

Lithostructural and Geochemical Characterization of the Metavolcanic and Granitoid Formations of the Birimian Belt of East Boromo (Burkina Faso): Their Relationship with the Lawra Belt (Ghana)

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Abstract

The Boromo-East belt, located south of the Man ridge, runs generally NE-SW to N-S and consists of a belt of green rocks (volcanic and volcano-sedimentary) and various types of granitoids. Petrographic observations have shown that the volcanics generally contain large crystals of plagioclase and amphibole, newly formed in places, with garnet present exclusively within the metabasalt. The diverse nature of the granitoids reflects the fact that different subduction phenomena have produced several types of magma, which in turn have generated diverse rock formations. Deformation within the Boromo-East belt is generally ductile-brittle to brittle, evidence that the structural level was much higher at the time of deformation. Interpretation of the shear zones in the Boromo-East belt has revealed a major shear zone called the AMDSZ (Amélédibon Shear Zone), which is the continuation of the Jirapa shear zone (Jirapa shz) recognized within the Lawra belt. Geochemical data reveal negative anomalies in Nb, Ta, and Ti within the volcanic and granitoid formations of the Boromo-East and Lawra belts. However, the Boromo-East belt shows variability in the coexistence of IAT + CAB magmas, while the Lawra belt shows a more tholeiitic composition. The different collision implications affecting the more calc-alkaline and less tholeiitic Lawra belts suggest that the collision and the location of the shears led to a modification of magmatic differentiation on either side of the orogenic suture. In the Boromo-East belt, it appears that the collision with the Lawra belt could be interpreted as the result of late convergence between two crustal blocks of volcanic arcs of different ages and his-

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Keywords

Granitoid, Birimian Belt, Burkina Faso, Lawra Belt

1. Introduction

The Paleoproterozoic crust of the Man or Léo Ridge consists of a complex of volcanic and volcano-sedimentary formations, all of which are intruded by several generations of granitoids [1]-[4]. The granitoids range from Trondhjemite facies to syenites, including monzogranites. All of these formations were structured by a major orogenic cycle known as the Eburnean orogeny [5]. The numerous greenstone belts are composed of basalts, andesites, dacites, and rhyolites (Figure 1) [1]-[2] [6]. Furthermore, the Léo Ridge is also known for its relatively large volume of granitoids that were emplaced chronologically [1]-[3] [7] [8]. According to authors such as [2] [5] [9], the formations in this region were formed in an oceanic plateau setting. Others, however, suggest they formed in a volcanic arc setting [1] [6] [10] [11]. Greenstone belts exhibit long-term variations in their development and represent a variety of tectonic environments [12]. Studying the

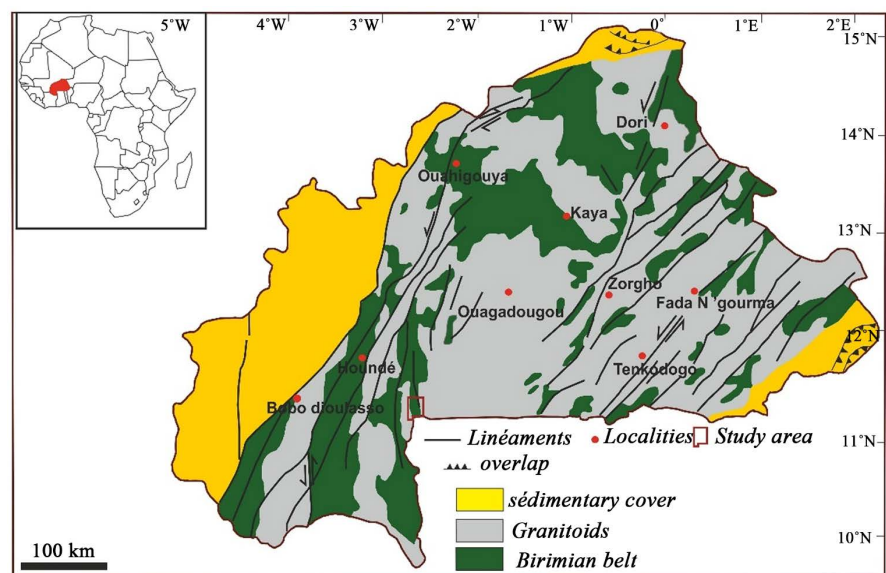


Figure 1. Simplified geological map of Burkina Faso at a scale of 1:1,000,000 [1].

geochemical, structural, and petrographic characteristics of the geological formations in the East Boromo Belt can help reconstruct the geodynamic environment and the conditions under which these formations were deformed. If the geochemistry and structural features differ, would this imply two distinct geodynamic environments for the Lawra and East Boromo belts? The findings derived from the analysis of these data may also help to highlight a possible collisional relationship between the Lawra and East Boromo belts.

2. Local Geological Context

The study area consists of a variety of geological formations that occur as sills in the case of the greenstone belts, and as elliptical bodies in the case of the granitoids. These granitoids also alternate with the greenstone belts [1] [8]. They consist of TTG batholiths and small plutons that formed successively and helped shape the greenstone belts that enclose them [1] [2] [8] [13]. The Boromo belt extends into the Boussouma-Korsimoro region, where it forms an arc known as the Goren Arc. The geological formations of western Burkina consist of tholeiitic basalts, andesites, and rhyolites; conglomeratic sandstones, dolerite, gabbros, diorite, and subvolcanic dikes [8] [11] [14]-[17] and sediments from the Tarkwa Basin, located primarily in the Houndé Belt [18] [19]. The Tarkwaian Formation in Burkina Faso begins in the Kampti region [16] and continues uninterrupted to Safané, where its mapping remains incomplete [19]. Studies by [20]-[22] have shown that the Tarkwaian rocks and sediments of the Bambela Basin extend as far as the Ivory Coast, where they are embedded in the Téhini Belt. Tholeiitic activity, dominated by basaltic lavas, began around 2350 Ma in an oceanic setting, according to Sm-Nd dating conducted by [17]. This was followed by a subduction process that gave rise to island arcs, within which a second episode of magmatic activity occurred between 2212 and 2160 Ma. The associated volcanic, volcano-sedimentary, and granitoid formations were metamorphosed under green schist facies conditions; the amphibolite facies is generally localized at the contact zones between green rocks and granitoids that have been orthogneissified [1]. Radiometric dating of these units places the age range for the accretion of the granitoids between 2097 ± 10 Ma [14] and 2177 ± 7 Ma [23]. The determination of neodymium model ages in the basalts of the Houndé Belt [16] suggests a possible contribution of pre-Birimian materials to the source.

The overall context of accretion of the Birimian formations in western Burkina Faso corresponds to an oceanic plateau that gave rise to successive volcanic arcs [1] [8] [11] [14] [17]. Apart from the studies by [11] on the ultrabasites of the Loraboué region, the studies by [24] on the albitites of the Larafella region, and the studies by [8] [13], the geology of the East Boromo Belt has largely been described by the work of [14]. The area lies within the Léo square degree, which consists primarily of Birimian Paleoproterozoic formations. It comprises metamorphosed volcano-sedimentary formations from the Eburnean stage and plutonic formations consisting mainly of granitoids and gabbroic bodies [14]. The volcanic and volcano-sedi-

mentary formations are generally oriented N-S in the southern part of the study area and NE-SW in the northern part. Volcanic rocks are found in the axial zone of the study area; they consist mainly of basalts (amphibolized in places), andesites, rhyodacites, lavas, and pyroclastics; the volcano-sedimentary rocks are located in the southern, central-western, and northwestern parts of the area (**Figure 2**) [14]. The granitoid formations found on either side of the volcanic rocks are largely oriented in a north-south direction, although small granitic bodies are found embedded within the volcanic rocks [13]. They consist of granodiorite, tonalite, and quartz diorite; amphibole-bearing porphyroid granites; and granite in the strict sense, with both coarse-grained and fine-grained facies. The studies by [8] and [13] on the interpretation of geophysical images have primarily made it possible, respectively, to identify plagioclase phenocryst basalt found in the western part of the study area and elliptical-shaped granitoid bodies.

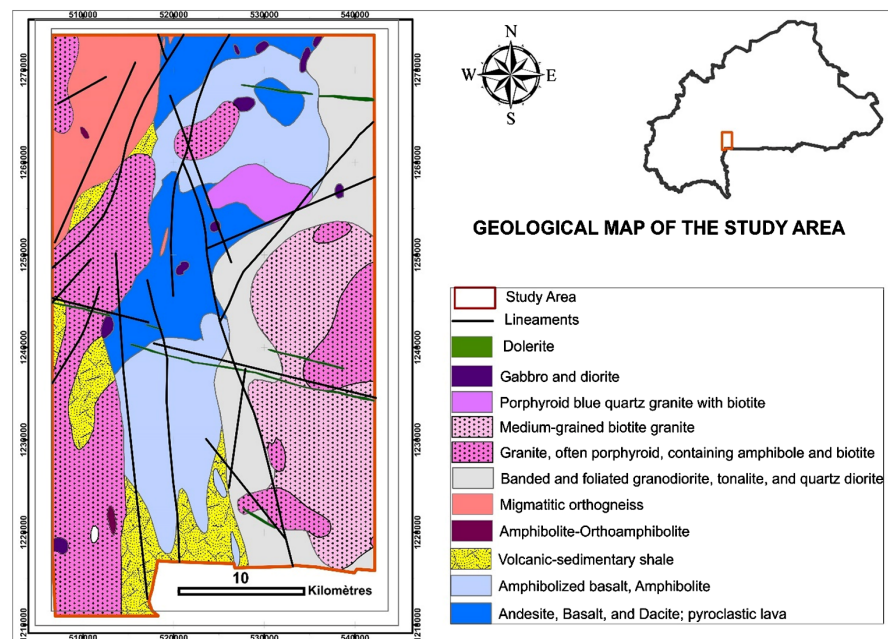


Figure 2. Geological Map of the East Boromo Belt (adapted from [14] (Léo's Square Degree); [13]).

3. Materials and Methods

3.1. Materials

This project required several resources for its effective implementation. These included various tools such as computers and specialized software for data collection, satellite image processing, and the creation of various geological maps. Software such as ArcGIS, QGIS, and ENVI was used to identify the study area, delineate its boundaries, and overlay the information necessary for the effective implementation of the study. Fieldwork required the acquisition of the following equipment: i) a 4×4 off-road vehicle; ii) compasses equipped with clinometers for measuring linear and planar geological structures; iii) a GPS device for geolocat-

4. Results

4.1. Petrography of the Rocks of the East Boromo Belt

4.1.1. Metavolcanic Rocks

Metabasalt occupies most of the study area and constitutes the bulk of the hills that make up the East Boromo Belt (**Figure 4(a)**, **Figure 4(b)**). It is also visible at the contact zones between granitoids and greenstone belts. Two groups can be distinguished among these metabasalts: one group containing plagioclase phenocrysts and the other consisting of massive metabasalts with almost no plagioclase phenocrysts (**Figure 4(e)**, **Figure 4(f)**). Meta-andesites alternate with metabasalts within the Boromo-East greenstone belt but are less common than the latter. Most of the meta-andesites sampled are associated with a major shear zone (AMDSZ, Améle-Dibon Shear Zone) identified by direct structural field measurements. These meta-andesites are relatively more leucocratic and also contain plagioclase phenocrysts (**Figure 4(c)**, **Figure 4(d)**).

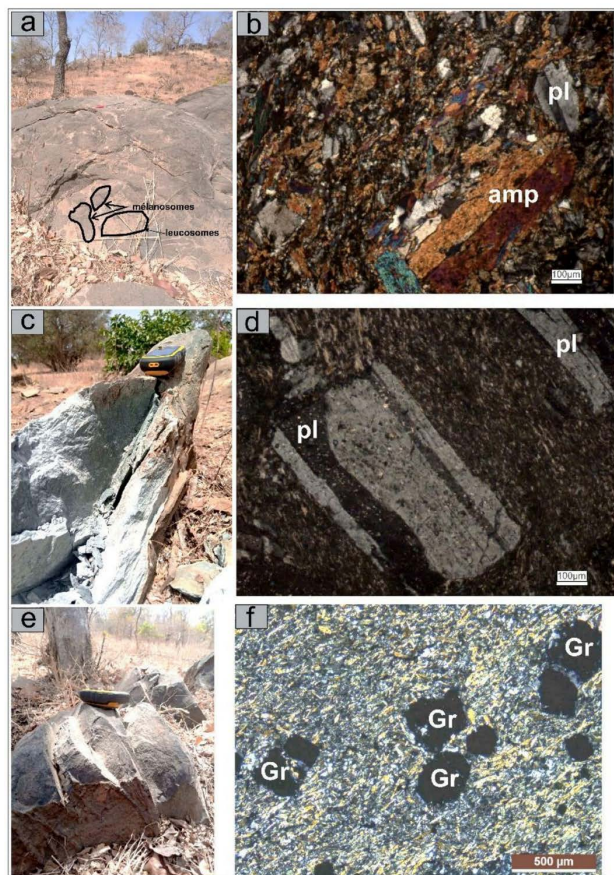


Figure 4. Macroscopic and microscopic images of volcanic rocks from the East Boromo Belt: (a) Facies of a volcanic rock with leucosomes and melanosomes indicative of migmatization; (b) Microphotograph of a basaltic facies showing an amphibole phenocryst; (c) Andesitic facies with a N-S shear direction; (d) Andesite viewed in a thin section with visible plagioclase phenocrysts; (e) Metabasalt from the THS58 site marked by faults; (f) The same basaltic facies characterized by the presence of garnet crystals. Amp: Amphibole; Pl: Plagioclase; Gr: Garnet.

Observation under a polarizing microscope reveals that the color ranges from melanocratic to holomelanocratic and that the texture is granoblastic to lepidoblastic. Despite the rock's deformation, the minerals that are still recognizable include biotite in the form of narrow lamellae and amphiboles (brown hornblende) in the form of neoformed crystals (**Figure 4(b)**). Plagioclases with polysynthetic twinning and in the form of elongated needles are also present (**Figure 4(d)**). The pyroxenes, which are present in small quantities, are embedded in a matrix of recrystallized quartz. Fracturing at the macroscopic scale is also observable under a polarizing microscope, manifesting as quartz veins that cut across certain facies.

4.1.2. Granitoids

They are characterized by their leucocratic colors and the more or less abundant presence of minerals such as plagioclases or potassium feldspars, which are present in varying proportions depending on the type of rock. Foliation is not very distinct in these granitoids (particularly the more potassium-rich ones), and most facies are relatively poor in ferromagnesian minerals (**Figure 5(f)**). The colored minerals are biotite and brown hornblende-type amphibole, which is more or less automorphic. The white minerals consist of quartz, plagioclases, and potassium feldspars (**Figure 5(d)**). The potassium feldspars are mostly microclines (**Figure 5(g)**), often perthitic, while quartz, which is relatively less abundant, exhibits good rolling extinction. The comagmatic inclusions within these granitoids tend to stretch in the same direction as the foliation (**Figure 5(c)**). Myrmecites are also observed (**Figure 5(c)**) in the granodioritic facies; their presence consistently attests to the magnitude of the geodynamic processes that prevailed in the East Boromo Belt. In certain granitoid facies, significant recrystallization of quartz (**Figure 5(g)**), remnants of plagioclases, and large areas of microperthitic microclines are observed. The plagioclase feldspars are represented by albite-type polysynthetic twins (**Figure 5(e)**). Locally, alteration twins (damouritization) of these plagioclases are observed. It is often possible to observe cases of poecilitic minerals (one mineral included within another mineral); this is the case with plagioclase crystals included within large potassium feldspar crystals.

- Tonalites

Tonalitic facies are fairly well represented within the East Boromo Belt; they are characterized by the fairly dominant presence of minerals such as plagioclases (**Figure 5(a)**, **Figure 5(b)**). The colored minerals are biotite (**Figure 5(b)**), a brown hornblende-type amphibole that most often occurs in more or less automorphic forms. The white minerals are quartz, plagioclase, and potassium feldspars, which most often occur in perthitic forms. The rock is fairly intact, and the minerals show no particular signs of alteration, with the exception of a few plagioclase crystals that exhibit signs of destabilization, indicating some degree of damouritization. In certain facies, significant recrystallization of quartz is observed, with remnants of plagioclase and large patches of microperthitic microcline present in places.

- Granodiorites

Granodiorites range from coarse-grained to fine-grained facies, including me-

dium-grained facies; most facies are granular. Under a polarizing microscope, the colored minerals are biotite and brown hornblende-type amphibole. The white minerals consist of quartz, plagioclases, and potassium feldspars (**Figure 5(d)**). The plagioclases are locally altered to sericite. The potassium feldspars are mostly perthitic microclines; the relatively less abundant quartz exhibits good rolling extinction. Accessory minerals include pistachite epidote and a few rare opaque minerals.

- Granites

Granites, strictly speaking, are quite widespread within the East Boromo Belt; they occur as intrusions into volcanic rocks. The facies are as diverse as those of granodiorites, with both coarse-grained and fine-grained varieties present. Some facies are rich in ferromagnesian minerals, while others are poor in them. Unlike granodiorites, which consistently accentuate foliation, these rocks show no preferential mineral orientation. Nevertheless, a fairly dynamic recrystallization of quartz with well-pronounced rolling extinction is observed (**Figure 5(g)**).

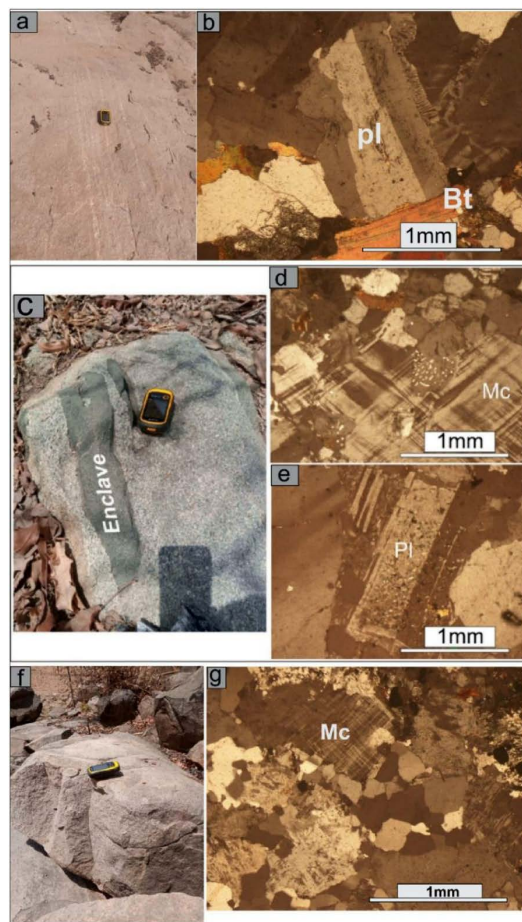


Figure 5. Microscopic photographs of the granitoid facies of the East Boromo Belt; (a) Tonalite facies cut by quartz veins; (b) The same facies viewed in a thin section, showing plagioclase phenocrysts and biotite; (c) Granodiorite with mafic inclusions; (d) Microphotograph showing a microcline crystal and a myrmekite; (e) Photograph showing a partially altered plagioclase crystal. (f) Relatively leucocratic granitic facies; (g) Same granitic facies with a visible plagioclase phenocryst. Mc: Microcline; Pl: Plagioclase; Bt: Biotite.

5. Structural Analysis

Deformation structures are fairly well represented in the Boromo-East Belt; these include ductile, ductile-brittle, and brittle deformation structures. Although their distribution is uneven, it is evident that ductile deformation structures, such as shear zones, are the most numerous (**Figure 6**). These structures coexist within certain zones where both types are observed simultaneously; this is likely due to the rheology of the rock materials. Rock materials respond differently to the applied stress. It is noted that ductile deformation structures are numerous in the axial part, where metabasalt tends to outcrop preferentially (**Figure 6**). Granitoid rocks primarily exhibit foliation and most of the brittle deformation structures within the study area. In total, 57 measurements were taken relating to fracturing; as regards ductile deformation structures, a total of 35 direct field measurements were carried out, comprising 19 shear zones, 5 schistosity zones and 11 foliations.

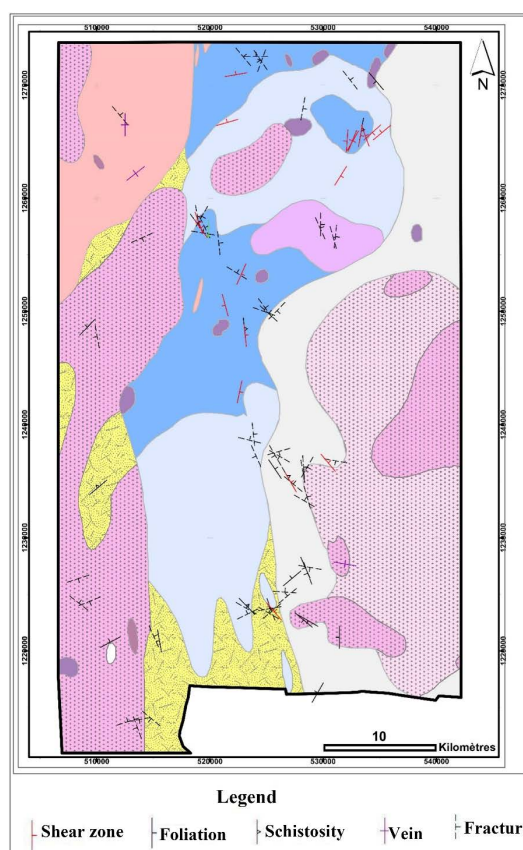


Figure 6. Structural map of the study area superimposed on the geological map based on Léo's square grid map [14].

5.1. Ductile Deformation

- Shear Zones

Shear zones are either ductile or brittle-ductile and have diverse orientations, but overall, it is possible to distinguish three preferred orientations: shear zones oriented NE-SW, NW-SE, and shear zones with an approximately E-W orientation (**Figure**

6). East-west shear zones generally accompany late-stage fracturing that affects the geological formations in the study area (**Figure 6**). In the northeastern part of the study area, there is a deformation corridor that can be characterized as a disturbed zone, where the shear zones have orientations ranging from NNE-SSW to ENE-SWS. This zone reflects a certain resumption of deformation in several episodes, thus indicating a polyphasic deformation process within the East Boromo Belt. Interpretation of the shear zones has revealed a probable continuation of the major Jirapa shear zone [25], which traverses the entire Lawra Belt and also affects the East Boromo Belt. It has a NNW orientation in its southern part, a N-S orientation at the axial level, and returns to a NNW orientation in the northern part. It is known as the Amélé-Dibon Shear Zone (AMDSZ) (**Figure 7**). This major shear zone was also partially identified by [13] based on aeromagnetic data.

- Schistosity

Schistosity is most commonly observed in areas of ductile shear; it generally follows the same directions as the shear zones it accompanies. The directions are either NW-SE or NE-SW, with steep dips of around 80° that become vertical in places (**Figure 6**). It should be noted that schistosity is virtually absent in granitoid formations. It is slate-like in places (volcanic-sedimentary schists) and quite massive on certain outcrops. Among all the lithologies of the East Boromo Belt, it is the volcano-sedimentary schists that have undergone the most deformation, as they exhibit fairly distinct schistosity with relatively tightly schistose domains on certain outcrops.

- Foliation

The foliation is oriented either NE-SW, N-S, or NW-SE; it is particularly prominent in the southern part of the area where granodioritic formations outcrop. It is barely perceptible on some outcrops but is clearly marked in the granodiorites that outcrop near the shear zones. It should also be noted that there are mafic enclaves oriented in the same direction as the foliation. The interpretation of the shear zones mapped by [13] roughly follows the same directions as the shear zones derived from direct field measurements, proving once again that direct field measurements confirm the existence of major regional lineaments affecting the East Boromo Belt. It is also noted that the interpreted foliation, although slightly offset from the aeromagnetic and direct measurements mentioned above, follows some NE-SW and NW-SE directions (**Figure 8**).

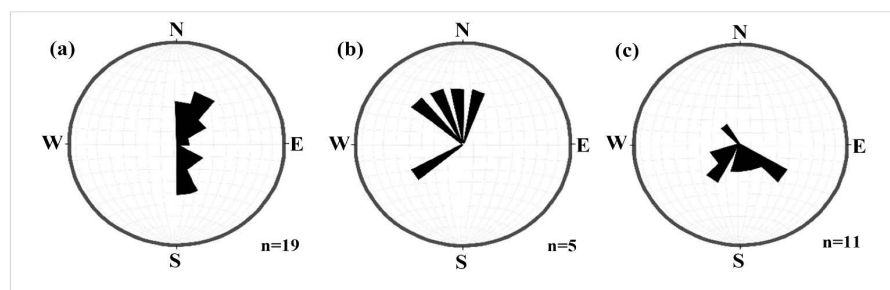


Figure 7. Schematic representation of directional rosettes for ductile deformation structures; (a) Directional rosettes for shear zones; (b) Directional rosette for schistosity; (c) Directional rosette for foliation.

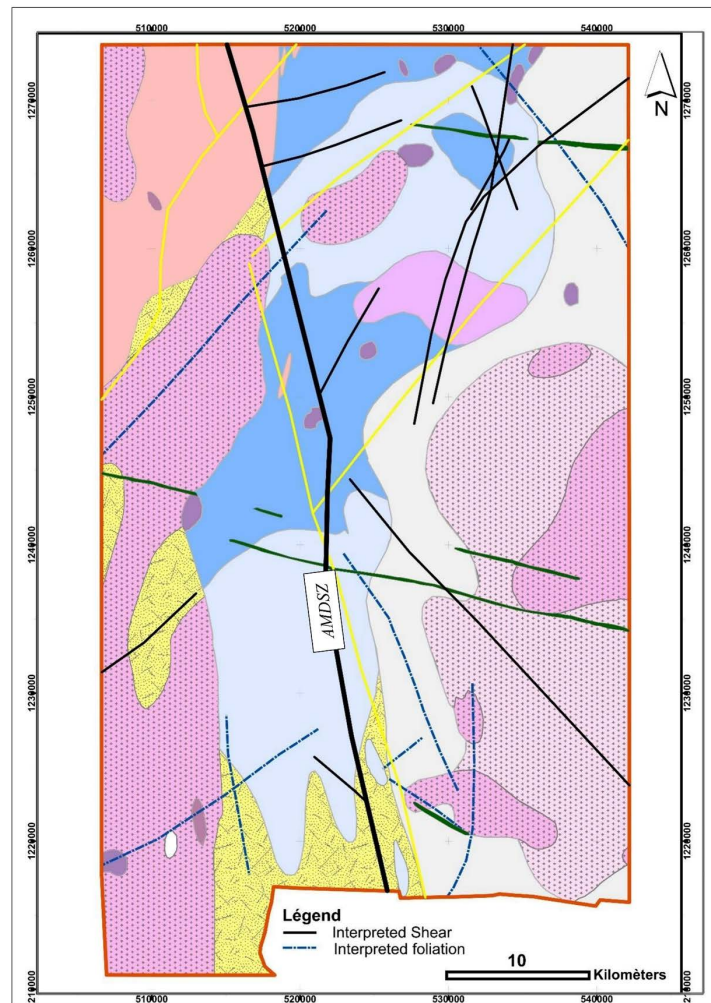


Figure 8. Structural map highlighting the major shear zones and interpreted foliation of the East Boromo Belt; the shear zones interpreted from geophysical images by [13] are shown in yellow.

5.2. Fracture Deformation

The main structures associated with fracture deformation are faults, which are less common, and fractures, which are relatively abundant. We distinguish between fractures that run in NE-SW or NW-SE directions and those that are closer to an E-W direction (**Figure 6**). These structures affect both volcanic rocks and granitoids and are usually quite deep-seated at the sample scale. These fractures are often filled with quartz, both in volcanic rocks—primarily metabasalt and meta-andesite—and in granitoids. In some granitoids, major intersecting fractures were observed, indicating that they formed successively and, most importantly, in accordance with the aforementioned preferred directions. The three fracture groups were plotted using the Stereonet software, revealing that: the group of NE-SW-trending fractures has an average direction of N236E7N (**Figure 9(a)**); the NW-SE-trending fractures have an average direction of N336E60E (**Figure 9(b)**); and the E-W-trending fractures have an average direction of N304E78N (**Figure 9(c)**).

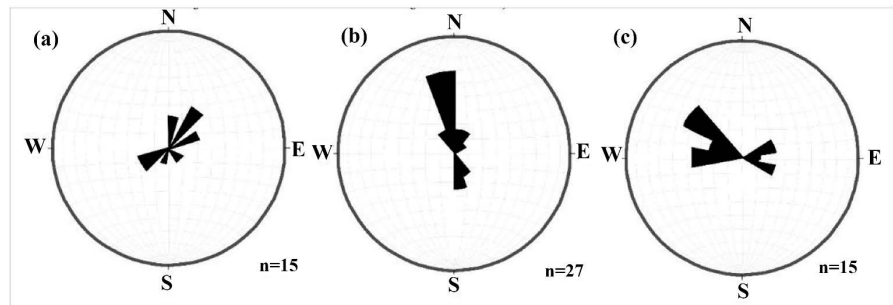


Figure 9. Schematic representation of the directional rosettes of brittle fracture structures: (a) Directional rosette of NE-trending fractures; (b) Directional rosette of NW-trending fractures; (c) Directional rosette of E-W-trending fractures.

It is noted that the three average orientations of these different fracture groups follow roughly the same directions as the schistosity and most other shear zones within the study area (**Figure 10**). This could be explained by the rheological behaviour of the various lithologies in the East Boromo Belt in response to the stresses acting upon them. Interpretation of the fracturing based on direct field measurements reveals that north-south-trending fractures are the most prevalent, followed by those trending roughly east-west, and finally those trending NW-SE (**Figure 11**).

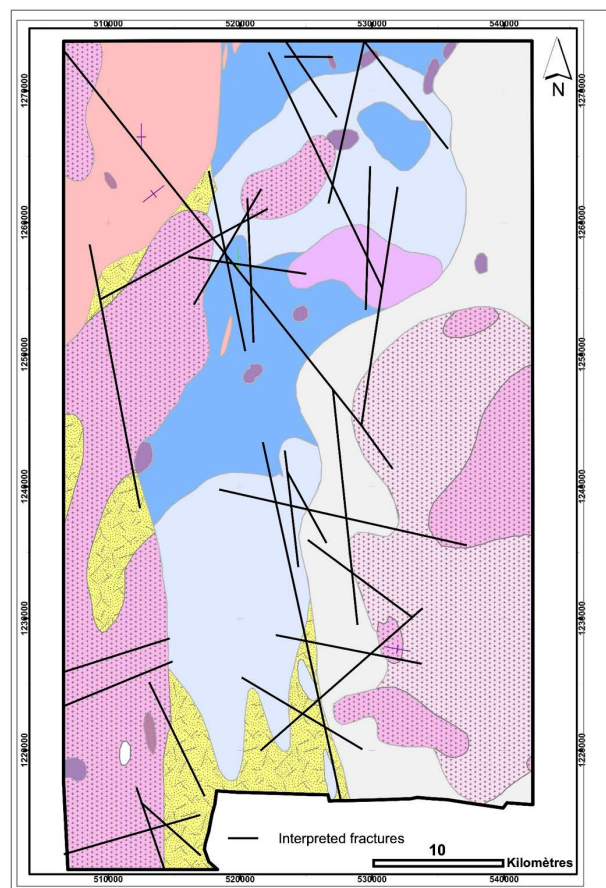


Figure 10. Structural map showing the fracturing affecting the formations of the East Boromo Belt.

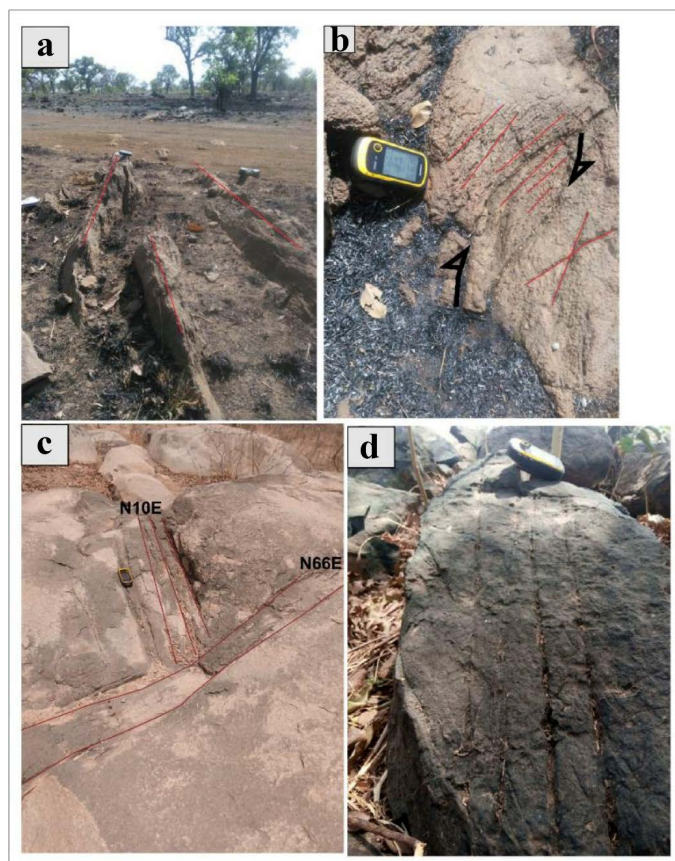


Figure 11. Macroscopic images of deformation structures in the study area: (a) Subvertical N320E schistosity within the metabasalt; (b) Dextro-dipping shear of strike N120E within the same facies; (c) Fracture of strike N10E cut by a fracture oriented N66E in the granitoids; (d) Series of subvertical fractures of strike N90E affecting the metabasalt.

6. Geochemistry

The geochemical data relate to granitoids and volcanic and volcano-sedimentary belts. These consist mainly of ten samples of greenstone and thirteen granitoids of various types. The samples were selected to ensure they were as pristine and fresh as possible.

6.1. Geochemistry of Volcanic Rocks

The samples have a silica (SiO_2) content ranging from 48.85 wt.% to 73.77 wt.%. The Fe_2O_3 content ranges from 2.95 wt.% to 10.45 wt.% for most samples, although it should be noted that sample THS58 has a content of approximately 18.16 wt.%. The alumina content ranges from 11.71 wt.% to 14.99 wt.%, with a maximum of 17.49 wt.% in sample THS43. The discrimination diagram from [26] ($(\text{Fe} + \text{Ti}) - \text{Mg} - \text{Al}$) allows the rocks studied to be classified into four groups, namely: i) the group of highly iron-rich tholeiitic basalts (THS58 and THS56), with an Fe_2O_3 content ranging from 11.62 to 18.12 per cent and a silica (SiO_2) content of 48.83 to 51.11 per cent. ii) High-magnesium tholeiitic basalts with a calco-alkaline tendency (THS39, THS44, THS104), with an Fe_2O_3 content ranging from 8.85 per cent to 10.45 per

cent and an average Al_2O_3 content of 12 wt.%. iii) Calco-alkaline andesite (THS43; THS29) with an Al_2O_3 content ranging from 17.49 wt.% to 12.92 wt.% (**Table 1**).

The average MgO content is 3.50 wt.%, with Fe_2O_3 content ranging from 7.72 to 6.25 wt.%. (iv) Rhyolite (THS49; THS54; THS60): The SiO_2 content is significantly high (67.03 wt.% to 73.77 wt.%). It is noted that the MgO content of these samples is relatively low ($0.08 < \text{MgO} < 1.04$ wt.%). The patterns shown by the rare-earth spectra normalised to chondrite [28] are different but generally take the form of sawtooth curves. The various facies generally exhibit flat spectra with fairly pronounced negative anomalies in Rb, Ti and Th. The negative anomalies in Rb are due to the fact that the parent magma was generated by high-temperature partial melting, in which rubidium remains in the residue (rubidium, due to its relatively large ionic radius, is unable to incorporate into the crystal lattice of the minerals and therefore concentrates in the liquid phase; it is said to be incompatible), whilst the negative anomaly in titanium (Ti), which is moderately incompatible, indicates magma originating from volcanic arcs (subduction). As for the negative anomaly in thorium (a highly incompatible element) and its enrichment in crustal materials, this indicates a mantle source poor in incompatible elements or an absence of recycled sediments in the magma, as Th is highly enriched in sediments [28]-[30].

Table 1. Whole rock geochemical data for volcanic rocks from the East Boromo Belt.

Samples	THS29	THS39	THS43	THS44	THS49	THS54	THS56	THS58	THS60	THS104
X(m)	518,786	521,000	518,719	522,912	530,097	532,445	533,855	535,102	531,979	511,202
Y(m)	1,250,405	1,255,540	1,258,190	1,253,262	1,256,937	1,265,143	1,265,597	1,265,920	1,265,063	1,244,451
rock type	Andésite	Basalte	Dacite	Basalte	Rhyolite	Rhyolite	Basalte	Basalte	Rhyolite	Basalte
Key elements										
SiO_2	66.09	54.47	56.45	48.85	73.77	67.03	48.83	51.11	72.91	53.50
Al_2O_3	12.92	12.07	17.49	12.13	12.99	14.08	14.99	14.50	12.24	11.72
Fe_2O_3	6.26	8.85	7.72	9.89	2.95	3.58	11.62	18.12	3.68	10.45
MnO	0.087	0.14	0.11	0.20	0.034	0.023	0.16	0.26	0.086	0.18
MgO	3.51	8.67	3.49	7.63	0.23	1.04	5.29	3.00	0.08	9.67
CaO	3.96	9.63	7.18	17.78	1.59	4.32	7.48	8.37	2.44	9.20
Na_2O	4.57	3.09	3.61	0.39	5.18	4.83	2.98	1.61	4.33	2.15
K_2O	0.18	0.66	1.04	0.15	1.36	0.98	0.014	0.38	1.43	1.60
TiO_2	0.51	0.31	0.69	0.49	0.18	0.30	0.70	1.10	0.16	0.60
P_2O_5	0.11	0.04	0.07	0.06	0.03	0.09	0.10	0.14	0.02	0.23
PF	1.66	1.35	1.21	1.49	0.87	3.54	7.62	0.44	2.86	1.39
Total	99.86	99.28	99.05	99.07	99.19	99.80	99.79	99.03	100.25	100.67

Continued

Minor elements										
As	0.26	1.99	0.60	6.85	0.68	0.40	0.33	0.56	1.02	2.31
Ba	84.1	253	287	183	342	238	18.7	154	409	346
Be	0.36	0.43	0.59	0.26	0.80	0.44	0.23	0.41	0.75	0.83
Bi	<L.D.	0.02	0.16	0.85	<L.D.	0.04	<L.D.	0.02	<L.D.	0.05
Cd	0.05	0.05	0.07	0.06	0.04	0.04	0.05	0.16	0.25	0.11
Co	21.1	42.5	25.1	44.7	2.67	6.12	44.6	45.0	0.48	44.1
Cr	122	705	31.2	527	22.3	54.3	120	25.6	13.4	649
Cs	0.09	0.34	2.20	0.30	1.41	0.77	0.04	0.23	1.43	0.76
Cu	52.8	36.8	72.9	83.3	2.5	<L.D.	94.9	106	8.4	28.5
Ga	10.6	8.94	16.3	10.7	14.8	13.9	12.4	18.6	19.9	13.4
Ge	0.90	1.08	0.88	1.90	1.21	0.67	1.03	1.54	1.35	1.63
Hf	1.89	0.58	1.74	0.74	4.85	2.52	1.36	2.61	6.21	1.75
In	0.029	0.037	0.038	0.040	0.038	0.017	0.060	0.109	0.120	0.053
Mo	0.32	0.26	10.5	0.55	0.83	0.31	<L.D.	0.64	0.73	0.23
Nb	2.40	0.725	2.01	0.816	7.45	2.54	1.73	3.28	6.11	2.15
Ni	68.6	277	39.2	147	4.6	20.8	98.4	21.5	2.5	69.6
Pb	1.31	1.51	3.89	2.42	3.75	1.78	0.69	1.45	3.28	5.12
Rb	2.81	13.5	23.9	4.80	34.5	24.2	0.30	6.73	39.5	36.8
Sb	0.14	0.78	0.16	0.75	0.18	0.37	0.23	0.12	0.87	0.11
Sc	16.50	34.36	17.99	39.66	4.51	6.18	35.31	42.10	4.74	38.34
Sn	<L.D.	<L.D.	<L.D.	<L.D.	0.86	<L.D.	<L.D.	0.78	2.11	1.00
Sr	98.7	237	358	112	68.1	171	97.0	41.4	74.6	396
Ta	0.23	0.06	0.17	0.06	0.85	0.31	0.14	0.27	0.56	0.21
Th	0.928	0.179	0.938	0.435	3.96	1.38	0.422	0.793	2.49	1.86
U	0.319	0.070	0.323	0.122	1.45	0.382	0.167	0.302	0.897	0.654
V	96.4	148	132	183	5.90	32.7	164	216	0.30	206
W	0.27	0.40	0.57	0.42	1.13	0.30	0.34	1.17	0.89	0.21
Y	12.1	10.0	11.9	12.7	41.9	5.47	20.6	41.2	79.3	14.1
Zn	60.6	62.1	66.9	61.2	19.0	43.5	93.0	170	147	94.6
Zr	76.8	21.7	66.4	27.9	163	103	50.2	102	226	63.5

Continued

Rare earth elements										
La	9.52	2.40	6.18	4.90	22.7	11.2	4.57	8.40	18.3	11.7
Ce	18.0	4.37	13.0	11.1	46.2	18.0	9.72	19.2	39.7	26.4
Pr	2.13	0.527	1.51	1.36	5.00	1.94	1.24	2.38	4.69	3.21
Nd	8.58	2.34	6.49	5.91	19.3	7.03	5.82	10.8	21.0	13.9
Sm	1.88	0.708	1.68	1.48	4.33	1.34	1.65	3.17	5.96	3.06
Eu	0.608	0.205	0.608	0.522	0.573	0.441	0.551	1.10	1.09	0.923
Gd	1.87	0.954	1.73	1.62	4.57	1.18	2.17	4.22	7.61	2.72
Tb	0.302	0.197	0.311	0.296	0.862	0.169	0.426	0.834	1.50	0.404
Dy	1.96	1.51	2.06	2.09	6.12	0.991	3.19	6.28	11.0	2.47
Ho	0.434	0.378	0.463	0.478	1.47	0.199	0.763	1.51	2.78	0.526
Er	1.22	1.14	1.30	1.39	4.52	0.530	2.25	4.53	8.23	1.41
Tm	0.181	0.186	0.200	0.215	0.740	0.077	0.360	0.733	1.37	0.210
Yb	1.20	1.28	1.33	1.46	5.14	0.483	2.39	4.88	9.28	1.38
Lu	0.190	0.209	0.207	0.229	0.793	0.072	0.375	0.780	1.44	0.210

It is also noted that certain facies exhibit positive potassium anomalies due to the fact that the mantle source was enriched; that is to say, the mantle source may have been altered by potassium-rich fluids. The negative potassium anomaly indicates that the mantle source was depleted, with a mantle poor in incompatible elements and fractionation of titanium-bearing minerals. The spectrum of sample THS56, which is an andesite, stands out from the others due to its depletion in multiple elements, with anomalies in Zr and Nd; this suggests that the mantle source is depleted or has been affected by leaching processes or crustal contamination (**Figure 12(a)**). A negative Sr anomaly is also observed, which may result from fractional crystallisation with plagioclase extraction [28] [31]-[33]. The Ti anomalies are controlled by the fractionation of titanium-bearing minerals such as rutile and ilmenite. In some cases, they reflect emplacement contexts similar to those of modern oceanic arcs [34]. The chondrite-normalised rare-earth spectrum [35] (**Figure 12(c)**) shows fractionated spectra. It reveals negative anomalies in Dy, Nd and Ce; the negative anomalies in Eu ($\text{Eu}/\text{Eu}^* = 0.394 - 0.992$) are due to the fractionation of plagioclases or the fractional crystallisation of hornblende. The negative anomaly in Dy, which is one of the heavy rare earth elements, is linked to the presence of HREE-rich phases (such as garnet) in the original mantle source. For neodymium, the negative anomaly indicates fractional crystallisation, whereby Nd-rich phases such as certain accessory minerals (monazite and apatite) are removed from the magma. The negative Ce anomaly in

certain facies is due to oxidising conditions in the magma. Overall, the volcanic rock facies show enrichment in light rare earth elements relative to heavy rare earth elements, with ratios of $((\text{La}/\text{Yb})\text{N} = 0.63 - 15.57)$ and $((\text{La}/\text{Sm})\text{N} = 0.83 - 5.23)$. However, there is one sample that stands out from the others due to a more pronounced depletion in light rare earth elements relative to heavy rare earth elements. Negative anomalies in europium are observed in all facies; which is due to the advanced fractionation of plagioclases; indeed, during the fractional crystallisation of a magma, plagioclase preferentially extracts Eu^{2+} from the magmatic liquid, leaving the residual liquid depleted in europium (Eu) and thus causing the negative Eu anomaly [30] [36]. Among the facies studied, there are three that exhibit positive Eu anomalies ($\text{Eu}/\text{Eu}^* = 1.032 - 1.088$), which reflects the minor role played by plagioclase, which does not appear to significantly influence the geochemical differentiation of these rocks. The positive anomaly may also be linked to hydrothermal alteration, which causes europium to be transported in solution and then precipitate as the fluids cool [37] [38]. The presence of plagioclase crystals in metabasalt and meta-andesite may partly explain the positive europium anomaly in certain facies [39]. However, there are two samples (a tholeiitic basalt (THS39) and a rhyolite (THS54)) that stand out from the others due to a more pronounced depletion in rare earth elements (REE); which, in the case of the rhyolite, may be due to the fact that several REE-rich minerals (monazite, apatite, titanite) crystallised, leaving the residual rhyolitic melt depleted [36]. As for the tholeiitic basalt, its depletion in rare earth elements is due to the fact that the magma originates from a mantle that was already depleted in incompatible elements, including REEs. This implies that there have probably been previous episodes of partial melting [40]. Among the volcanic rock facies studied, there are three (THS43; THS44; THS54) that exhibit positive Eu anomalies ($\text{Eu}/\text{Eu}^* = 1.032 - 1.088$), reflecting the minor role played by plagioclase, which does not appear to significantly influence the geochemical differentiation of these rocks [16]. The Th-Ta-Hf/3 diagram from [29] is designed to distinguish between geodynamic environments on the basis of incompatible elements such as thorium (Th), hafnium (Hf) and tantalum (Ta). As these elements are relatively immobile during weathering and metamorphism, they remain reliable indicators even in rocks that are more advanced in differentiation, such as rhyolites. Analysis of this diagram shows that the majority of volcanic rocks from the East Boromo Belt (THS49, THS104, THS44, THS43, THS54, THS29) belong to the calc-alkaline basalt (CAB) field of subduction zones, which are rich in Th and poor in Ta. The fact that these rocks belong to the calc-alkaline basalt field suggests, on the one hand, that they have undergone fairly significant crustal contamination [34] (Figure 12(b)). Only two samples (THS56, THS58) originate from island arc tholeiites that are low in Th and Ta [40] [41]. The majority of volcanic rocks in the East Boromo Belt originate from calc-alkaline volcanic arc-type environments, corresponding to subduction-related magmatism where fluids derived from the subducting plate have enriched the source mantle with incompatible elements such as Th. The fact that certain sam-

ples belong to the IATs suggests a more tholeiitic magmatism linked to temporal or spatial evolution within the volcanic system. We therefore see an evolution within an overall context of subduction, where the CAB-IAT association is typical of an evolved island arc or a continental arc. The distribution of volcanic rocks from the East Boromo belt between the two trends (CAB and IAT) (**Figure 12(d)**) also indicates a diversity of mantle sources.

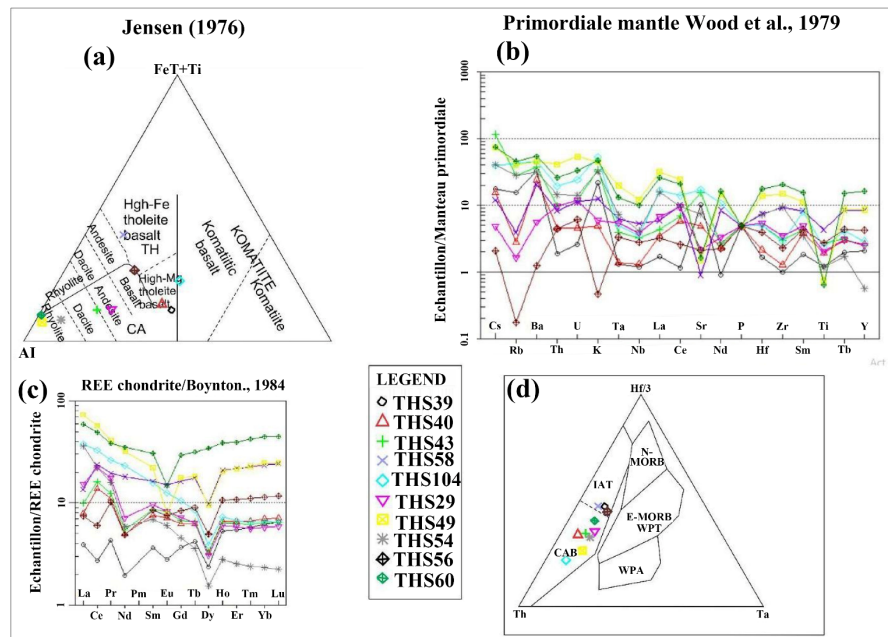


Figure 12. (a) Fet + Ti – Mg – Al diagram from [26] showing the classification of volcanic rocks from the East Boromo Belt; (b) Multi-element spectra normalised to the primordial mantle from [27] for volcanic rocks from the East Boromo Belt; (c) Rare-earth spectra normalised to chondrites [35] for volcanic rocks from the East Boromo Belt; (d) Hf/³Th-Ta diagram from [28] used to classify rocks from the East Boromo Belt according to geodynamic zones.

6.2. Geochemistry of Granitoids

A total of thirteen granitoid samples were analysed from the Boromo-East belt. The silica content varies from one sample to another, ranging from 64.36 per cent to 76.80 per cent. Most of these granitoids are fairly rich in Al₂O₃ (Al₂O₃ varies between 11.02 wt.% and 16.09 wt.%). Their MgO content is nevertheless significant to a greater or lesser extent (0.08 wt.% to 3.78 wt.%). The Fe₂O₃ content also varies (Fe₂O₃ = 1.70 wt.% – 5.47 wt.%), with the majority of facies being enriched in Na₂O relative to K₂O (**Table 2**). This indicates, in part, that the granitoids of the East Boromo Belt are predominantly sodic. In the diagram from [42], modified by [43] (**Figure 13(a)**), most samples fall within the granodiorite and granite fields, although a few samples also fall within the trondhjemite and tonalite fields. The same trend is observed in the diagram from [44] (**Figure 13(b)**), where the samples fall within the granodiorite and granite field. Only one sample falls within the diorite field. Analysis of the two diagrams shows that most of the granitoids

of the East Boromo Belt are predominantly situated within the granodiorite and granite fields. In the diagram in [45], it can be seen that only one sample falls within the highly potassic calc-alkaline series on the one hand, and only one sample belongs to the tholeiitic series on the other (**Figure 13(c)**). Most of the samples fall within the field of the high-potassium calc-alkaline series. In the diagram in [46], the facies studied belong exclusively to the calc-alkaline series. This result confirms that of [45] (**Figure 13(d)**), which classifies most of the granitoids studied within the field of the calc-alkaline series.

Table 2. Total whole rock geochemical data for the granitoids of the East Boromo Belt.

Sample	THS03	THS04	THS15	THS16	THS22	THS34	THS51	THS80	THS83	THS90	THS96	THS106	THS108
X (m)	530,101	528,890	526,352	525,635	525,865	525,319	531,1974	527,148	529,040	511,281	511,966	509,793	508,618
Y (m)	1,222,877	1,233,129	1,237,013	1,237,328	1,236,146	1,249226	1,256,064	1,225,319	1,227,667	1,211,747	1,222,828	1,248,290	1,249,565
Rock type	Granodiorite	Granite	Granodiorite	Tonalite	Granodiorite	Trondjémite	Trondjémite	Granodiorite	Granodiorite	Granite	Granite	Granite	Granite
Key elements													
SiO ₂	65.22	71.86	65.53	61.26	65.70	76.80	75.80	65.24	64.54	74.61	72.14	64.36	71.52
Al ₂ O ₃	14.85	14.18	14.85	16.09	15.16	11.02	12.06	14.59	14.56	13.86	14.70	15.07	14.37
Fe ₂ O ₃	4.17	2.70	4.32	5.47	4.01	3.03	3.56	4.58	5.00	1.70	2.20	5.69	2.78
MnO	0.066	0.047	0.065	0.078	0.062	0.086	0.036	0.071	0.083	0.039	0.023	0.085	0.041
MgO	3.14	0.66	3.20	3.99	2.80	0.15	0.08	3.77	4.08	0.35	0.51	3.10	1.07
CaO	3.71	1.94	3.77	5.19	3.43	1.10	1.19	4.16	4.47	0.97	1.39	4.50	2.22
Na ₂ O	3.82	4.17	3.84	4.07	3.73	4.51	5.44	3.71	3.73	3.99	4.05	3.35	3.88
K ₂ O	2.76	3.55	2.72	1.71	3.32	1.91	0.82	2.73	2.44	4.50	4.18	3.20	3.86
TiO ₂	0.34	0.27	0.36	0.49	0.33	0.15	0.14	0.40	0.41	0.19	0.26	0.51	0.26
P ₂ O ₅	0.13	0.10	0.13	0.17	0.13	0.01	0.02	0.12	0.13	0.06	0.09	0.19	0.10
PF	0.89	0.54	0.73	1.04	1.00	0.69	0.50	0.82	0.96	0.50	1.05	0.93	0.66
Total	99.09	100.03	99.51	99.54	99.65	99.44	99.64	100.19	100.42	100.76	100.58	100.98	100.74

Continued

	Minor elements (ppm)												
As	2.92	0.81	1.52	0.64	1.74	0.71	0.52	3.79	5.92	0.30	1.06	1.11	0.90
Ba	940	1096	833	821	2025	529	635	819	685	414	1269	788	812
Be	1.19	1.36	1.24	1.00	0.98	1.19	0.98	1.13	1.14	2.31	2.28	1.29	1.84
Bi	0.05	0.05	0.09	0.02	0.03	0.06	2.03	0.06	0.10	0.24	0.25	0.12	0.12
Cd	0.06	0.06	0.06	0.08	0.06	0.17	0.08	0.06	0.06	0.04	0.05	0.09	0.04
Co	13.7	3.74	14.2	18.5	13.1	1.19	1.22	16.7	18.2	2.59	8.02	16.0	5.56
Cr	219	20.7	211	240	180	22.0	15.0	261	283	18.6	22.5	126	49.1
Cs	2.70	1.82	4.48	1.33	2.43	0.33	0.58	2.47	3.16	8.05	4.81	4.07	6.99
Cu	5.8	6.5	45.6	7.1	9.0	4.8	<L.D.	10.6	17.5	6.7	21.0	25.1	7.5
Ga	15.5	17.8	16.1	18.5	15.5	15.3	18.7	15.7	16.1	21.1	20.6	17.3	17.2
Ge	1.06	1.06	1.07	1.05	0.91	1.53	1.17	1.08	1.13	1.10	1.61	1.37	1.16
Hf	3.27	3.49	3.66	3.70	2.95	7.28	5.98	3.63	3.30	3.14	3.83	3.87	3.32
In	0.021	0.022	0.023	0.030	0.020	0.099	0.016	0.024	0.026	0.016	0.015	0.036	0.017
Mo	0.34	0.47	0.35	0.35	0.25	0.61	0.40	0.28	0.35	0.32	0.27	0.46	0.42
Nb	4.46	6.26	4.48	3.55	3.33	11.2	9.02	4.54	4.66	8.56	5.22	5.51	4.55
Ni	65.6	7.7	73.3	87.0	61.0	7.7	3.4	84.6	95.7	5.5	16.3	29.4	12.2
Pb	13.4	13.2	13.7	8.34	13.0	3.65	2.62	12.8	10.9	22.8	17.7	11.1	18.5
Rb	80.1	81.4	90.8	53.6	80.0	45.4	24.9	76.6	71.8	240	171	103	129
Sb	0.30	0.18	0.30	0.17	0.20	0.16	0.13	0.32	0.60	0.09	0.13	0.16	0.14
Sc	9.26	3.36	9.75	12.45	9.04	3.57	3.32	11.15	12.11	2.77	2.55	15.91	5.21
Sn	0.90	0.93	1.04	0.92	0.90	2.22	1.41	1.15	0.90	1.98	1.45	1.66	1.66
Sr	610	444	549	840	685	50.8	61.8	535	535	132	311	452	350
Ta	0.46	0.68	0.50	0.25	0.27	0.99	0.89	0.47	0.40	1.35	0.70	0.62	0.72
Th	8.35	5.29	6.24	4.11	4.49	3.71	3.62	7.88	7.06	19.5	12.2	5.35	12.2
U	1.38	2.08	1.48	0.620	0.641	1.22	1.21	1.52	1.15	2.79	3.88	1.68	9.94
V	54.0	20.4	52.5	75.4	47.7	1.84	1.60	66.1	68.4	11.9	18.4	89.4	28.7
W	0.31	0.17	0.25	0.22	0.30	0.44	0.84	0.43	0.55	0.21	0.35	0.39	0.21
Y	8.32	11.4	9.34	9.70	7.56	56.5	60.7	10.0	10.8	5.90	51.7	17.0	7.44
Zn	45.5	51.3	50.6	64.4	50.4	110	40.4	48.2	55.5	38.8	51.5	62.8	38.5
Zr	129	126	141	152	120	260	217	142	142	101	150	144	116

Continued

Rare earth elements (ppm)													
La	32.3	29.5	22.0	35.3	25.0	32.7	28.8	29.6	28.1	25.3	121	24.8	28.5
Ce	55.9	54.1	42.2	57.6	50.9	64.8	57.9	53.4	51.3	47.0	144	52.0	51.0
Pr	5.71	6.36	4.24	6.18	4.93	8.14	7.17	5.70	5.68	4.79	21.5	6.09	5.05
Nd	19.5	24.0	16.4	21.5	17.7	32.7	29.2	20.9	20.8	16.7	82.6	23.9	17.4
Sm	3.05	4.42	2.96	3.25	2.95	7.31	6.80	3.51	3.44	3.00	12.9	4.74	2.82
Eu	0.761	1.04	0.773	0.934	0.854	1.07	1.06	0.865	0.833	0.418	3.14	1.11	0.648
Gd	2.07	3.06	2.19	2.46	2.04	7.40	7.16	2.47	2.42	1.87	12.3	3.78	1.96
Tb	0.265	0.381	0.291	0.305	0.258	1.31	1.29	0.318	0.313	0.218	1.42	0.520	0.239
Dy	1.43	1.99	1.65	1.64	1.39	8.87	9.01	1.79	1.77	1.09	7.29	2.99	1.31
Ho	0.286	0.386	0.332	0.328	0.277	2.06	2.10	0.358	0.345	0.197	1.42	0.613	0.255
Er	0.782	1.03	0.901	0.861	0.736	6.05	6.33	0.958	0.913	0.510	3.30	1.65	0.682
Tm	0.119	0.149	0.142	0.130	0.108	0.955	1.03	0.147	0.141	0.074	0.397	0.250	0.105
Yb	0.845	1.04	0.987	0.884	0.724	6.50	6.94	0.986	0.947	0.489	2.14	1.64	0.714
Lu	0.129	0.153	0.149	0.133	0.110	1.02	1.10	0.148	0.145	0.070	0.322	0.250	0.110

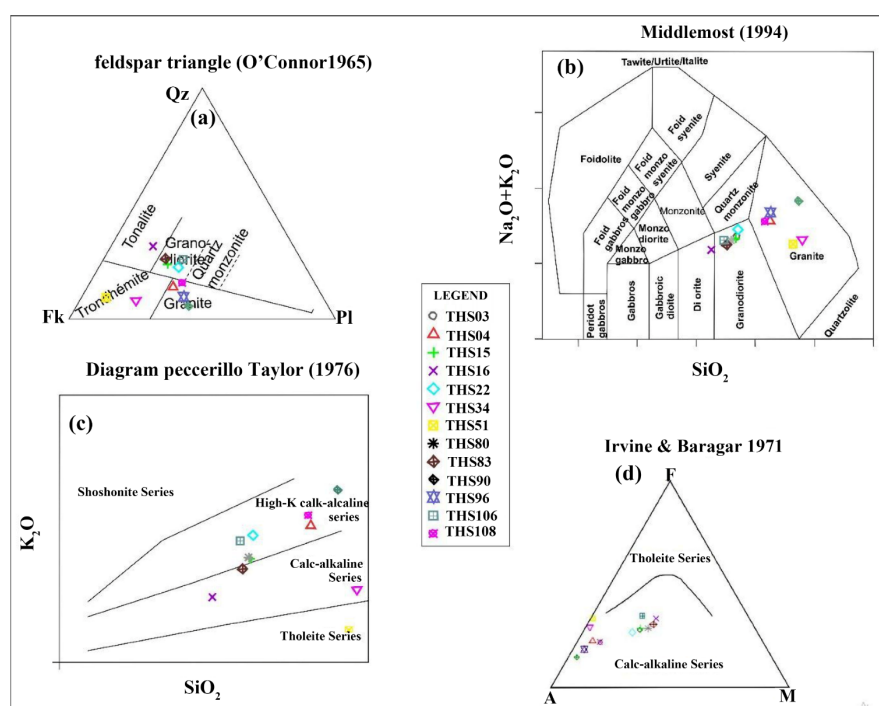


Figure 13. (a) An-Ab-Or diagram [42] [43] classifying the granitoids of the East Boromo belt; (b) SiO_2 vs $\text{Na}_2\text{O} + \text{K}_2\text{O}$ diagram [44] also enabling the classification of rocks from the East Boromo belt; (c) Diagram from [45] enabling the classification of formations according to magmatic series; (d) A-F-M diagram from [46] showing the series of granitoids in the East Boromo Belt.

With regard to the diagram in [47], which deals with the origin of the rocks, the majority of the facies in the study area fall within the field of highly potassium-rich mafic rocks (Figure 14(a)). Two facies are tonalitic in nature and one belongs to the low-potassium mafic rock field. As regards the A/CNK vs A/NK diagram [48], most of the rocks in the study area are metaluminous. Only a few facies fall within the peraluminous granitoid field. Metalluminous rocks have A/CNK ratios ranging from 0.8 to 1, whilst the A/NK ratio lies between 1 and 2. Peraluminous rocks, on the other hand, have an A/CNK ratio varying between 1 and 1.1, with an A/NK ratio ranging from 1.2 to 1.4. The (La/Yb)_N vs Yb_N diagram from [49] highlights the adakitic nature of the granitoid formations in the East Boromo Belt. Thus, the rocks of the East Boromo Belt are situated within the adakite field. The chondrite-normalised rare-earth spectrum [49] shows an enrichment in light rare earth elements relative to heavy rare earth elements (Figure 14(b)). Most samples exhibit negative anomalies in europium, due to the fractionation of plagioclases or the fractional crystallisation of hornblende. The facies are generally quite fractionated ((La/Yb)_N varies between 2.80 and 38.27). Sample THS96 exhibits a more pronounced enrichment in rare earth elements compared with the others; it is characterised by an enrichment in light rare earth elements relative to heavy rare earth elements and exhibits a negative Ce anomaly (Figure 14(c)). The negative Ce anomaly is typical of magmas originating from modern arcs; it may also be linked to post-magmatic alterations such as hydrothermal fluid circulation [9] [10].

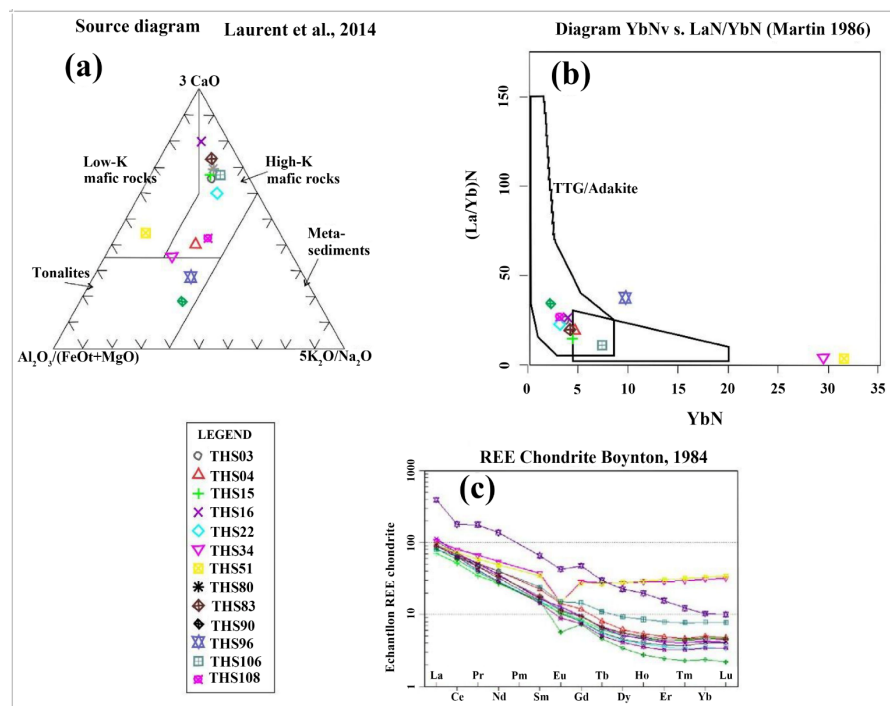


Figure 14. (a) Diagram from [47] defining the source of the granitoids in the East Boromo belt; (b) Diagram from [49] highlighting the Adakitic nature of the rocks in the East Boromo belt; (c) Chondrite-normalised rare-earth spectrum of the granitoids from the study area [35].

In the (Y + N) vs Rb diagram from [29], the granitoids of the East Boromo belt lie within the field of volcanic arc granitoids and, to a lesser extent, syn-collisional granitoids (**Figure 15(a)**). It is also noted that some samples lie within the field of intraplate granitoids. The same applies to the (Ta + Yb) vs Rb diagram [29]. The Yb vs Ta diagram, meanwhile, classifies the granitoids of the East Boromo Belt within the fields of syn-collisional granitoids, volcanic arc granitoids and orogenic granitoids. The Y vs Nb diagram classifies the granitoids studied exclusively within the field of syn-collisional volcanic arc granitoids and orogenic granitoids (**Figure 15(b)**). In general, it can be seen that most of the granitoids of the East Boromo Belt fall within the field of volcanic arc granitoids and volcanic arc granitoids in a syn-collisional context. Most granitoids belonging to calc-alkaline volcanic arcs contain hornblende and biotite as ferromagnesian minerals, and generally belong to the “calc-alkaline” suites (**Figure 15(c)**). The high-potassium and shoshonitic calc-alkaline granites of active continental margins are mainly found within the quartz monzonite, granodiorite and granite fields [28]. Syntectonic granites are generally situated in the granite field on the Streckeisen diagram, contain muscovite, are peraluminous and exhibit most of the characteristics associated with S-type granites (**Figure 15(d)**).

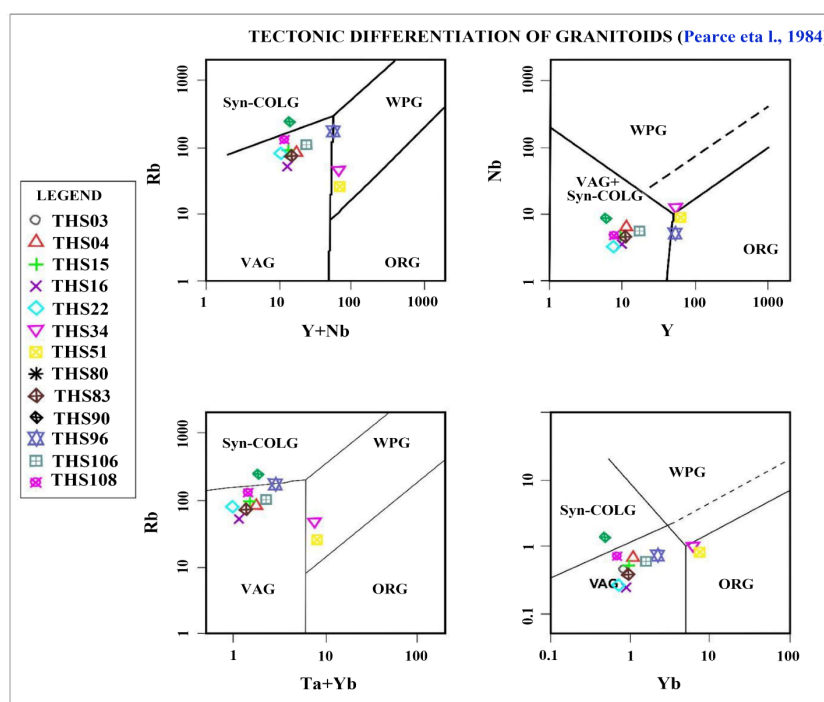


Figure 15. Diagram from [30] showing the classification of granitoids in the East Boromo belt according to orogenic zone; (a) (Y + N) vs Rb diagram; (b) Y vs Nb diagram; (c) (Ta + Yb) vs Rb diagram; (d) Yb vs Ta diagram. syn-ColG: syn-collisional; WPG: intraplate granitoids; VAG: volcanic arc granitoids; ORG: orogenic granitoids.

7. Discussion

Investigations carried out within the Boromo-East belt have yielded some signifi-

cant results. Although the geochemistry and petrography have been characterised, some grey areas remain to be clarified. This study, based on petrogeochemical and structural data, aims to provide further details on the petrography, geochemistry and geodynamic environment in which the Boromo-East belt developed. The mineralogical associations (parageneses) within the metabasalts show that minerals such as amphiboles and garnet (**Figure 4(b)** and **Figure 4(f)**) are predominant; it is also noted that there are facies containing large plagioclase crystals, which have been described by [8] as megacrystalline basalts. Megacrystalline basalts have been observed on the eastern and western margins of the Houndé and Boromo-West belts respectively, leading [8] to conclude that the two belts were once adjacent. The amphibole-garnet and muscovite mineral associations within the metabasalt rocks of the East Boromo Belt bear witness to the steep metamorphic gradient that affected the belt's formations. This metamorphic gradient ranges from the amphibolite facies to the lower granulite facies. It is also evident in other regions of Burkina Faso, such as Arbinda and Tampilga, and in other parts of the Man Ridge, where metamorphism extends from the green schist facies to the amphibolite facies [50] [51]. The andesitic rocks also contain plagioclase megacrystals, which are often even slightly flexed; this fact attests to the extent of shearing in these meta-andesitic facies. The granitoids range from the tonalitic facies to the granitic facies, passing through granodiorites. The comagmatic enclaves (mafic enclaves) observed within these facies are also present within the granitoids of the Lawra Belt in Ghana [52] [53], suggesting that these formations share, in part, a common magmatic history, albeit during distinct periods. Like the granitoids of the Lawra Belt, the granitoids of the East Boromo Belt contain biotite and amphibole as the main ferromagnesian minerals [2] [3] [7] [52]. Unlike the other granitoids of the East Boromo Belt, the granitoids of the Lawra Belt are much more structured, with ferromagnesian minerals arranged in flakes alternating with the leucocratic minerals—feldspars and quartz [52] [53]. The orthogneissification of the granitoids in the Lawra Belt indicates that deformation occurred whilst the protolith had not yet cooled completely, and was therefore capable of undergoing ductile deformation. Once again, it is evident that the structural level was much lower at the time of deformation in the case of the Lawra Belt. Structurally, the study area is fairly well-structured, although the deformation structures are rather unevenly distributed. It is evident that it is the volcanic and volcano-sedimentary formations that have primarily recorded most of the deformation; this may be due to their high content of mafic minerals such as pyroxenes and olivine. The granitoids, for their part, exhibit foliation localised in the southern part of the study area. Interpretation of the ductile and brittle deformation structures in the study area has led to the following conclusions: i) schistosity, foliation and shear zones follow almost the same directions, with the exception of a few areas where a slight deviation in the interpreted structures is observed; ii) the shear zones interpreted from geophysical images by [13] generally correspond to the orientation of structural measurements taken in the field; iii) the different directions of schistosity,

foliation and shear suggest that these structures were formed during several phases of deformation, indicating a polyphasic deformation process within the lithologies of the East Boromo Belt; iv) Deformation is predominantly brittle throughout the study area, and this is undoubtedly due to the fact that the study area belonged to a much higher structural level at the time of deformation. The identification of a major NNW-SSE-trending shear zone in the East Boromo Belt, in continuity with the Jirapa shear zone [25], reinforces the idea that this structure represents a major tectonic corridor, active during the late phase of the Eburnean orogeny (~2.1 Ga), within the Man Ridge. In other Birimian belts, such shear zones have been interpreted as boundaries between crustal blocks and channels for the transfer of deformation [54] [55]. Structural observations also allow for the proposal of the following sequence regarding the structural evolution of the East Boromo belt: i) (D1B-E): Initial shortening following the emplacement of the earliest granitoids, associated with the development of a NW-SE foliation—likely linked to oblique convergence—and the alignment of mafic enclaves parallel to that foliation; ii) (D2B-E): Development of a syn-metamorphic NE-SW schistosity, coinciding with a regional shear regime; iii) (D3B-E): Late-stage brittle deformation involving the development of three fracture sets, possibly linked to tectonic relaxation or active shearing; the E-W trending dolerite dykes associated with this late fracturing of the East Boromo belt formations almost certainly originated during this D3B-E deformation phase. The suite of volcanic rock samples ranges from metabasalts to meta-andesites, including dacites and rhyolites, with SiO₂ contents varying from 48 wt.% to 74 wt.%. The diagram from [26] allows the volcanic rocks of the East Boromo belt to be classified into several trends: i) a group of high-iron tholeiitic basalts (THS58 and THS56), high-magnesium tholeiitic basalts (THS39, THS44, THS104), calc-alkaline-affinity andesites (THS43; THS29), rhyolites (THS49; THS54; THS60), and dacites (THS43). The presence of these diverse volcanic rock facies within a single Birimian belt suggests a common parental magma that underwent significant magmatic differentiation, evolving from basalts (the most basic members) to dacites and rhyolites (the most differentiated members). This indicates an advanced stage of magmatic evolution for the volcanic rocks of the East Boromo belt. The diagram from [26], based on incompatible trace elements, demonstrates that these Archean and Proterozoic volcanic rocks fall into series comparable to modern magmatic settings (MORB, OIB, and arcs). The same work by [54] provided a fundamental framework for the tectonomagmatic interpretation of greenstone belts in general. Evidence of magmatic evolution is also observed in the Sr anomaly, which indicates fractional crystallization of the magma—specifically involving plagioclase. It is evident that the volcanic rocks of the East Boromo belt formed from already differentiated magmas following several stages of evolution within the original magma chamber [28] [31]–[33]. The East Boromo belt exhibits greater variability (coexistence of IAT and CAB magmas, unlike the Lawra belt; presence of both Fe-rich and Mg-rich tholeiitic basalts; and more contrasting REE/multi-element patterns, such as the

depleted THS56 sample). In chondrite-normalized rare-earth element (REE) patterns [35], the combination of features—such as a negative europium anomaly and HREE signatures reflecting amphibole or garnet fractionation at the source—points to an evolving volcanic arc fed by a metasomatized mantle and modulated by varying degrees of fractionation and mixing.

The granitoids of the East Boromo belt exhibit SiO₂ contents ranging from 64.35 wt.% to 76.80 wt.%, representing a spectrum from relatively basic tonalites to highly differentiated trondhjemites. High Al₂O₃ abundances (11.10 wt.% - 16.09 wt.%) and a general enrichment in Na₂O relative to K₂O—with the exception of potassic granites—indicate a calc-alkaline affinity with sodic tendencies, typical of TTG (tonalite-trondhjemite-granodiorite) type granitoids [49] [56]. Diagrams from [45] and [46] confirm that the majority belong to calc-alkaline series (high- to medium-K), with a single sample trending toward the tholeiitic field, likely reflecting a less differentiated magmatic input or reduced crustal contamination. The 3CaO-Al₂O₃/(FeO + MgO)-5K₂O/Na₂O diagram from [47] places most samples within the field of high-K mafic granitoids, suggesting a link to magmas derived from thickened crust, typical of active continental arcs or collisional settings. The tectonic diagram from [29] confirms that the granitoids predominantly fall within the volcanic arc and syn-collisional granitoid fields, with some orogenic trends, reflecting a convergent environment.

In any case, the granitoids of the East Boromo belt—like other granitoids of the Man Shield—were emplaced within a transcurrent tectonic setting [2] [7] [57]. Chondrite-normalized rare-earth element patterns [35] show marked LREE enrichment relative to HREE, along with negative europium anomalies typical of plagioclase fractional crystallization. Primitive mantle-normalized multi-element diagrams [27] [39] reveal negative Nb-Ta and Ti anomalies, characteristic of a volcanic arc signature [52]. In summary, these granitoids are predominantly calc-alkaline, of the adakitic TTG type with a continental arc signature; they show some syn-collisional influences and originated from the partial melting of hydrated basaltic crust [1] [29]—in the presence of residual garnet—within a context of widespread convergence.

Relations lithostratigraphiques et géochimiques entre les ceintures de Lawra (Ghana) et de Boromo-Est (Burkina Faso)

In the Lawra belt, published data describe predominantly calc-alkaline suites with moderate potassium contents and marked Nb-Ta-Ti depletion [52]-[53], characterized by LREE/HREE slopes typical of mature continental arcs. Distinctly tholeiitic rocks are less abundant, and shoshonitic trends are rarer [20], [8], [52]. In contrast to the Lawra belt, the East Boromo belt exhibits greater variability (co-existence of IAT and CAB, Fe-rich and Mg-rich tholeiitic basalts, and a localized shoshonitic signature) and more contrasting rare-earth and multi-element patterns (e.g., depleted THS56). Island-arc tholeiitic basalts, specifically, are characterized by low alkali content and are often associated with oceanic crust. For the East Boromo belt, this situation reflects a more heterogeneous mantle source and/or

more varied magma chamber conditions (crystallization rates, depth) compared to the Lawra belt, where the arc appears more homogeneous and calc-alkaline. Geochemical evidence from the volcanic rocks regarding collisional implications focuses on the following points: i) the coexistence of magmas (IAT and CAB) and widespread Nb-Ta-Ti depletion attest to an active arc; ii) the appearance of rhyolite/dacite and a late shoshonitic signature indicates an evolution toward crustal thickening and/or a reorganization of the tectonic regime (crustal flux, contamination, anatexis) consistent with a collisional/transpressional stage. iii) Contrasts with the Lawra belt (more calc-alkaline, less tholeiitic) suggest that collision and shear zone localization differentially modulated magmatic differentiation on either side of the orogenic suture. The East Boromo belt recorded more primitive injections and more diverse fractionation processes during or immediately after the collision, whereas the Lawra belt reflects more steady maturation.

The Lawra granitoids exhibit higher K₂O contents, reflecting a more potassic character [58], whereas the East Boromo belt is predominantly sodic, with the exception of purely granitic facies. The Lawra granitoids comprise both I- and S-type varieties, though a higher proportion of S-types is observed, suggesting a more significant crustal contribution. Negative europium anomalies are also less pronounced, indicating either reduced plagioclase fractionation or a different source. Most Lawra granitoids are associated with late syn-collisional granitoids [52], whereas an arc signature remains dominant in the East Boromo belt. Geodynamic data from the East Boromo belt granitoids suggest an origin linked to subduction processes and an active orogenic setting, possibly involving a late collisional phase. High LREE/HREE ratios, systematic depletion in Nb, Ta, and Ti, and negative Sr anomalies in several facies are characteristic of magmas derived from a mantle metasomatized by subduction-zone fluids [30] [49]. Their predominantly calc-alkaline—and sometimes highly potassic—nature confirms a strong link to volcanic arcs. In contrast, the granitoids of the Lawra belt in Ghana, while displaying calc-alkaline signatures and negative Nb, Ta, and Ti anomalies [59], show a stronger affinity with Archean TTGs, characterized by often more moderate (La/Yb)_N ratios and less pronounced HREE fractionation. The collision involving the Lawra belt can thus be interpreted as the result of late-stage convergence between two crustal blocks representing volcanic arcs of distinct ages and histories. The granitoids of the East Boromo belt—which are more enriched in LILE (Rb, Ba, K, Th, U) and exhibit marked negative europium (Eu) anomalies—indicate more extensive fractional crystallization and a more evolved magmatic stage than those of the Lawra belt. This difference likely reflects a temporal offset between the respective magmatic peaks of the two domains, as well as variations in the depth and nature of the magmatic sources, resulting in distinct geochemical signatures despite a shared orogenic setting. In summary, the convergence of the East Boromo and Lawra belts illustrates an arc-arc collision scenario involving differing geochemical legacies; the East Boromo belt appears to have recorded a more differentiated and enriched magmatic episode, possibly linked to more advanced crustal matu-

ration prior to the final amalgamation of the crustal blocks. This has previously been highlighted by the work of [26], who identified a collisional event between northeastern Ghana and southwestern Burkina Faso. A similar situation is observed in the Doropo region of extreme northeastern Côte d'Ivoire, where [60] identified a collisional episode between northeastern Côte d'Ivoire and the southernmost part of Burkina Faso.

8. Conclusion

Investigations within the Boromo-East belt have identified an orogenic segment that is both related to and distinct from the Lawra belt. Petrographic and structural data reveal a crustal level that is shallower and less foliated than that of the Lawra belt, while geochemical analysis highlights calc-alkaline signatures typical of magmatic arcs evolving toward a collisional setting. Structural data indicate that the deformation affecting the Boromo-East belt occurred at a shallow structural level, explaining the predominantly brittle nature of the deformation within the belt. In contrast, the Lawra belt exhibits much more ductile deformation, a difference attributable to the distinct structural levels prevailing at the time of deformation. Collectively, these data support a scenario involving a collision between the Boromo-East and Lawra belts during the final phase of the Eburnean orogeny, reflecting the convergence and suturing of crustal blocks within the West African Craton.

Author Contributions

Professor Naba helped to proofread the article at every stage of its preparation, right up to the final version. Dr. Abraham Seydoux Taore was part of the field team and also took the time to proofread the article. Dr. Saga Sawadogo, for his part, supervised the work from start to finish and was on hand to ensure effective communication between the research team and the scientific journal. Mr. Sampegbo Souleymame drafted the scientific article.

Conflicts of Interest

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

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