

# A Regional Structural Mapping Approach for Mineral Exploration: Application in the Southwestern Region of Burkina Faso

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## Abstract

From a harmonized structural map at the scale of a portion of SW Burkina Faso (90 × 80 km<sup>2</sup>), we targeted prospective zones on the basis of structural criteria and structure-geology relationships. The map was constructed from an aeromagnetic image, and the geology was deduced from old geological maps. The procedure involved extracting the magnetic fabric and deducing the deformation gradients, which led to the identification of shear zones. Analysis and interpretation of the structural geometry of the obtained structural pattern led us to target areas of interference between structures or geology-structures interplays, which are conducive to the deposition of metallic elements. The subsequent overlay of known gold prospects and deposits documented in the region revealed the validity of the predefined prospects. This result reinforces the applicability of the methodology as a first-order regional approach to mineral exploration.

## Keywords

Magnetic Fabric, Shear Zones, Targeting, Gold Mining Exploration, sWAC, Burkina Faso

## 1. Introduction

Petro-structural mapping and targeting prospective areas are crucial and are a

priority step in strategic mining exploration. These activities give orientations to the pursuit of investigation (tactic exploration) but need time and money for realization. Hence, the management of time in exploration is a need to reduce the cost of investment. The targeting of prospective zones can be assessed as quickly as possible by applying structural geophysics in cartography. Indeed, geophysical data such as aeromagnetic survey images give an excellent overview of basement geology at the expense of sedimentary covers [1]-[3]. This facilitates the extraction of some characteristics, such as magnetic trajectories, which are related to deformation because of the good agreement of their trend with those of the planar fabric [4] [5]. The magnetic trajectories of an area underline the magnetic fabric that can be assimilated to the tectonic fabric whose analysis and characterization result in the identification of shear zones or and/or folds. This procedure allows us to understand the timeline of structural deformation and to search for possible relations between structures, lithologies and mineralizations applied in exploration.

In Burkina Faso, like in other countries of West Africa, the research of mining resources and their access are hindered by the ubiquitous presence of lateritic and cover that hides structures and dilutes surface anomalies [6]-[8]. Then, the use of structural geophysical mapping in this context is necessary to bypass these difficulties. It is notably justified during the exploration phase (so-called strategic phase) when the identification of target prospects is biased by the scarcity of fresh rock outcrops. So, we present in this document a regional structural mapping realized from aeromagnetic geophysical images covering a portion of SW Burkina Faso. We built a structural map covering an area of  $90 \times 80 \text{ km}^2$  (largely superior to the average size of an exploration permit), and showing a harmonized view of the internal deformation structure and a refined geometry of shear zones. This result, associated with regional geology, has proven to be relevant for the identification of prospective target zones that are validated by the documented presence of many gold prospects, indices and deposits.

## 2. Geological and Structural Contexts

### 2.1. Geographic Localization

The study zone is centered on Diebouougou city, and covers the administrative provinces of Bougouriba, Ioba, and a minor part of the provinces of Poni in the SW, and Tuy in the NE (**Figure 1**). It covers a total area of  $7329 \text{ km}^2$ . The biggest locality is Diebouougou, accessible from the national roads RN12, RN20 and RN27 (**Figure 1**).

### 2.2. Regional Geological Setting

The study area belongs to the Baoule-Mossi province of the meridional West African Craton of Leo-Man Ridge (**Figure 2**), stabilized around 1.9 Ga [9]. This Paleoproterozoic age domain is also called Birimian province. It is juxtaposed by the Kénéma-Man province in the west, which is an archaean crust strongly remobilized and restructured during the magmatic and tectono-metamorphic events

related to the formation and the deformation of the birimian domain [10] [11]. The Baoule-Mossi domain is composed of greenstone belts and a vast surface of gneiss-granitoids (Figure 2). The greenstone belts are composed of meta-volcanic rocks varying from tholeiitic basalts to calc-alkaline andesite, dacite and rhyolite, of meta-volcano-sedimentary units (pyroclastite) and meta-sedimentary units (meta-argillite, metapelite, meta-sandstone, carbonates) (see synthesis in [12]). These metavolcanic and meta-volcano-sedimentary assemblages constitute the Birimian formations. They are unconformably overlain by sandstone-conglomeratic units of the Tarkwaian [13] [14]. These authors consider that the Tarkwaian sediments are deposited in a continental rift setting by shallow water [12] [15].

Granitoids are the dominant lithologies of the Baoule-Mossi province (Figure 2). They outcrop as vast batholith bordering the greenstone belts or intrusive within them [16]-[19]. Aside from that, mafic intrusions are also reported in many parts of the Baoule-Mossi province (amphibolite, gabbro and diorites) [20] [21]. A review of geochronological ages of granitoids in the Baoule-Mossi province allows distinguishing three successive generations of magmatism [7] [17]-[19] [22]-[26]. They are: i) first generation granitoid characterized by large tonalitic-trondhjemite-granodiorite (TTG)-like unit having a calc-alkaline affinity; ii) potassic calc-alkaline intrusion in TTG-like and in greenstone belts, iii) alkaline syenite, syenogranite and granite.

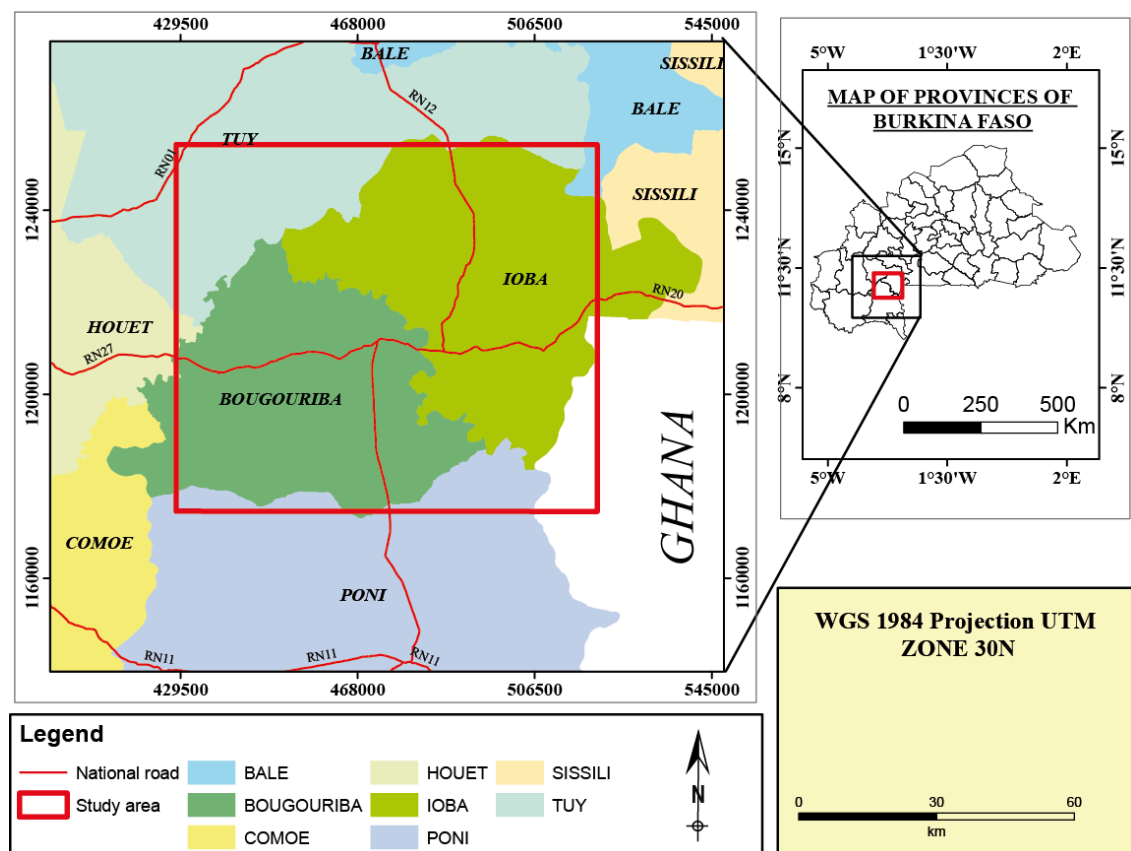
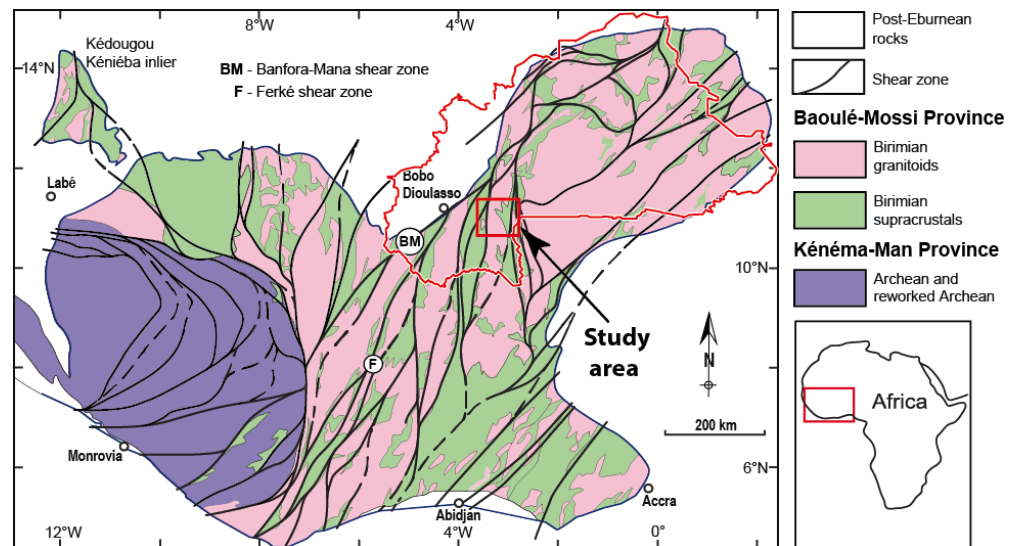


Figure 1. Administrative provinces of Burkina Faso (SW). The red frame delimits the study area.

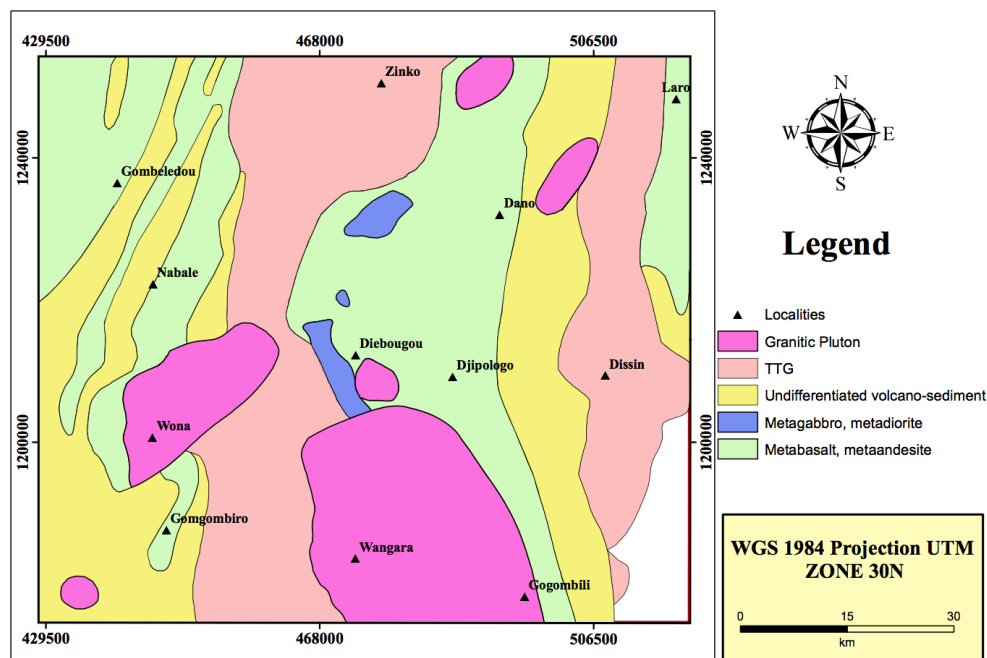


**Figure 2.** Geological map of the southern West African craton (modified after [4]). The red polygon indicates the political borders of Burkina Faso, and the study area is marked by the red quadrilateral.

The formation of granitoids is generally accompanied by metamorphic contact reaching amphibolite facies [17] [18] [27]. However, the birimian formations of the Baoule-Mossi domain are affected by regional metamorphism of greenschist facies. In some birimian belts in the NE, high-pressure metamorphism typical of subduction zones has been identified [28]. The documented metamorphic facies are synchronous with the regional shortening, induced by the eburnean orogenesis between 2.17 Ga and 1.9 Ga [10] [29] [30]. This compression results from the collision between the two crusts of contrasting ages (archean and paleoproterozoic) of the southern West African craton. So, the petro-structural evolution of the Baoule-Mossi can be summarized into a long period of juvenile magmatic accretion [31] [32] and a compressive long-lasting deformation following the collision of the younger crust with the Archean Kenema-Man domain around 2.0 Ga [11] [24].

### 2.3. Local Geology

The study area covers square degrees (geographical units representing a square area where each side is equivalent to one degree in geodetic coordinates) of Houndé, Léo, and Gaoua-Monoa. It presents a portion of the greenstone belts of Houndé in the west and Boromo in the east (Figure 2 and Figure 3). These belts are separated by TTG-like granitoids (Figure 3). The Houndé greenstone belt is oriented NNE-SSW, while the Boromo belt takes on a primarily N-S direction, slightly curved and convex to the west (Figure 3). The two greenstone belts are metamorphosed to greenschist facies and locally reach amphibolite facies in the aureole contact of granitoids [22]. Biotite granite and alkaline granite plutons are intrusive in the lithologies of the greenstone belt in the south and the NE (Figure 3; [20] [22] [33] [34]). The more or less elliptic to ovoid shape of these intrusives (Figure 3) accounts for their syn to late-tectonic nature.



**Figure 3.** Synthetic geological map of the study area (modified from [33]-[36]).

#### 2.4. Tectono-Metamorphic History of the West African Craton and Genesis of Gold Deposits

The southern West African Craton is both an accretionary orogen of juvenile magmas and a collisional orogen. The combination of these two characteristics seems to be the main and underlying cause of the numerous gold deposits and occurrences present in the craton. This abundance led to the recognizing of the West African Craton as the first gold paleoproterozoic province in the world [15] [37]-[40]. The formation of mineralizations results from a complex history of sedimentary, magmatic and tectono-metamorphic events related to the Eburnean orogenic cycle between 2.27 and 1.96 Ga [10] [14] [24]. The spatial repartition of documented gold deposits and prospects is not random, but is correlated with magmatism, metamorphism and deformation zones [15] [41]-[43]. This association suggests that pre-orogenic gold concentration can occur under high-grade metamorphism between 2.25 and 2.12 Ga [12] [14] and late orogenic gold concentrations under low metamorphism degree [40] [44]-[47], maybe during retrogression.

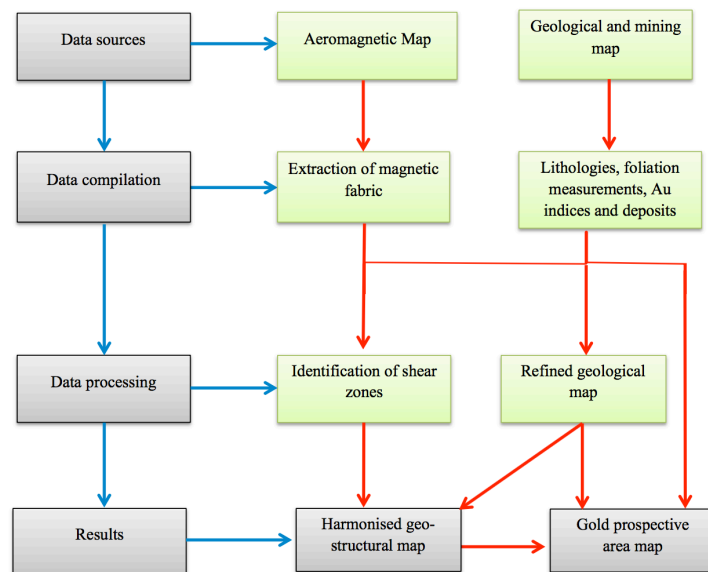
The analysis of relationships between most of the reported gold deposits in birimian geological context, and the regional deformation suggest that gold deposits belong to orogenic type (having a strong structural control), occurring after metamorphic peak with the remarkable presence of plutonic intrusions [15] [39] [48]-[51]. This setting can be explained by the fact that in these deposits, deformation and the post-peak or retrograde metamorphism from the eburnean orogeny created a structural context that is favorable to the genesis and circulation of mineralizing fluids. This setting also permits the remobilization and reconcentration of an important amount of gold in the preexisting structural traps (folds, shear

zones...) or neoformed traps (veins, faults...) in late Tarkwaian metasediments [14] [43] [47] [52]-[55]. However, the areas favorable for gold mineralization are mainly categorized, based on their structural geometry and/or the cinematic timeline, as release zones, extensional relay zones, dilation zones, changes point in shear zones/faults directions, and above all, interference zones [39] [56]. The present study aims to constrain these favorable zones using a regional and structural mapping approach on an area of  $90 \times 80 \text{ km}^2$  in the SW of Burkina Faso. We will reveal the regional internal structure of the study area (specifically the shear zone, their geometry and their kinematics), and we will provide target areas according to the structural and litho-structural relationships.

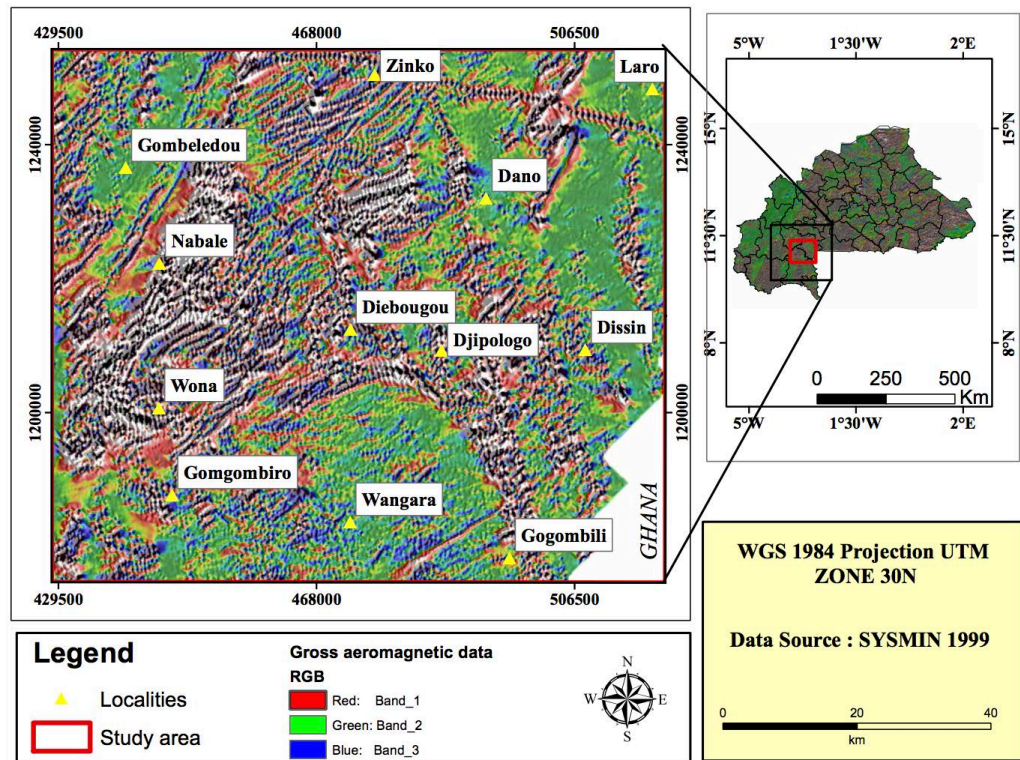
### 3. Methodology

#### 3.1. Data

**Figure 4** summarises the methodology's steps. It shows that to reveal the internal structure of the basement despite the lateritic cover in our study area; we used the first vertical derivate map of total magnetic intensity, superposed to a relief gray-scale image (**Figure 5**) acquired from the Bureau des Mines et de la Géologie du Burkina Faso (BuMiGeB). This map is derived from geophysical aeromagnetic data acquired by the SYSMIN project (1998-1999), whose spatial resolution is 250 m. These data proved their relevance in structural mapping in tropical contexts, particularly in the West African craton [4] [57]-[64]. The mapping was completed with a compilation of geological maps that cover the study zone at scales of 1:200 000 and 1:1 000 000. Foliation measurements and emplacement of gold occurrences, indices and deposits have also been extracted from these maps [22] [33]-[36]. So, fifty-six (56) measures of foliation have been collected using the software QGIS.



**Figure 4.** Methodology of structural analysis and the conception of predictive geological maps. Blue arrows indicate data and related uses. Red arrows indicate the results of data processing and reuse.



**Figure 5.** Aeromagnetic map of the study area extracted from the aeromagnetic survey of SYSMYN project [65].

### 3.2. Extraction of the Magnetic Fabric

The extraction of the magnetic fabric procedure is inspired by one of [4] based on the analysis of magnetic signature of the total magnetic intensity map to highlight the morphological and textural contrasts. It consists of a manual extraction (through the Adobe Illustrator software) of the magnetic alignments (magnetic trajectories) that are expressed by the ridge and the troughs of images and the color contrasts (Figure 5 and Figure 6). This assemblage of variable-length alignments constitutes the magnetic fabric (Figure 7). This magnetic fabric is similar to the tectonic fabric harmonized according to a single technique, largely due to the good concordance of their direction with that of the foliation measurements (Figure 8; [4]). This harmonized view is devoid of concerns regarding successive deformation phases, which are incompatible from one region to another and are quite common across the craton.

### 3.3. Identification and Mapping of Shear Zones

The presence of shear zones is reflected in different ways within the tectonic fabric. It causes significant perturbations of the fabric (indicating deformation gradient) evidenced by asymmetrical trajectories marking a continuous alignment. They can follow an alignment of dense and parallel trajectories, indicating a homogeneous fabric. They also preferentially develop along lithological contacts, which act as zones of weakness due to petrographic heterogeneity. Through these

characteristics that are identifiable through the qualitative geometric analysis of the tectonic fabric, we have highlighted the geometry of the shear zones in our study zone (Figure 8). The criteria that we used to identify shear zones have proven relevant in other studies and/or different geotectonic contexts [1] [11] [66]-[68].

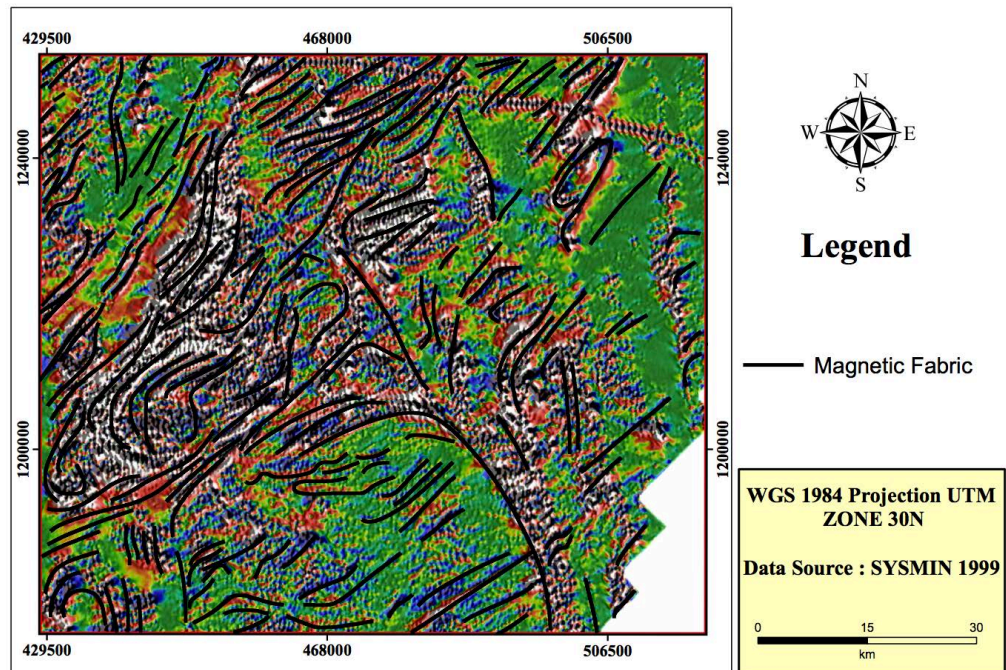


Figure 6. Magnetic fabric manually extracted and interpreted from aeromagnetic image.

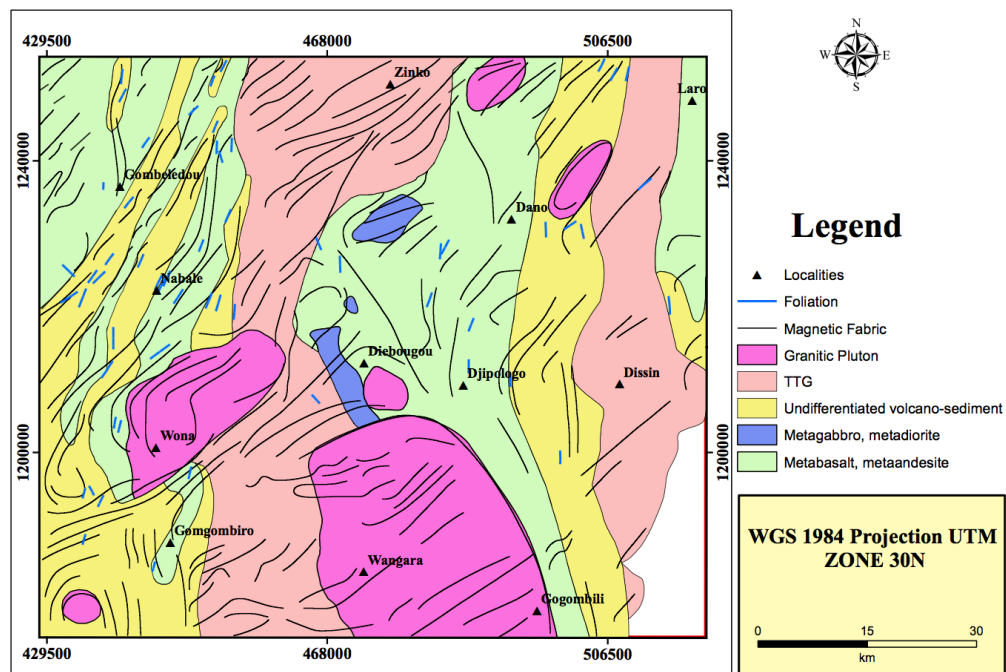
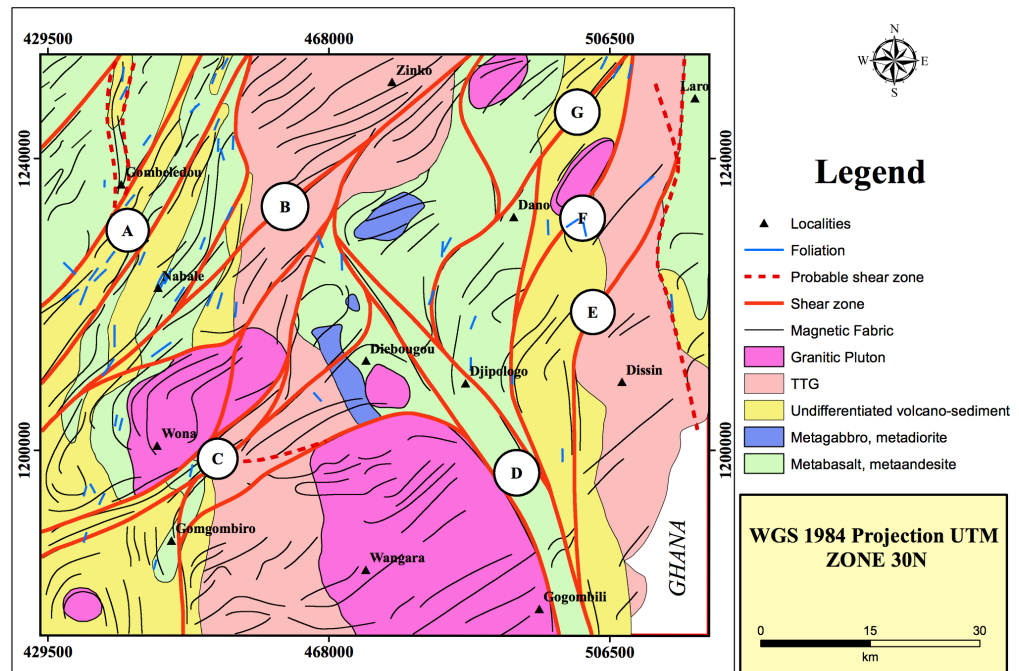


Figure 7. Extracted magnetic fabric superimposed on geological background.



**Figure 8.** Litho-structural map of the study area.

We obtained a lithostructural map by superimposing the magnetic fabric, the shear zones and the harmonized lithologies from older geological maps covering the study zone. Based on this map, we have identified zones of structural interferences or structure-geology interplays like elliptic pluton extremities that are known to be favorable for the concentration of mineralizations like gold [56] [69]-[72]. This targeting of prospective areas was reinforced by the analysis of kinematics and global structural geometry.

Numerous gold occurrences are documented in the study area. Their locations and information were extracted from the national database of mineral deposits in Burkina Faso [22]. They were then classified into three main categories (occurrences, small deposits, and mines). The overlay of the gold prospects and deposits with the interpreted lithostructural map allowed for the evaluation of the relevance of the targets selected through structural interpretation.

## 4. Results and Interpretations

### 4.1. Map of the Magnetic Fabric and Foliation Measurements

The magnetic fabric and foliation measurements exhibit satisfactory spatial coverage (Figure 7). They have a dominant orientation of NE to NNE. In the NW half, where the magnetic signature is homogeneous (Figure 6), the fabric is well expressed with more or less dense and continuous trajectories that are straight and parallel (Figure 7). However in the SW half, the trajectories are less pronounced (more spaced out), and therefore less dense (Figure 7 and Figure 8). This indicates less deformation compared to the NW and also suggests that the expression of the magnetic fabric is controlled by the intensity of deformation

independently of lithology.

## 4.2. Geometry and Structural Analysis of the Strain Field

We have identified seven major shear zones named A, B, C, D, E, F, and G (**Figure 8**). At the scale of the study area, these structures are all interconnected and define an anastomosing network [73]. The interconnection occurs at low angles in the NW half, where the shear zones are parallel to subparallel to the tectonic fabric and to lithological contacts (**Figure 7** and **Figure 8**). This suggests a more or less homogeneous deformation in the NW, whose intensity is expressed by the density of the magnetic fabric. The elongation of the Wona granitic pluton, aligned with the fabric and shear zone orientation (**Figure 8**), is consistent with this homogeneity. However, the emplacement of this pluton introduces deformation heterogeneity, marked at its SW edge by curved trajectories (**Figure 7** and **Figure 8**). This heterogeneity indicates a structural interference between regional strain field and pluton emplacement strain field. In the SE, around Wangara, Djipologo, Dissin, and Gogompili, the magnetic trajectories form a large angle with the shear zones, which also interconnect at moderate to high angles (**Figure 8**). This suggests a less intense deformation in the SE compared to the NW, consistent with the lower density of the magnetic fabric (**Figure 7**).

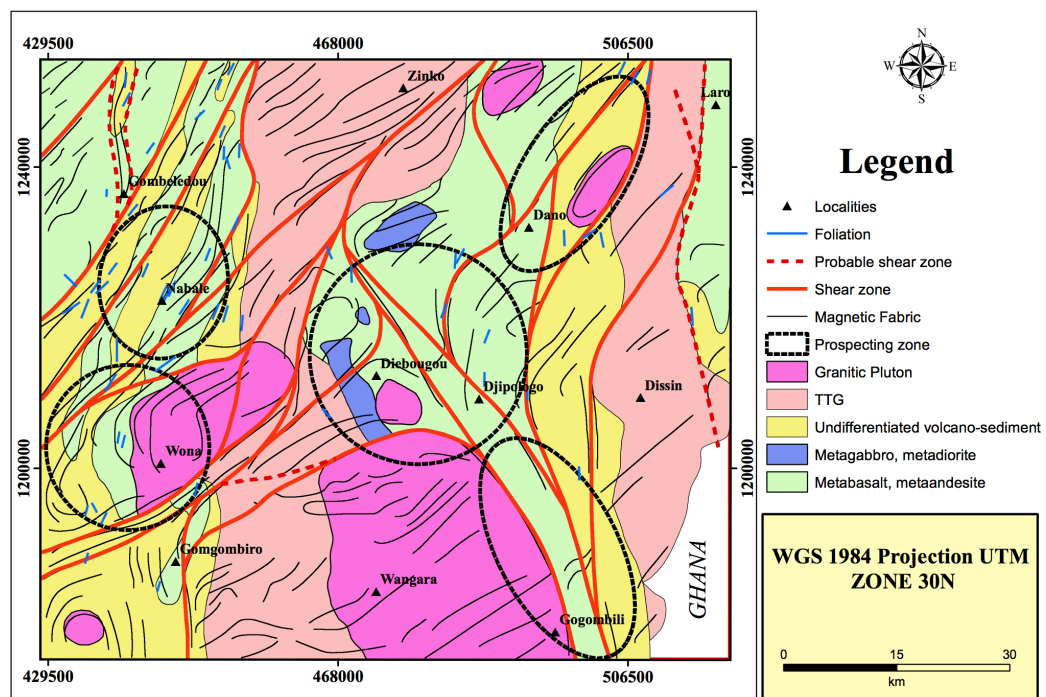
Three main orientations of shear zones can be distinguished. The NE to NNE orientation includes shear zones A, B, and C in the western half of the study area (**Figure 8**). Shear zones A and C are 3 km and 6 km wide, respectively, while shear zone B is the longest, extending continuously to 80 km. The asymmetric deflection of the magnetic fabric along these shear zones indicates dextral kinematics. The NW orientation is adopted solely by shear zone D, which molds the eastern flank of the Wangara pluton from Gogombili in the SE to Djipologo in the SE-NW direction (**Figure 8**). Between these two locations, shear zone D has a width exceeding 5 km. Beyond Djipologo, its width decreases towards the NW, where it is deflected in a dextral movement along shear zone B, to which it connects in the south of Zinko. The N-S to NNE orientation pertains to shear zones E, F, and G (**Figure 8**). Their asymmetric shape appears to result from dextral slip and deflection along shear zone D (**Figure 8**). This latter also deflects shear zone C and its numerous branches dextrally to the east of Nabalé (**Figure 8**). This indicates that shear zone D has dextral movement, similar to the NE to NNE-oriented shear zones. The asymmetric deflection of the magnetic fabric along the N-S to NNE-oriented shear zones suggests that they exhibit sinistral movement (**Figure 8**).

In summary, some NE to NNE-oriented shear zones (A and B) deflect the NW-oriented shear zone (D), which in turn deflects other NE to NNE-oriented shear zones (C) and N-S to NNE-oriented shear zones (E, F, and G). This interaction pattern among the different shear zones reveals that there is no chronological hierarchy among these structures. This indicates that they have operated together to maintain kinematic coherence, or in part, during the eburnean tectono-kinematic cycle. Furthermore, the main structural geometry of the study area results from the interconnection pattern between the three structural orientations,

causing structural interferences (perturbations). More specifically, the primary interference is associated with the development and functioning of shear zone D, particularly in the Djipologo-Zinko-Nabalé triangle (Figure 8). A counterclockwise rotation in the triangle, which follows the significant dextral deflection of shear zone D along shear zone B, and its dextral movement can explain this interference. Another interference results from the emplacement of the Wona granitic pluton mentioned above (Figure 8).

### 4.3. Prospective Areas Targeting

The analysis and structural-kinematic interpretation have revealed that the study area is particularly interesting for gold exploration due to its network of shear zones and structural interferences. The shear zones facilitate the drainage of mineralizing fluids, while areas of structural interference or reworking are often hosts for gold concentrations in the West African craton [39]. These zones are therefore our priority in terms of targeting. So two regions of the study area are noted: the Djipologo-Diéboucou area and the southwestern end of the Wona granitic pluton (Figure 9). In addition to these interference zones, sheared lithological contacts and areas with a diverse petrographic composition within the greenstone belts are also significant targets. These preceding characteristics are observed around Nabalé, along Gogombili-Djipologo and to the NE of Dano (Figure 9). However, the criteria mentioned are not exhaustive. [39] and [56] add that areas of release, extensional relay, dilation zone and shear zones/faults curvature should be given attention in the strategic exploration of potentially mineralized targets.



**Figure 9.** Map of prospective areas for gold, developed based on criteria of structural interferences, sheared lithological contacts, or lithological diversity coupled with the presence of major shear zones.

Next, we have overlaid the listed gold occurrences, small deposits and mines on our prospective area map (**Figure 10**). All five predefined targets showed significant potential for gold. The interference zones are the most interesting, as the widest one in the center contains the highest number of small deposits, while the narrowest one in the west of the Wona pluton in the SW contains two mines (**Figure 10**). These findings indicate that the combination of regional structural mapping and the determination of the tectono-kinematic history is a relevant tool in strategic mineral exploration. It is a cost-effective approach that saves time when planning exploration activities like drilling troughs.

## 5. Discussion

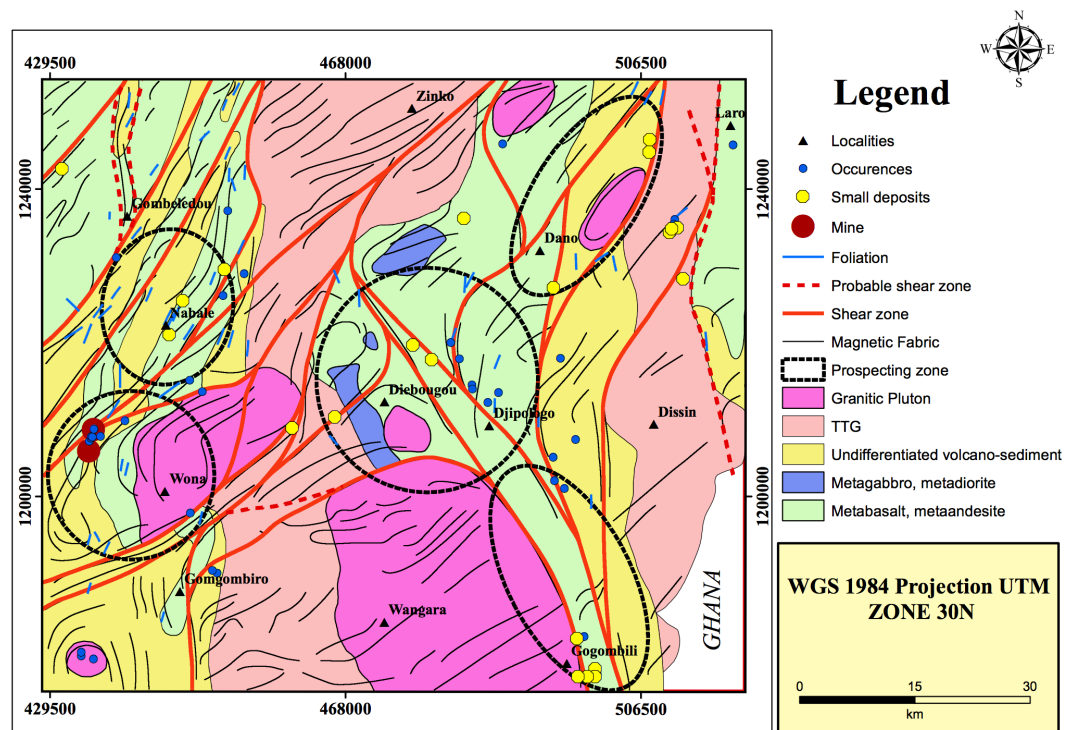
### 5.1. Structural Pattern and Age of Deformation

Our new structural pattern shows more shear zones compared to the map of [4] obtained using the same method. This can be explained by the difference in mapping scale approach, with the local scale providing more details. Nevertheless, this structural pattern is consistent with the one described by [24] and the one of the structural domain 2 of Burkina Faso [4], to which it belongs. This domain is structurally characterized by a converging pattern towards the north of the various shear zones. This pattern developed during the eburnean transpressive deformation, partitioned here into more intense deformation in the western half than in the eastern half of the study area (**Figure 8**; [4] [24]). The dominant steeply dipping foliation measurements and the variable plunge values of the stretching lineation measurements attest to this transpression [4] [51]. The granitic plutons (e.g., Wona and Wangara, **Figure 8**) molded by the shear zones and/or oriented in accordance with the directions of regional pattern suggest that their emplacement is syn-tectonic. The U-Pb age of these plutons (like those in the domain) is estimated to be between 2.16 Ga and 2.1 Ga [24] [35] [36]. This indicates that tectono-kinematic activity operated until 2.1 Ga in the study area.

### 5.2. Significance of Shear Zones in Mining Exploration

The majority of gold deposits and concentrations in the southern West African craton are of orogenic type, spatially related to major structures [15] [39] [43] [48] [49], such as shear zones. This can be explained by the fact that shear zones can reach significant depths and serve as conduits for the ascent of plutons and mineralizing fluids [18] [74]-[76]. Additionally, their interconnection enhances the permeability of the medium for the circulation of these ascended fluids or shallower fluids that can result in part from dehydration reactions related to metamorphism [43] [72] [74]. The spatial relationship between shear zones and gold deposits is evident in our study area, particularly with the location of the Wona mine (21 million tons at a grade of 3.2 g/t, estimated resource by SEMAFO S.A.) to the west, associated with shear zone B (**Figure 10**). Additionally, numerous small deposits and gold occurrences are associated with shear zones D (near Gogombili in the extreme SE) and F (NE of Dano) (**Figure 10**). An example of

favorable interconnection zones with multiple gold occurrences is located north of Djipologo in the center of **Figure 10**. Out of the study zone, the SW of Burkina Faso is gold-rich deposits closely related to shear zones. These include orogenic-type deposits such as Mana, Wona-Kona, and Nassara, Cu-gold type deposits at Goua, and VMS gold deposits at Poura [15] [77]-[79]. At a regional scale, the Syama deposits in Mali, the Obuasi and Ogozo-Prestea deposits in Ghana, the Essakane deposit in northeastern Burkina Faso, as well as the majority of gold deposits in the Kédougou-Kéniéba inlier are notable examples of gold mineralizations linked to or controlled by shear zones [37] [44]. We therefore confirm that shear zones are key structures spatially connected to gold mineralizations in West Africa.



**Figure 10.** Map of gold prospective areas confirmed by the presence of gold indices in the areas predefined. Sources of data: [22].

Moreover, the documented gold occurrences in our study area are not all only associated with the mapped shear zones, as seen in the vicinity of Nabalé in the SW and east of Dano in the NE (**Figure 10**). This proves that structures are not the only spatial criteria favorable for mineral trapping. The example near Nabalé in the SW (**Figure 10**) shows a lithological control at the contact between metabasalt/meta-andesite and volcano-sediments. In the NE of Dano (**Figure 10**), the lithological contact is between volcanic-sediments (greenstone belts) and granitoids (TTG-like domains). These so-called contact occurrences are found in various regions of the West African craton. A few examples include the Belahourou deposits in Burkina Faso [76], the Ity deposit in Côte d'Ivoire [70], and the Sadiola

deposit in Mali [80]. In these deposits, the dominant style of gold mineralization is manifested as auriferous quartz veins, stockworks, or disseminated mineralization within the surrounding rocks. However, as seen in the cases of the Ity deposits [70] and Tonghon [81] in Côte d'Ivoire, as well as Essakane in the NE of Burkina Faso [82], deformation plays a significant role in creating spatial conditions favorable for gold trapping. The omnipresence of deformation, particularly marked by the presence of sheared and mineralized faulted lithological contacts, as observed in the eastern region of Gogombili in the far SE (Figure 10), indicates a dominant litho-structural control over gold mineralization. Additionally, kinematic analyses in various studies have indicated that release zones, extensional relay zones, dilation sites, and shear zones/faults curvature are favorable locations for gold concentrations [37] [44]. In summary, the spatial distribution of gold deposits or concentrations in the southern West African craton is dependent on deformation.

### 5.3. Contribution and Relevance of the Cartographic Approach

We have developed a harmonized and refined structural pattern for a portion of southwestern Burkina Faso, which is significant for gold exploration (Figure 9). This pattern provides valuable insights into the internal structuring of the mapped terrains, particularly regarding the location of shear zones, their interactions, and overall geometry. Analyzing it structurally and kinematically, in light of previous geological, structural, and geochronological information, enhances our understanding of its tectonic framework. It also facilitates the identification of tactical prospecting targets at the regional scale based on structural and geological criteria, resulting in time-saving and, consequently, a reduction in investment costs. This can be easily explained by the reduction in the number of geochemical samples, which is the most commonly used method in mineral exploration targeting.

## 6. Conclusion

We presented a regional structural mapping process applied in this study, illustrated in a portion of southwestern Burkina Faso using an aeromagnetic image of the area. This process involves manually extracting the magnetic fabric, which is a qualitative approximation of the deformation. It allowed us to construct a harmonized and refined structural pattern of the study area, consistent with those of previous studies. Shear zones distributed in three main structural orientations organized into an anastomosed network characterize this pattern. The NE to NNE and NW orientations show dextral shear, while the N-S to NNE orientation exhibits sinistral movement. The interaction pattern between these different orientations results in structural interference zones that we have defined as prospecting targets, as well as the interference zones generated by the pluton's syn-kinematic emplacement. The subsequent superposition of documented gold occurrences in the study area confirmed the validity of our predefined prospecting targets. This allows us to assert that the structural mapping approach applied in this work is a

relevant strategy for targeting prospective areas, particularly in the West African tropical context, and serves as a quick and effective means of optimizing regional exploration efforts.

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## Conflicts of Interest

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

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