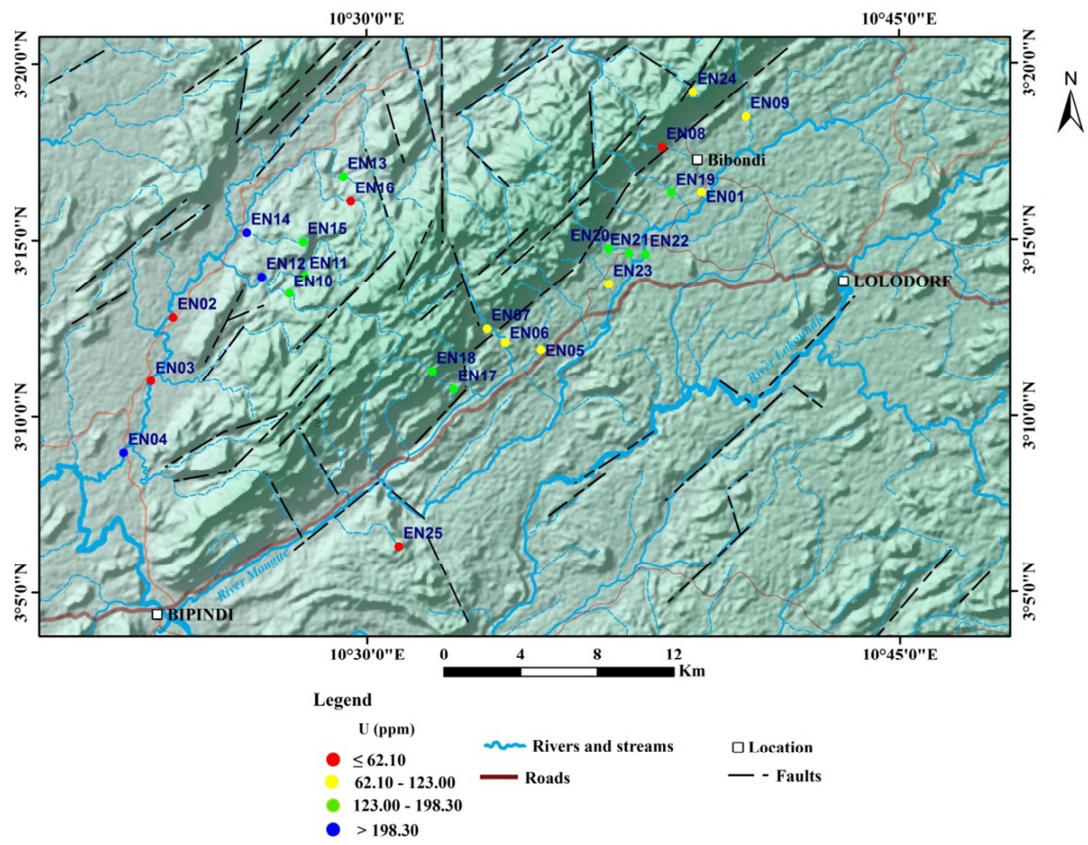


Figure 3c. Distribution of Pb concentrations in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.



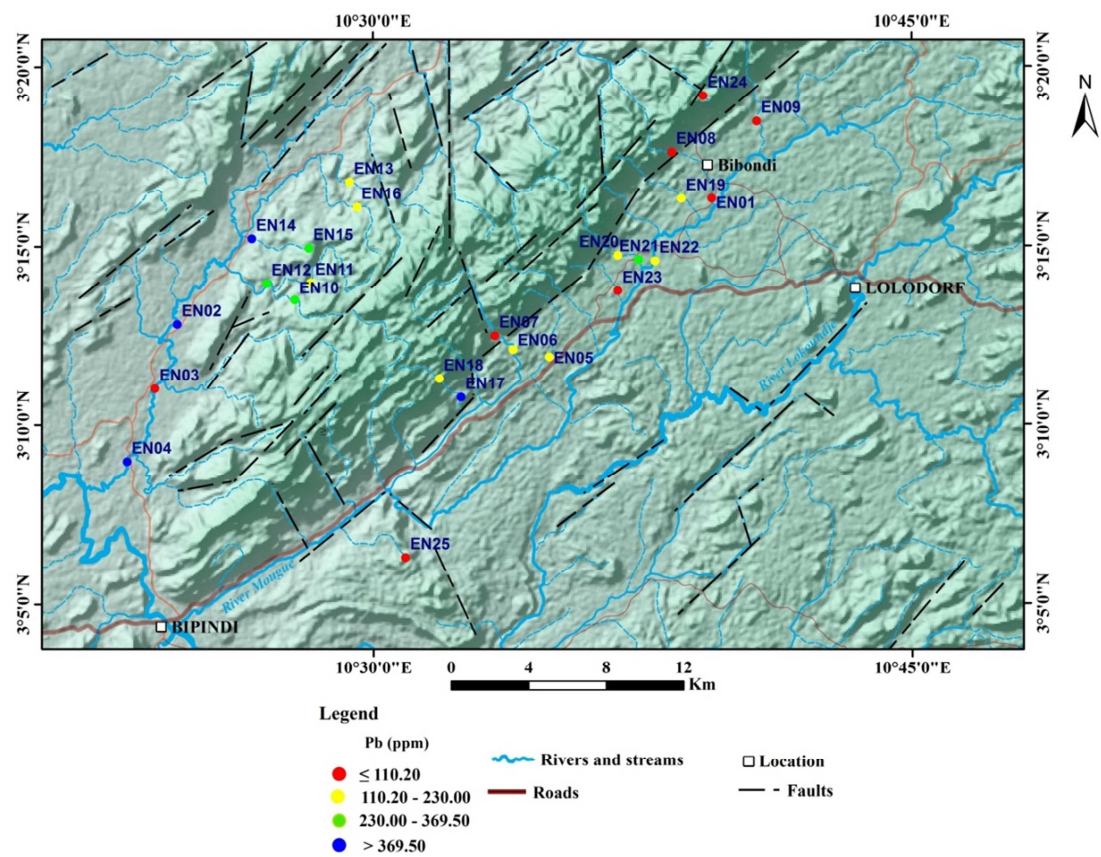


Figure 3d. Distribution of U concentrations in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.

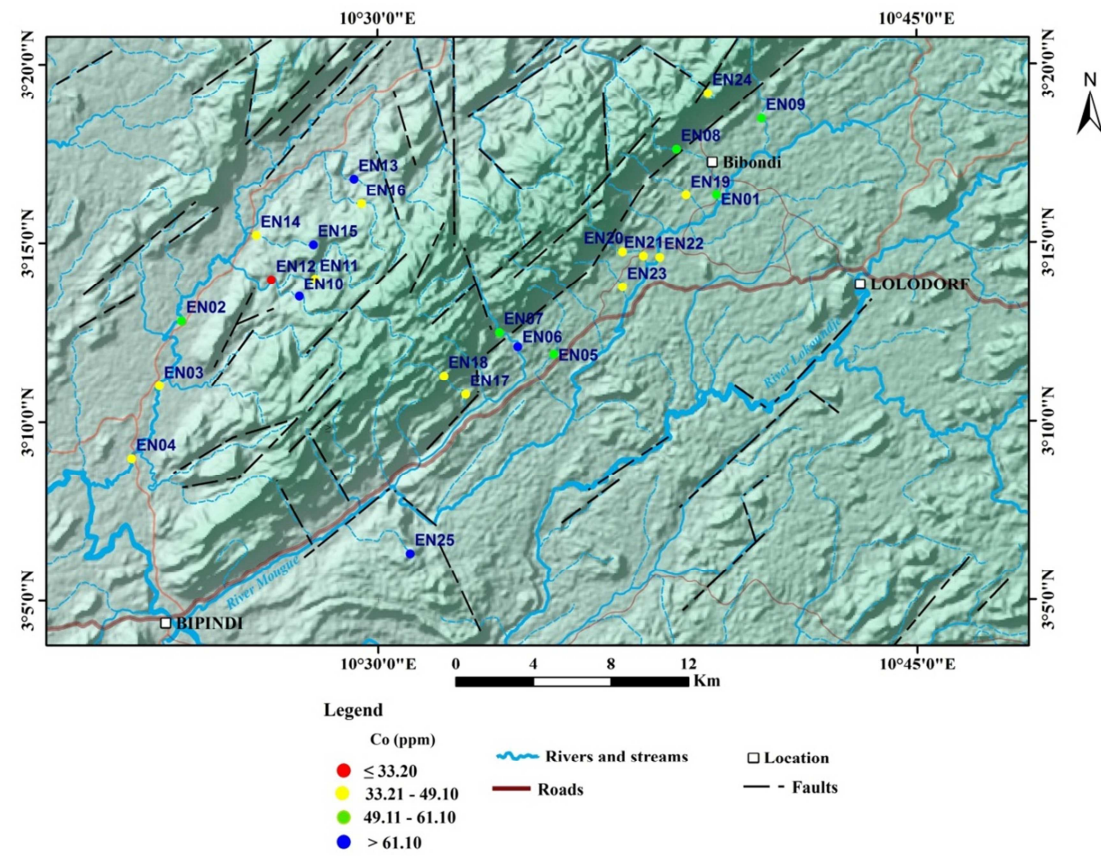
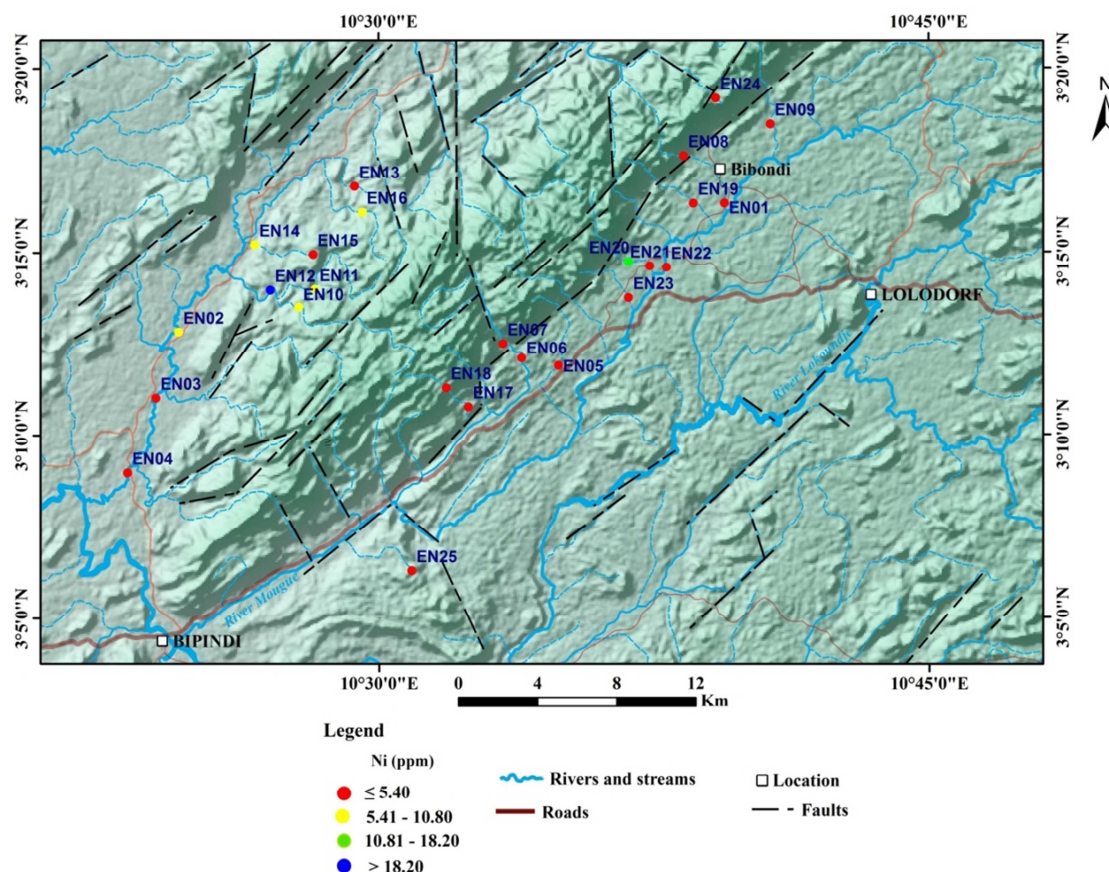


Figure 3e. Distribution of Co concentrations in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon





**Figure 3f.** Distribution of Ni concentrations in the heavy mineral fraction of stream sediments within the Nyong Series, southern Cameroon.

## 5. Conclusions

- Heavy mineral geochemistry has been shown to be a suitable exploration technique for gold within the Nyong Series.
- Gold is clearly its own best pathfinder element in this region.
- Statistical and spatial analyses have been used to relate the concentration and distribution of elements in the stream samples to lithology and mineralization.
- The Factor analysis applied to the data explained 77.02 % of the total variance through four factors. Factor 1 accommodated elements (U-Th-Pb-W) which suggest the occurrence of heavy mineral phases such as garnet, zircon and monazite in the concentrates. Factor 2 (Nb-Ta-Co-V) is probably associated with columbite and tantalite present in the stream samples. Factor 3 (Au-Hf) is a mineralization factor. The single element factor Cu possibly corresponds to the presence of Cu-bearing sulphides in the concentrates.
- The distribution of U, Pb, Co Ni and Ag show no significant pattern and essentially reflect the primary geology. Gold exhibits anomalous concentrations mostly in the northeastern part
- The geochemical data permit an appraisal of the Au-bearing potential of the area. The anomalies are high

and clustered, well defining the potential target.

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