

Research Article

Spatial Relations between Geological Structures and Precious and Base Metal Deposits from Magnetic Investigation of the Pangar-Djérem Zone, Cameroon

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Received 9 September 2022; Accepted 4 May 2023; Published 29 May 2023

Academic Editor: Arkoprovo Biswas

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The version three of Earth Magnetic Anomaly Grid (EMAG2-v3) used in this work is aimed at establishing the spatial relationships between tectonic structures and gold and associated mineralization in the Pangar-Djérem area, central and southern Cameroon. Various processing and transformation of image data such as the reduction to the equator, horizontal gradient, generalized derivative, and pseudogravity allowed the identification and delineation of numerous faults related to Syn-D1, Syn-D2, and Syn-D3 deformations. The main orientations, W-E, SW-NE, and SE-NW, obtained from these faults define the intensity of the Pan-African and Eburnian tectonics in the Cameroonian basement. Correlations between mapped faults and mineral occurrences define a structural control of gold mineralization in the study area. Furthermore, the spatial relationships between these faults and the igneous/metasedimentary rocks demonstrate that the Eburnian and Pan-African orogenies favoured the circulation of gold-enriched fluids along faults and shear zones. Gold mineralization in the Pangar-Djérem zone is of the vein type (primary gold), resulting from the intrusion of type I granites and the circulation of enriched fluids in a brittle to ductile shear context. The pseudogravity anomalies associated with the sedimentary deposits/rocks and the SW-NE structures of the Sanaga and Bétaré-Oya Faults define an environment of detrital sedimentary deposits, consisting of metavolcanic and metasedimentary rocks, and justify the existence of gold-bearing quartz veins.

1. Introduction

The study area is located in the Central African Fold Belt "CAFB" [1–3] in Cameroon, between meridians $11^{\circ} 30' 0''$ E to $15^{\circ} 30' 0''$ E and parallels $3^{\circ} 0' 0''$ N to $7^{\circ} 30' 0''$ N (Figures 1 and 2). Numerous geochemistry, petrography, and geophysical studies (magnetic, gravimetric, electromag-

netic, and electrical resistivity) have been carried out to understand its geological context, as to evaluate its mineral potential. A remarkable contribution was the Mining Capacity Building Project (named "Precasem"), which aimed to evaluate Cameroon's mineral potential and produced a 1:200,000 geological map from a series of airborne geophysical surveys over $160,000 \text{ km}^2$ covering six regions (North,



FIGURE 1: Location map of the study area (after [15]).

Adamaoua, West, East, Littoral, and Centre). The geology of Cameroon in general is characterized by Archean massifs and Proterozoic volcano-sedimentary complexes similar to those of the Birimian gold belt in West Africa [4]. Several late intrusive events favoured the development of mineral deposits such as cobalt, nickel, rutile, iron, bauxite, uranium, and gold (alluvial and vein). Since the 1940s, several alluvial gold deposits were discovered in the Lom Basin (Lower and Upper Lom series) and Bétaré-Oya area of Cameroon. A total of 2256 kg of alluvial gold were produced in 1951 from the southeast area of Cameroon [5]. Although the exploitation activities have not been documented since 1951, the gold production continued [4, 6]. Work in relation to gold mineralization in Cameroon has focused on the alteration and variations in the gold grade of the Lom series [7], morphology and geochemistry of gold grains [8], and the occurrence of mineralization [5]. [9] has demonstrated that sulphide minerals bearing hydrothermal fluids are associated with the auriferous vein system in the Batouri gold district. [10] has used an electrical method to delineate favourable gold-bearing structures. [6] found anomalous gold concentrations associated with Pan-African orogeny in N-S sinistral shear zones, faults, and fractures. They demonstrated that U-Th-Pb, W, Nb-Ta-Co-V, Au-Hf, and Cu metal associations reflect the lithological controlled gold mineralization. [11] related the lode-gold mineralization in the Bétaré-Oya gold district to a series of quartz sulphide veins with NNE-SSW trend of brittle-ductile shear zone. [4] has demonstrated that primary gold mineralization displays a spatial and temporal relationship with felsic to intermediate I-type

granitoids. The work of [12] revealed that gold vein mineralizations in Batouri trend NE-SW. [13] revealed that gold ore deposits are found around faulted zones, mostly in the Tcholliré shear zone. [14] has also shown that the gold mineralization along Bétaré-Oya shear zone (BOF in Figure 2) is controlled by structure-oriented NNE-SSW and NE-SW at the regional scale and ENE-WSW at the deposit scale. The gold mineralization, much in demand for its economic value, is becoming increasingly scarce because of the relative lack of new discoveries. In most cases, outcropping ore is not easy to find, which inhibits the expansion of mining exploration. Therefore, it is important to identify new potential mining areas, with little or no expression on the surface, and not previously inventoried. The present work represents the continuation of the above-mentioned work related to the identification and characterization of gold mineralization at a regional scale in Cameroon. It aims to suggest the spatial-temporal relationship between gold mineralization and tectonic structures on the one hand and the gold mineralization related to mafic intrusive bodies on the other hand for the southern and central areas of Cameroon.

2. Geology and Tectonic Setting

Located in the Central African Fold Belt, the study area is mainly composed of Precambrian rocks [1, 3, 16, 17]. The basement rocks can be divided into two main geological domains: Southern Cameroon Domain (SCD) and Adamawa-Yadé Domain (AYD).



FIGURE 2: Simplified geological map of Cameroon highlighting the area of interest the main lithostratigraphic domains of the Neoproterozoic Pan-African orogenic belt. NCD: Northern Cameroon Domain; AYD: Adamaoua Yadé Domain; SCD: Southern Cameroon Domain; KF: Kribi Fault; SF: Sanaga Fault; BOF: Bétaré-Oya Fault; AF: Adamaoua Fault; TBF: Tcholliré-Banyo Fault; CCS: Central Cameroon Shear and the study area (modified from [36, 37]).

The AYD extends from the southeast of the Tcholliré Banyo Fault (TBF) to the south of the Sanaga Fault (SF). It highlights tertiary to current volcanoes, post-Pan-African coverage, syn- to posttectonic granitoids, pre- to syntectonic orthogneiss, Proterozoic gneiss, and orthogneiss [18-22]. The SCD goes from the south of the SF to the southern part of the country. It consists of the Ntem complex, the Oubanguid complex (represented by Meso- to Neoproterozoic unit), and the Yokadouma and Dja groups (Figure 2). The volcanic complex (Cenozoic) is nearly 2000 km long and corresponds to an active thermomagmatic alignment N30°E. It is represented by the Cameroon Volcanic Line (CVL), which extends from the Pagalu Island in the Atlantic Ocean to the Lake Chad [23] in the continental sector. In Cameroon, the CVL is represented by the hot line segment N70°E that corresponds to the shear zones of Pan-African age [24].

The Oubanguid complex corresponds to the polycyclic granitic of Adamaoua base, constituted of syntectonic polycyclic intrusive complex oriented N130°. It consists of remobilized Precambrian formations including magmatic and metamorphic rocks. The Ntem complex corresponds to the northwestern part of the Archean Congo craton in Central Africa [25–31]. It is a homogeneous ensemble, a little various in tonalitic to granitic alkaline composition. The complex is limited to the north by a major thrust that marks the contact with the Pan-African orogenic belt. It covers the southwestern part of the study area and is composed of various rock types organized in granitic, tonalities trondhjemite granodiorites (TTG) suite, and charnockite rocks.

The study area has been affected by intense volcanic and tectonic activity, which allows the highlighting of the basin structure and deep fractures or major crustal lineaments. From this intense volcano-tectonic activity arises three deformation phases associated with granitoid intrusions [21, 22, 29, 32] and three major structural directions: NW, NE, and N30. These latter are coincident with the structural direction of the CVL, the Cameroon Shear Zone (CSZ), the Sanaga Shear Zone (SSZ), and the Tcholliré-Banyo Shear Zone (TBSZ) which correspond to the preferred areas of primary gold and base metal accumulation [33]. Many oxidized and sulphidic mining deposits of great economic importance are present in many of these units (Volcanic, Oubanguid, and Ntem complexes). Ntem cratonic base contains iron, stone quarry material, and gold associated to the charnockitic series and banded eruptive complexes. In the Ntem unit, N-S structural directions are answerable to the implementation of

strong vein quartz; thus, some are auriferous, and the ferriferous formations are organized by a continuous and narrow bundle linked to basaltic gneiss with volcanic origin [34]. The volcanic zone of the Adamaoua polycyclic granitic [1, 35] base abounds with uranium, lead, copper, tin, sapphire, gold, iron, bauxite, pozzolan, olivine, zinc, and manganese set up in favour of the ditch intersections of the Yaoundé group and CVL, associated to ancient granitic and granodioritic tectonized complex, intense volcanic activity, and young magmatic intrusions [4, 34]. The Yokadouma, Dja, and Lom series contain cobalt, nickel, gold, rutile, copper, lead, ruby, iron, diamond, and uranium associated with nickel and cobalt laterites (Yokadouma series), paraderived cover with volcanosedimentary footprints crossed by recent granitoid intrusions, pelitic, greso-quartzitic group (with intrusion in the form of sills, dykes, dolerites, and andesites) [34]. They are polymetallic ore bodies more or less dominated by metamorphosed volcanosedimentary deposits and mineralized intrusions related to rhyolite and rhyo-dacitic volcanism or to the differentiation of basalt magma in the study area. These mineral deposits (gold particularly) are artisanal, mined in detrital sedimentary rocks (conglomerates of East Cameroon region) and quartz veins and becoming increasingly rare, hence, the need to identify new areas of exploitation.

3. Magnetic Data and Processing

3.1. Magnetic Data. The magnetic data used in this study were sourced from version three of the global Earth Magnetic Anomaly Grid 2 (EMAG2-v3 [38]). It is a compilation of satellite, ground, and aeromagnetic data. EMAG2v3 is an updated grid compared to the first local magnetic anomaly grid (EMAG2-v2) from 3-arc-minute to 2-arcminute, by adding track line data over land and ocean. All wavelengths more than 330 km have been replaced with the lithospheric MF7 CHAMP satellite model, and the altitude has been reduced from 5 km to 4 km above sea level [39, 40]. This database contains 11.5 million and more of marine and aeromagnetic data and many precompiled and updated grids [40]. While EMAG2-v2 was based on the synthetic models representing local geology, in order to fill gaps of available data, the EMAG2-v3 is based on available datasets [40]. EMAG2-v3 database better represents the complexity of the anomaly and more accurately reflects the areas where no data was collected. This dataset allowed investigating the tectonic and structural relationships across land and oceanic boundaries, between the continental plate's integrated local interpretation and global context from magnetic data interpretation, and the global mapping of the depth of the Curie isotherm. It was used for comparing and testing geologic hypotheses and models at a global scale ([39, 41] references therein); investigating the crustal thickness, Curie depth, and thermal structures in the Central African subregions-Cameroon, Central African Republic, and adjacent countries [42]; identifying and mapping the deep structures of southern Cameroon [43]; and making a regional interpretation of the West and Central African rift system [44].

In this work, the data was converted to UTM zone 32N (WGS84) coordinates. Considering the low latitude of the studied region, the magnetic anomalies are reduced to the equator [45] instead of North Pole using *Oasis Montaj Educational 9.5.2* software.

3.2. Magnetic Data Processing. Three filters, such as horizontal gradient, generalized derivative, and pseudogravity, were used to examine the spatial characteristics of magnetic anomalies, as some special shape characteristics can aid in geological interpretation. For example, lineaments can infer the presence of faults, geological contacts between different formations, or dykes. Isolated anomalies could be related to intrusions that are often targeted as a heat source of mineralization.

Horizontal gradient is a data processing technique used to sharpen the edges of geophysical anomalies, therefore providing a clearer image of horizontal discontinuities. Used for both magnetic and gravity anomalies, the horizontal gradient, according to [46], is the simplest approach for localizing geological contacts of bodies even buried at certain depths. The gradient along the axis x accentuates the discontinuities along the N-S directions, while the gradient along the axis y highlights W-E-oriented structures. The amplitude of the horizontal gradient for a potential field M, which is given by the expression of [47]

$$\mathrm{HGM}(x,y) = \sqrt{\left(\frac{\partial \mathrm{M}}{\partial x}\right)^2 + \left(\frac{\partial \mathrm{M}}{\partial y}\right)^2},\qquad(1)$$

where $(\partial M/\partial x)$ and $(\partial M/\partial y)$ are the components of the horizontal gradient along the *x* and *y* axes, respectively.

Generalized derivative ([45]; Geosoft Oasis Montaj 9.5.2 Program, Geosoft Mapping and Application System, 2014. Users' Manual) is a more flexible technique used to map lineaments in geophysical prospecting in three dimensions. The method calculates the horizontal derivative or vertical derivative in user-designed direction to highlight a discontinuity in any direction in 3D space. We applied the generalized derivative by setting a zero value to the inclination and filtered the residual magnetic anomalies of second order (Figure 3) with horizontal azimuth angle values $\alpha = 0 \circ$, 20° , 30° , 70° , 90° , 120° , 130° , and 140° , to distinguish anomalies related to N-S, SE-NW, W-E, and SW-NE lineaments associated with the major tectonic and shear zones.

Pseudogravity [48] magnetic transformation is an approach used to study deep magnetic source rocks owing to Poisson's theorem. It is an excellent interpretive tool for the detection of deep magnetic igneous plutons and volcanic deposits [48]. In this work, the pseudodensity distribution was used to characterize the magnetic susceptibility distribution below sediments and to look at the structural geology of the bedrock. The transformation of the magnetic field into a pseudogravimetric field was done using a density contrast of 1 g/cm³, a magnetization of 0.5 gauss, and an inclination and declination of -13.3° and -5.3° , respectively. First, the derivative of the gravity is calculated along the total magnetization vector direction assuming a common source of magnetic and gravity anomalies. The calculation is based on the



FIGURE 3: Generalized derivative anomalies of the study area highlighting the N-S, W-E, SW-NE, and SE-NW trends.

equation defined by [48], in which the remanence magnetization is not considered.

$$\rho = \frac{kH}{\gamma},\tag{2}$$

where ρ is the density contrast, *k* is the magnetic susceptibility, *H* is the total magnetic field intensity, and γ is the universal gravitational constant.

Data processing was made in the Oasis Montaj 9.5.2 software.

4. Interpretation

Since observed, geophysical anomalies are from multiple sources, which means that they cannot be explained solely by surface geological features. To reduce effects other than the geological response to the magnetic field, a few prepro-

cessing is necessary, for example, the elimination of the effects of the magnetic inclination due to changes in latitude. In high latitude regions, it is usually referred to reduction of a pole (RTP). However, when the inclination angle is less than 15° as in our study area, the total magnetic anomalies are reduced to the equator to make them symmetrically central to their corresponding sources. They were processed with -13.3° and -5.3° representing the inclination and the declination of the geomagnetic field, respectively. The processed magnetic anomalies (Figure 4(b)) highlight three main geological terranes. High magnetic anomalies in the central eastern zone represent the syn- to posttectonic granitoids of Adamaoua Yadé Domain. The volcanic and metamorphic domain of northwest zone corresponds to intermediate magnetic anomalies with obvious heterogeneity. Low magnetic anomalies reflect probably metasedimentary and TTG formations of the Yaoundé group in the southern zone. The SW-NE tectonic structure separates the volcanic



FIGURE 4: Magnetic anomalies of the study area: (a) total magnetic field; (b) reduced to the equator (BOF: Bétaré-Oya Fault; SF: Sanaga Fault; CCS: Central Cameroon Shear; TBF: Tibati/Tcholliré Banyo Fault; AF: Adamaoua Fault).

domain (in the west) and the plutonic domain (in the east). The shape of the geological contact at the depth between the plutonic domain and the south-central Meso-Neoproterozoic units is unclear. Therefore, further interpretation that tends to get deep structural geological information is addressed in Section 4.3.

4.1. Horizontal Gradient. The horizontal gradient anomaly (Figure 5) was obtained using [47] approach. The filter allows locating and delineating linear structure such as faults and geological contact base on sudden changing of anomaly intensity. The anomalies are linear and elongated in two preferential directions SW-NE and W-E. Some SE-NW features are present in central-south of study area below the fifth parallel. In general, magnetic lineaments are discontinuities in the anomalies with a clear interruption of one or more magnetic axes of anomalies defined as secant magnetic lineaments. These secant lineaments may present brittle faults transverse to the major SW-NE fault system dominant in Cameroon.

The positive subcircular magnetic anomaly with SE-NW main axis (140 km) between Gouyoum, Bertoua, and Nanga-Eboko (Figure 5) characterizes the presence of mafic intrusion bodies resulting from the subduction of the Congo craton under the mobile zone (Pan-African orogenesis).

4.2. Generalized Derivative. Considering the main direction of the regional stresses syn-D1, -D2, and -D3 (blue arrow, Figure 2) and the above observations from magnetic anomalies, generalized derivatives were performed along four directions: N-S ($\alpha = 0 \circ$), SW-NE ($\alpha = 70 \circ$), W-E ($\alpha = 90 \circ$

), and SE-NW ($\alpha = 130 \circ$). The white dashed lines represent the average trend of anomalies on Figure 3, which show different orientations. Those four generalized derivative results highlight N-S-, SE-NW-, W-E-, and SW-NE-oriented anomalies, related to the direction of main tectonic structure (SF, TBF, AF, BOF, and CCS). In addition, a series of W-Eoriented anomalies ($\alpha = 70 \circ$ and 90°) have an echelon distribution along SW-NE direction. Those different orientations of anomalies might indicate that different tectonic deformation events have influenced the distribution of magnetic rocks. It would be interesting to study their relationship with main tectonic events.

4.3. Maxima Gradient Analysis and Magnetic Lineament *Map.* The source edge detection (SED) tool in Geosoft Oasis Montaj 9.5.2 Program is useful for locating geological contacts or high magnetic contrast bodies by identifying maxima (peaks) on a grid of horizontal gradient magnitudes (Geosoft Oasis Montaj 9.5.2 Program, Geosoft Mapping and Application System, 2014. Users' Manual). After calculating the gradient following x and y, with different values of α , we obtain the magnetic peaks, which materialize the geological structures of the locality. Figure 6 shows the major directions SW-NE and W-E and a slight presence of SE-NW and N-S lineaments trends. They constitute the main boundaries between more or less contrasting susceptibility zones, and many of them may correspond to buried and unmapped structures. The magnetic peaks revealed the presence of linear structures associated with faults or fractures or joints oriented W-E, N-S, SW-NE, and SE-NW. Some major tectonic lines (TBF, AF, SF, and BOF) and the extension



FIGURE 5: Horizontal gradient map of magnetic anomalies reduced to equator.

(between Bétaré-Oya and Baboua) of the Tibati fault towards Central Africa Republic (CAR) are observed. New lineaments are identified with W-E dominance trend, which are mostly observed in the southern area. The maxima in the centre and the east of the study area (Pangar-Djérem) reveal different orientations of lineaments, which reflect the structural complexity of the Cameroonian Precambrian basement and demonstrate that it was subjected to several tectonic events that have given its current geological configuration.

This result makes it possible to highlight the traces of Yokadouma Fault (at SE corner of the map) and the main tectonic structures defined in the region by previous geological and geophysical work of [1, 15, 16]. To the southeast and as in most of the south of the map, the maxima are W-E oriented, referring to Pan-African age lineaments. These magnetic peaks reveal the footprints of the different orogenic cycles (Eburnean and Pan-African) at the origin of the establishment of geological formations, lineaments, and mineralizations. The coupled maxima of horizontal gradient and generalized derivative (Figure 6) reveal most linear structures (faults/fractures/joints) in the form of peaks corresponding to the source's magnetic signatures. The coloured symbols characterize the magnetic peaks obtained from the horizontal gradient (solid black circle) and the generalized derivative (other symbols) according to the values of the angle between 0° and 140°. The simplified map of these magnetic lineaments (Figure 7) shows many secant lineaments with different trend and length between 23.17 km and 163.43 km, the shortest and longest fault, respectively. Seventy-six secant magnetic lineaments are identified and are listed in Table 1. In addition to these new tectonic structures, known faults and shear zones of the region are represented in black bold lines. All brittle faults (vertical, horizontal, or oblique) represent discontinuities (contrast, breakage, or abrupt rupture of magnetic susceptibility with

or without displacement, i.e., a clear stop of one or more magnetic ridges or anomaly axes). These fragile deformation zones are favourable for precious and base metal mineralization. In Figure 7, the SE extension of the Tibati fault corresponds to the lineament passing south of Baboua. The SW extension of the Sanaga Fault is attributed to the SW-NEoriented lineament from NW of Yaoundé to NE of Nanga-Eboko. The SW-NE elongated anomaly to the southeast of the map is positioned in favour of the Yokadouma Fault. In connection with the works of [1, 16, 49-52], these lineaments confirm the existence of two structural domains whose susceptibility contrasts refer to Eburnean and Pan-African orogenesis. The first, associated to Paleoproterozoic (3.2-1.8 Ga [53, 54]) formations of Nyong and Ayna, is characterized by SW-NE, SE-NW, and N-S lineaments (18.41%). The latter (N-S trend), which are highly observed in the southern part of Cameroon, are responsible for the establishment of several gold-bearing quartz veins. The second orogenesis marked by Neoproterozoic formations (1000 ± 10) and 500 ± 50 Ma [32, 52, 55]) corresponds to the known major structural (black bold lines) and those newly obtained, represented by W-E, WNW-ESE, and WSW-ENE lineaments. The SSW-NNE-oriented lineaments (7.89%) attached to the N30° and N70° corridors of the CVL characterize the Adamaoua volcanoes (tertiary to current [56]) with Pan-African age.

Table 1 is a summary of the information specific to each type of secant magnetic lineament preferentially oriented W-E, ESE-WNW, SW-NE, and SE-NW. W-E lineaments are most present in the south, on cratonic, Oubanguides and late to syntectonic subalkaline formations. From this table, it can be seen that 57.87% of the lineaments are linked to the Pan-African event compared to 42.08% for Eburnean orogenesis. This shows that the Cameroonian Precambrian basement has been mainly affected by Pan-African tectonics, favouring



FIGURE 6: Magnetic peaks of horizontal gradient and directional gradient anomalies of the study area.

the establishment of new geological formations in association with mineralizations in precious metals, base metals, and hydrocarbons.

The statistical study was carried out based on the analyses of previous geological and geophysical studies. Figure 7 synthesizes the features that showing the Cameroon basement has been highly faulted and deformed. The directions of the obtained lineaments are represented on rose diagrams as known faults and shear zones (a), magnetic lineaments (b), and combination of both results (c). This makes it possible to correlate the directions of lineaments with the mineralized bodies.

The first rose diagram presents two major trends (SW-NE and N-S) which relate to the directions of the Eburnean tectonic structures (1.8-2.4 Ga). Rose diagram (b) and (c) show a predominance of subhorizontal directions W-E and WNW-ESE directions dated Pan-African (0.5-0.6 Ga). The latter are the result of the replay of older subvertical faults in a dextral or sinister direction during the Pan-African orogeny. According to [57, 58], W-E and some SW-NE and SE-NW faults resulted from deformations and remobilizations during the Pan-African orogeny (about 600 to 500 \pm 50 Ma). The first two lineament directions (N30° and N70°) favour the establishment of volcanic massifs and the intrusion of plutonic formations (500-600 Ma). The third lineament trend (SE-NW: present in the northern east area of the map) refers to Eburnean orogenesis. As for the ENE-WSW lineament, it reflects the subduction direction of the Congo craton under the Pan-African belt. Its intersection with the N30° direction of the CVL contributes to the establishment of anorogenic complexes [59]. Those old faults probably have periodically replayed over time and where basalt, dolerite, and ultrabasic rocks are found. The correlations between this map and the geological map reveal an almost uniform distribution of lineaments over the rocks encountered and positions that best coincide with those of volcanic intrusions and quartz veins, some of which are believed to be gold bearing. These intrusions are complex in composition (migmatite, granite, granodiorite, diorite, metasediment, and meta-volcano-sediment) and might be the result of the different orogenic phases and tectonic deformations.

4.4. Magnetic Sources and Mineralization

4.4.1. Residual Anomalies. Apart from some specific cases, such as iron formation, usually the short wavelength magnetic anomaly represents a shallow source, and the long wavelength anomaly reflects a deep source [60]. The contributions to the magnetic anomaly from different sources are summed in the measured total field. In the case of mineral potential evaluation, the ideal exploration target would be up to 3 km deep. Therefore, the separation of shallow source response of those targets from deeper sources is relevant.

In this study, polynomial fitting [61] is first used to perform regional/residual separation. The second-order polynomial surface is retained to represent the regional field,



FIGURE 7: Map of tectonic structures in the study area and corresponding rose diagram directions ((a) the directions of the major tectonic lines, (b) the direction of the identified magnetic lineaments, and (c) the direction of the tectonic structures in the study area).

Data	Lineaments	Number	Directions	Percentage	Length min (km)	Length max (km)	Signification	Orogenesis
EMAG 2	Secants 76	29	W-E	38.15	23.17	89.58	Brittle faults	Pan-African (0.55–0.6 Ga
		3	WSW- ENE	3.94	25.28	108.45		
		12	ESE- WNW	15.78	28.92	163.23		
		10	SW-NE	13.15	26.45	116.52		Eburnean (1.8–2.4 Ga)
		6	SSW-NNE	7.89	24.28	98.71		
		9	SE-NW	11.84	32.78	95.96		
		2	SSE-NNW	2.63	41.25	70.35		
		2	N-S	6.57	27.19	93.25		

TABLE 1: Propriety of magnetic lineaments.

because the extracted residual anomalies reflect betterknown geological features. The residual magnetic anomalies vary from -243 nT to 196 nT (Figure 8). Negative anomalies are observed at Yokadouma (S1) corresponding to the Paleoproterozoic series in east south. The correct sentenceThe negative anomaly observed at Yokadouma (S1) corresponds to the Paleoproterozoic series of south-eastern Cameroon. Those observed north of Yaoundé (S2 and S3 elongated SW-NE) are associated with metasediments. The Sanaga Fault marked the east margin of S3 from Goyoum to CAR along SE-NW direction.

Gold is the most dominant mineral occurrence in the study area. The most mineralized part is the eastern region

(Cameroon and CAR), which are abundantly observed at Bétaré-Oya mainly sedimentary and granitic rocks in shear zone context, containing pinched flakes of Lom schists [34]. Most of the faults which control gold mineralization distribution are found in granitoids (Pan-African age), migmatites, TTGs, charnockites, and also in metasediments and meta-volcano-sediments formations. The concentrations of gold mineralization near or along the faults are the result of a major tectonic event (Pan-African orogenesis) and folding of boulders subjected to increasingly high temperatures (catazonales). The tectonic structures associated with this orogeny represent excellent areas of accumulation of useful minerals in the form of gold rich in quartz

Ga)



FIGURE 8: Residual field illustrating the main tectonic lines and the various mineral occurrence extracted from the maps "Geology and mineral resources of Cameroon, [62]" and "Potential mining sites in the Central African Republic, in [63]."



FIGURE 9: Pseudogravity anomaly map of the study area.



FIGURE 10: Spatial relationship between mineral occurrences, fault system, and igneous/metamorphic/sedimentary rock extracts from EMAG2-v3 data grid.

veins and associated minerals (pyrite, hematite, and other metallic sulphides). Most of the mineral occurrences are concentrated on positive magnetic anomaly areas. Therefore, further study on the plausible sources of those anomalies is necessary.

4.4.2. Pseudogravity. Pseudogravity transforms [60] have been applied to the total magnetic intensity grid using FFT filter package available in *Oasis Montaj*. This operation is aimed at detecting the presence of deep magnetic igneous rocks and looking at their spatial distribution related to known mineralization. In the present study, we only produced the pseudogravity field, but not residual pseudogravity anomalies; therefore, the source of pseudogravity will not be quantified. The pseudogravity anomalies (Figure 9) have a WSW-ENE to W-E preferential orientation. The high gravity reaches 3.0 mGal and might be due to the presence of deep high magnetic source of Pan-African in the northern and the southern area. The most significant anomalies are

observed at Yokadouma and south of Bengbis on cratonic formations (>2700 Ma [64]) and NW and NE of Ngaoundéré on tertiary presenting volcanic rocks. The lowest gravity is observed in the centre of the map. From Tibati-Ngaoundal to Ayos, it covers 323.5 km. This anomaly reflects either a crustal thinning or the presence of light bodies such as sedimentary rocks or both. Analysis of this map reveals three distinct lithostructural domains. The lowest gravity observed at Goyoum, Bétaré-Oya, Baboua, and Bouar refers to the existence of a sedimentary basin or a collapse ditch that would have been filled with light sediments. This is the most likely hypothesis, as the N-S extension (369.1 km, evaluated between the gravity curves equal to 0 mGal) outlines more or less the Sanaga basin (320 km) as proposed in 1975 by [65]. The ENE orientation highlighted by these gravities coincides with that of the Central African Shear which contains useful mineral substances. The integration of pseudoravity into the geological map reveals high gradients associated with highly mineralized igneous rocks (late

syntectonic granitoids and volcano-sedimentary formations) resulting from continental collisions. The locations of this potential mineralization are in agreement with the anomalies of the generalized derivative. This shows that the region's mineral resources (particularly for subsurface and deep sources) are structurally controlled.

4.4.3. Spatial Relation between Geological Structures and Mineral Occurrence. In Cameroon, mining research to determine the origin and potential gold deposits is very limited. The few results obtained remain the property of the government or national/international investors. To establish the relationship between geophysical lineaments and gold mineralization, the analysis was done by combining all magnetic lineaments (Figure 10) on mineral occurrences. The concentrations of gold occurrences observed at fault intersections (Bétaré-Oya, Bengbis, Yokadouma, and Messok) and in the shear zones demonstrate that structural events and hydrothermalism influenced the mineralization in the study area and favoured the birth of gold-bearing quartz veins. Our result is in accordance with the work result of [66] in Canada. In the study area, gold occurrences were widely observed along and near SE-NW-, SW-NE-, WSW-ENE-, N-S-, and W-E-oriented faults and shear zones, and they present potential primary gold targets in the area. At Bengbis, the iron occurrences are controlled by the SW-NE to WSW-ENE and N-S trending faults, which seems to represent the preferential orientation of the gold mineralization. According to [67-69], gold mineralization in the study area can be found in the banded iron formation "BIF" in the form of small inclusions or in microfractures. In the same locality, nickel is associated with the SE-NW and SW-NE lineaments. Cobalt at the south of the map binds to the SW-NE, SSW-NNE, and N-S faults. Bauxite at Tibati and Ngaoundal is observed along the SE-NW and SW-NE structures at WSW-ENE and in association with the gold occurrence on the Tcholliré Banyo shear. This suggests that mineralization in the study area has been set up in favour of a fault and shear zone system.

Three types of zones for mining interest have been identified: (1) high pseudogravity, which implied in deep intrusive bodies and/or volcanic rocks (north and south of the study zone); revisiting gold-bearing magmatic locations, it was noticed the occurrence of simple veins occupying fissures, structures related to crustal discontinuities and shear zones, associated granitic rocks, and metamorphic rocks [70]. (2) Low gravity is associated with sedimentary deposits/rocks (centre) and SW-NE structures of the SF and BOF, defining a detrital sedimentary deposit environment (sedimentary basin). This sector consists of metavolcanic and metasedimentary rocks containing gold-bearing quartz veins. In a geological context dominated by metasediments, plutonic, and volcanic igneous rocks, the faults in the study area would have been filled with fluids enriched in gold and base metals resulting from the combined action of Pan-African tectonics, metamorphism, and regional magmatism. (3) The latter zone to the southeast of the map is thought to consist of a series of quartz veins mineralized in brittle and ductile shear zones with SW-NE, W-E, N-S, and SSW-NNE trends. It is a gold-bearing vein mineralization found in quartz veins (such as revealed by [5, 10]), resulting from an intense tectonic event and accompanied by granitoid intrusion and fluid flow (case of gold in the Tcholliré shear zone and the localities of Bandjoukri and Rey Bouba).

5. Conclusion

The present work tends to establish the spatial relationships between magnetic lineaments, structural geology, and precious and base metals. From this work, the following conclusions can be drawn:

Magnetic lineaments highlight a system of W-E-, SW-NE-, and SE-NW-oriented faults that define two structural domains (Adamaoua Yadé and Congo craton) characterized by different magnetic intensity and SW-NE- and W-E- oriented structures and testified the intensity of the Pan-African and Eburnean tectonics on the Cameroonian Precambrian basement (Central Africa).

Gold mineralization in the study area corresponds to goldbearing quartz veins found in volcano-plutonic environments and detrital sedimentary deposits occupying fissures, crustal discontinuities, and shear zones (NE, NNE, and N-S) and associated with granitic and metamorphic rocks.

Three zones of mining interest are identified: two at the high pseudogravity area associated with deep intrusive bodies and/or volcanic rocks (North and South) and one at the low pseudogravity area associated with sedimentary rocks (centre).

Gold and associated minerals in the study area are structurally controlled and spatially and temporally related to granitoids (type I granite, granodiorite, and diorite).

Most of the mineralization found in Cameroon is controlled by important tectonic (faults and shear zones) and complex regional geological structures buried in the crust which have been activated and reactivated several times. The study area is therefore a prime location for the accumulation of gold mineralization for which the information generated is essential for the detection of potential sites for small-scale primary gold mineralization in the region.

Data Availability

The EMAG2-v3 data used in this work were obtained free of charge from the NOAA (National Oceanic and Atmospheric Administration) database.

Additional Points

Code Availability. Data processing was performed with Geosoft Oasis Montaj 9.5.2, Adobe Ulustrator CS3, Global Mapper 13.2, RoseNet 1.0, and ArcGis 10.5.

Conflicts of Interest

The authors approve the submission of this article for publication and declare no conflict of interest.

Acknowledgments

The authors would like to thank the organizations whose names appear on this address http://geomag.org/models/ EMAG/acknowledgments.html for providing them EMAG2-v3 magnetic data used in this work. They would like to express their gratitude to the AUF (Agence Universitaire de la Francophonie) and the IRME-UQAT, Canada, for their support in the finalization of this project. This work was supported by the Agence Universitaire de la Francophonie, which provided the financial means to travel to the Institut de Recherche en Mines et Environnements (Université du Québec en Abitibi Témiscamingue) where most of the work was done.

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