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Regional Geochemical Stream Sediment Survey for Gold Exploration in the Upper Lom Basin, Eastern Cameroon

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Abstract

Stream sediments are widely employed in reconnaissance exploration for gold especially in areas where outcrops are scarce and the overburden thick such as in the eastern Cameroon goldfields. In this study, 337 stream sediment samples were collected from the Lom river drainage basin. The study aims at identifying the main geological processes affecting the geochemical data from the sediments by considering the multi-elements relationships and spatial features of single elements. The samples were collected in duplicate. One set was panned, gold grains picked and weighed while the second set was wet sieved and the ≤100 microns size fraction retained. This fraction was eventually analyzed for gold by fire assay and a suite of elements by inductively coupled plasma mass spectrometry (ICP-MS). Single element maps were constructed using ArcGIS and the relationship between elements measured using Pearson correlation and principal component analysis (PCA). Gold concentrations in the samples are erratic, most below the detection limit and attain a high of 450 ppm. Five factors are derived from the PCA including single element factors for As and Au reflecting bedrock-hosted mineralization. The Cu-Zn-Y-Nb-Pb factor suggests sulphide mineralization perhaps related to felsic intrusions while the Sr-Ba-La-Ce-Zr factor is linked to lithologic control. These results demonstrate the usefulness of multi-element analysis and data interpretation using GIS tools in the exploration efforts for gold worldwide.

Keywords

Cameroon, Gold, Stream Sediments, PCA, ArcGIS

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1. Introduction

Stream sediments are essential in regional exploration programmes considering that the geology of the catchment can be readily perceived through multi-elements associations identified in the sediments [1]-[3]. Regional geochemical survey data do not only express the distribution of a target element, but once built into a GIS platform the spatial relationship between different elements becomes readily palpable. This is particularly useful when data from heavy mineral fraction of the stream sediment are also available. In many stream sediment surveys, gold concentrations are always below the detection limit and the anomalies are erratic. Also the gold concentration in sediments is easily affected by the nugget effect and the resulting heterogeneous distribution of gold in the samples can mask the true gold geochemical signal in an area and erroneously reduce the region's prospectivity e.g. [4] [5]. However, the use of gold concentration estimated by the panning and weighing method in combination with gold and other element concentrations determined by geochemical techniques usually enhance the applicability of stream sediment data in mineral exploration. This is particularly true when multivariate statistical techniques are also employed. These approaches are used in this present study. Here, we present the results of gold grades in 337 stream sediment samples collected from the Lom River drainage system of eastern Cameroon. We also present the data in a range of other elements with the aim of identifying potential pathfinder elements for gold in the system. PCA is employed to characterize the principal inter-element relationships and to identify the factors influencing the dispersion of elements. We show that Au is its own pathfinder element although the As single element factor also suggests sulphide mineralization.

In eastern Cameroon gold is won from quartz veins related to granitic intrusions as well as Proterozoic metasedimentary units (**Figure 1**). Although several exploration efforts including airborne regional surveys and restricted soil geochemical sampling [6]-[12] have been undertaken in this area, finding economically viable primary deposits in the bedrock has remained elusive. This is particularly true of the Lom region where although alluvial gold is worked by small scale artisanal miners and semi mechanized industrial operations, the primary source of the gold is not yet well constrained**.**

This study provides support for the development of the mineral sector in this region and allows for the comparison of the stream sediment samples of this region to other parts of the world.

2. Location and Geology of Study Area

The study area (**Figure 2**) lies within the well recognized Lom basin [13]-[19]. This is essentially a Neoproterozoic rock sequence consisting of metasedimentary and metavolcanic rocks with late granitic intrusions [16] collectively termed the Lom series. The Lom series occupies a classical pull-apart structure that lies between transtensional strike slip faults defining its length and normal faults that define its width.

The lithologic units have a strong NE-SW regional foliation deflected in places by the granitic pluton reflecting dextral and sinistral shear sense [14]-[16]. The rocks have been metamorphosed to greenschist facies and hydrothermal alteration especially around the granitic plutons is marked by the development of tourmalinization (**Figure 3**) and widespread sericitization (**Figure 4**). Gold is sporadically identified in quartz veins associated with early pyrite whereas a vug-filling late pyritization event is barren [21].

3. Method of Study

The stream sediment samples were generally collected above stream confluences not based on a grid. At each sampling site ~3 kg of active stream sediment samples were collected, panned, and the heavy mineral fraction retained and stored in a clearly labeled self sealing plastic bag. A second sample of approximately the same weight was collected and sieved on site and the 100 μm fraction retained. All the sampling sites were located using a GPS and eventually introduced into a GIS. At the base camp, the heavy mineral fraction was dried and the gold grains handpicked under a binocular microscope and weighed. Their weight was related to the weight of the bulk sample and expressed in g/t. The ≤100 microns fraction was dried, pulverised and shipped to the analytical laboratory where gold was analyzed by fire assay with a nickel finish and a range of other elements analyzed by ICP-MS [12]. The statistical treatment of the data laid emphasis on the production of the distribution maps for the various elements as well as the determination of elements association through correlation coefficient and PCA.

Only 11 of the over 20 elements analyzed for were detected. To take care of elements with asymmetrical

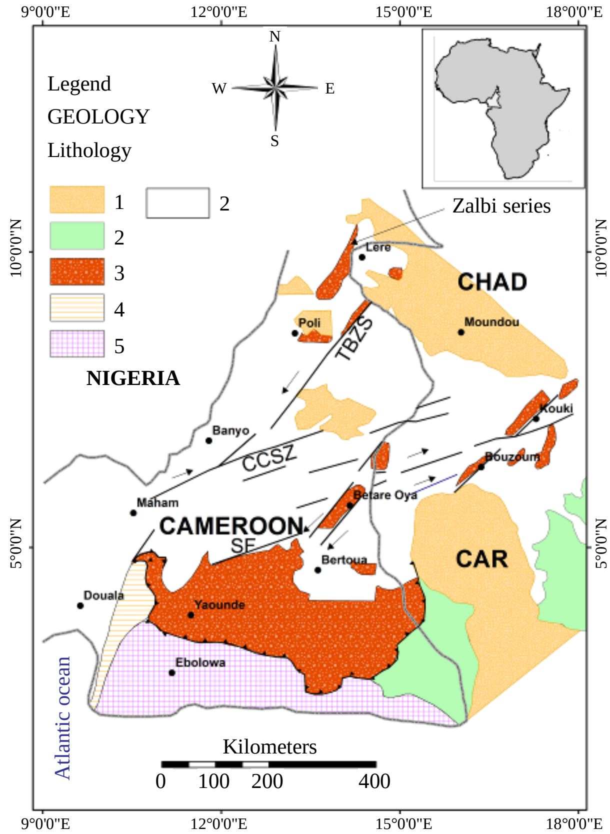


Figure 1. Regional geology and structural map of Cameroon. (1) Post-pan African cover, (2) Platform cover on the Congo Craton (Paleoproterozoic), (3) Neoproterozoic units, (4) Palaeoproterozoic Nyong Group, (5) Congo Craton, (6) undifferentiated basement complex. TBSZ: Tchollire-Banyo shear zone; SF: Sanaga Fault; CCSZ: Central Cameroonian Shear Zone; modified from [16] [20]-[22].

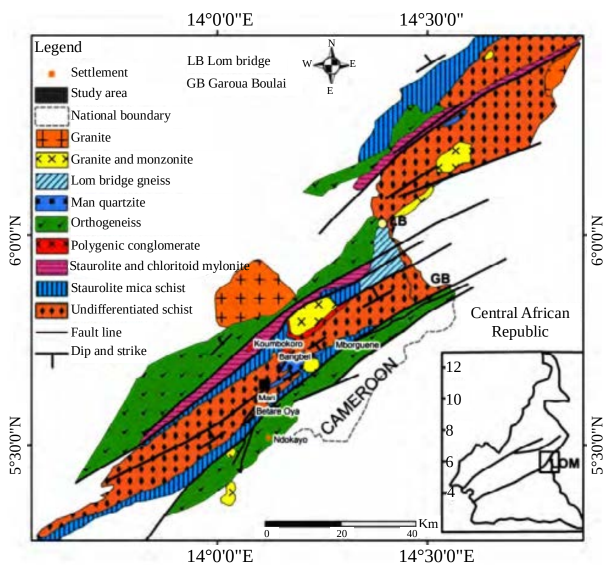


Figure 2. Geologic map of the Lom Basin (Adapted from Ngako *et al.* 2003).

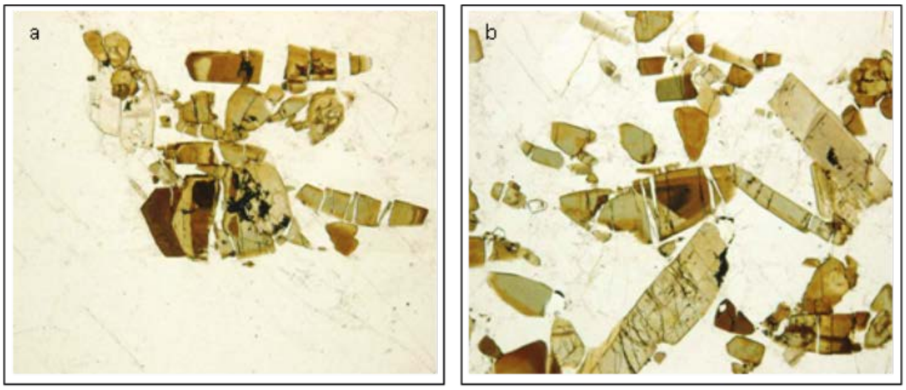
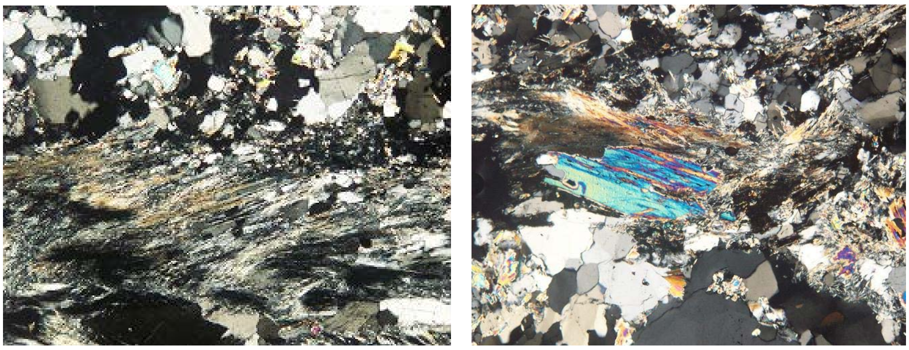


Figure 3. (a) Photomicrograph of tourmaline with complex colour zoning in tourmaline altered wallrock in the Lom series (plane polarized light); (b) Photomicrograph of fractured, brecciated and subhedral tourmaline crystals (plane polarized light).



(a) (b)

Figure 4. (a) and (b) photomicrograph showing mineralogical banding in schist, defined by sericite + chlorite fibres (cross polars).

unimodal distribution, the element concentrations were transformed to their natural logarithms prior to statistical treatment of the data.

4. Results

The gold grade derived by the panning and weighing method ranges from 0.3 g/t to 1.5 g/t and the spatial distribution is depicted in **Figure 5(a)**. Most of the samples returned gold grade that exceeds 0.6 g/t especially along river Lom, Mama and Dembez tributaries (**Figure 5(a)**). The gold concentration determined by fire assay attains a maximum of 450 ppm, although sporadic occurrences exceeding 90 ppm are encountered in the head waters of river Mama and Dembez (**Figure 5(b)**), similar to the gold grade determined by the panning and weighing technique. The summary statistics for the suite of elements analyzed alongside gold are given in Table (The full listing of the element concentrations per sample can be obtained from the corresponding author upon request) The most widely used pathfinder elements for Au in include As, Ag, Mo, Sb and W. In this study, these elements have concentrations that range from <1 to 272 ppm (**Table 1**). The chalcophilic elements (Cu, Pb, and Zn) have concentrations that span from 5 to 532 ppm. In order to evaluate the element association, the inter element relationship was calculated using the Pearson correlation coefficient and the resulting correlation matrix is given on **Table 2**. Prior to this multivariate statistical analysis Mo, Ag, Sn and Cd were dropped because their concentrations in at least 70% of the samples were below detection limit.

The Pearson correlation matrix (**Table 2**) shows high positive correlation between Sr-Ba-La-Ce-Zr. Indeed the r value for La-Ce is 0.85, slightly lower than the r value of 0.89 for Sr-Ba. Gold generally has low to negative correlation with all the elements. From the PCA four factors were generated as shown in **Table 3**,

Factor 1: Sr-Ba-La-Ce-Zr

Factor 2: Cu-Zn-Y-Nb-Pb

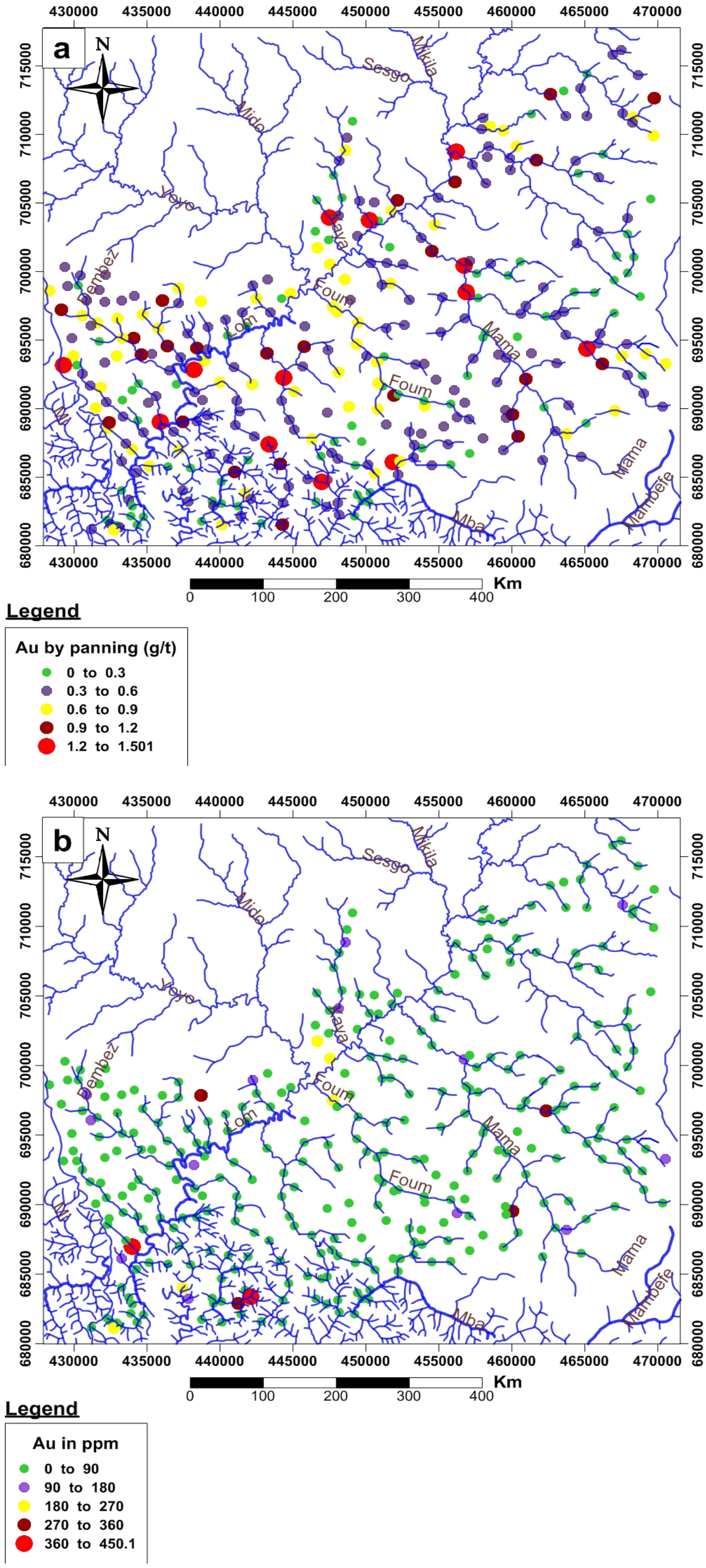


Figure 5. Graduated symbol plots for (a) Au by panning (g/t) (b) Au by fire assay (ppm) superimposed on the drainage map of the upper Lom Basin.

Table 1. Descriptive statistics of Au and associated elements determined by geochemical analysis of 337 stream sediment samples from the Lom basin, eastern Cameroon.

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Au	333	450.00	0.00	450.00	24.89	58.98	3478.25
Cu	333	147.00	5.00	152.00	39.03	15.39	236.88
Zn	333	513.00	19.00	532.00	66.64	39.14	15331.71
As	333	267.00	5.00	272.00	23.44	28.89	834.44
Sr	333	477.00	17.00	494.00	62.90	71.78	5152.17
Y	333	82.00	20.00	102.00	44.63	11.70	136.89
Nb	333	111.00	7.00	118.00	61.98	17.01	289.18
Mo	333	8.00	1.00	9.00	1.59	1.16	1.34
Ag	333	0.40	0.10	0.50	0.11	0.03	0.00
Cd	333	4.00	1.00	5.00	1.36	0.72	0.52
Sn	333	0.00	5.00	5.00	5.00	0.00	0.00
Sb	333	11.00	5.00	16.00	5.47	1.48	2.18
Ba	333	3372.00	128.00	3500.00	549.38	433.28	187729.80
La	333	111.00	10.00	121.00	26.95	18.45	340.43
Ce	333	295.00	27.00	322.00	110.82	40.92	1674.56
W	333	8.00	1.00	9.00	1.77	1.66	2.74
Pb	333	72.00	5.00	77.00	24.83	10.99	120.83
Bi	333	0.00	1.00	1.00	1.00	0.00	0.00
Zr	333	3503.00	278.00	3781.00	818.13	477.58	228077.70

Table 2. Pearson correlation matrix (r) for various elements determined from stream sediments from the Lom basin, eastern Cameroon.

	Au	**Cu**	**Zn**	**As**	**Sr**	**Y**	**Nb**	**Ba**	**La**	**Ce**	**Pb**	**Zr**
Au	1.00											
Cu	−0.01	1.00										
Zn	−0.03	0.21	1.00									
As	−0.03	0.19	0.06	1.00								
Sr	−0.06	−0.12	0.11	−0.08	1.00							
Y	0.00	0.38	0.22	−0.14	−0.14	1.00						
Nb	−0.03	**0.43**	0.09	0.12	0.09	0.19	1.00					
Ba	0.00	−0.16	0.09	−0.08	**0.89**	−0.17	0.08	1.00				
La	−0.05	0.09	0.13	−0.19	**0.56**	0.41	0.09	0.44	1.00			
Ce	−0.07	0.23	0.13	−0.15	**0.52**	0.46	0.33	0.40	**0.85**	1.00		
Pb	0.00	0.28	0.14	−0.05	0.08	0.19	0.33	0.12	0.29	0.31	1.00	
Zr	−0.04	−0.14	0.05	−0.18	**0.67**	0.04	0.27	**0.59**	**0.55**	**0.55**	0.22	1.00

Table 3. Extraction Method: Principal component analysis.

	Component			
	1	2	3	4
Au	−0.073	−0.015	−0.109	0.803
Cu	0.126	0.778	0.253	0.024
Zn	0.221	0.297	0.151	−0.389
As	−0.195	0.158	0.714	−0.154
Sr	0.794	−0.467	0.218	−0.054
Y	0.300	0.676	−0.468	−0.119
Nb	0.349	0.489	0.456	0.268
Ba	0.717	−0.497	0.262	0.028
La	0.846	0.078	−0.299	−0.097
Ce	0.862	0.228	−0.179	−0.046
Pb	0.404	0.409	0.119	0.286
Zr	0.784	−0.265	0.058	0.107

Factor 3: As

Factor 4: Au

Factor 1 is dominated by incompatible trace elements reflecting essentially a lithological control. This factor accounts for 30.8% of the total variance of the data set. Factor 2 noticeably has the chalcophilic elements Cu, Zn and Pb suggesting the presence of sulphide mineralization in the surrounding rock. This accounts for 18.1% of the total variance of the data set. Factors 3 and 4 are single element factors comprising As and Au, respectively, and they combined account for 19% of the data variability of this model. The spatial distributions of the element that define each factor are given in **Figures 5-8**, drawn to the same scale on a GIS platform for easy comparison.

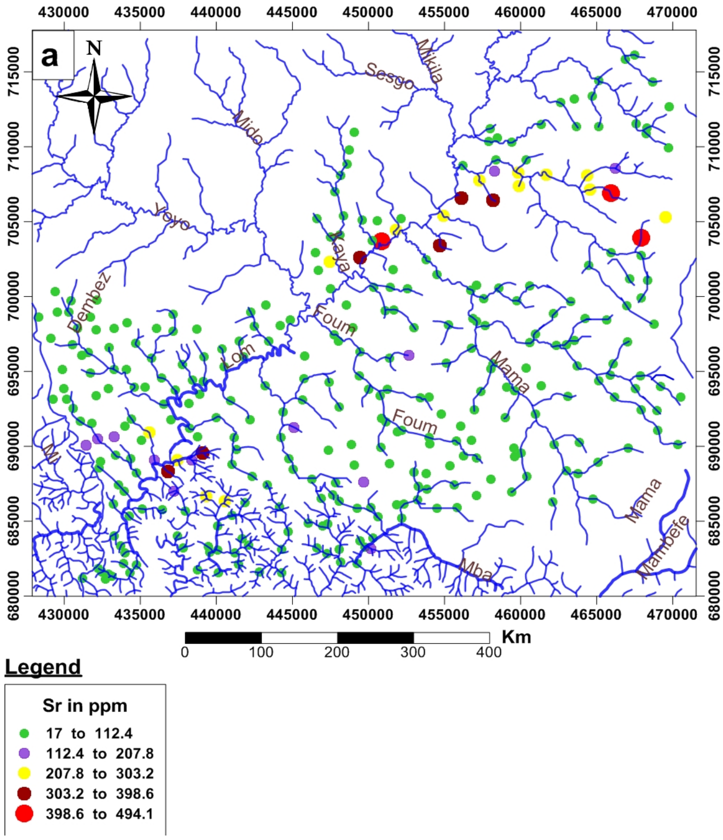
5. Discussion and Conclusions

Owing to its chemical stability and ductility/malleability, gold survives the rigours of transportation within streams. Consequently panning often recovers gold grains within the heavy mineral fraction. Of interest to regional scale exploration is to determine if areas with high gold grade derived from the panning and weighing method match high gold values determined chemically.

The results of this study suggest that this expectation is met, although some areas with high grade from the weighing method returned very poor gold grade from the geochemical analysis as depicted in **Figure 5(a)** & **Figure 5(b)**. This can be as a result of nugget effect considering that the size fraction analyzed chemically is devoid of gold grains larger than 100 µm size fraction.

This problem is usually encountered in stream sediment investigations for gold exploration [4]. This study also demonstrates the usefulness of PCA for identifying multi-element association that may be related to mineralization or reflect the underlying geology of the catchment area. Factor 1 basically corresponds to the presence of granitic rocks and other felsic metasedimentary rocks such as quartzite and schist in the basin. This factor is not deemed to be related to gold mineralization in the primary rocks. [4] [5] identified Ca-P-La-Y-Th association in their stream sediment samples that they also attributed to the presence of apatite and monazite in felsic lithologies in the region.

Factor 2 comprises chalcophilic elements [24] identified Cu-Zn ($r = 0.55$) and Cu-Pb ($r = 0.63$) in stream sediment surveys in Pakistan related to sulphide mineralization in the bedrock as in this study. Factor 2 in addition also suggests the presence of sphalerite (Zn) and galena (Pb). Indeed these sulphides have been reported from the bedrock in previous studies [11] [12] [23]. The sulphidation of the wallrock in the Lom area is even accentuated by the presence of As as a single element factor and it is most likely related to arsenopyrite dissemination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Sr in ppm
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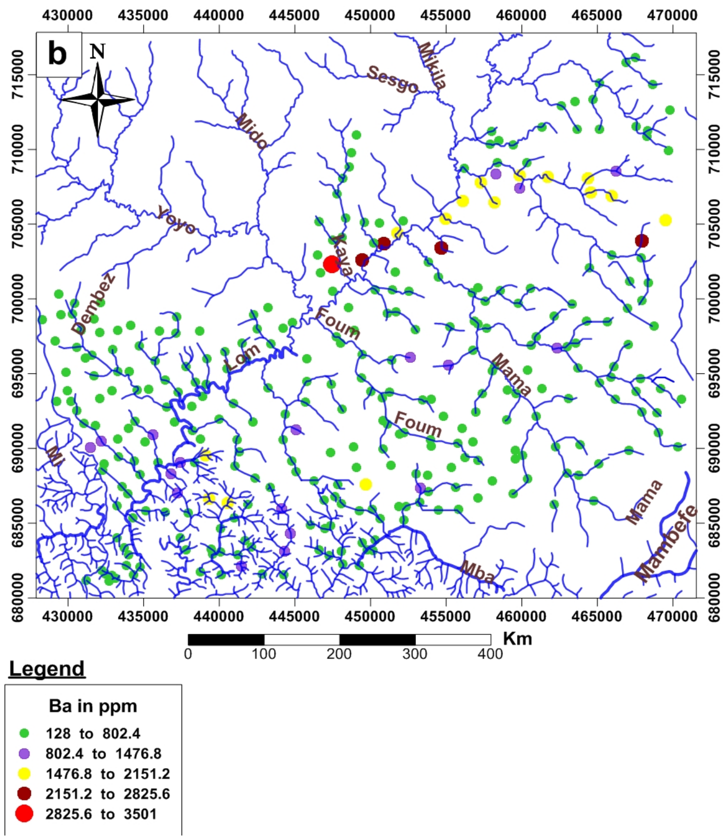
207.8 to 303.2
303.2 to 398.6
398.6 to 494.1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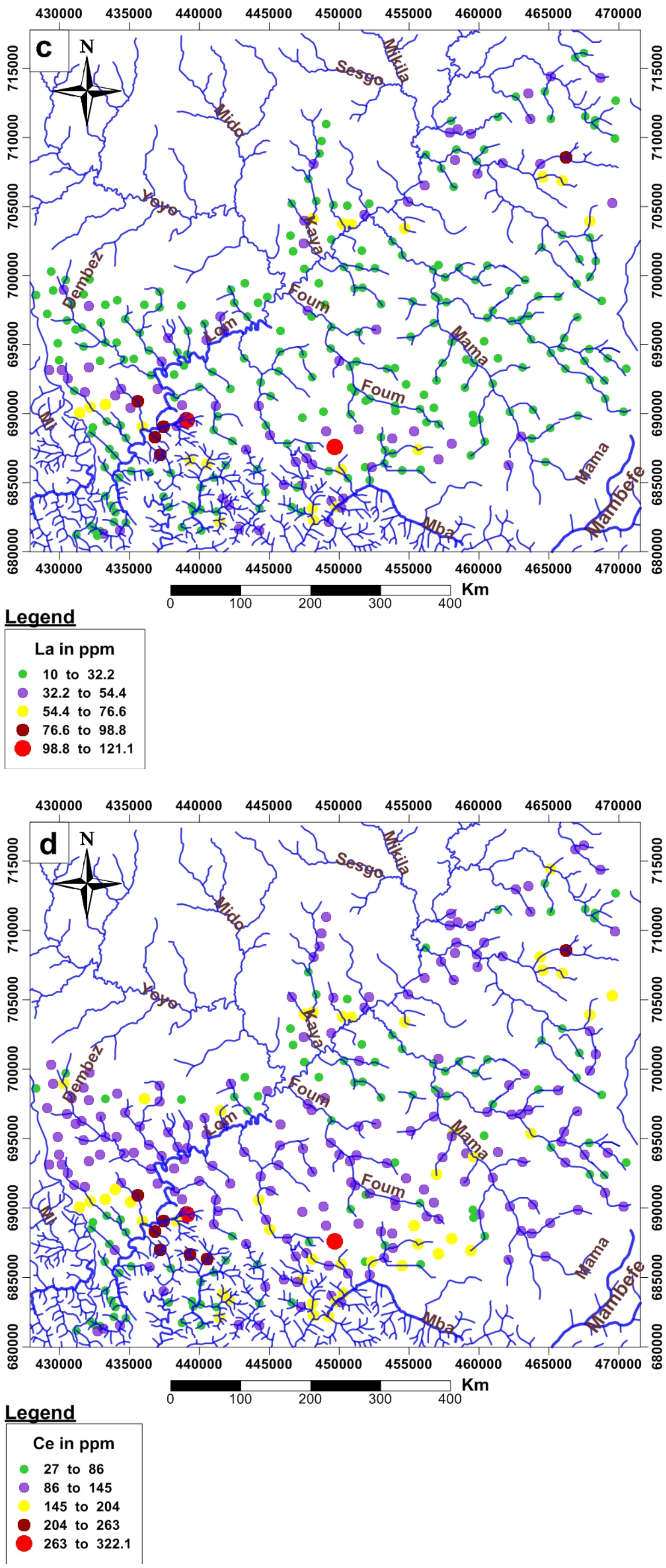
2151.2 to 2825.6
2825.6 to 3501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La in ppm
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86 to 145
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263 to 322.1

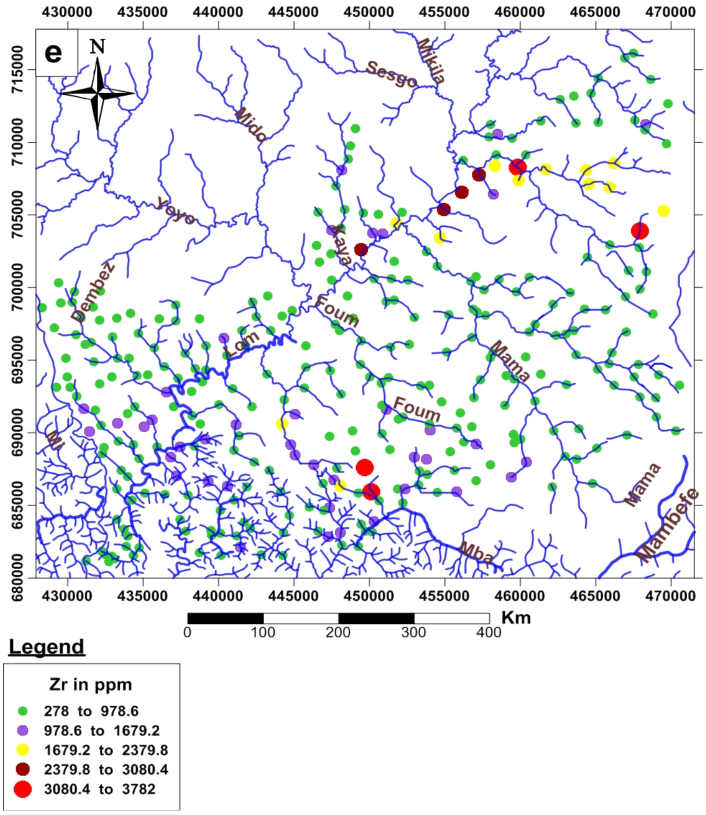
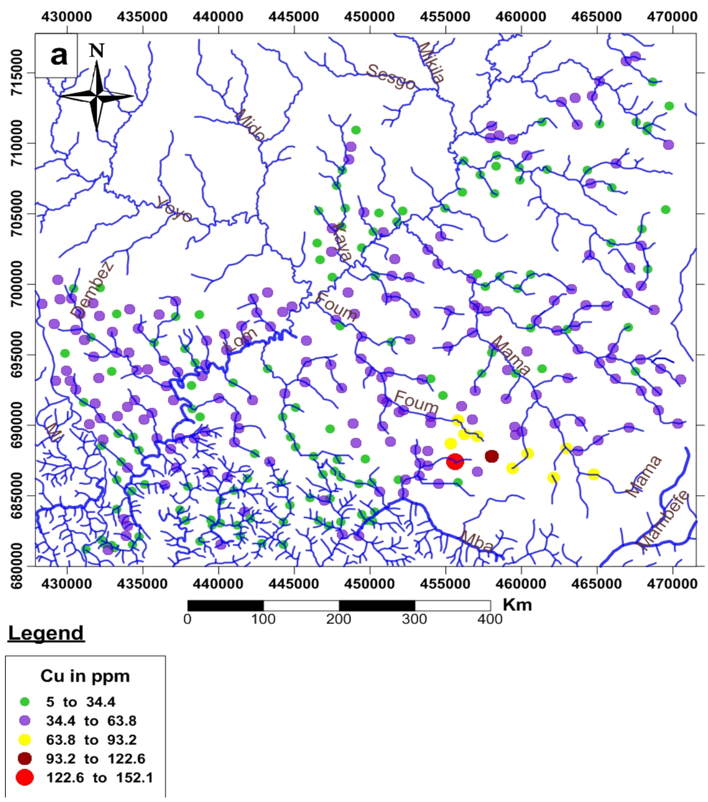
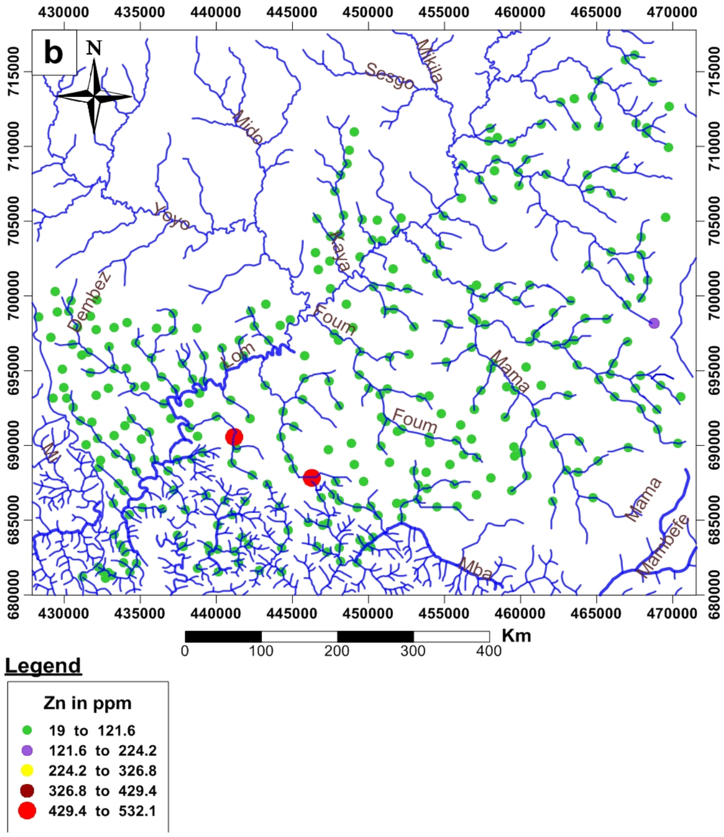


Figure 6. Graduated symbol plots for (a) Sr (b) Ba (c) La (d) Ce (e) Zr (ppm) superimposed on the drainage map of the upper Lom Basin.

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Zn in ppm
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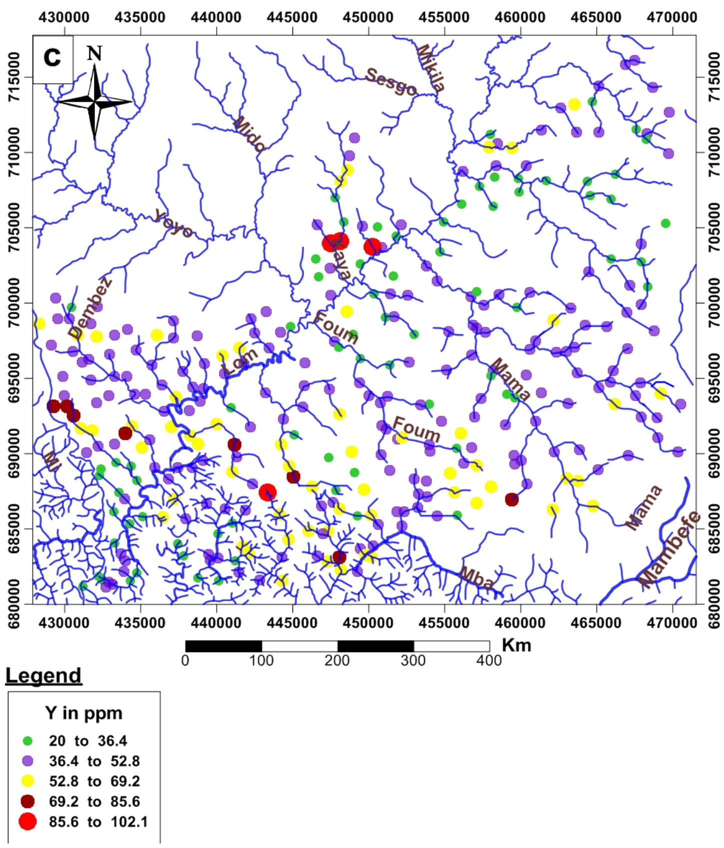
121.6 to 224.2
224.2 to 326.8
326.8 to 429.4
429.4 to 532.1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Y in ppm
20 to 36.4
36.4 to 52.8
52.8 to 69.2
69.2 to 85.6
85.6 to 102.1

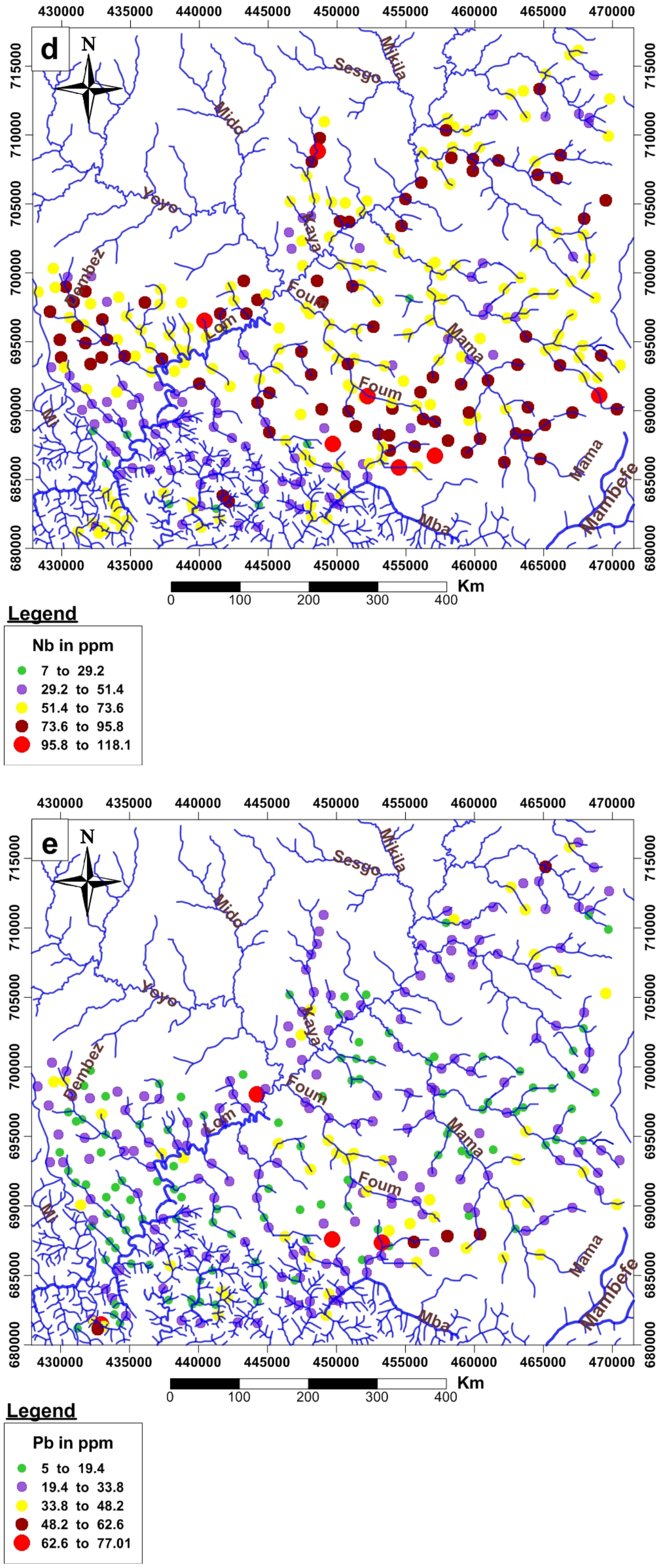

Figure 7. Graduated symbol plots for (a) Cu (b) Zn (c) Y (d) Nb (e) Pb (ppm) superimposed on the drainage map of the upper Lom Basin.

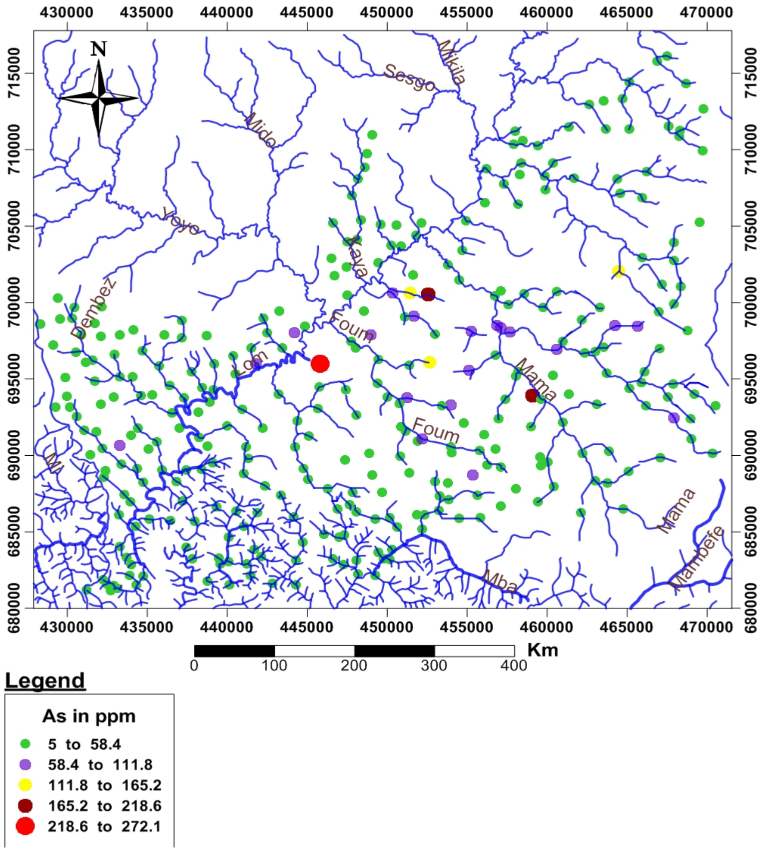

Figure 8. Graduated symbol plots for as superimposed on the drainage map of the upper Lom Basin.

in the rock. In this case the arsenopyrite may represent a different generation of sulphide mineralization distinct from the chalcopyrite dominated-sulphide mineralization depicted by factor 2. Identifying and distinguishing these two separate sulphidation events may hold the key for further exploration for primary gold in this region and this is a significant contribution of this study.

Considering that gold defines a single element factor (Factor 4), allows us to propose that the gold mineralization in the bed rock is quartz vein-related, otherwise known as free gold and not necessarily synchronous with sulphide precipitation. [25] reported Au-As-Hg-Ni-Co element associated in stream sediments from China and interpreted this factor to represent gold mineralization related to deep, high temperature ore-forming processes. Conversely [25] attributed the Pb-Ag-Hg factor in a similar study to shallower, lower temperature gold mineralization. By defining a single factor, we postulate that the gold mineralization in the bedrock in this region is related to shallow ductile-brittle quartz veining hydrothermal events. This aspect should be taken into consideration during subsequent exploration studies in this area.

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