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Characterization of Gold Bearing Placers and Associated Minerals in the Elogo Region (North-West Congo Republic)

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Abstract

The Elogo region has been subjected to craft industry and semi-industrial mining for gold-bearing placers, since the colonial times. It is actually undergoing an intensive exploration for a primary gold deposit. The goal of this study is to contribute to the exploration of the primary gold deposit in the Elogo Region (North-West of Congo Republic). The methodology consisted of characterization of placers deposits by their lithology, mineralogy and the gold grains shape, in order to constrain the source of gold with the respect to the local geology. The results obtained show that alluviums are polygenic and yields seventeen mineral species composed of zircon, olivine, magnetite, ilmenite, gold, garnet, rutile, coltan, cassiterite, monazite, apatite, amphibole, tourmaline, pyrite, limonite, chromite, and amphibole. The morphoscopy of gold grain shows single grains and grains with quartz inclusions that suggest their relationship with quartz veins. The gold grains are flattened, sub-flattened, and rounded. The northern region of Elogo characterized by a dominance of coarser quartz-included gold grains indicates a proximal pro-parte origin (less than 50 m), while the southern region, showing less coarse and more evolved grains with choc marks, appears to be associated with a distal pro-parte origin (more than 300 m). The multivariate statistical analysis shows seven classes of samples corresponding to the mineralogical paragenesis suggesting various sources, consisting of high-grade metamorphic, granitoids, pegmatites, basic and ultrabasic rocks, and BIFs that provided minerals to the placers. Gold mainly comes from hydrothermal quartz veins and probably from the peptization of gold from the weathering of sulfides occurring in the BIF. In the Elogo region, gold exploration for primary deposits should look for and follow the hydrothermal system developed in this region. Chemical analysis for the gold grains and associated minerals is necessary to better guide the proposed geochemical prospecting.

Keywords

Auriferous Placers, Associated Minerals, Correspondence Factor Analysis, Principal Component Analysis, Elogo, Gold Exploration

1. Introduction

More than half of the world's gold, titanium, diamonds, zircon, and thorium come from placers [1] [2]. Placer accounts for nearly 31% of global gold production between 1984 and 2006 [3]. In the Republic of Congo, artisanal mining is the only mean for exploiting placer deposits that prevail since the colonial times. This applies not only for gold but also for diamond, tin, tungsten, and coltan. However, artisanal mining does not guarantee large volume of ores for economic development. Additionally, continuing artisanal mining can cause several environmental impacts for drainage and water access. While the geological context of the region provides lots possibilities of primary gold deposits, there are no studies that assessed source rocks of these gold bearing placers [4] [5] [6] [7]. Indeed, this search for source rocks can be done by characterizing the mineralogy and morphology but also the microchemistry of the gold grains in the placers [2] [7] [8] [9] [10] [11] [12]. In this perspective, this paper analyses forty (40) samples from several rivers in the Elogo region in northwestern of Republic of Congo for tracking the possible source rocks of gold placers.

This study combines two approaches. Firstly, it assesses the distribution of heavy minerals within the placers of the Elogo region. Secondly, it shows the source of gold by comparing the different mineralogical paragenesis. Geological setting of the Elogo region is part of the Ivindo basement, which is part of the Congo craton [10] [13] (**Figure 1**). This basement of Archean age, is a granito-gneissic complex. Its petrographic assemblage is dominated by Tonalites-Trondjénites-Granodiorites (TTG), hosted along granulites, gneiss, charnockites, greenstones belts and BIF [10] [11] [13] [14].

At the local level, the structure of the basic and ultrabasic complex of Elogo has been interpreted as a lopolite, or a large sill, bent into a bowl [10] [11] [13] [14]. This complex consists of from top to bottom to extremely fine-grained rocks, basalts with olivine, occupying a plateau of about fifteen km^2; much more grainy rocks: peridotites with fairly serpentinized dunites and locally comprising asbestos veins, high-crystallization actinotites and finer-crystallized actinotites with talc, soapstones, and talcshists in contact with peridotites. Towards the periphery of the massif, these same rocks are riddled with stockwerk veins of

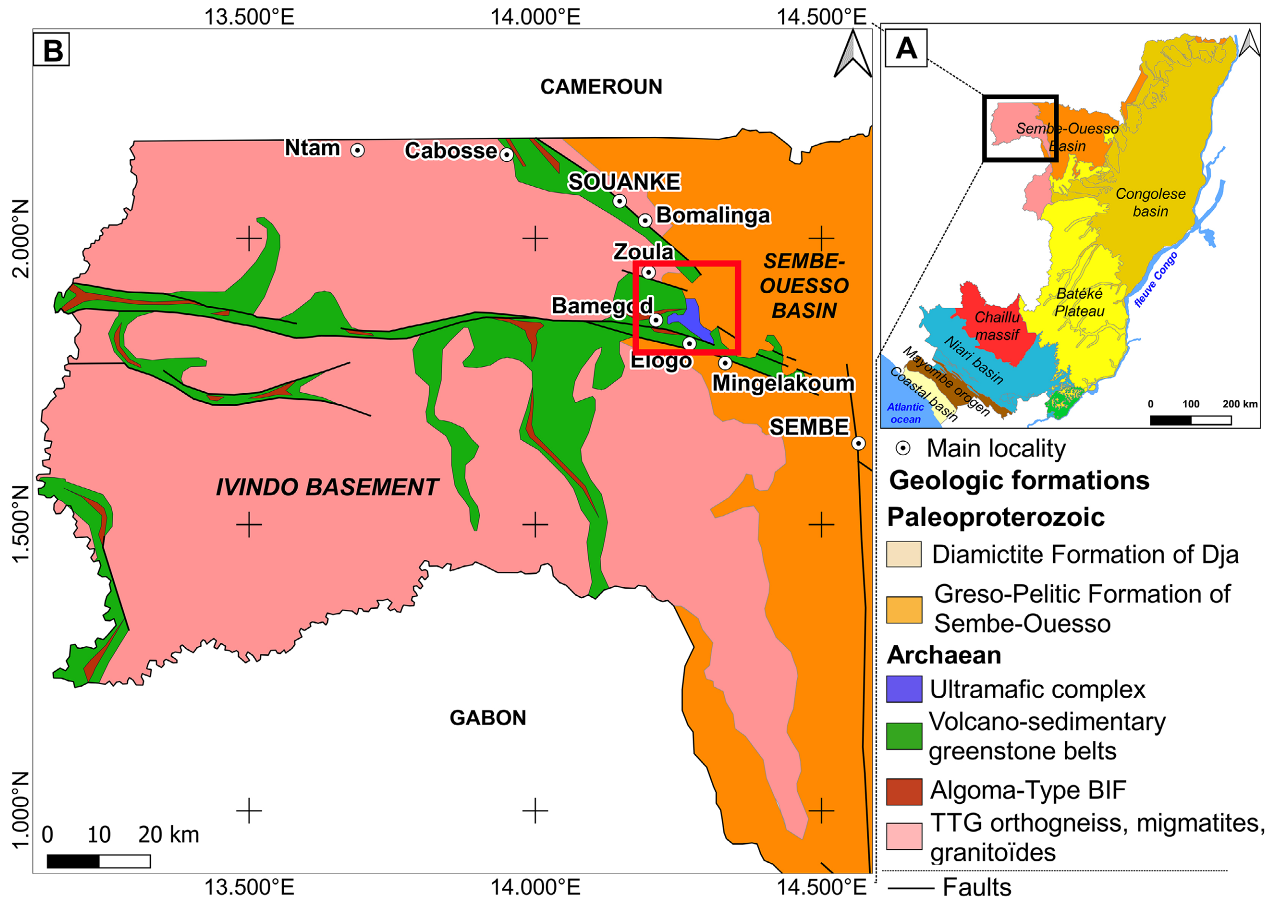

Figure 1. Location of the study area on an extract of the geological map of the Republic of Congo at 1:1,000,000 (modified from [15]).

quartz and pyrite. The purpose of this work is to study the morphology of gold grains as well as the parageneses of heavy minerals associated to gold, in order to contribute to the discovery of a primary gold deposit in the Elogo sector.

2. Methodology

2.1. Location and Description of Sampling Sites

The Elogo region area (Figure 2) is located in the Department of Sangha, in the Northwestern of the Republic of Congo, in the Ivindo basement, which is the northern extension of the Chaillu massif belonging to the Congo craton. This region is full of many placer resources, mainly mined for gold. There are both alluvial and eluvial placers. This study concerns the mineralogical analysis of 40 samples of pan concentrates taken from the placers of an area that seemed interesting to us from the field observations. Sampling points are located on the watersheds map of the study area (Figure 2).

2.2. Placer Lithology and Sampling

The lithology of the placers was established by sinking the wells at the level of about twenty alluvial placers in the three geographical zones of the Elogo region.

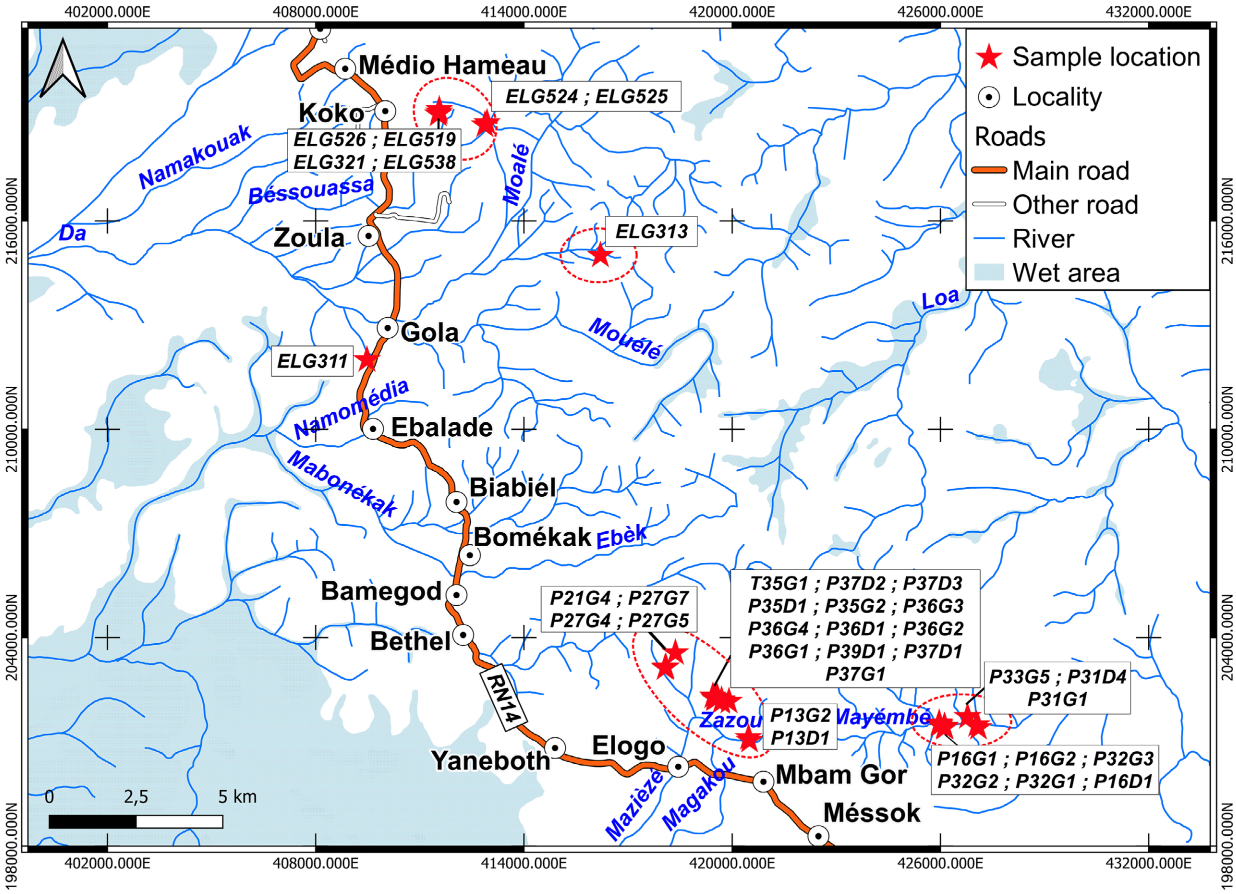

Figure 2. Location of the studied sites on the hydrological background of the Sangha department and its surroundings.

Then, we build a description profile of the lithological horizons encountered. The description consisted in specification of the grain-size, and measuring the thicknesses of alluvium. The sampling consisted in taking 4 samples from each rich horizon, which was then processed in order to obtain heavy mineral inputs by panning.

2.3. Sample Processing and Identification of Heavy Minerals

The mineral concentrates obtained were dried and studied according to the protocol proposed by [16]. The heavy minerals were described and identified using a binocular magnifying glass brand Jeulin birefringent led and reassessments x2 and x4 at the Laboratory of Geosciences, Faculty of Sciences and Technologies of Marien Ngouabi University of Brazzaville. The descriptions covered the shape, color, cleavage, pleochroism, magnetic susceptibility, malleability, hardness, and hydrochloric acid reactivity. The determination was based on the work of [17] and the Miner@lia software (second edition, 2004). Lithological profile surveys were used to define the placers lithology, while data from the relative percentage of each heavy mineral species were used for statistical analyses using Correspondence Factor Analysis (CFA) and Principal Component Analysis (PCA).

2.4. Analytical Technique

We analyzed 200 transparent and opaque minerals after quartering. After we identified mineralogical species in relative percentage presents in the sample. Then we use mineralogical paragenesis of each sample to determine the possible petrographic provinces that sourced the sample.

The history of the sediment transport was determined by morphoscopic analysis [18]. This required analysis of appearance, shape and surfaces of mineral-rain. Particularly, the morphology of gold-grain, surfaces contours, appearance of the grain surfaces, and the minerals in the inclusions are good indicators of the distance from the probable source [7] [19]. A multivariate statistical analysis, that uses Correspondence Factorial Analysis of Functions (AFC) and Principal Component Analysis (PCA) helps treated the shape of gold grains. Only samples with more than twenty gold grain were considered. The largest gold grains tend to settle close to the source, and the finest tend to go as far as possible [7].

AFC is used to process information obtained in various domains, in very complex situations where large number of variables are correlated [20]. AFC was carried out with R software (Version 64 3.3.3) using relative percentages of each heavy mineral species contained in the samples. The aim is to identify the overall distribution of heavy minerals within river formations and to establish possible mineralogical filiations between the latter and the underlying formations that are considered sources. The study of the overall distribution of heavy minerals within river formations by AFC provides an overview of their evolution related to the geographical context [21].

The PCA uses relative percentage provides the most relevant summary of the initial data [22]. It is an effective method for analyzing quantitative data. It allows the paragenesis definition that can be linked to potential sources by establishing relationships or filiations between observation points and/or variables.

3. Results and Discussion

3.1. Results

3.1.1. Lithology of Placers

Forty logs have been established in the studied sites. Their analysis reveals four lithological types for the Elogo placers (**Figure 3**):

Type 1 consists of sequence of two horizons (**Figure 3(a)**) and shows from the top to the bottom: 1) a horizon of black or brown soil, sometimes arable, containing plant debris and gravels of quartzite. Its average thickness is 0.25 m; 2) a horizon of rusty-yellow clayey gravel free of plant debris. Its average thickness is 0.41 m.

The bedrock of this type is sometimes rocky, showing amphibolites more or less intact displaying figures of dissolution and sometimes green argillite.

Type 2 consists of sequence with three horizons (**Figure 3(b)**) and shows from the top to the bottom: 1) a horizon of blackish to reddish, arable clayey soil, containing plant debris. This horizon has 0.8 m average thickness; 2) an

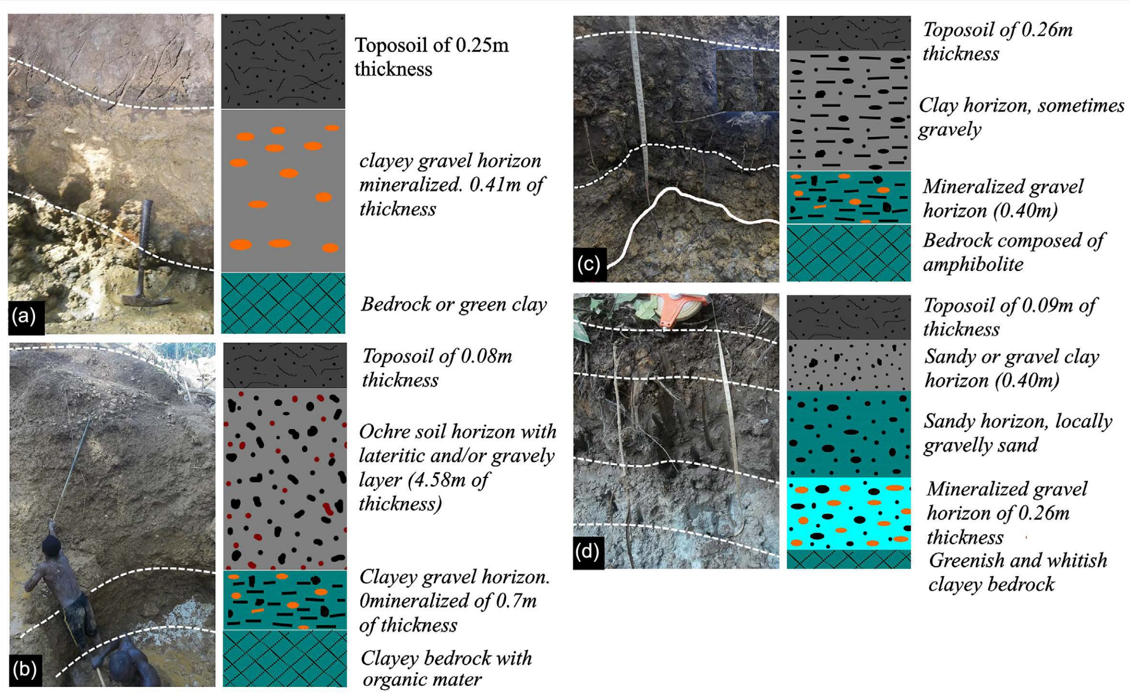

Figure 3. Profiles of the different types of placers described in the Elogo region.

ochre soil horizon of 4.58 m average thickness, but sometimes exceeding 10 m in some cases (12 m at the Ekokola site). This horizon sometimes presents intercalations of lateritic duricrust and gravelly levels up to 0.70 m or dispersed gravels in red to brownish-yellow clayey matrix. In sometimes, the lateritic duricrust level constituted the false bedrock; 3) a mineralized clayey gravel horizon of 0.7 m average of thickness. Bedrock of this type is clay of various colors.

Type 3 is composed of sequence with three horizons (**Figure 3(c)**). It shows from the top to the bottom: 1) a horizon of black or brown arable soil, sometimes sandy, containing plant debris. Its thickness is 0.26 m average; 2) a yellow or dark grey, sometimes gravelly clay horizon. The thickness of this horizon is 0.41 m average; 3) a mineralized clayey gravel horizon, sometimes containing blunt quartz sandstone blocks. Its thickness is 0.4 m average.

Bedrock of this type is either amphibolites, weathered green shales, or versicolor clays.

Type 4 is composed of sequence with four (4) horizons (**Figure 3(d)**). It shows from the top to the bottom: 1) a horizon of clayey, arable, black or brown soil, containing plant debris. Its thickness is 0.9 m; 2) a sandy clay horizon sometimes gravelly, containing locally plant debris. This horizon reaches 0.4 m average of thickness; 3) a horizon of light white or greyish sand sometimes gravelly. Its thickness is 0.29 m average; 4) a horizon of sometimes sandy and mineralized gravel. The thickness of this horizon is 0.26 m average. Bedrock is composed of versicolor clay.

In all the studied sites, the sterile level has thickness that varies between 5 and 10 m. The thickness of the productive horizon rarely exceeds 0.8 m. The horizons above the productive level, sometimes showing continuous and metric lateritic levels, implying a laterization affecting the placers and the in-situ materials on 5 m of thickness. The petrographic nature of gravels and cobbles shows little variation in the deposit. They consist of largely white or milky-white angular centimeter to decimeter quartz fragments. Lithic elements such as green shales, amphibolites and BIF are scarce.

3.1.2. Mineralogical Assemblages

Seventeen mineral species have been identified. These are zircon, olivine, magnetite, ilmenite, gold, garnet, rutile, coltan, cassiterite, monazite, apatite, amphibole, tourmaline, pyrite, limonite, chromite, and hornblende.

The identification of the different mineralogical assemblages shows the almost systematic presence of magnetite in all samples (except sample P36G1). It is often associated with ilmenite. Gold is present in twenty-three (23) samples in proportions ranging from 1.17% to 45.45%. The largest proportions are observed in samples T35G1 and P35D1 where gold represents 40% - 45% of counted minerals (**Figure 4** and **Figure 5**).

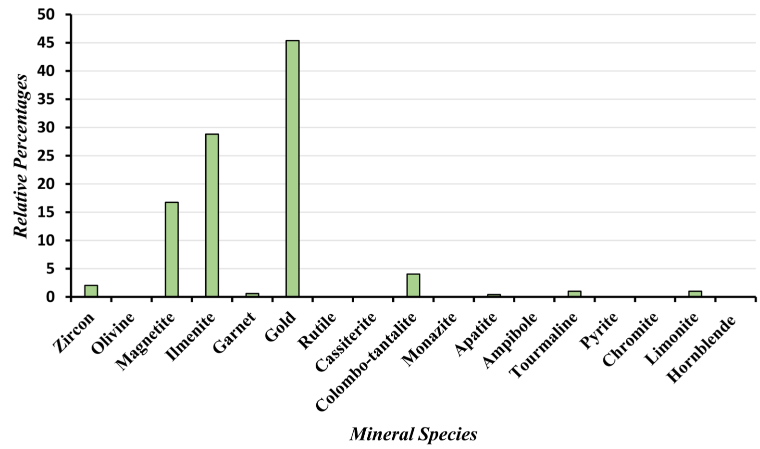

Figure 4. Relative percentages of identified minerals in sample T35G1.

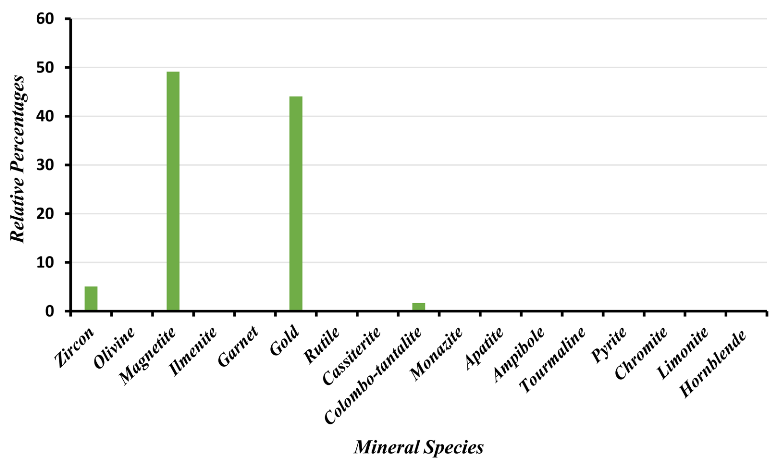

Figure 5. Relative percentages of identified minerals in sample P35D1.

3.1.3. Morphological Characterization of Gold Grains

Figure 6 displays various type and morphological pattern of gold found in sixteen (16) samples chosen for statistical analysis. The grains are crystalline, sub-crystalline, spherical, sub-rounded, and occasionally flattened. Regardless the site, the degree of flattening generally rises from upstream to downstream. Quartz crystals are included in some gold grains.

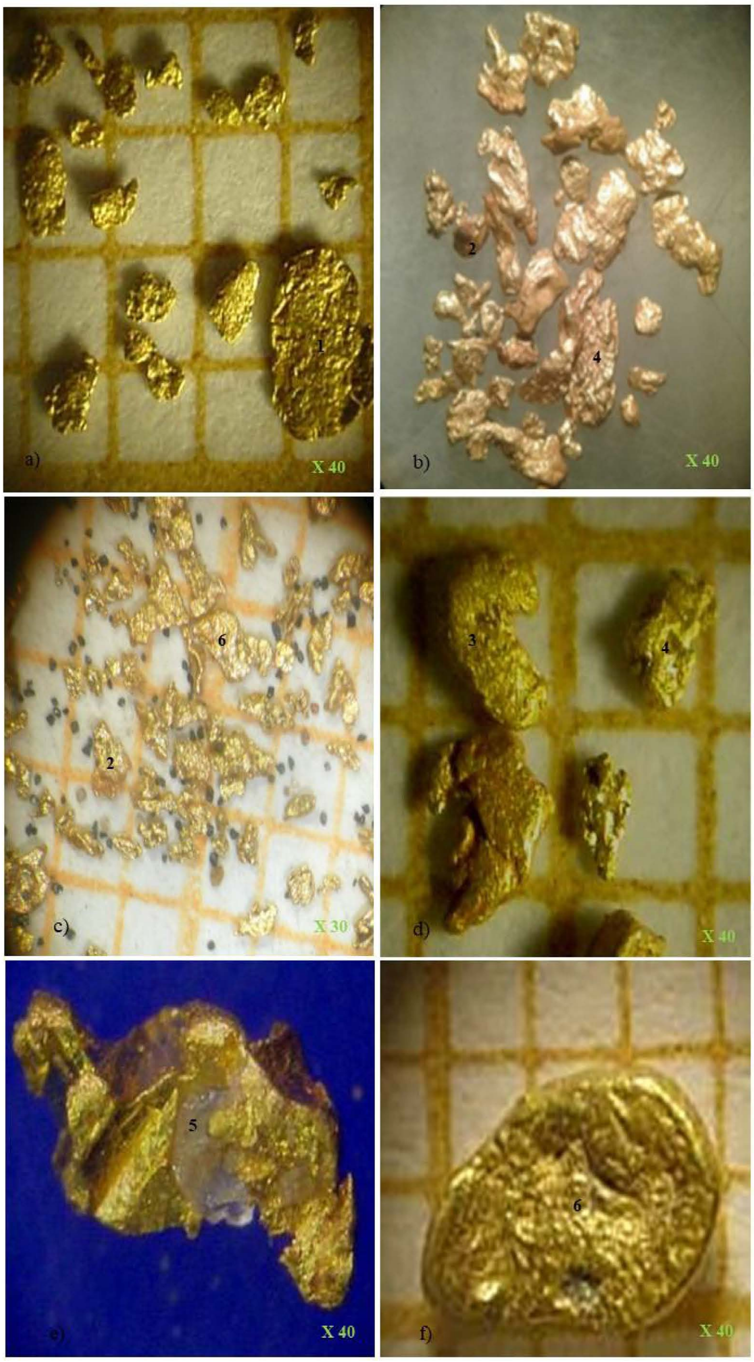

Figure 6. Facies and morphoscopy of gold grains observed in the Elogo region. 1. flattened and sub-rounded gold gains; 2. oxide-plated gold; 3. crystalline gold grain; 4. Grains in aggregate form; 5. gold grain with quartz inclusion; 6. sub-rounded gold grain.

Some gold grains are oxidated, while others present shock marks. 68% to 95% of gold grains measured have a diameter greater than 0.5 mm. Approximately, 5% to 32% of counted gold grains have a diameter less than 0.5 mm. The morphological characteristics of gold grains are shown in Table 1.

Table 1. Statistics on the gold grains morphology.

Upstream sampling: T35G1, ELG321, ELG315 and ELG317									
Average grains	With quartz	Quartz free	Flattened	Sub-flattened	Aggregates	Total	Waist		Other observations
							>0.5 mm	<0.5 mm	
Round	-	23	7	10	6	20.17%	32%	68%	6 flattened grains show shock marks
Sub-round	-	31	14	15	2	27.19%			
Crystalline	-	18	2	15	1	15.78%			
Sub-crystalline	-	28	9	17	2	24.56%			
Oxidized	-	14	2	3	9	12.28%			
Total	-	100%	29.82%	52.63%	17.54%				
Upstream sampling: P36D1, P35G2, P35D3 and P35D4									
Average grains	With quartz	Quartz free	Flattens	Sub-flattened	Aggregate	Total	>0.5 mm	<0.5 mm	Other observations
Round	-	4	-	1	3	4.94%	27%	73%	4 flattened grains show shock marks
Sub-round	4	19	7	6	10	28.39%			
Crystalline	-	19	1	7	11	23.45%			
Sub-crystalline	-	30	5	7	18	37.03%			
Oxidized	-	5	3	3	7	6.17%			
Total	4.94 %	95.06%	19.75%	29.62 %	60.49%				
Downstream sampling: P32G1, P32G2 P32G3 and P32G4									
Average grains	With quartz	Quartz free	Flattened	Sub-flattened	Aggregates	Total	>0.5 mm	<0.5 mm	Other observations
Round	4	9	7	6	-	13.97%	19%	81%	12 flattened grains show shock marks
Sub-round	1	28	7	22	-	31.18%			
Crystalline	3	14	1	1	15	18.27%			
Sub-crystalline	1	29	17	3	10	32.25%			
Oxidized	1	3	1	-	3	4.30 %			
Total	10.75%	89.25%	35.48%	34.40 %	30.10%				
Downstream sampling: P16G1, P16G2, P16G4 and P36D1									
Average grains	With quartz	Quartz free	Flattened	Sub-flattened	Aggregates	Total	>0.5 mm	<0.5 mm	Other observations
Round	-	1	1	-	-	1.88%	5%	95%	9 flattened grains show shock marks
Sub-round	-	6	6	-	-	11.32%			
Crystalline	1	27	9	2	17	52.83%			
Sub-crystalline	3	15	15	-	3	33.96%			
Oxidized	-	-	1	-	1	3.77%			
Total	7.55%	92.45%	60.37%	3.77%	39.62%				

3.1.4. Analysis of Mineralogical Assemblages

The Analysis of mineralogical assemblages focuses on AFC, PCA and morphological characterization of gold grains.

- Multivariate statistical analyses

The results of multivariate statistical analysis (AFC and PCA) are presented in Figure 7. The statistical results of the AFC show that the first three axes express 58.98% of the total inertia, in other words, a percentage of 45.81% of the total variability of the cloud of minerals. This percentage is important and represents the variability contained throughout the active dataset. For the PCA, the first three axes express 40.54% of total inertia. In other words, a percentage of 46.133% of the total variability of the variable cloud.

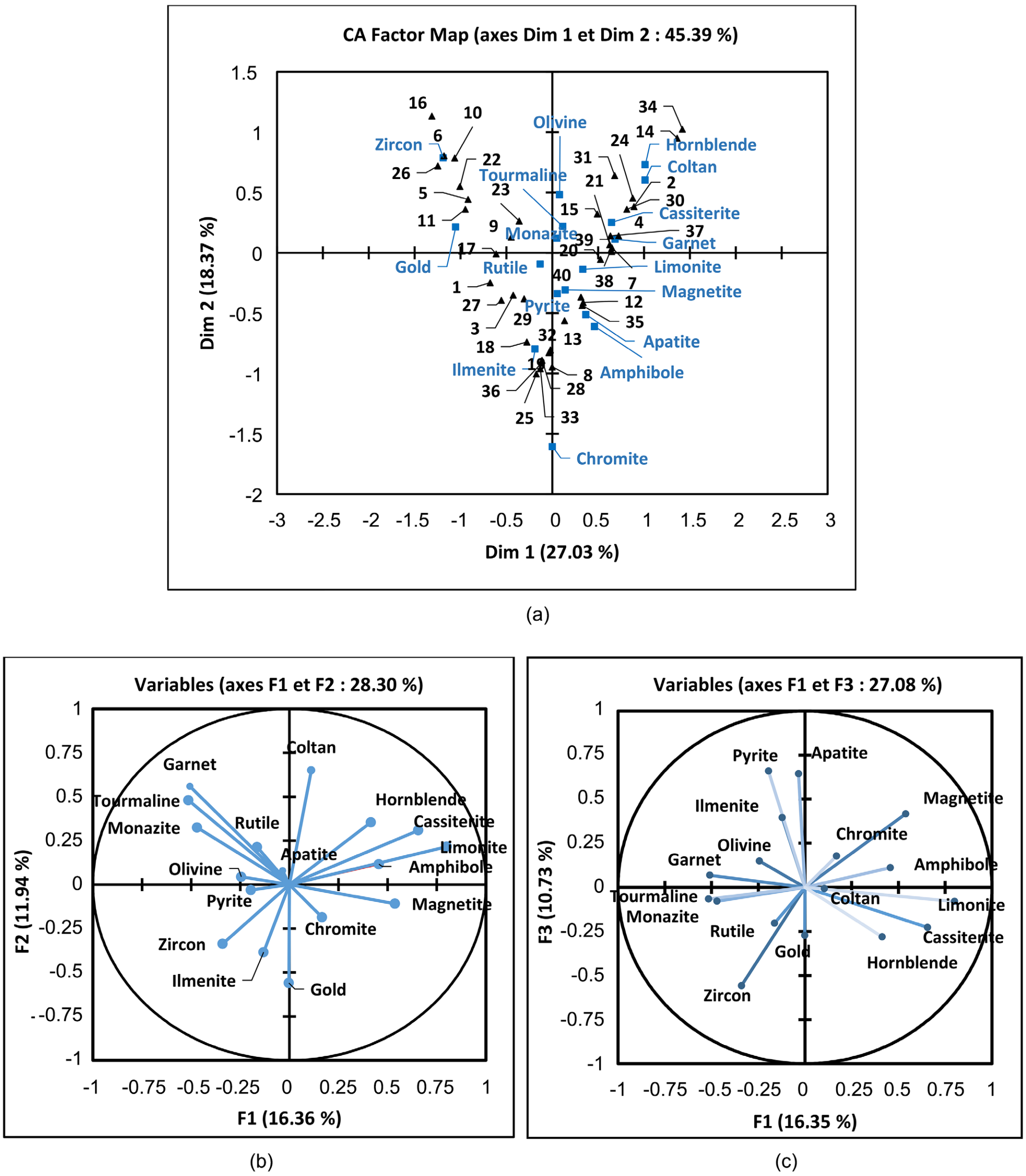

Figure 7. Analysis of mineralogical groups: (a) correspondence factorial analysis; (b) and (c) principal component analysis: Projection in the planes (F1, F2) and (F1, F3).

AFC (Figure 7(a)) shows two mineral clouds in the plane Dim 1, Dim 2. The first cloud is consisted of hornblende, coltan, cassiterite, tourmaline, garnet and monazite. The second cloud shows magnetite, pyrite, amphibole, apatite, ilmenite and chromite. Gold deviates considerably from these two clouds and is associated with zircon.

PCA (Figure 7(b)) shows in the plane F1, F2, two distinct clouds of heavy minerals. The first cloud is composed of hornblende, cassiterite, amphibole, limonite, chromite and magnetite.

The second cloud is composed of garnet, rutile, tourmaline, monazite, olivine, rutile, pyrite and apatite. Gold is negatively, strongly correlated along the F1 axis. Gold is associated with zircon and ilmenite and forms the third cloud. The plan F1, F3 (Figure 7(c)) shows four distinct clouds of heavy minerals. The first cloud is similar to the thirst cloud of Dim 1, Dim 2. However, it shows addition of coltans species. The second cloud is composed of pyrite, apatite and ilmenite. The third cloud is composed of tourmaline, olivine, garnet and monazite. This cloud of heavy minerals is identical to the second cloud highlighted by the plane Dim 1, Dim 2. Gold is moderately and negatively correlated through the F2 axis in the same way as in the plane Dim 1, Dim 2. It forms a fourth cloud associated with zircon and rutile.

The samples were classified by using the Principal Component Hierarchical Classification (HCPC), which is presented in Figure 8. The classification reveals seven (7) classes highlighting the relationships between the samples.

The first class is consisted of ELG526 sample and characterized by the presence of rutile and olivine. The second and third classes include samples containing zircon, magnetite, ilmenite, coltan, tourmaline and olivine in varying proportions. The fourth class is composed of samples with high proportions in gold and low proportions in coltan. The fifth class is made up of samples of small proportions of gold and high proportions of coltan. The sixth class represented

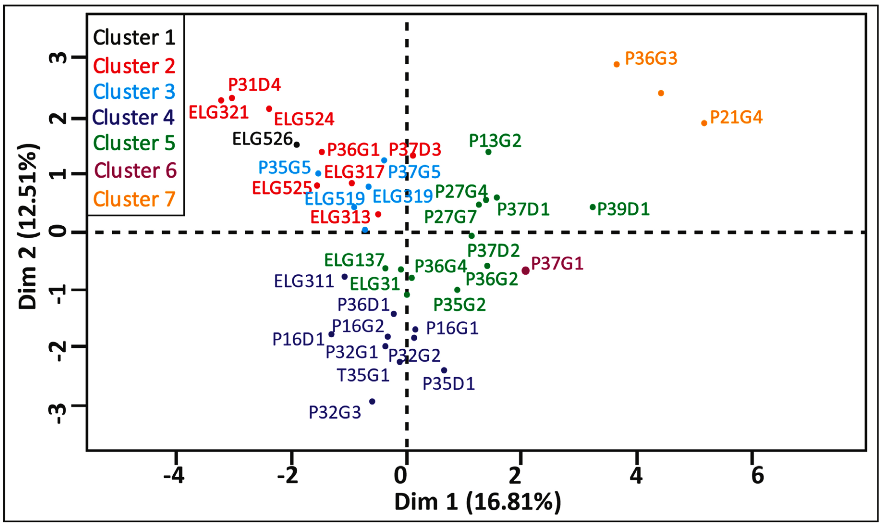

Figure 8. Hierarchical classification on main components of samples.

by P37G1, shows magnetic minerals (Magnetite, Ilmenite and sometimes limonite). The seventh class is characterized by samples where the cassiterite is associated with zircon and coltan.

- The spatial evolution of the different mineralogical assemblages

The evolution of mineralogical assemblages has been examined for each river basin (Figure 9). We compare the average percentages of each mineral species observed, but low percentage and punctual minerals were not taken into a count. This is the case of pyrite, apatite, chromite, amphibole and cassiterite. While the heavy minerals present in small quantities (amphibole, apatite) do not give any particular indications, the distribution of the most abundant minerals does not seem any:

✓ Regardless of the geographical area considered, the percentage of zircon, tourmaline and rutile samples is roughly constant. However, it is noted that it increases significantly in samples in the southern position in the two watersheds; this could be related to the resistance of these minerals during transport;

✓ Olivine and garnet are largely expressed in the first watershed located to the north of the studied area;

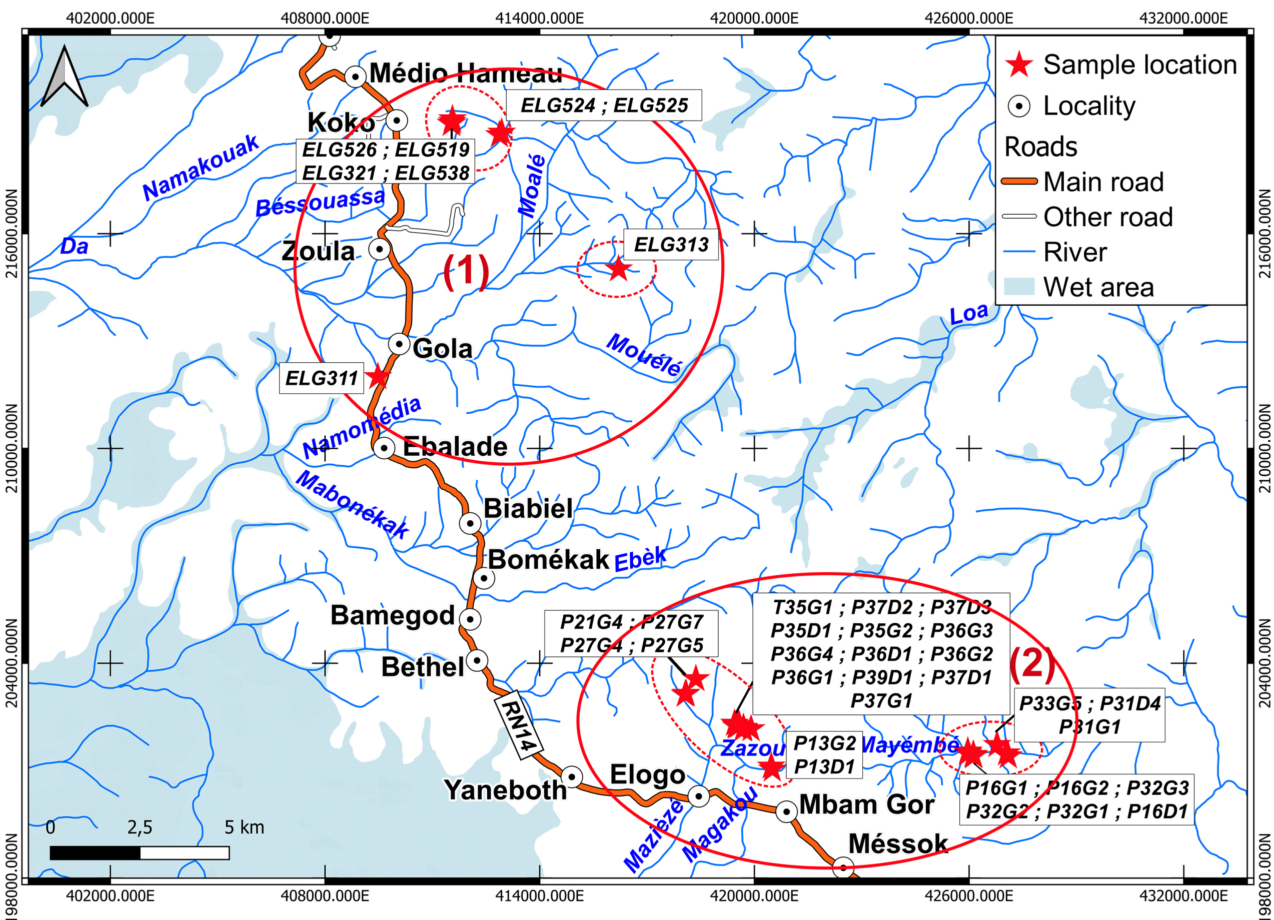

Figure 9. Location of identified lines of enquiry.

- ✓ The highest proportions of gold are to be reported in the second watershed (southern part of the studied area) with a systematic presence of gold grains in almost samples taken in this basin, while in the first basin, only three samples out of twelve contain gold;
- ✓ Whatever the watershed, the percentage of magnetite and ilmenite is approximately constant and these two minerals are present in all samples taken from these basins;
- ✓ Coltan is present in both basins, however its percentage is higher in the second basin;
- ✓ Olivine is best expressed upstream in the first basin and shows a lesser extent in the second basin, but it is absent in the samples observed downstream of both basins;
- ✓ Limonite, absent in the samples of the first basin, is best expressed in those of the second basin.

The examination of the mineralogical assemblages helps classify the heavy minerals encountered into three categories: 1) essential heavy minerals, more or less abundant and classified by decreasing abundance: zircon, magnetite, ilmenite, coltan, rutile and tourmaline; 2) minor heavy minerals, which are rare: garnet, olivine, monazite, amphibole, apatite and limonite; 3) exceptional heavy minerals, which are detected only in a few samples: pyrite, hornblende, chromite and cassiterite.

In general, samples further downstream have rounded to sub-rounded minerals, while upstream samples show angular to sub-angular minerals. Additionally, this was observed in both watersheds.

The morphology of these gold grains reveals the existence of diversity of forms (**Figure 6**, **Table 1**). Upstream samples yield 65.51% gold grains containing quartz inclusions, 86.2% crystalline grains and 45% grains larger than 0.5 mm, while downstream samples yield 20% gold grains with quartz inclusions, 32% crystalline grains and 75% gold grains less than 0.5 mm size.

3.2. Discussion

The description of placers shows four types of lithologies. The typology described is similar to that already encountered for the placers of Chaillu [5] and those of Kelle-Ngoyiboma region [23] which are part of the same craton. However, the thicknesses appear more important at Elogo. The Thicknesses of the productive level rarely exceed 1 m, while the sterile horizon can reach 10 m. All these levels rarely exceed 3 m in the Kelle-Ngoyiboma region and Chaillu [5]. The presence of single polygenic gravel horizon indicates that placers are of fluvial origin, and they derived from the erosion of primary mineralization by watercourse [23]. The presence of duricrust in some cases suggests that these placers are old, even if the gravel horizon is not consolidated. These old placers are similar to those observed in Bolivia along the Andes Era, dated from Miocene and having polygenic zones [23]. This suggests many possibilities of finding polygenic placers in the areas where the erosion have been very active, to the point of leaving preserved high relief such as Mount Nabemba. This is also confirmed by an oral communication from an engineer of the SEMI SA company, who reports placers with several levels of gravel in the mining exploitation of Yangadou region. The Elogo placers are therefore alluvial placers of modest size compared to the Tipuani placers or the famous Amazonian plain of Madre de Dios placers, which are several km^2 for a thickness varying from 10 to 30 m [24] [25]. But, the exploitation of these studied placers can be made difficult by the presence of duricrust encountered in several parts. The angular character of quartz and lithoclasts in the gravel of the placers indicates that these debris have not undergone significant transformation and transportation. These are the sub-endogenous clasts, reflecting the sources rocks of the placers. Moreover, in some sites such as Yangadou, the fragments of quartz vein are present with laterite gangues. This type of mineralogical characterizes the placers with native elements. This would include placers with autochthonous elements moved slightly by solifluxion as also observed by [5] in the placers of Chaillu massif in Mayoko region. In some of these horizons, the important proportion of zircons as well as gold grains with dissolution cavities reflect, according to [26] [27], the mark of intense alteration in a humid tropical environment with high organic matter.

The seventeen mineral species identified are zircon, olivine, magnetite, ilmenite, garnet, rutile, cassiterite, monazite, apatite, amphibole, tourmaline, pyrite, limonite and hornblende, gold, coltan, pyrite and chromite. Some of these minerals had already been reported in this region [13] [14] [28] and may generate economic interest. Thus, the work of [13] highlighted the presence of gold, coltan and pyrite in the Elogo region [14] describe gold and chromium anomalies in this region. This study corroborates these results and reveals a high diversity of mineral species within the placers of the Elogo and its surroundings.

The mineralogical paragenesis analysis suggests two distinct regions and highlights paragenesis that correspond to metamorphic, magmatic and meta-sedimentary rocks. The differential behavior of gold deviates from all heavy mineral clouds (**Figure 7(b)** and **Figure 7(c)**) is indicative of particular mechanisms of gold mineralization, and could be from processes different to the rock setting. The observed gold grain facies indicate grains associated with vein of plutonic origin. The presence of this type of grain suggests a hydrothermal origin of gold and corroborates the work carried out in the district of Mana in Burkina Faso [29]. This is also the case for the major gold placers of Arizona which are associated with crystalline rock, such as shale, granite, and gneiss, where veins tend to be mesothermal and hypothermic types [30]. However, in Africa, gold in granitoids is a recent discovery and the parameters that characterize it remain little known [31].

The first emerging paragenesis, consisting of garnet, tourmaline, monazite (**Figure 7(b)**) would correspond to a mineralogical association characterizing high metamorphic grade rocks [32] [33]. The second grouping limonite, magnetite, cassiterite seems to come from the alteration of BIF present in the region as already encountered at Mayoko in Chaillu by [5] [34]. This observation confirms the work of [13], although Mayoko subsequently demonstrated a negative correlation between gold and BIF [35].

Regarding the gold grains morphology, this study shows a diversity of gold grains shape. It suggests that they would come from several sources and probably from several transportation mechanisms [36]. The recurrent presence of gold with quartz inclusions indicates that at least some of the primary gold is related to quartz veins as observed in the Chaillu massif by [5] and by [36] in Central Yukon (Canada). Gold grains have several occurrences and gold grains with quartz inclusions had also been connected to quartz veins in USA [37] [38] like in Belgium [12].

The mineralogical analysis clearly highlights two regions corresponding to two hydrologic basins: 1) the northern region located to the East and South-East of Koko village; 2) the southern region comprising the Kampala, Tripoli, Mayembe and Zazou sites. The first region is characterized by identical mineralogical paragenesis with the exception of olivine, coltan and apatite. The second is characterized by the paragenesis consisting of limonite, magnetite, rutile, cassiterite, coltan, zircon, olivine, monazite, amphibole, pyrite, gold, ilmenite and chromite.

Taking into account the CA factor (**Figure 7(a)**), the minerals that have a strong relative contribution on the three factorial axes (zircon, gold and coltan) are positioned essentially according to their mechanical and chemical resistance (more broadly for zircon and tourmaline).

With regard to PCA (**Figure 7(b)** and **Figure 7(c)**), the rather closed angles formed respectively between garnet and monazite, tourmaline and monazite and between limonite and amphibole, indicate that these minerals are fairly well correlated with each other, thus reflecting granitic and pegmatitic rocks as sources of these mineralizations [39].

The results of principal component analysis show that garnet, monazite and tourmaline have a strong correlation with each other. Also, limonite is quite well correlated with amphibole. The hierarchical ascending classification that complements the correspondence factor analysis as well as the principal component analysis separates these samples into seven (7) classes based on mineralogical relationships (**Figure 8**). It shows that classes 2, 3, 4 and 5 show good prospects. Thus, class 2 has monazite and tourmaline as correlation factors. Class 3 has magnetite and rutile as correlation factors in more or less the same conditions. Class 4 confirms the antagonistic effect between gold and coltan observed in **Figure 7(b)** and **Figure 7(c)**, and is the class of samples with the largest proportions of gold. Class 5 has magnetite as tourmaline, pyrite, chromite, limonite and hornblende as correlation factor.

The lack of correlation and the antagonism observed between gold and all other minerals suggest that it would probably be a free gold associated with quartz as observed in some occurrences of the Eburnean basement [40] [41]. Gold would be from the hydrothermal processes regarding his link to the quartz veins crossing outcrops of various rocks such as granites, high grade metamorphic rocks and BIFs. These rocks constitute the bedrock and the sourced of the mineralization encountered in the placers. Identical phenomenon has been observed in gold pepitization of Mayoko from the alteration of sulphides present in BIF. Those veins would be or coexist with columbo-tantalite pegmatites and greisens.

The samples from the southern basin, characterized by flattened gold grains of small size and sometimes showing shock marks, assume that these grains have rolled a lot. In agreement with [6] these grains would come from a distance greater than 300 m, so their origin would be pro-parte distal. On the other hand, irregular contours observed in the Eastern and South-eastern regions of Koko village (northern basin), marked by a dominance of gold grains with quartz inclusions, crystalline form and slightly larger size indicate a proximal pro-parte origin, with a distance of about 50 m.

4. Conclusion

This study demonstrates that the placers of the Elogo region and its surroundings are of four types. Placers are polygenic and contain seventeen (17) heavy mineral species: zircon, olivine, magnetite, ilmenite, gold, garnet, rutile, coltan, cassiterite, monazite, apatite, amphibole, tourmaline, pyrite, limonite, chromite, and hornblende. The heavy minerals paragenesis suggests several sources of primary mineralization. The gold appears to be linked with quartz veins and granitic, pegmatitic, high-grade metamorphic and basic to ultrabasic rocks or BIF. In the southern part of Elogo, gold grains would come from a distance greater than 300 m. In the northern part, gold grains would come from a short distance of about 50 m from the rock source of the placers. The primary gold deposits of this alluvium are therefore quartz veins, or BIF, to be sought in the immediate vicinity of the placers in the northern part and at a distance greater than 300 m in the southern part. Main rocks source are granitoids, high grade metamorphic, basic and ultrabasic rocks associated with coltan pegmatites and greisens. However, in order to facilitate the subsequent prospecting phase, the geochemical analysis of the gold grains and associated minerals remain necessary in order to determine the geochemical signature of the gold and confirm the rocks in the predicted context.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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