

Structural Relationship between Brittle Deformation and Paleozoic to Mesozoic Basalt Dykes in the Precambrian Basement of the Southern Continental Part of the Cameroon Volcanic Line

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Abstract

The work is a vivid description of the structural relationship between brittle deformation of the Precambrian basement in the southern continental part of the Cameroon Line and intrusive Paleozoic and Mesozoic basalt dykes swarms. A multidisciplinary approach that involves a combination of remote sensing techniques and field studies show that the major trend of brittle structures correspond to well-known regional structures: N70°E (Adamawa Shear Zone), N135°E (upper Benue trend) and N30°E (Cameroon Volcanic Line) corresponding to E-W and N-S directions respectively. Basalt dykes are associated to NE-SW, E-W and NW-SE oriented fractures. An integration of the available information on brittle structures and basalt dykes directions suggest an emplacement of the Mesozoic and Paleozoic basalt dykes structurally controlled by Precambrian structures that were originated through Riedel's fracture kinematic model with dextral strike-slip Adamawa Shear Zone as the main shear zone during late stage of the Pan-African collision. Spatially, the restriction of the basalt dykes to the corridor of the Adamawa Shear Zone indicate that a rejuvenation of Precambrian faults may very well be the origin of the dykes with possibility that they may have been reworked several times during the Phanerozoic eon.

Keywords

Basalt Dykes, Brittle Tectonics, Adamawa Shear Zone, Riedel Model, Western Gondwana

1. Introduction

The presence of basalt dyke swarms in any region is a surface expression of fractures of lithospheric importance and inversely provides a better understanding of these fracture distribution in the earth: This is considered as vectors of fissural eruptions channeling magma from source chamber to the Earth's surface. Dyke swarms may be characterized by up to several hundred intrusions, established almost simultaneously during a single intrusive event. These events are key indicators of geological processes and by extension, the reconstruction of ancient supercontinents [10]. Several authors believe that dyke swarms are remnants of supercontinent assembly: Rodinia and Gondwana for example [3] [36] [21] or of the establishment of volcanic structures [9] [17].

Basalt dykes of Paleozoic and Mesozoic age intrude the Precambrian basement in West Cameroon (Figure 1 and Figure 2), a basement bearing two lineaments of regional importance: 1) the N70°E striking Adamawa Shear Zone (ASZ) also known as Central Cameroon Shear Zone (CCSZ) [25] which extends from the Gulf of Guinea in Central Africa to the Red Sea. The ASZ resulted from subduction-collision events (ca. 600 - 540 Ma) that involved the Congo-Sao Francisco Craton, West African Craton and Saharan Metacraton [1] [28]. It is well-known as the prolongation into Africa of the Pernambuco Shear Zone of North East Brazil after palinspatic reconstructions [23] before the opening of the South Atlantic Ocean during the Mesozoic [2] [53], 2) the Cameroon Volcanic Line (CVL) with a N30°E orientation that runs from the Atlantic Ocean in the Gulf of Guinea to Lake Chad over a distance of more than 1500 km. If abundant works document relations between the CVL and ASZ [19] [27] [31] [35], little is known concerning basalt dykes discovered only recently and for which the only information related to petrology and geochronology are available in [46] [47].

In the present study, brittle structures of the Precambrian basement are investigated as well as the intrusive basalt dykes in the West Cameroon area located in the ASZ corridor (**Figure 1**). This work involves geometrical and kinematic analyses of the brittle deformation of the basement in order to constrain the mechanism at the origin of the observed network of basalt dykes and to bring some answers to following major geological questions of the geology of the southern continental part of the Cameroon Volcanic Line:

- Does it exist relations between fracturation of the basement and the propagation of the basalt dykes?
- What are the links between the N30°E direction of the CVL and the N70°E direction of the Precambrian Adamawa Shear Zone?
- How can the studied basalt dykes help to explain the Paleozoic to Mesozoic crustal evolution in Cameroon?

2. Geological Background

The Precambrian terrane of west Cameroon is a polycyclic domain consisting of Paleoproterozoic to Archean high grade metamorphic rocks formed during the 2.1 Ga collision between Trans-Amazonian and Congo Cratons [38] [52] which



Figure 1. Geology map of Cameroon after [52]. The study area is indicated by the frame. SF: Sanaga Fault, ASZ: Adamawa Shear Zone, CCSZ: Central Cameroon Shear Zone, TBF: Tcholliré-Banyo Fault.

was remobilized during subsequent Pan-African orogeny [8]. The collision resulted in high grade metamorphic rock recrystallized under the amphibolite and granulites facies metamorphism [1] [37] [43] and crustal and mantle derived high-K calc-alkaline to shoshonitic, and alkaline affinity magma emplaced during 630 - 550 Ma [20] [29] [44] [48] [51]. The chronology of the Pan-African tectonic evolution of the area is diversely interpreted. Some authors e.g. [28] [30] [34] suggest three deformation events which is characterized by an early crustal thickening (D1) constrained at 630 - 600 Ma manifested by a sub-horizontal S1 foliation and F1 fold [32]. This stage is followed by sinistral shearing movement





Figure 2. Reconnaissance geology map of West-Cameroon (Simplified after [54] with location of basalt dykes swarms. A = Tertiary volcanic rocks; B = Quaternary alluvial deposits; C = Pan-African granitoids; D = Undifferentiated gneiss; E = basalt dykes.

(D2) bracketed between 613 and 590 Ma [14]. The dextral shearing movement constrained at 570 - 550 Ma is underlain by N30 and N70°E striking transpressional/transcurrent strike-slip shear zones [26] [31] [32] [34] [45] which is regarded as possible prolongations of the major shear zones of NE Brazil in a pre-drift Gondwana reconstruction [2] [24] [31]. [51] mentions a fourth deformation event (D₄) which is marked by N80-110°E dextral and N160-180°E sinistral shear zones which occur during the right lateral wrench movements (585 - 540 Ma) mainly marked by the Adamawa Shear Zone. This shear zone is associated with a fracture network whose main trends are N25-30°E, N70°E, W-E, N135°E in the Tombel area [33] Foumban [34] and Bafia [22]. Some of them are associated with tholeiitic basalt dykes in the Dschang, Maham, Kendem and Bangwa area, with whole rock ⁴⁰Ar/³⁰Ar ages ranging between 421.3 ± 3.5 and 149.2 ± 3.8 Ma (Tchouankoue *et al.*, 2014). A SW-NE oriented alkaline igneous

magmatism composed of anorogenic complex and floods basalt that partially covered both Paleoproterozoic and Pan-African formation; runs from Annobon Island in the Gulf of Guinea to Lake Chad that belong to the Cameroon Volcanic Line (CVL) and has been active since Eocene to Present [4] [49].

3. Data and Methods

The use of remote sensing data such as Shuttle Radar Topographic Mission (SRTM) is a good source for the mapping of topographic expression of tectolineaments [7] [12]. SRTM satellite images were used to extract lineaments. Image processing techniques such as directional filtering of Sobel 7×7 [6] [16] [39] for edge detection were used as well as shady relief methods and image enhancement by using Global Mapper 12 and X-Pro software. Lineaments with a minimum straight segment length of 500 m were mapped. The manual extraction of lineaments was performed while eliminating human-generated lineaments. The final lineament map is validated after comparison with field data. Global Mapper 12 and Geoplot were used for lineament statistical analyses. At the field scale, seven topographical maps (1/50.000 scale) have been used. A study of trends of lineaments was undertaken for rectilinear arms of rivers; the objective being to appreciate the various groups of fractures and their orientations separately inside granitoid massifs and the gneissic basement. Field data also include the orientation of the dykes. For detailed analysis, the studied area was divided into two sectors based on relative geological features: a Northwestern sector (sector 1) characterized by abundant Pan-African granitoids and a limited volcanic cover sector (sector 2) almost totally covered by volcanic rocks associated to Precambrian gneiss and granitoids (Figure 3).

4. Results

4.1. Geometrical Analysis and Distribution of Lineament

The statistical analysis revealed 1152 lineaments in the studied area (Figure 3). In sector 1, 242 lineaments were recorded with two main trending directions: N30-40°E and NW-SE. Both directions are recorded in syn-tectonic granite plutons elongated and parallel to the N-S to NNE-SSW foliation, of the gneissic Precambrian basement rocks. These rocks are cut by sinistral NE-SW to NNE-SSW trending shear zones [50]. In sector 2, a rose diagram of 910 lineaments revealed three dominant trends: NE-SW, NW-SE and E-W. The NE-SW trending lineaments bear two lineaments continuous over more than 136 km through Bafoussam and Foumban cities (Figure 3). It matches with the Foutoni-Fond-jomokwet Shear Zone [45] which is the SW prolongation of the Adamawa Shear Zone. Another NE-SW trending lineaments with a length of 55 km, filled with quartzite is recorded at the southwest of the city of Bangangte (Figure 3).

These main trends are confirmed by the synthesis rose diagram and histogram (**Figure 3** and **Figure 4**) which shows that the N60°E oriented lineaments are the dominant set. This orientation contains various lineaments lengths, >35 km and 15 - 35 km long lineaments are most dominant. These lineaments are predomi-



Figure 3. Map of lineaments. Bidirectional rose diagrams of lineaments in each sector. Number of measured elements (N) is indicated within each rose diagram. Dash line delineates two sectors: sector I (North West), sector II (South East).



Figure 4. Lineaments characterisation: strikes and lengths based on the interpretation of structural map. Bold frame represent direction of basalt dykes.

nantly observed in polycyclic metamorphic high grade and their orientations match with the N60-70°E striking ASZ [26] [34]. The conjugate sets of N70-80°E and N130-140°E striking lineaments are dominated by lineament of length greater than 35 km followed by 15 - 35 km long lineaments. These conjugate sets are widespread in both sectors. The N-S oriented lineaments contain 15 - 35 km, 5 - 15 km and 0 - 5 km long lineaments which are widespread in the studied area.

4.2. Geometrical Description of the Basalts Dyke

Basalt dykes are widespread in the studied area. The contact between dykes and basement rocks is sharp and fluidal textures in the outer part of the dykes show that the dykes were emplaced in a liquid state and cooled at very low rates. Basalt dykes are widespread in the Precambrian gneiss and in late Pan-African granitoids of West Cameroon. Ten NNE-SSW trending basalt dykes are predominantly exposed in the northwest of the studied area at Batibo and Kendem between Bamenda and Mamfe (Figure 5(a)). They cut across syn-tectonic granite plutons elongated and parallel to the N-S to NNE-SSW foliation of the Precambrian gneissic basement rocks. These rocks are cut by sinistral NE-SW to NNE-SSW trending shear zones [50]. Similar NNE-SSW oriented basalt dyke are also found at Bangoua village located in the centre of the studied area. Their thickness is not greater than 30m with a sub-vertical dip cut. These NNE-SSW oriented basalt dykes yielded ages between 200 - 140 Ma [47]. The N70-90°E and E-W oriented, sub vertical basalt dykes (Figure 5(b)) are restricted to sector 2 at Dschang and Maham and are usually of metric dimensions. They yielded a 420 -400 Ma Paleozoic age [47]. N130°E and N150°E oriented fractures are also filled with basalt. Figure 6 summarises the occurrence of basalt dykes in the NW-SE



Figure 5. Basalt dyke outcrops. (a) Dyke trending N70°E at Maham. Coordinates: 5°02'02"N/10°41'51"E attitude: N70 85°N. (b) Dyke trending N25°E at Bangoua. Coordinates: 5°12'20"N/10°27'04"E attitude: N25E 35°W.





Figure 6. SE-NW cross section in the studied area (Basalt dykes not to scale).

cross section of the study area.

5. Discussion

5.1. Kinematics of Faults Network

As shown in paragraph 4.1, NNE-SSW, ENE-WSW, NW-SE and E-W striking lineaments are the main trends with ENE-WSW matching with the ASZ. Numerical modeling of the mode of deformation [5] [13] [18] [40] within strikeslip shear zone show that five direction families of associated fractures. P, R, R', P', Y are formed from the main shear zone. R' and R shear bands correspond respectively to synthetic and antithetic fractures which form an angle of 75° and 15° - 20° from the main shear zone (Figure 7). P' and P shears are conjugate and P shears are symmetrical to R shears with respect to the main faults. Y shears are parallel to the main fault. Their geometrical relationship defines sinistral or dextral shearing movement. In the case of the studied area, the ENE-WSE striking shear zone is the main shear zone which corresponds to the ASZ. This shear zone forms an angle of around 20° with the E-W trending fault conjugate with NW-SE oriented fractures. The geometrical arrangement between recorded fault networks is consistent with Riedel's fractures kinematic model as the main mode of deformation which is the origin of the observed fracture network. The reconstruction of stress field in this area is seen in Figure 7. From the above features N85°E and 145°E are conjugate sets. It has been demonstrated that the maximal stress direction bisects a conjugate set at 30° which implies that the maximum stress direction (σ 1) matches the orientation NW-SE. N70-80°E and N80-90°E striking lineaments are conjugate sets of N130-140°E and N140-150°E. This geometric arrangement of the main lineament trends show an angular relationship as follows: 15° - 20° between ENE-WSW and N80-90°E, 75° between ENE-WSW and N140-150°E which is consistent with Riedel's shears [13]. Therefore, the NW-SW striking is the plausible orientation of the maximum stress because numerical modeling of brittle deformation shows that the maximum stress direction bisects the conjugate set at 30°. When applied in this case, the N115°E corresponds to the maximum stress direction and the minimum stress direction is perpendicular to it which is NNE-SSW. Structural fingerprints of regional stress can therefore fit in a Riedel fracture model (Figure 7) characterized by



Figure 7. Riedel fracturation model of study area. T = N115°, R' = N145°, R = N85; σ 1 = N135°, σ 3 = N45°, P = N55.T: tension gashes; R and R': conjugate shear faults; P: symmetrical to R; σ 3 and σ 1: tensional stress axes.

a NW-SE shortening (σ 1) and a NNE-NE to NE-NW stretching (σ 3). Mega fractures appear mostly inside the Precambrian gneisses or at the contact between granites and country rocks and show ENE-WSW and NW-SE strike which correspond to the direction of the Cameroon Line (σ 3), the Adamawa Shear Zone as superimposed shear and the Upper Benue (σ 1) respectively. This kinematic model fit very well with that reported in the areas of Tombel [33] Bafia [22] and in Ngoura-colomines [42] sandwiched by N70°E striking ASZ and Sanaga Fault (SF). The ubiquitous character of the Riedel's shears between ENE-WSW striking parallel CCSZ and SF suggest that they originated from the activity of this zone. The spatial distribution is also compatible with dextral shearing movement along both crustal shear zones that may be interpreted as shear zone boundaries.

5.2. Basement Control on Paleozoic and Mesozoic Basalt Dykes **Emplacement**

Field observations and brittle deformation studies show that basalt dykes are scarce in late Pan-African granitoids except in the Kendem area where the N25-30°E trending basalt dykes are exposed in syn-tectonic granitoids. They are predominantly recorded in highly deformed Precambrian high grade gneiss where they are associated to N25-30, N70°E and E-W which correspond respectively to P', R and R' in the Riedel's fractures kinematic model. Moreover, the contact between dykes and basement rocks is sharp and fluidal textures are recorded in outer part of the dykes. These fluidal textures are characteristic of emplacement in a liquid state at very slow cooling rates. The orientation of mineral at the outer part of the dykes is controlled by a fault wall. These features point to a structural control of the emplacement of Mesozoic and Paleozoic magmatism by pre-existent structures of which the geometrical arrangement is consistent with Riedel's structures kinematics. Furthermore, the stress field direction of this



fault network is consistent with that of the last dextral shearing movement (D3 event) in the Central Africa fold belt [22] [34] [45]. This dextral shearing movement which was still active at 552 Ma [43] following collision between West Africa and Congo Cratons [28] resulted in this fault network which controlled the emplacement of N30°E oriented late Pan-African grani-toids [41] or NE-SW to E-W transcurrent/transpressive movement that controlled the late pan-African granitization [15] [48]. Therefore, this fracture network is a heritage of the Pan-African deformation which has also served as pathways for Phanerozoic magma ascent. This argument is compatible with the tectonic model of the CVL of Moreau *et al.*, 1987, which stated that the CVL corresponds to N30°E tension gashes along Pan-African paleosutures [19] originated from the reactivation of Precambrian structures. This argument is supported by the geochronological data obtained from magmatic rocks associated to these paleostructures which show that the CVL was active from 82 Ma to present [11] and was proceeded by Paleozoic (420 - 400 Ma) and Mesozoic (200 - 140 Ma) magmatic events [47].

6. Conclusions

The following main results can be summarised from the studies of the relationship between fracturation of the Precambrian basement and intrusive Paleozoic and Mesozoic basalt dykes in West Cameroon:

- Brittle structures in the Precambrian basement show the following major directions N70°E, N135°E N30°E, N-S and E-W. Their spatial arrangement is consistent with a Riedel fractures kinematic model originating from dextral shearing movement along the ASZ related to collision between the Congo and West African Cratons.
- Basalts dykes are associated to NE-SW and E-W striking fractures with subvertical dips and mainly intrusive in gneissic rocks which are thought to have undergone brittle deformation during the formation of the Adamawa Shear Zone;

The basalt dykes as well as the Cameroon Volcanic Line may share a common origin in the reworking of Precambrian fractures during the Phanerozoic.

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