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Research Article

Petro-Structural Characterizations of the Hypovolcanic Formations of the Pan-African Basement and the Cretaceous Sedimentary Basins of Figuil (North Cameroon) and Léré (South-West Chad): Geodynamic Implication of the Pan-African Range of Central Africa (CPAC)

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ABSTRACT

The localities of Figuil (Northern Cameroon) and Léré (Southwest Chad) belong to the northern domain of the Pan-African Range of Central Africa (CPAC). Field observations and petrographic and structural studies have revealed the existence of two categories of dolerites depending on the nature of the surrounding rock: (1) dolerites of the Pan-African base (DSP) made up of dolerites with pyrite and calcite , dolerites with pyrite and basement enclaves, dolerites with amphibole and titanite and dolerites with pyrite and dolerites from the Cretaceous sedimentary basins (DBSC) composed of amphibole dolerites, biotite and pyroxene dolerites, pyroxene dolerites, gabbros with fine grain and trachytes. The textures of these rocks are intergranular to granophyre, doleritic, sub-ophitic, ophitic to granophyre, ophitic and subdoleritic. The installation of these magmatic rocks is probably linked to major accidents in the study area in NNW-SSE, NE-SW, E-W and ESE-WNW directions, similar to those of the Pan-African faults which would be close to the direction affecting the base of the Pan-African Chain of Central Africa (CPAC).

Keywords: Hypovolcanic formations, Petro-structural, Pan-African basement, Cretaceous sedimentary basin, Figuil and Léré

Introduction

Intrusive magmatism generally exploits synchronous fracturing systems and can also follow regenerated pre-existing systems that exhibit network organizations. Magmatic intrusions in these systems are composed of basic and ultrabasic rocks.

In Central Africa, magmatic intrusions of a doleritic nature are designated under two sets: the dolerites of the extensional basins and the dolerites known as continental tholeiites. Dolerites from extensional basins have been identified in Anambra in Nigeria[1] and in North Cameroon, in the region of Mayo Oulo-Léré and Babouri-Figuil[2]. The establishment of basic to intermediate intrusions which very often outcrop in the form of dykes and sills is considered to be a direct consequence of the tectonic events which affected the Pan-African basement[3,4].

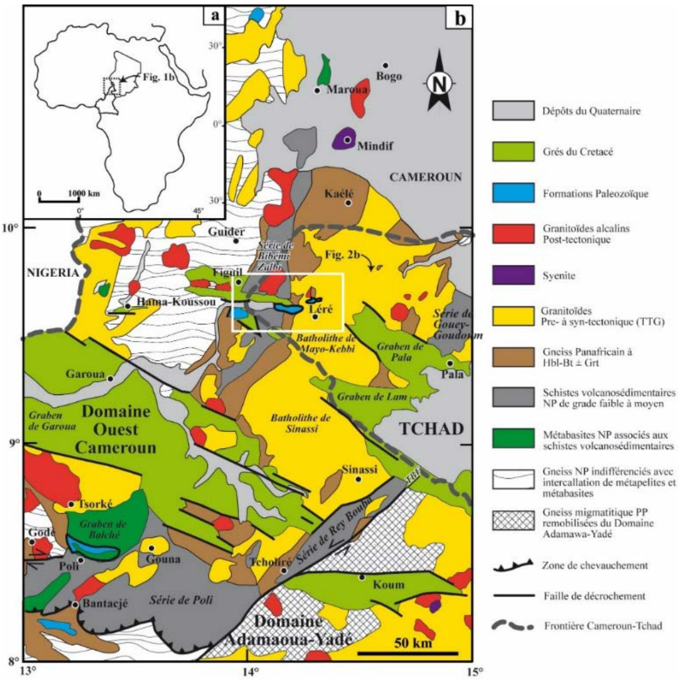


Figure 1: Location of the study area (white rectangle) in the geological map of North Cameroon and South-West Chad (b). In box Cameroon and Chad in Africa (a).

The small sedimentary basins of North Cameroon (Hamakoussou, Babouri-Figuil, Mayo Oulo-Léré) and the Zalbi basin in Léré in southwest Chad are half-grabens which are part of the extension of the Yola branch, of the rift from Bénoué to Cameroon[5]. The late formations intruding into the base in the form of dikes and sills of a doleritic or basaltic nature appear to be generally linked to the process of lithospheric fissuring indicating the end or beginning of the orogenic cycle.

In the Cretaceous sedimentary basins and on the Pan-African basement of Figuil (North Cameroon) and Léré (South-West Chad), basic to intermediate magmatic intrusions of metric to decametric power and of doleritic nature are identified and briefly studied. petrographically and geochemically **(Figure 1)**.

In this article, we will use field data coupled with petro-structural studies to highlight the hypovolcanic formations affecting the Pan-African basement and the Cretaceous sedimentary basins of Figuil (North Cameroon) and Léré (Southwest Chad).

Geological setting

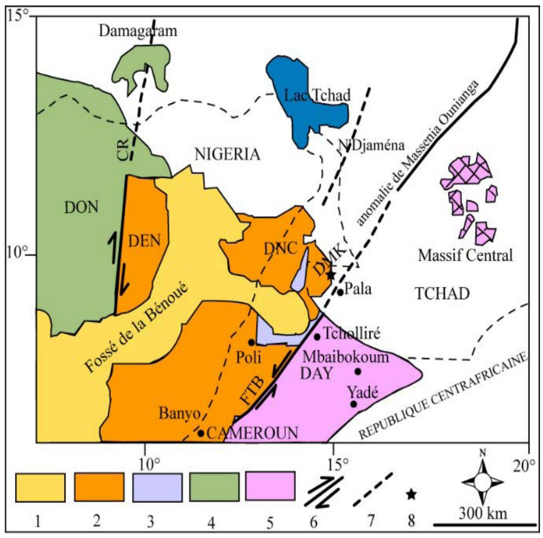
The Pan-African Range of Central Africa (CPAC) in Africa corresponds to a mega orogenic belt elongated in the E-W direction, with a length greater than 5,000 km and 300 km wide. It extends over Nigeria, Cameroon, Chad and the Central African Republic. The Middle to Late Proterozoic age basement consists of granites and gneisses, which were folded NNE-SSW by the Pan-African orogeny. The magmatic rocks of Mayo Oulo-Léré and Babouri-Figuil affected this base which is covered by sediments of Lower Cretaceous age[7-10] **(Figure 1)**. The Cretaceous sediments were emplaced in the two basins (Mayo Oulo-Léré and Babouri-Figuil) limited by major Pan-African faults-oriented E-W, whose extensional replay, at the beginning of the Cretaceous, controlled the facies and thicknesses of the continental Cretaceous sediments as well as the establishment of veins and sills[11].

Pan-African base of Figuil and Léré

The mafic magmatic rocks of Figuil and Léré crossed a basement of middle to upper Proterozoic age, covered by sediments of Lower Cretaceous age (Fosso-Menkem, 2018) **(Figure 1)**. The bedrock of Mayo Kebbi, which extends from Poli in Cameroon to southwest Chad, is interpreted as a Neoproterozoic middle arc, stabilized around 640 Ma[12]. The base of this region is made up of granites and gneisses, which were folded NNE-SSW by the Pan-African orogeny and characterized by the presence of foliations-oriented N-S to NNE-SSW carrying an E-W stretching lineation with dips greater than 50° towards the West[12]. The base of the Léré basin belongs to the large group known as the Mayo Kebbi region. This set represents the NE extension of the Pan-African base of Poli in North Central Cameroon[12]. It is an assemblage consisting of a Phanerozoic sedimentary platform which covers a Precambrian substratum dominated by the tonalitic batholith intrusive in medium to high grade amphibolic gneissic complexes[13].

Cretaceous sedimentary basins of Figuil and Léré (Mayo-Oulo-Léré)

The Mayo Oulo-Léré basin is a half-graben with an asymmetrical syncline structure belonging to the northern Cameroonian intracontinental basins[14]. It makes up the other small basins (Babouri-Figuil, Hama-koussou and Koum) of the Wealidian facies sedimentary basins of the Lower Cretaceous whose history is linked to the establishment of the Bénoué ditch **(Figure 2)**.



(Figure 2) Geological sketch of the North Cameroon domain and the neighboring domains of Mayo-Kebbi, Adamaoua-Yadé and North-East Nigeria[12]. 1: Sedimentary basin, 2: Neoproterozoic domain with Paleoproterozoic relics, 3: Metavolcano-sedimentary formation, 4: Reactivated Paleoproterozoic basement, 5: Reactivated Archean to Paleoproterozoic basement, 6: Strike-slip zone, 7: Massenia Ounianga gravity anomaly; 8.

Location of the study area; DONATION: West Nigeria Estate. DEN: East-Nigeria Domain, DNC: North-Cameroon Domain, DMK: Mayo Kébbi Domain, DAY: Adamaoua-Yadé Domain, CR: Rahgane Shear, FTB: Tchollíré-Banyo Fault.

The crystalline sedimentary base of Babouri-Figuil is covered by a sedimentary series approximately 1500 m thick[15]. The half-grabens underwent subsidence (Upper Hauterivian-Lower Aptian), followed by post-rift transpression which affected the entire Senonian fold belt of Central Africa[16] from the Upper Santonian[16]. The Léré series contains formations from the Lower Cretaceous (Aptian-Albian). These formations are composed of weak conglomerates, topped with coarse, more or less arkosic sandstones and fine, soft sandstones, sometimes with ripplemarks (elongated ridges forming a relief) alternating with greenish marls which contain some limestone pastes. Dolerite sills are interstratified there. These conglomerates, arkosic sandstones alternate with shales. In Figuil (Northern Cameroon), oil shales occupy a graben which continues towards the east of Lake Léré and develops on Cameroonian territory. An important dike characterizes the northern limit with the Proterozoic formations **(Figure 2)**.

Material and Methods

Material

Twenty (20) fresh and representative samples from two groups of dolerites were selected for petrographic and geochemical studies.

Each sample was carefully cleaned then sawed into two rock sugar tiles. These tiles were sent to the Key laboratory coalbeb methane resource and reservoir formation in China, for the manufacture of thin sections.

Methods

To try to best resolve the problems posed by hypovolcanic formations, the following methodological approach was adopted.

- A field study, the basis of any petrological study, was carried out. Various aspects were addressed during the field campaigns. The main ones are: identification of the different petrographic types, identification of deformations, relationships between facies and other formations, mapping and sampling;
- A microscopic study of the materials collected made it possible to identify the different mineral phases and to clarify the crystallographic history of the hypovolcanic formations. The results of the petrographic and field studies made it possible to set the constraints necessary for the subsequent petrological study;
- Structural analysis made it possible to have the different measurements (directions and lineaments) taken in the field which are subjected to processing with the Stéréo32 Software to obtain direction rosettes.

Results

Petrography of dolerite from the Pan-African basement

The dolerite dykes subject to this study vary in length but their thickness rarely exceeds twenty meters. The petrographic study revealed four facies of dolerites based on color and mineralogical composition. These are dolerites with pyrite and calcite, dolerites with pyrite and basement enclaves rich in alkali feldspars, dolerites with pyrite and dolerites with amphibole and titanite presenting intergranular to granophyre, classic doleritic, ophitic and ophitic to granophyre textures respectively. The primary mineralogical assemblage of these rocks is often completely or partially transformed. Plagioclase and pyroxene are the dominant mineral phases.

Dolerites with pyrite and calcite: The Léré pyrite and calcite dolerites are observed at Teufoultréné and Lampagame **(Figure 9)**. They crop out in the form of rectilinear dykes **(Figure 3a)** trending NNW-SSE to ENE-WSW at Teufoultréné and NNE-SSW at Lampagame. They are fragmented into balls (20 to 35 cm) and blocks (10 cm to 15 dm) **(Figure 3a)**. Under the microscope, the rocks are characterized by an intergranular to granophyre texture **(Figure 3b)**. For this texture, the interstices between the plagioclase laths are occupied by phenocrysts and microcrystals of olivines, clinopyroxenes, opaque minerals and calcites **(Figure 3c,3d)**. The most abundant plagioclases occur in microlites and generally quite automorphic phenocrysts. Inclusions of accessory minerals such as opaque minerals and apatite are observed in certain sections as well as secondary minerals (epidote and chlorite) have been identified.

Dolerites with pyrite and basement enclaves rich in alkali feldspars: Dolerites with pyrite and basement enclaves rich in alkali feldspars crop out in the form of rectilinear dykes trending NW-SE at Tréné, Berliang and in Mayo at Zabili **(Figure 9)**. These doleritic dikes form balls (15 to 25 cm in diameter) and blocks (35 cm to 25 dm). Under the microscope, dolerites show a classic doleritic texture. The rocks are composed of plagioclase laths, phenocrysts and microcrystals of clinopyroxene, amphiboles, alkali feldspars and opaque minerals. Plagioclase occurs in microlites and phenocrysts that are generally quite automorphic. Secondary minerals (epidote, chlorite) are also observed.

Dolerites with amphibole and titanite: The amphibole and titanite dolerite dykes of Poubamé and Poutalet are oriented NNW-SSE, those of Zabili, NE-SW **(Figure 9)**. They emerge in the form of centimeter to decimeter balls. The rock is compact, hard and massive and has a doleritic structure. The dark matrix contains feldspar crystals, dark crystals (pyroxene or oxides). Under the microscope, dolerites show an ophitic texture.

The rocks are characterized by pyroxene phenocrysts encompassing plagioclase laths. The latter appear in the form of microliths and generally automorphic phenocrysts. Phenocrysts and microcrystals of alkali feldspars, clinopyroxenes, biotites and opaque minerals are identified. Inclusions of accessory minerals (apatite and titanite) associated with secondary minerals (epidote, chlorite) were also detected in the thin sections.

Pyrite dolerites: In Figuil, pyrite dolerites crop out in the form of dykes to the east on the Léré road and in the city, center following directions from NNE-SSW to NE-SW **(Figure 9)**. The dykes cut into balls (20 to 35 cm), blocks and slabs (10 cm to 15 dm). The sample is a hard, massive, dark fresh rock with a doleritic structure. Under microscopy, dolerites present an ophitic to granophyre texture. They are made up of plagioclase laths less encompassed by pyroxenes. In addition to pyroxenes and plagioclases, alkali feldspar crystals, opaque minerals and plagioclase phenocrysts were distinguished. The plagioclase crystals are transformed into damourite. Secondary minerals (epidote, chlorite) were also observed.

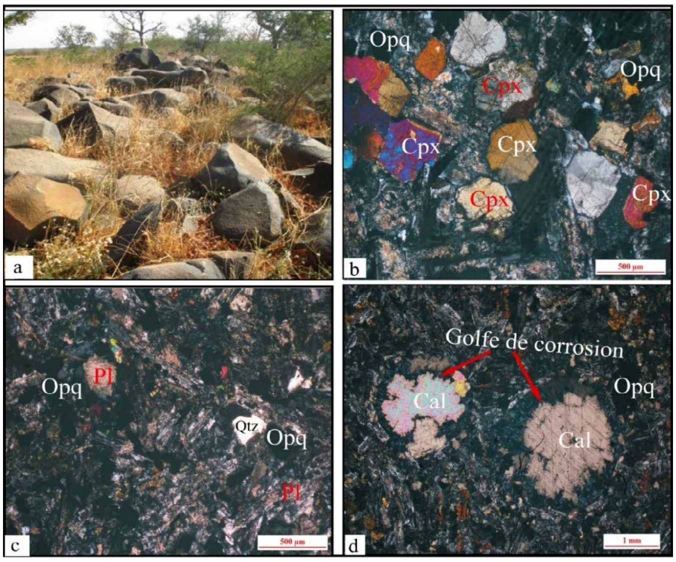


Figure 3: Field photograph showing the outcrop of a dyke at Toufeultréné and photomicrograph attesting to the magmatic texture. a: Outcrop in the form of balls and blocks of dolerite dykes with pyrite and calcite at Teufoultréné; b: Intergranular to granophyre texture. Note the abundance of opaque minerals and the presence of quartz in the dolerite with pyrite and calcite in LPA (sample TERM4); c: Note the presence of clinopyroxene phenocrysts and opaque minerals (TESM4 thin section, LPA); d: Calcite crystals with corrosion gulfs in dolerite with pyrite and calcite in LPA (sample TEIM3). Opq: opaque, Cpx: clinopyroxene, Pl: plagioclase, Qtz: quartz and Cal: calcite.

Petrography of dolerites from the cretaceous sedimentary basin

The hypovolcanic rock dikes subject to this study have a variable length but their thickness is less than or equal to one hundred meters. The petrographic study of magmatic rocks **(Figure 4)** in Cretaceous sedimentary basins reveals dolerites, microgabbros and trachyte. These are massive rocks with a sub-ophitic texture for amphibole dolerites and dolerites, microlitic for gray dolerites, subdoleritic for microgabbros **(Figure 4h)** and trachytic for trachytes **(Figure 4g)**. These rocks are characterized by a fairly constant mineralogical composition formed by plagioclase and pyroxenes. The alteration products are represented by damourite, chlorite and titanite.

Amphibole dolerites: At Dissing, amphibole dolerites crop out in the form of a dyke-oriented NE-SW **(Figure 9)**. The dyke produces decimetric (2 to 5 dm) to metric (1 to 1.5 m) blocks and centimeter balls (24 to 52 cm in diameter). Microscopic observations show a sub-ophitic texture **(Figure 4c)**. The minerals observed are plagioclase laths, phenocrysts and microcrystals of clinopyroxenes, amphiboles, biotite, opaque alkali feldspars. Plagioclase being the most abundant minerals occurs in generally quite automorphic phenocrysts and microliths **(Figure 4c).** Inclusions of accessory minerals such as apatite and titanite have been observed in some sections. Secondary minerals (epidotes, chlorites) were also detected in the rock (DiM3 thin section).

Gray dolerites: Gray dolerites are observed at Zalbi, Teuchéné and Djalingo **(Figure 9)**. They crop out in the form of rectilinear dykes-oriented NNE-SSW to NW-SE at Zalbi, NNE-SSW to NNW-SSE at Teuchéné **(Figure 3b)** and NNW-SSE at Djalingo **(Figure 4a)**. These dikes crop out in the form of large decimetric (2 to 2.5 dm) to metric (1.2 to 3.7 m) blocks and slabs and centimetric balls (15 to 28 cm in diameter). At the fresh break, the doleritic rocks are gray in color, very hard, massive and have a microlitic structure **(Figure 4a)**. Microscopically, dolerites have an intergranular texture **(Figure 4a).** Plagioclase, which is the most abundant mineral, occurs in microliths and automorphic phenocrysts. Secondary minerals (epidote and chlorite) were also observed in the thin sections (ZaM1, T2M, T2M3 and DjM3).

Dark dolerites: The dark dolerites of Tchontchi Golombé crop out in the form of a rectilinear dike-oriented NE-SW **(Figure 9)**. The dikes crop out in centimetric (17 x 35 cm) to decimetric (1.2 x 2.8 dm) blocks and sometimes in centimetric balls (10 to 24 cm in diameter) **(Figure 4b)**. The dolerite dyke has a thickness varying from 75 to 100 m and a length greater than 5000 m. The dark dolerites have a sub-ophitic texture with plagioclase laths partially encompassed by the pyroxene sections under the microscope **(Figure 4e)**. They are composed of phenocrysts and microcrystals of clinopyroxenes, alkali feldspars and oxides. Plagioclase, the most abundant minerals, occurs in phenocrysts and microliths. Secondary minerals such as epidote and chlorite were detected in the thin section (FtgM3).

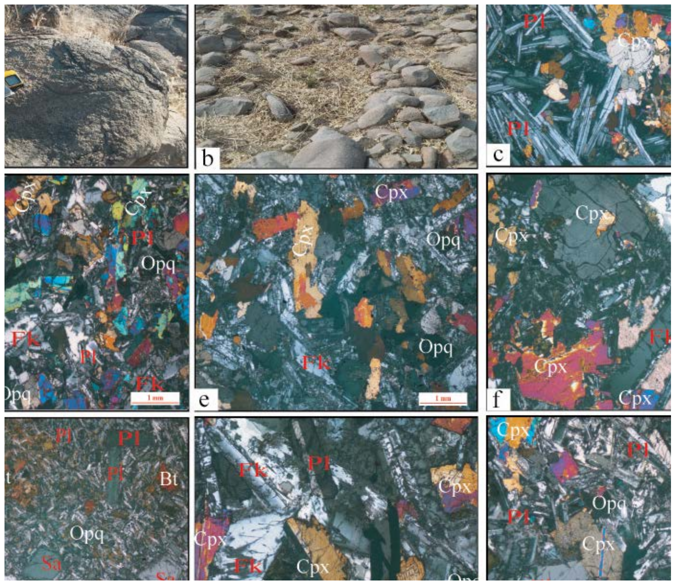


Figure 4: Photograph showing the outcrop of dolerite dykes and the appearance of the mode of installation then photomicrograph illustrating the texture of dolerites from sedimentary basins. a: Outcrop of clusters of rocky blocks and balls of biotite and pyroxene dolerites, extending in the form of dykes from Zalbi to Djalingo; b: Outcrop of dark dolerites in centimeter to decimetric blocks at the level of Tchontchi Golombé; c: Sub-ophitic texture of Dissing amphibole dolerites. Observe the arrangement of plagioclase crystals around the clinopyroxene sections and the abundance of automorphic plagioclase patches presenting albite twins in LPA (sample DiM2); d: Pyroxenes are the most abundant minerals occurring in microcrystals within doletites in LPA (T2M3); e: Intergranual texture of gray dolerites. Note the presence of opaque and clinopyroxene phenocrysts in LPNA dolerites (DjM3) f: Clinopyroxene phenocrysts in the mesostasis made up of rod-shaped plagioclase microliths of Zalbi dolerites; g: Trachytic texture of the trachyte. Note the presence of sanidine phenocrysts and very automorphic plagioclases in the matrix and biotite flakes surrounded by sanidine microliths (thin

section FmsM1, LPA); h: Subdoleritic texture of microgabbros; i: Opaque and clinopyroxene crystals included in the mesostasis made up of rod-shaped plagioclase microliths. Note the abundance of plagioclase crystals in the thin section. Opq: opaque, Cpx: clinopyroxene, Pl: plagioclase, Amp: amphiboles and Fk: alkali feldspars.

Microgabbros: The Bissoli and Badadji microgabbros crop out as rectilinear dykes in the Cretaceous sedimentary basin **(Figure 9)**. The dykes are oriented SE-NW to NE-SW in Bissoli and E-W in Badadji. They are sold in decimetric balls (2 to 3.5 dm) and centimeter blocks (10 x 30 cm) to decimetric blocks (10 x 15 dm). Under microscopy, the microgabbros have a subdoleritic texture. The rocks are composed of the minerals clinopyroxenes, amphiboles, biotites, plagioclase, alkali feldspars, opaques and quartz. Chlorite and epidote were detected in the thin sections.

Trachyte: Trachyte crops out as a straight dyke (E-W) in Cretaceous sedimentary basins (Fig. 9). The dyke is made up of large decimetric (9 x 12 dm) to metric (1.5 x 4.2 m) blocks and slabs. This dyke has a thickness varying from 45 to 75 m and a length greater than 3000 m. The trachyte shows, under microscopy, large rods of plagioclase, sanidine, biotite phenocrysts, opaques and microcrystals of plagioclase, microliths of sanidine embedded in the mesostasis. The rock has a trachytic texture or fluid microlitic texture. The plagioclase and sanidine sections are oriented in a preferential direction in the matrix, thus defining the fluid texture. Opaque inclusions and epidote and chlorite were observed in the thin section (FmsM1).

Structural analysis

The structural study undertaken concerns the orientations of dolerite dykes, fine-grained gabbros, trachyte, altered pegmatite veins (Appendix 3) and the directions of linear segments of the watercourses which constitute the hydrographic network of the zone ‘study.

Orientation of dolerite dykes and altered quartz and pegmatite veins of the Pan-African basement

Orientation of dolerite dikes: Orientation measurements of the dolerite dikes cutting the Pan-African basement were taken in the field.

The dolerites of Teufoultréné and Lampagame have a direction varying from NNW-SSE to ENE-WSW in Teufoultréné and NNE-SSW in Lampagame.

The dolerites which form rectilinear dykes at Tréné and Berliang have directions varying from NW-SE.

The dolerite dikes of Pougbamé and Poutalet oriented NNW-SSE oriented NNW-SSE on the other hand those of Zabili oriented NE-SW.

At Figuil, the dolerites outcropping in the form of dykes are oriented almost in the same direction from NNE-SSW to NE-SW.

The rosette of directions produced from the orientations of the dolerite dykes **(Figure 5)** shows three NW-SE (main) directions; N-S to NNE-SSW (intermediate) and E-W (minor). The main NW-SE direction which is the major direction observed on the lineaments of the Pan-African base of Léré coincides with the main opening of the dolerites cutting the base of the study area.

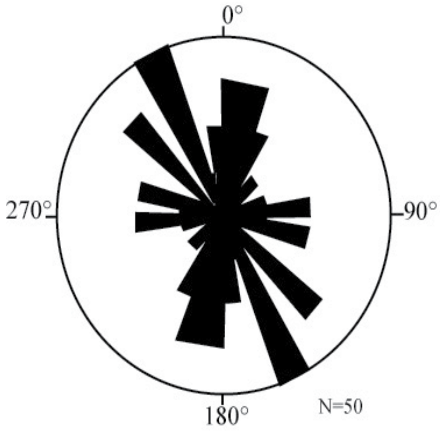


Figure 5: Rosette of the directions of the dolerites of the Pan-African basement (DSP).

Orientation of altered pegmatite veins: The altered pegmatite veins observed in the different rock formations of the study area are aplite veins, pegmatite veins and quartz veins. The quartzite veins are cut by doleritic dykes. These veins are altered and have directions varying from NE-SW to NNE-SSW, the major of which is NE-SW. The length of these pegmatitic veins oscillates between 20 and 45 m with a power varying from 15 to 35 cm.

Orientation of dikes of magmatic formations of Cretaceous sedimentary basins

The biotite and pyroxene dolerites of Zalbi, Teuchéné and Djalingo crop out in the form of rectilinear dykes-oriented NNE-SSW to NNW-SSE at Zalbi Teuchéné and NNW-SSE at Djalingo in the sedimentary basins of Mayo-Oulo-Léré.

The trachytes crop out in the form of dikes oriented rectilinearly E-W in the sedimentary basins of Babouri-Figuil across the Mayo-Sorowel.

The pyroxene dolerites of Tchontchi Golombé are rectilinear dykes-oriented NE-SW in the Mayo-Oulo-Léré sedimentary basins.

The fine-grained gabbros of Bissoli and Badadji outcropping as rectilinear dikes in the Mayo-Oulo-Léré sedimentary basin are oriented NW-SE to NE-SW in Bissoli and E-W in Badadji.

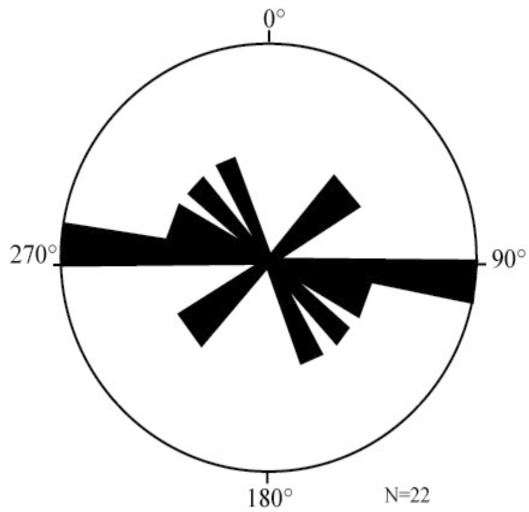


Figure 6: Rosette of dolerite directions in Cretaceous sedimentary basins (DBSC).

In the Cretaceous sedimentary basins, the dikes of magmatic formations are oriented along a major direction N100°E. The directional rosette of the mafic hypovolcanic rock dykes of the Cretaceous sedimentary basins presents a major direction E-W and 2 secondary directions ENE-WSW and NE-SW **(Figure 6)**.

Lineamental map

The lineaments represent discontinuities corresponding either to fractures showing an offset between geological formations or to extensions of faults known on the existing map or to an abnormal contact between two different geological formations without offset (interministerial commission for aerospace remote sensing terminology), 1998). The study of lineaments is very important for mining and oil exploitation, in hydrography and seismology. To extract the lineaments in the case of the present study, the choice was made on SRTM images, which are digital radar terrain models that best represent physical elements such as the hydrographic network, structural accidents, etc. The approach used to extract these lineaments is that used by Toutin. This method consists of filtering and enhancing the SRTM image with a sun azimuth of 345, an altitude of 45 with an elevation factor (z) of 3. The image is then processed in "Surfing in shaded relief mode". This method allowed us to create a map of linear segments **(Figure 7)** and extract 389 lineaments in the study area for the structural study.

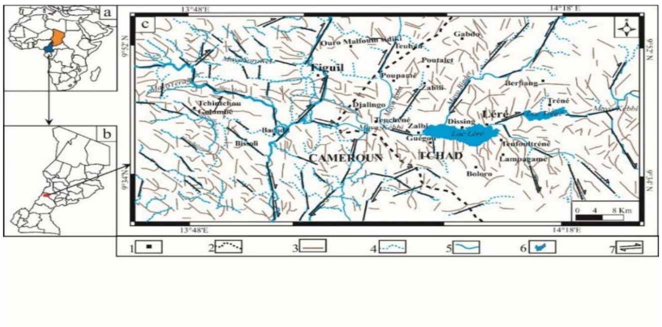


Figure 7: Lineamental map of the study area extracted from the topographic map of the Guider-Léré region at 1/250,000, 1: Localities, 2: Border limit, 3: Lineament, 4: Temporary watercourse, 5: Permanent watercourse, 6: Lake, 7: Structural element.

The direction rosette **(Figure 8)** produced from the orientation values of the structural lineaments highlights two major directions NE-SW and ENE-WSW, secondary directions, NW-SE, NNE-SSW, ESE- W NW. These directions tend to approach those of the dyke directions of the granitic basement.

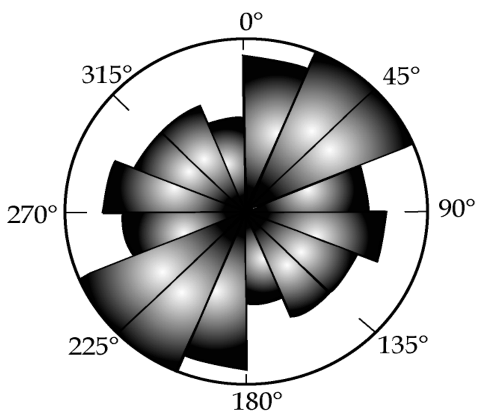


Figure 8: Direction rosette of linear segments of the study area.

Two summary tables emerge from this petrographic study and structural analysis (Tables 1 and 2) which present the petrographic types, directions, dimensions and mineralogy of the dolerites, fine-grained gabbros and trachytes studied.

Summary of the petrography and structural analysis of the mafic hypovolcanic rocks of Figuil and Léré

From the geological map **(Figure 9 a-b)** which summarizes all the geological formations studied, two geological sections A-A' and B-B' **(Figure 9 c)** were made.

- **Section A-A':** along this section in SW-NE direction, the following are successively crossed: the Phanerozoic cover, metabasalts, Zalbi granites, metasediments, mafic schists and tonalites. In the Phanerozoic cover, outcrops of fine-grained gabbros dikes and biotite and pyroxene dolerites are observed. Within the metasediments, we look at the Zalbi shear zone which crosses the Phanerozoic cover. We notice a Léré shear zone characterizing the limit between the mafic shales and the mafic and intermediate complexes. In the middle of the tonalites, we consider the outcrops of dolerite dykes with pyrites and enclave of the basement.
- **Section B-B':** along this NNW-SSE direction section, we find successively: orthogneisses, mafic and intermediate complexes, granites, metasediments, mafic schists, mafic and intermediate complexes and tonalites. In the orthogneisses, we see the Figuil shear zone. Within the mafic and intermediate complexes, outcrops of dolerite to pyrite dikes are observed. In the middle of Zalbi granite, outcrops of amphibole and titanite dolerite dykes are observed. Inside the metasediments, we observe the Zalbi shear zone. We also note a Léré shear zone illustrating the limit between mafic shales and mafic and intermediate complexes. We see a fault showing the limit between the Phenorozoic cover and the tonalites. Among the tonalites, dolerite dikes with pyrites and calcite are formed.

Tables (1 and 2) summarize the mineralogical assemblages of the different types of facies, different directions and dimensions of the hypovolcanic rocks studied at Figuil and Léré. They thus make it possible to make a comparison between the dolerites of the Pan-African basement and the mafic magmatic rocks of the Cretaceous sedimentary basins.

Discussion

In this part, the petrographic data and the structural analysis make it possible to categorize, determine the facies and understand: (i) its structural evolution and (ii) the implication of this structural evolution on the establishment of the dykes.

Macroscopic characteristics

Field observations allowed us to reveal the existence of two groups of dolerites. These are DSPs made up of dolerite dikes affecting the Pan-African basement aged 640 Ma[12] to 630 ± 1 Ma[17]. This mode of outcrop, posterior to the Pan-African base, can reflect their post-tectonic character. The absence of macroscopic deformation structure and stresses in thin sections may reflect their post-tectonic character. DBSCs outcropping in Cretaceous sedimentary basins are distinguished from DSPs mainly by their lithological association, size and also by the abundance of pyrite in the DSPs. Klamadji, et al[6]. states that the mode of installation of these two groups of dolerites in the Pan-African basement seems to be a direct consequence of the tectonic events that affected this area. Dolerite, fine-grained gabbros and trachyte dykes from Cretaceous sedimentary basins are several hundred meters to several kilometers long with a thickness ranging from 20 to 100 m. These dykes would be considered "giant dykes" in the classification of Bryan and Ernes[18] because they are wider than those of the Pan-African basement (5 to 15 m thick and a few tens of meters long). The dikes in the study area are wider. Dyke widths appear to be related to crustal extension[19]. The size of dikes can also provide some information about the location mechanism. Campbell[20] suggested that the primitive magma flows giving rise to continental dikes greater than 3 m wide would be turbulent rather than laminar.

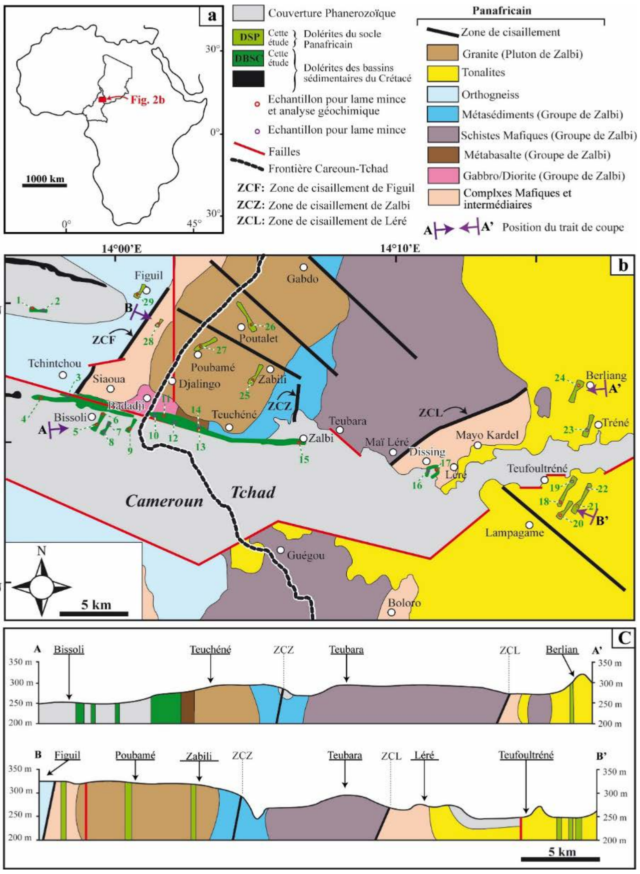


Figure 9: Geological and structural map of Figuil and Léré[17]. a: Location map of Cameroon and Chad in Africa; b: Geological, sampling and structural map of the study area; c: Geological sections in the study area (synthetic section summarizing the petrographic and structural observations in the study area); A-A' and B-B' represent the cutting lines. The numbers shown on the geological map (b) designate the samples taken for thin sections and geochemical analyses.

Microscopic characteristics

Microscopic observations of the rocks studied made it possible to highlight the different textures such as intergranular to granophyre, classic doleritic, sub-ophitic, ophitic to granophyre, subdoleritic and trachytic textures. Textural relationships may suggest two phases of magma crystallization with the first phase characterized by the crystallization of phenocrysts of ferromagnesian minerals (such as clinopyroxene, amphibole and opaques) and the second phase marked by the crystallization of titanite microcrystals and microliths. These textural relationships involve two modes of mineral growth: simultaneous crystallization and early crystallization of minerals according to Shelley. DSPs are sometimes characterized by hydrothermal alteration which is highlighted by the presence of pyrite, which is not the case for DBSCs. Such phenomena have been mentioned to explain the metasomatic phenomena which affected the petrogenesis of dolerites[21]. The main minerals are plagioclase phenocrysts, clinopyroxene, titanite, microcrystals and microliths. Primary minerals include titanites, pyroxenes, plagioclase, amphiboles, biotite and zircon. Secondary minerals are chlorite, epidote, sericite, pyrite and calcite.

Thus, a secondary paragenesis with chlorite, albite, sphene, epidote, sericite, calcite, pyrite and quartz developed, at the expense of primary minerals. The established order of crystallization is as follows: titanites would have crystallized first, clinopyroxene crystals second, amphiboles, biotite and finally those of plagioclase and alkali feldspar. The absence of macroscopic deformation structure and stresses in thin sections proves that the rocks were put in place during post-tectonic periods, that is to say after the formation of the cracks they occupy (during the period of pan-African relaxation).

Characteristics of Pan-African basement dykes and Cretaceous sedimentary basins

All these directions of DSP and DBSC are similar to those identified by Moreau et al, Klamadji[7] as characteristic of the Pan-African tectonic events that affected the CPAC[21-23]. The orientations of the dolerite dykes of the Pan-African basement probably correspond to the directions of the fractures which affected the Pan-African basement of South-West Mayo Kebbi and North Cameroon[4,12,17]. The NNE-SSW direction is similar to the major deformation phase, highlighted in the orthogneisses, both in the Guider sector and in the Mayo-Oulo sector[24]. These directions argue for the establishment of dolerites in the study area linked to Pan-African post-tectonic events which affected the Pan-African basement and the Cretaceous sedimentary basins of Mayo-Oulo-Léré and Babouri-Figuil[33]. However, Maurin, et al.[11] and Maurin and Guiraud proposed an opening of the South Atlantic Ocean to explain the formation of small basins in North Cameroon during the Lower Cretaceous.

- The directions obtained in the study area are related to those known in the sub-region. These are:
- the N153°E direction corresponding to the direction of the faults which border the Cretaceous series of Lamé to the South of Pala and that which limits the Yadé massif to the North-West with the Doba basin[25].
- the N135°E direction is the direction of the large Tibesti lineament recognized in the North-East of Chad[26] crossing the North of Chad from the South-East of Algeria to Kenya. It is also a pan-African fault direction which also affected the basement of the CPAC.
- the direction N30°E corresponding to the direction of the Cameroon Line oriented NNE-SSW;
- the N70°E direction which corresponds to the direction of the Adamaoua-Yadé shear.

The directions of dykes made it possible to determine the common orientation (N68°E) of certain formations. This orientation is significantly similar to that of ENE-WSW (N70°E) which is one of the major directions of the C.C.C (Cameroon Shear Centers)[27]. The petrographic and structural similarities between the Léré regions[12,17,6,7,10], Mongo[28] and Figuil show that these regions forming part of the same terrain are welded during the Pan-African orogeny to the Adamoua-Yadé domain[29], that is to say in outside the "Saharan metacraton". According to field observations, the dykes were emplaced during the last stages of the Pan-African orogen along three different directions NNE-SSW, NE-SW and ENE-WSW which may suggest that they form the different swarms[30,6,7,10], the faults also underline the borders of the Cretaceous sedimentary basins. Faults with a preferential orientation N90°E to N110°E are also observed in the Chutes Gauthiot massif. According to Maurin et al., 1990; Guiraud et al., 1991, these faults would be part of the Guinean-Nubian lineaments. They are probably the legacy of normal E-W to N110°E fracturing resulting from the extension which saw the intrusion of doleritic dykes.

Conclusion

Petrographic and geochemical studies show the existence of two groups of dolerites in the study area. The field work carried out in Figuil and Léré made it possible to distinguish more than twenty (20) dykes divided into two groups on the basis of the surrounding area: the DSPs are dolerites which outcrop in the form of dykes intersecting the base more or less vertically. pan-African and dolerites made up of different facies which crop out in the form of dykes in the Cretaceous sedimentary basins (DBSC. Fragile structures NNE-SSW, NE-SW and ENE-WSW could have formed between 740 and 737 Ma. Hence the installation of these magmatic rocks is probably linked to major accidents in the study area, in particular directional accidents. NNW-SSE, NE-SW, E-W and ESE-WNW Microscopy reveals dolerites with intergranular to granophyre, classic doleritic textures. sub-ophitic, ophitic to granophyre, sub-doleritic and trachytic. The primary parageneses of rocks are modified by alterations resulting from hydrothermal alteration manifested by intense pyritization. The primary minerals of these mafic magmatic rocks have undergone more or less significant and very heterogeneous post-magmatic transformations, both on the scale of the mineral and that of the different magmatic facies. DSPs are sometimes characterized by hydrothermal alteration which is highlighted by the presence of pyrite. Likewise, secondary paragenesis with chlorite, albite, sphene, epidote, sericite, calcite, pyrite and quartz developed, at the expense of primary minerals.

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