Journal of Geosciences and Geomatics, 2019, Vol. 7, No. 1, 15-27
Available online at http://pubs.sciepub.com/jgg/7/1/3
Published by Science and Education Publishing
DOI:10.12691/jgg-7-1-3

Contribution to the Imagery of Landsat 8 for Identification of the Corridors of Mineralisation: Application for Formations of Precambrians Bindiba

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Received November 17, 2018; Revised January 06, 2019; Accepted February 02, 2019

Abstract The Bindiba gold district study in the East Cameroon region was done using a combination of Landsat 8 ETM image processing techniques, SRTM imagery and fieldwork. The various digital processing methods of treatment applied such as color compositions and component analysis showed lithological differentiation of the different formations of the study area. Directional filtering and treatments such as the Sobel have made a good linear mapping where we have been able to list more than 293 lineaments in which two types have been distinguished. The type I lineaments or penetrative lineaments correspond to schistosity trajectories. This interpretation is confirmed from field data which revealed schistosity plans mainly oriented NE-SW. Type II lineaments or non-penetrative lineaments are characterized by greater cartographic continuity and lesser spatial density. These lineaments thus represent the fracturing of the study area. The results of this lithology and linearization mapping, based on the superposition of the different images from the treatments and the field data, made it possible to identify the zones favorable for gold concentration and highlighted two gold mineralization corridors. This is the N30-35E steering corridor and the N110-135E steering corridor.

Keywords: *Bindiba, gold district, mineralization corridors, Landsat 8 ETM +/ SRTM image*

Cite This Article: Jacques Wassouo Wadjou, Abakar Mahamat, Fodoué Yaya, Ethel Ashukem Nkongho, Eugene Pascal Binam Mandeng, Dagwai Nguihdama, and Ismaela Ngounounou, "Contribution to the Imagery of Landsat 8 for Identification of the Corridors of Mineralisation:Application for Formations of Precambrians Bindiba." *Journal of Geosciences and Geomatics*, vol. 7, no. 1 (2019): 15-27. doi: 10.12691/jgg-7-1-3.

1. Introduction

The analysis of lineaments is of great importance in geological mapping and prospecting for mineral resources. Lineaments are linear or curvilinear structures often associated with geomorphological features or various tectonic structures [1]. Geological mapping allows to present not only the spatial distribution of the lithological facies, their succession, as well as the various structures of tectonic order, but also to identify and describe the different types of rock in a given region and the mapping of geological data collected in the field. As a result, it has moved away from its classical aspect based solely on field missions to the integration of a new aspect based on remote sensing and the geological information system and therefore, the importance is to facilitate the analysis, interpretation and preparation of geological maps. For this purpose, remote sensing offers a set of tools to improve the location of geological structures and allows the mapping of lineaments with precision. Two types of structures result from the cartography of the lineaments notably the lineaments of tectonic origin (faults, joints, schistosity) and the lineaments with geomorphological implication (line of crest, river ...). Remote sensing thus offers methods for the extraction of lineaments. It can be manual (photo-interpretation) [2,3,4,5], semi-automatic [3,6], or automatic [7,8,9,10]. The main objective of this study is to map structural lineaments by the manual extraction method in order to correlate them with data from the field campaigns in order to define the gold mineralization corridors in the Bindiba locality in North Central Cameroon located between latitudes 5°59'29" and 6°6'11" North and longitudes 14°16'32" and 14°25'21" East (Figure 1). The study of the density and the orientations of the lineaments will lead to an understanding of the relationship between lineaments and structural elements.

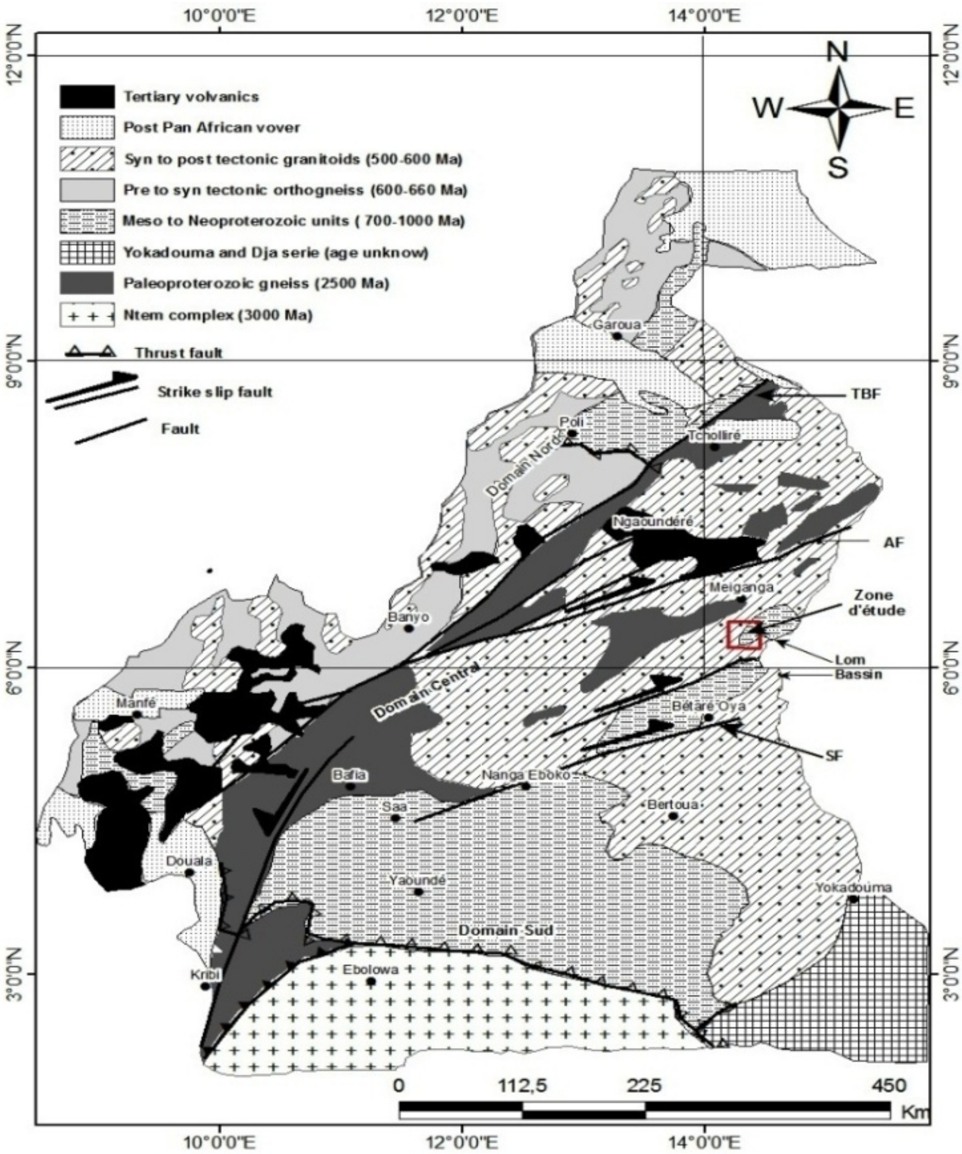

Figure 1. Cameroon geological according to [12] showing the study zone

2. Presentation of the Study Area

2.1. Geological Setting

Cameroon, according to its physical geography, is located in the north of the "stable" zone of the Congo Craton and its geological framework reflects its membership in Central African Panafrican Channel (CPAC) [11,12], or North-Equatorial Pan-African Chain (NEPC) [13,14] or Oubanguide Chain [15]. This study area is located in this Central African Pan African chain in Cameroon (CPAC) (Figure 1). It consists of large blocks of Precambrian rocks and is separated by large extension of metamorphosed sediment basins defined as vast limited to the west by the Trans-Saharan, and to the south by the craton of the Congo [16,17,18]. It extends to the Northeast of Brazil in the province of Borborema and forms the Pan-African-Brazilian chain [19,20] or Sergipano chain. This is a mega-chain oriented EW in its southern part and NE-SW at NNE-SSW in its northern part, with a length of more than 5000 km over a width of 3000 km [21]. The contrasting geological, geochemical and geophysical data has allowed this chain to be subdivided into three domains in Cameroon: the southern domain, the central domain (Adamaoua Yadé) and North Cameroon domain [22,23,24,25,26]. The locality of Bindiba belongs to the central domain of the pan-African chain of Central Africa or Adamawa-Yadé domain. This (Adamoua-Yadé) domain is limited to the North by the Choliré-Banyo shear and to the South by the Sanaga fault. Work in this area describes the presence of large Paleoproterozoic orthogneiss and metasedimentary relicts [27,28], metasediments and volcano-clastic rocks of Lom series [29,30] and pan-African syn-to tarditectonic granitoids [12,31]. In a geodynamic plane, it is marked by large setbacks: Shear-Center-Cameroon (CCC), Sanaga Fault, Tcholliré Fault and an abundance of plutonites [32], mostly syntectonic and orthogneissified (Figure 1). It emerges from the work of [33,34] that the formations of the center domain are affected by three main phases of deformation: -D1phase associated with an amphibolitic metamorphism. This phase develops schistosity S1 whose planes reveal a linearization L1 stretching; -D2 phase associated with an amphibolitic metamorphism of average degree. This phase is transcendent with syn-D2 intrusions, which are set up in parallel with regional structures [33,35,36]. It sets up shears C2, folds P2, axial plane schistosity S2 and lineation L2. According to [11,23], this phase is characterized by the presence of Paleoproterozoic age gneisses (2100 Ma) intruded by pan-African syntectonic plutonites (550±50 Ma), indicating that it is an ancient continental domain. Paleoproterozoic age resumed in Pan-African. [37], shows that the granulitic material is pan-African and contemporary with the setting up of certain granites. -D3 phase deformation, which is essentially brittle and characterized by C3 shears and large corrugations. The lithological and metamorphic characteristics of this Cameroon Center area are essentially composed of: (i) Paleoproterozoic metasediments and orthogneiss, with significant Archean contribution, evidenced by CT model ages and zircon inheritances [23,31,38]. (ii) Neoproterozoic metavolcano-sedimentary assemblies described as the Lom series, affected by a low to medium degree of metamorphism; (iii) and abundant syn-to late tectonic granitoids of crustal or mixed origin [35,36,29,12,31]. These characters and the presence of Paleoproterozoic (2100Ma) Archean inheritances enveloped by pan-African deformation structures indicate that the Adamaoua-Yadé domain is a pre-neoproterozoic basement reactivated during pan-African orogeny. At the metallogenic level, gold mineralization occurs along NE-SW shear boundaries that intersect with Neoproteroic metavolcanics and metasedial rocks [39]. This mineralization is also reported to be in contact between the formation cited above and granitic panafrican massifs [40,41].

3. Methodology

3.1. Analysis of Landsat 8 + Images

3.1.1. Data Used

As part of this work in the Bindiba area, scenes 055-056 of the Landsat 8 ETM + satellite (launched in 2013, equipped with a multispectral sensor called Operational Land Imager (OLI) and a thermal infrared sensor) acquired on 05 January 2015 was used in favorable weather conditions (dry season). It does not show clouds. The swath is 185 km x 185 km. The characteristics of the images acquired by the Landsat 8 satellite are generally as follows: altitude 705 km, tilt 98.2 degree, orbit sun-synchronous polar, period of revolution 98.9 minutes, capacity 16 days, swath 185 km x 185 km. Auxiliary data used for the completion of this work include the 1/200 000 topographic map, the SRTM images, the 1: 500 000 geological map of [13], the map of the reconstruction of pan-African domains NE Brazilian and West African showing the continuity between the Sergipano and North Equatorial ranges after [42] modified, the schematic structural map of Cameroon [43], modified Field observations made it possible to collect petro-structural data and to identify zones of essentially gold-bearing mineralization in the area (characterized by the presence of important gold panning sites). The field missions conducted in the Bindiba area validated the data obtained after Landsat 8 images were processed. Cross-analysis of the multi-source data was done using the ArcGis 10.2 software.

3.2. Methods of Pre-treatment of the Image

Two preprocessing methods were carried out in this work: radiometric corrections and geometric corrections.

3.2.1. Radiometric Corrections

The radiometric corrections are applied to the images in order to reassign to each pixel a radiometric value, closer than possible to that measured in the field according to [44].

3.2.2. Geometric Corrections

Geometric corrections are applied to the images to reduce the geometric deformations that occur during the recording of the scene. These include distortions caused by the environment, distortions due to measurement system errors and distortions from platform movements.

3.3. Treatment of Satellite Images

The treatment applied consisted of the extraction of the study area and the application of the mask, and on the other hand the enhancement of the image (colored compositions, combinations of the bands, analysis in principal components, filtering's) and finally to the extraction of the network of lineaments.

3.4. Extraction of the Study Area and Application of the Mask

The principle of the mask is to make the product of 2 images, an image which is the area of interest and the mask which is a binary image or 0 is assigned to the outer part of the area of interest and 1 to the internal part.

3.5. Enhancing the Image

The objective here is to increase the perception of the image by improving its visual quality, in order to highlight certain elements that characterize the geology namely the faults and the discontinuities.

3.6. Principal Component Analysis (PCA)

The purpose of this method is to combine the different sources of information in order to enhance certain features or properties of the data that are less obvious in the original image. The maximum amount of information is usually concentrated in the first 3 bands.

Table 1. Concentration of information in a ACP of the study area

PC Layer	Eigen Value	Percent of Eigen Value
1	24104,50122	90,256
2	1686,97548	6,3167
3	612,81490	2,2946
4	207,91795	0,7785
5	46,80898	0,1753
6	38,40106	0,1438
7	9,35032	0.0350

3.7. Colorful Composition

Series of composition for three spectral bands was performed to obtain a false and true color image closer to the reality of the terrain. The aim is to identify as much as possible of the soil cover for a better appreciation of the lineaments.

Table 2. Band Ratio Combinations

Band ratios combinations		
6/1 4/2 5/3	2/3 2/3 5/2	3/2 2/1 1/4
1/4 1/5 1/6	6/1 3/4 6/5	3/4 4/2 5/1
3/4 1/5 2/6	4/2 1/3 4/6	3/4 4/2 5/3
5/4 4/5 3/6	6/3 5/4 5/4	3/2 1/3 1/4
2/1 4/2 5/3	1/2 2/3 1/5	3/1 3/4 4/5
3/1 3/2 5/3	2/1 2/4 2/5	4/1 4/3 4/6

3.8. Filter: Convolutions and Morphology

Sobel and directional filters were used to highlight the majority of linear structures. For this work, the 3x3, 5x5 and 7x7 matrix filters were used for the extraction of minor and major structures. The objective is to highlight the different forms of the objects constituting this image, to discriminate the contours and to flatten the image.

Table 3. The matrix of applied filters

-1.15846	-0.173648	0.811160
-0.984808	0.00000	0.984808
-0.811160	0.173648	1.15846

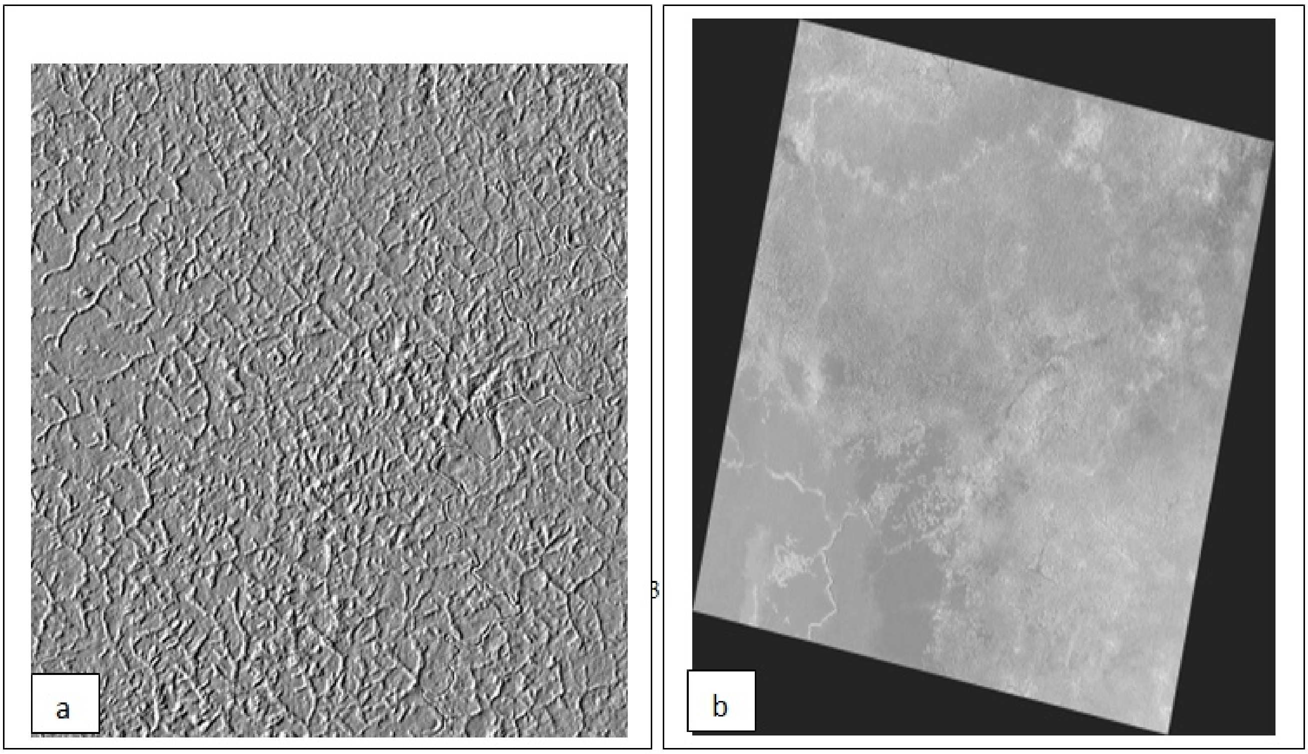

Figure 2. a) Directional filtration 3 x 3; b) Sobel Directional filter 7X7properties

Table 4. Sobel filter 5 x 5 properties

-1.3660	-1.3660	-0.5000	0.3660	0.3660
-1.3660	-1.3660	-0.5000	0.3660	0.3660
-0.8660	-0.8660	0.0000	-0.8660	-0.8660
-0.3660	-0.3660	-0.5000	-1.3660	-1.3660
-0.3660	-0.3660	-0.5000	-1.3660	-1.3660

Table 5. Directional filter 7X7properties; Directional filter angle = 10

-1.1585	-1.1585	-1.1585	-0.1736	0.8112	0.8112	0.8112
-1.1585	-1.1585	-1.1585	-0.1736	0.8112	0.8112	0.8112
-1.1585	-1.1585	-1.1585	-0.1736	0.8112	0.8112	0.8112
-0.9848	-0.9848	-0.9848	0.0000	0.9848	0.9848	0.9848
-0.8112	-0.8112	-0.8112	0.1736	1.1585	1.1585	1.1585
-0.8112	-0.8112	-0.8112	0.1736	1.1585	1.1585	1.1585
-0.8112	-0.8112	-0.8112	0.1736	1.1585	1.1585	1.1585

3.9. Manual Extraction of Lineaments

Pretreated and filtered images on Envi 4.7 are used to draw lineaments and fractures. The QGIS 2.18.21 software was used to draw a lineation map. The first step was to highlight the linear objects of anthropic and natural origins (roads, tracks, alignment of trees) on the image. All the linear structures observed on the image are redrawn. After this digitization phase, the resulting lineaments are validated based on some maps (geological maps, structural maps, topographic maps, previous field work and field work) covering the project area. The attribute table of the lineaments is exported in the DXF format to be supported by the Rockworks 15 software for the realization of the rosette.

3.10. Control and Validation

The structures identified from the Landsat 8 ETM + images were analyzed where the main directions were compared with those of the accidents recorded on the photo- geological map [45]. Data from geological maps and SRTM images have been compared to linear structures extracted from satellite images to give them structural significance [46,47]. When a linear structure such as roads, tracks, boundaries of forests or cultivated areas have been detected, they are directly removed.

4. Results and Discussion

4.1. Image Processing

4.1.1. Principal Component Analysis (PCA)

In order to improve the contrast of the image and to avoid redundancies, it was wise to apply the principal component analysis to the raw image of the study area. Thus, the application of the PCA on the first three bands made it possible to obtain a good percentage on the first three bands. These bands bring together the best information and allowed the tracing of lineaments.

4.1.2. The Density of Lineaments

Density calculates the frequency of lineaments per unit area [48]. The resulting map of the density analysis shows the lineament concentrations per unit area. In this study we used the algorithm Line density in (ArcGis 10.2). The resulting map shows a disparate density of lineaments.

4.1.3. Band Ratios

After the color composition of the image, band ratios were used to identify and distinguish geological structure information. Eleven (11) bands combinations were performed. The best one used for this work to extract lineation is: 3/2 2/1 1/4; 3/4 4/2 5/1, 2/3 2/3 4/1 and 4/2 4/3 4/1 in the RGB color list band (Figure 3-b).

4.1.4. Manual Extraction of Lineaments

Pretreated and filtered images on Envi 4.7 are used to draw lineaments and fractures. The QGIS 2.18.21 software was used to draw a lineation map. The first step was to highlight the linear objects of anthropic and natural origins (roads, tracks, alignment of trees,) on the image. All the linear structures observed on the image are redrawn. After this digitization phase, the resulting lineaments are validated based on some maps (geological maps, structural maps, topographic maps, previous field work and field work) covering the project area. The attribute table of the lineaments is exported in the DXF format to be supported by the Rockworks 15 software for the realization of the rosette.

4.1.5. Realization of the Directional Rosettes of the Lineaments Using Rockworks 15 Software

The directional rosette of the lineaments was realized using RockWorks15 software. This rosette of lineaments is obtained on the basis of the coordinate data of the lineaments imported in the DXF format. It makes it possible to highlight the statistical information on the cumulative lengths and classifies the data by interval of 10.

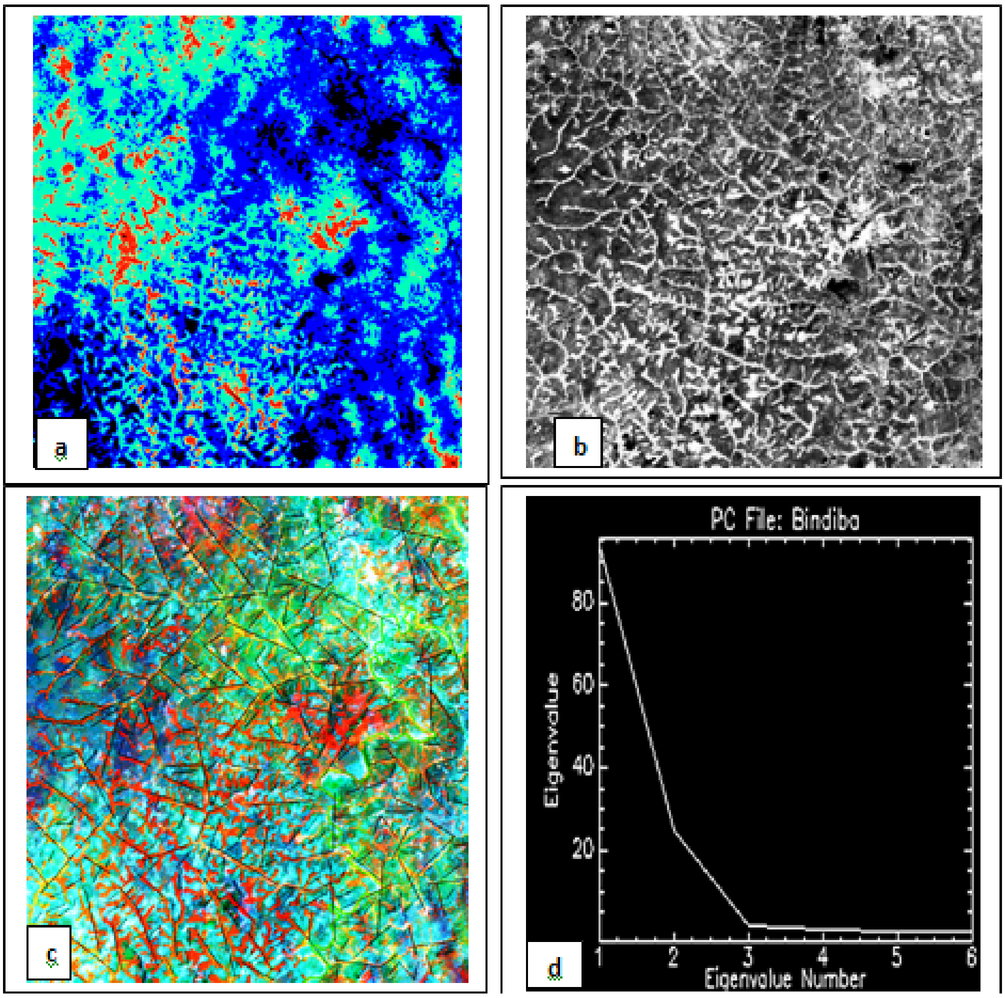

Figure 3. a and d) color composition; b) band rations 3/4 4/2 5/1; c) Sobel filter

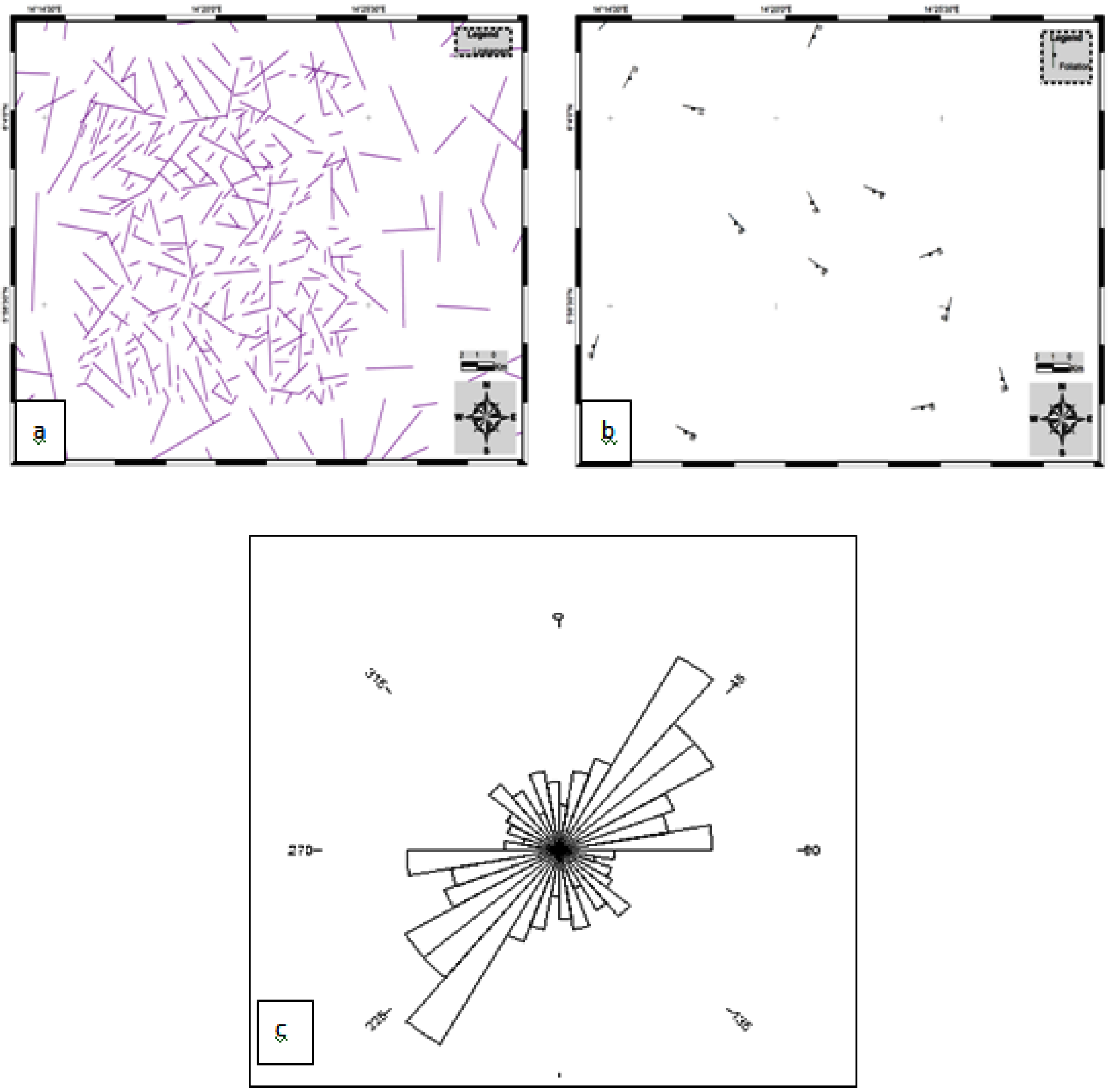

Figure 4. a) Linear map of the Bindiba area; b) foliation map of the study area; c) rosette of distribution of the directions of the lineaments

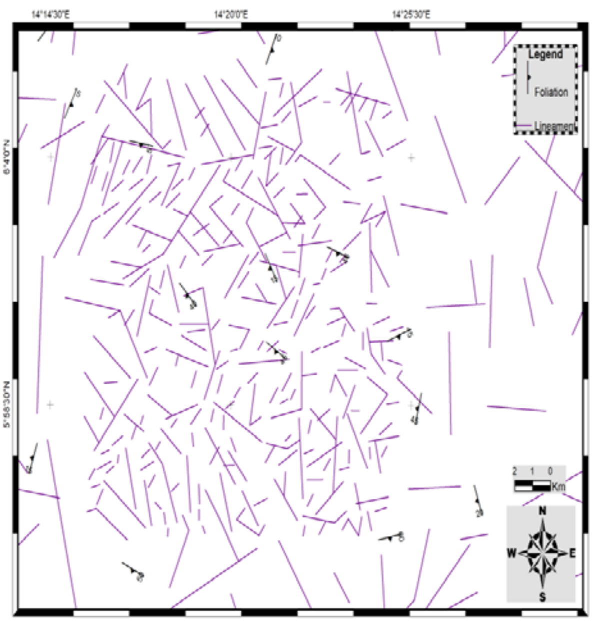

Figure 5. Lineation and foliation map

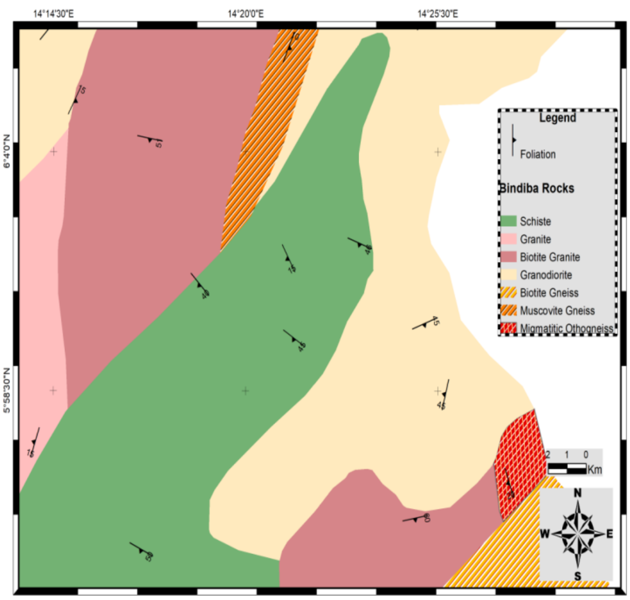

Figure 6. Geological sketch of the Bindiba area

4.1.6. Mapping lineaments

The lineaments represent linear geological objects or alignments of geological objects close enough, topographic discontinuities or geomorphological structures inherited from ancient topographies [49]. In the present work, the extraction of the resulting lineaments of the landsat bands 8+ image has been the subject of a visual interpretation in which the lineaments, and their locally curvilinear junctions, have been highlighted. Figure 5 above gives a good illustration.

4.1.7. Statistical Analysis of Linear Networks

The statistical analysis of the lineament networks made it possible to count 293 linear elements with a total length of 748.28 km. This analysis shows two major families of directions: the principal directions (N30, N50, N60, N90) and the secondary directions (N10, N100, N140, N175).

4.1.8. Structural Significance of Lineaments

The interpretation of the linear map coupled with field data made it possible to distinguish two major meanings to these lineaments: Type I lineaments or penetrative lineaments correspond to schistosity trajectories [50]. This interpretation is confirmed by the field data which revealed NE-SW oriented schistosity planes (N35 to N45) in accordance with the directions observed on the rosette of the lineaments. The shale structure thus highlighted in accordance with the direction of the lineaments extracted from the satellite images is, in places, turned back on both sides by lineaments with a more continuous cartographic pattern. Type II lineaments or non-penetrative lineaments are characterized by greater cartographic continuity and lesser spatial density. These lineaments thus represent the fracturing of the study area. Four (04) large families of management have been highlighted in Figure 5 and they are also consistent with the data from the field including the gold mineralization corridors. These families are: N10E, N45E, N90E, N135E.

Plutonic rocks: they are found throughout the study area. These include granites, diorites and granodiorites. These are rocks that have undergone more or less tectonic formations. In general, the gold exploited in this petrographic type is associated with the quartz veins that intersect these rocks, and sometimes which espouses the direction of the deformation. (Figure 7 A, C and E).

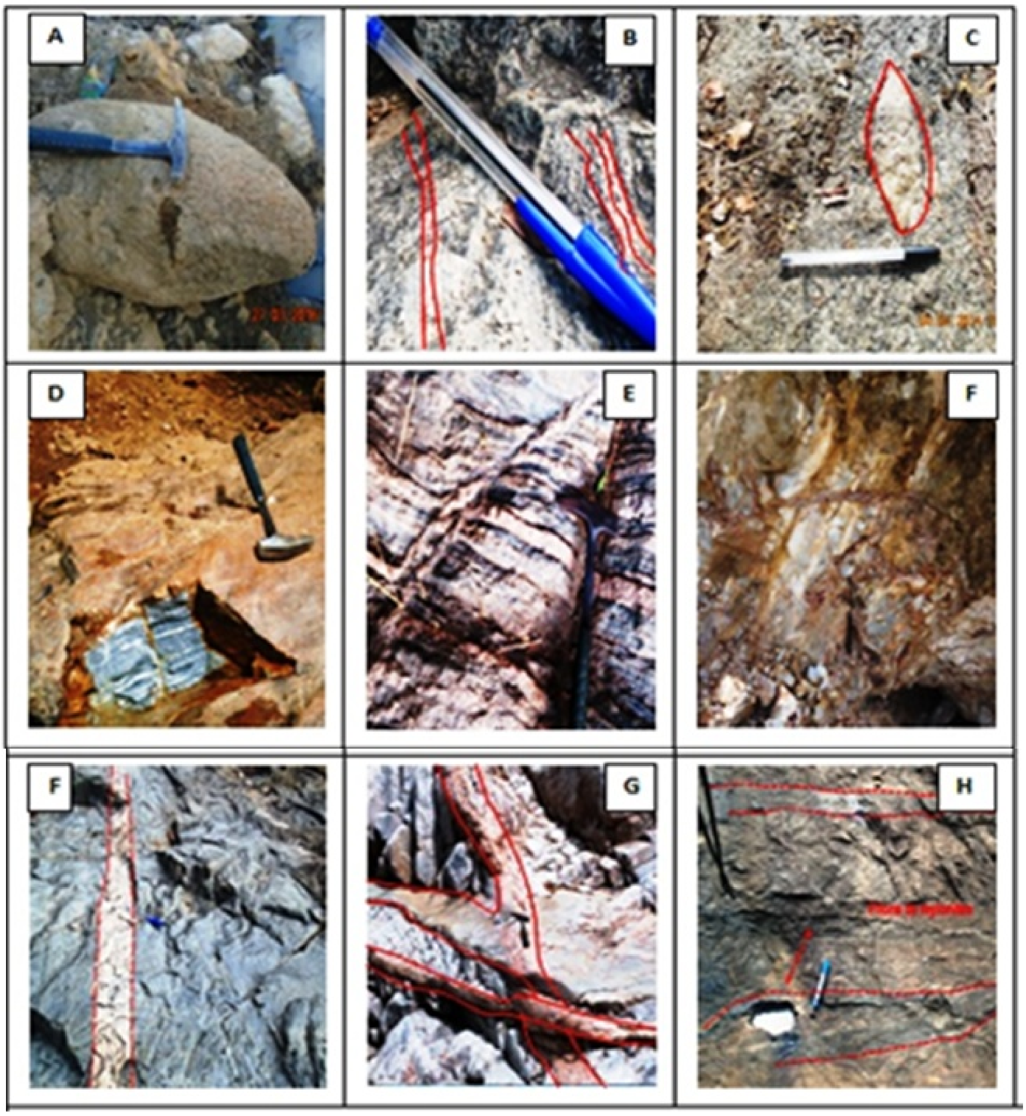

Figure 7. (a) granite outcropping; (b) outcrop of othogneiss slabs; (c) show diorites showing a quartz enclave; d) gneiss showing alternation of light and dark band; e) metagranite; outcropping of weathered schists; f) aplite vein intersecting the orthogneisses; g) pegmatite vein intersecting quartzites; (h) mylonite vein intersecting orthogneiss

Metamorphic rocks: they consist of schists, gneiss, orthogneiss and quartzites. The metamorphic character of these rocks is related to the mechanical organization of minerals (preferential orientation of alkali feldspar phenocrysts, biotite flakes and quartz ribbons or slats) and the deformation marks recorded by them. These rocks are generally intersected by aplitic veins, and pegmatitic and secant and /or parallel mylonites. Some outcrops show clusters of tapered or lenticular basic rocks whose differential alteration leaves ovoid cavities on the gneiss surface. We also note in these rocks, the presence of veins that intersect these rocks or that follow the direction of the deformation (Figure 7 F, D and B).

Vein rocks; Depending on size and minerals, aplitic veins, pegmatitic veins and quartz veins are distinguished. These rocks are also represented by many secant veins and veinlets giving a brittle stockwork appearance to the host rock. Some veins found in the study area are of variable color. (pinkish-black, dark gray) and show traces of metallic sulphides and gold mineralization. (Figure 7 F, G and H).

4.2. Gold Zones

Shales, quartzites, granites, gneisses and diorites are the petrographic types encountered in which gold mineralization is concentrated or disseminated. These rocks are also intersected by mineralized quartz veins. The gold mineralization of the study area is of three types: alluvial gold found in the lowlands of rivers, eluvial gold results from the alteration of the primary vein, and which have not been transported. These can be trapped by an obstacle of relief. They are found in soil horizons containing stone line, at a depth of about 3 to 4m from the surface of the soil, and finally the primary gold which is the subject of this study. Several veins or traces of auriferous veins have been observed in the study site. Sometimes they are traces of veins that have been destroyed for crushing.

For this purpose, 22 measurements of the veins and traces of destroyed gold veins were made and a direction distribution rosette was made (Figure 9). It emerges from this rosette, the main directions N30E, N110E and secondary directions EW and NW, SW. These directions are consistent with the major structural directions established by [51].

Shear tectonics has played a key role in the emplacement of quartz veins (N30E; N110E) carrying gold mineralization in our study area. The superposition of satellite imagery and field data revealed two gold mineralization corridors in the study area. This is the N30E steering corridor and the N105-110E steering corridor.

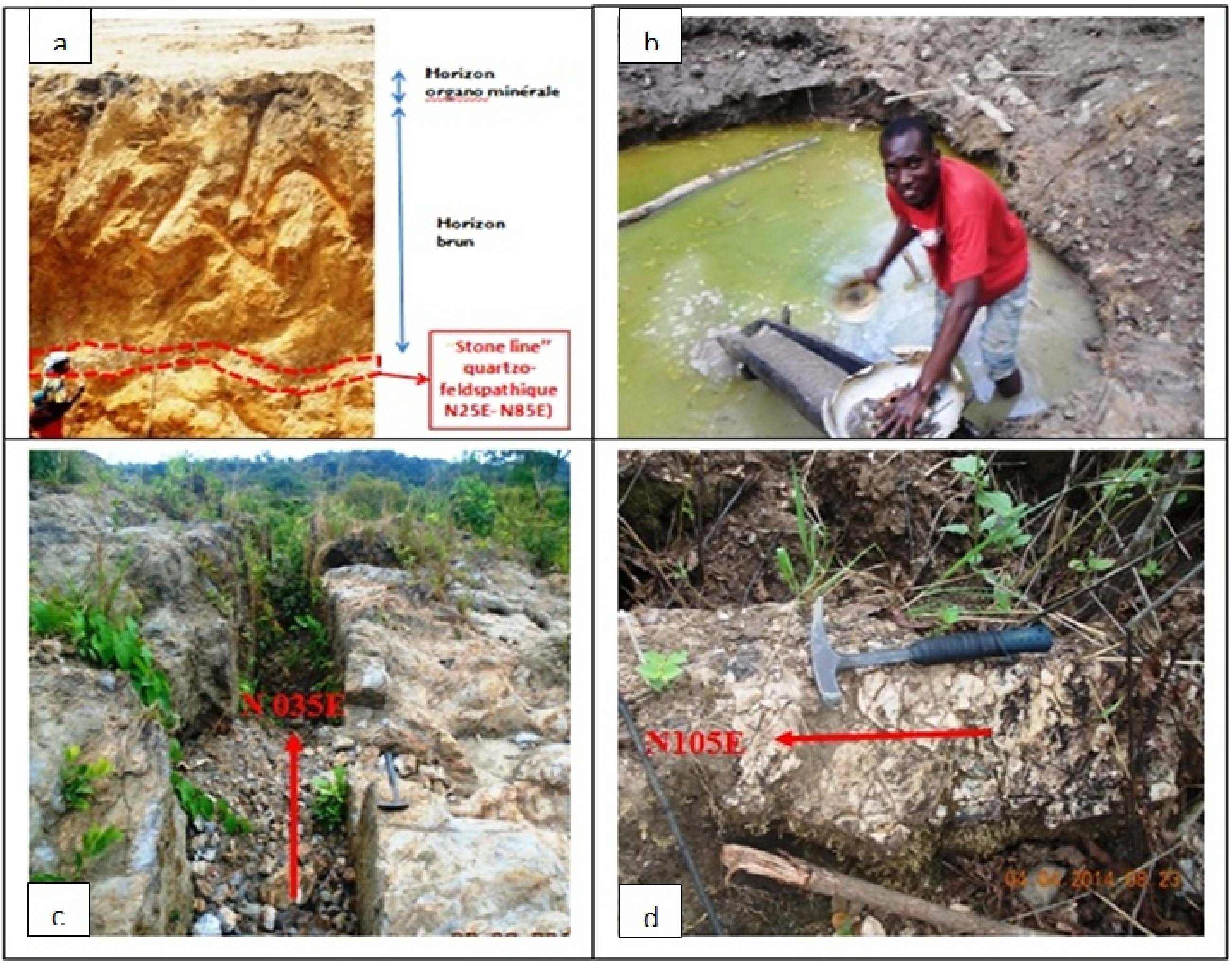

Figure 8. a) Soil profile showing mineralized quartzo feldspar stones; (b) artisanal gold mining in the lowlands; c-d) traces and marks of gold veins

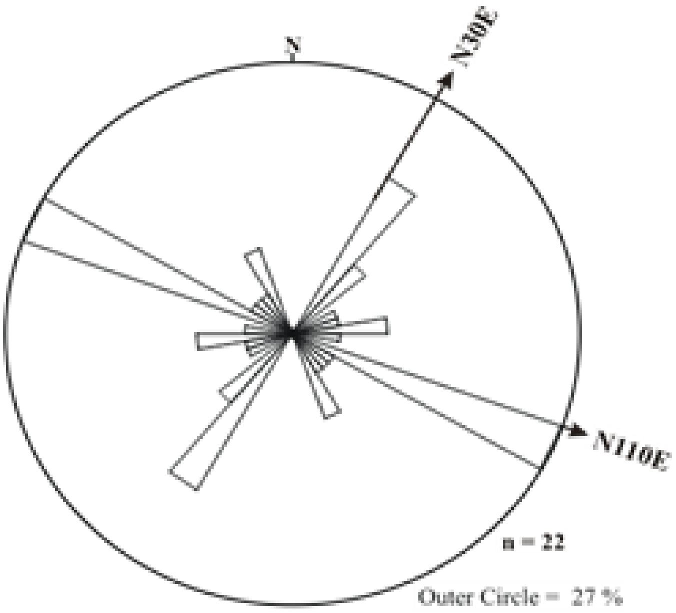

Figure 9. Directional rosette of the gold bearing seams

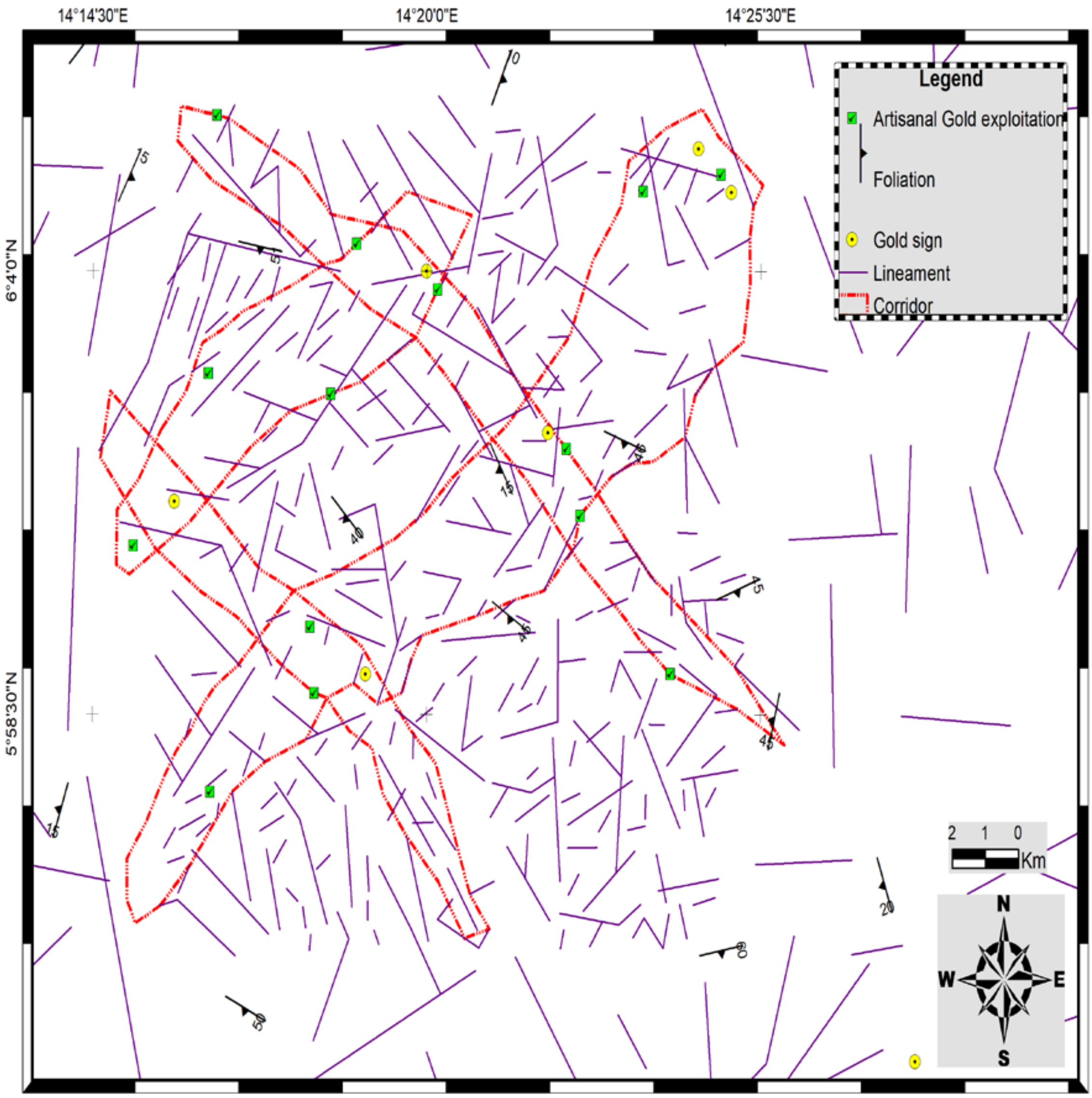

Figure 10. Map showing the gold mineralization corridors of the study area

4.3. Structural Study

Field observations revealed two phases of deformation: a flexible phase (schistosity, foliation, folds) and a brittle phase consisting of clogged joint (vein) and dry joints (fracturing and fault).

4.3.1. Ductile Phase

This phase is found in metamorphic rocks (shale, orthogneiss) and plutonic rocks (deformed granites). This phase is responsible for the S1 foliation. This deformation is observed. In the Lom gneisses, the S1 foliation is characterized by the alternation of quartzo-feldspathic beds and beds rich in ferromagnesian minerals or by the planar orientation of minerals such as amphibole, biotite and feldspars.

In schists, it is manifested by the orientation of phyllites and quartz or alternating levels of composition or grain size or even different colors. This foliation is in places folded in certain lithologic types and has variable attitudes. The directions vary between N5E and N175E with varying dips between 5° and 40° East or West. The stereographic projections of the poles of the attitudes of this rosette foliation above (Figure 12) show a concentration of poles in the dial NE (mayo danagbakoa, and Koumboul) and SE (mayo Mboussa and Lom bridge). These characters attest to the slight dip and wrinkling observed in the field.

In areas of intense deformation such as mylonite corridors, this foliation is completely transposed and rectified by the second phase of deformation. The folds P2 affect the schistosity S. In the orthogneisses, the folds P2 are the asymmetric folds with a long flank and a side flank (Figure 11 b). In shales, the folds P2 are undulations of the So-1 foliation. It is usually large and sometimes crenulated with parallel breaks at the hinge.

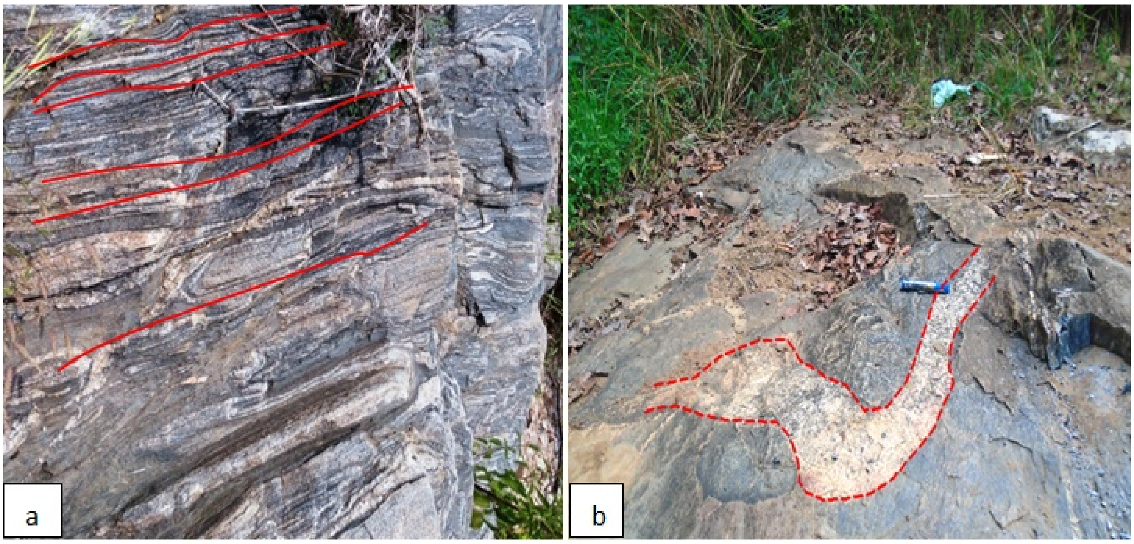

Figure 11. a) outcrop showing orthogenesis of foliations; b) dissymmetrical P2 folds with a long side and a side court in orthogenesis

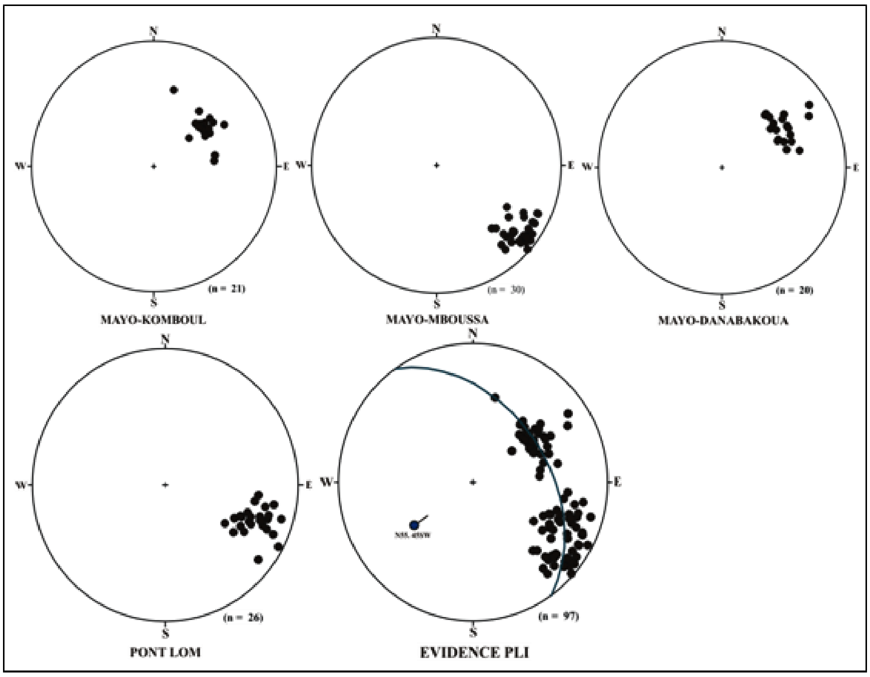

Figure 12. Rosettes showing stereographic projections of poles in the attitudes of the foliations highlighting the presence of fold

4.3.2 The Brittle Deformation Phase

It is represented in the field by joints (vein joints, joints or dry joints) and veins which are non-penetrating discontinuities .The vein joints and diaclases are a set of fracturing networks that highlight brittle tectonics. Their direction varies and most often marries the fracturing plan. The vein joints affect all formations in the study area. The faults in countries in the study area are horizontal component faults we could not measure the dip of the faults because their surfaces were not accessible. The fracture measurements made it possible to construct rosettes of fracture direction distributions. Figure 13, a general rosette was made showing a general direction and a secondary direction. These rosettes of fracturing can be grouped in four types according to the major directions as indicated by the rosettes opposite.

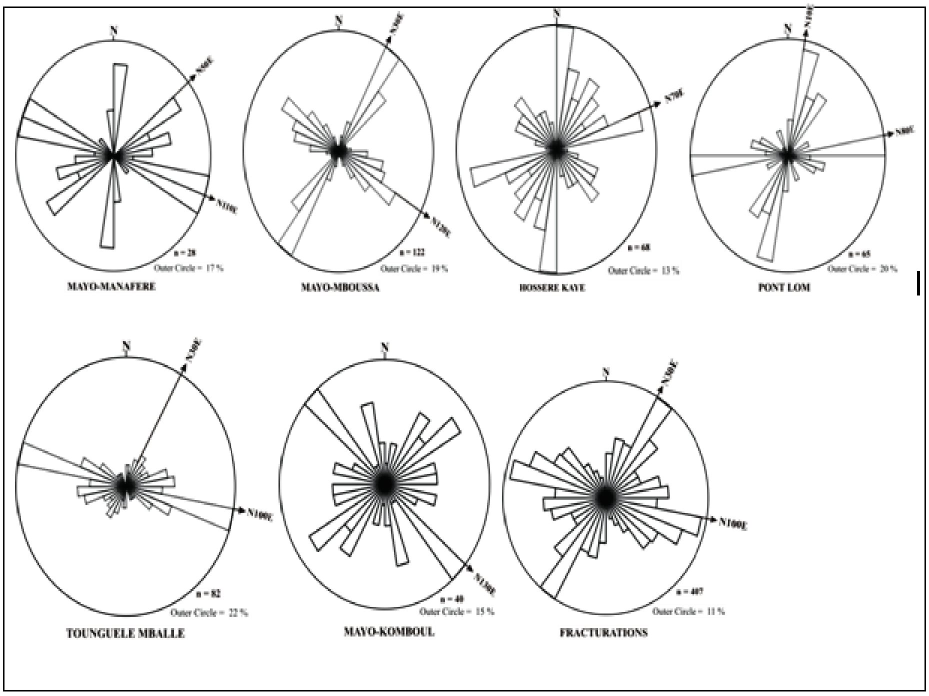

Figure 13. Rosettes of fracture direction distributions

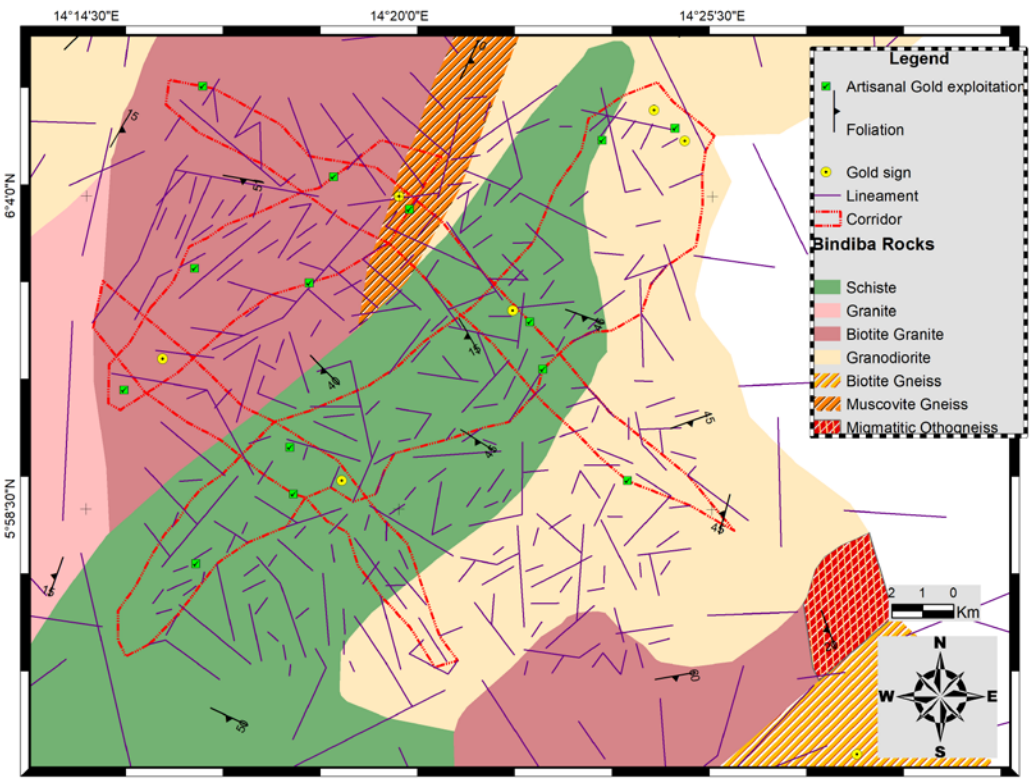

Figure 14. Bindiba geological map showing linear structures and gold mineralization corridors

Finally, the measures distributed in degree of 10 give five principal directions which correspond to the directions well known in the geological history of Cameroon:

- N40-50E: identical to the average direction of the Tchollir é fault (N50E).

- N20-40E: identical in average to the direction of the hot line of Cameroon (N30E) [5] and [53].

- between N60-80E: identical on average to the Adamaoua fault (N70E) [54].

- N50-60E correspond to the many Cretaceous ditches.

- NW-SE corresponds to the direction of the Bénoué ditch and the dexter Tanganyika-Malawi corridor. This being the case, these results confirm the idea that the Cameroon line and the shear of the Adamaoua are set up by borrowing the fracking of the Precambrian basement. They also show that our study area is located in a large shear corridor that would be an extension on the continent of transforming faults located in the Atlantic Ocean. These directions have also been highlighted by [55,56] and [57] and are also identical to those observed in the region of Pernambucco and Patos in northeastern Brazil by [53], and would be favorable to the circulation of fluids. hydrothermal systems that allowed the emplacement of gold veins [26] and deduced auriferous concentration corridors from our study area (Figure 8).

5. Conclusion

The Bindiba Gold District consists of plutonic rocks (granites, diorites, granodiorite), metamorphic rocks (schists, gneiss, ortogneiss, quartzites) and vein rocks (aplitites, pegmatitites, mylonites, quartz). These rocks are sometimes intersected by mineralized gold veins oriented N30 and N110. Field prospecting and Landsat 8 TM image analysis mapped the fractures in this gold district. The statistical study of the lineaments obtained from the satellite image reveals preferential orientations (N45E) for lineaments with curvilinear portions (lineaments of type I called penetrative) and for linear lineaments (non-penetrating: N10, N45, N90 and N135). Type I lineaments, referred to as penetrative, represent the schistosity of the sector of studies, whereas the so-called non-penetrative type II lineaments (5 large families that correspond to well-known directions in the geological history of Cameroon) represent the fracturing of the sector study. The structural study confirmed two phases of deformation in the study area, namely a ductile phase represented by schistosities and folds and a brittle phase represented by vein joints, diaclases and faults. Overlaying satellite imagery, field data, and mineralization indices in gold panning areas have mapped zones favorable to gold concentration and highlighted two mineralization corridors (N35 and N135).

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