Structural Interpretation of Lineament from Nlonako Area and Surroundings: Contribution to Pan-African Tectonic Reconstruction

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ABSTRACT

The Nlonako anorogenic complex (NAC) is located in the south western part of the Cameroon Line and is superposed on the N50E section of the central Cameroon shear zone. It is suggested to be a ring complex of 10 km diameter which was emplaced as sill intrusive body during the Tertiary. In order to do characterize the Nlonako complex shape and characterize the tectonic history in the study area and surrounding, spatial technology (Landsat 8 ETM+ and SRTM images) were used for geological mapping and structural reconstruction based on lineament analysis.

Data extracted from Landsat 8 ETM and SRTM images show a sub-circular shape for the NAC and the superposition of field and petrographic data from our previous research works confirm the fact that the NAC is a ring or annular complex slightly elongated NNE-SSW, thus it is known as the Nlonako ring complex (NRC). Map of lineament synthesis and the SRTM image of the study area display NE-SW, NW-SE and N-S trend structures. (1) The dominant NE-SW trend mostly displayed by the NRC and its basement rock is parallel to (i) the main metamorphic foliation trend and (ii) to the central Cameroon shear zone regional fault, corresponds to the trending of the regional foliation, structures and the Ngondo pluton elongated shape. (2) The secondary N-S direction may correspond to the late deformational phase in the area because, the N-S-related structures transposing NE-SW structures towards a meridional direction in the NRC basement rock. (3) The NW-SE trend corresponds to the direction of NW-SE fault cross cutting the NRC.

Field data and synthetic lineament map enable to identify: (1) a Compressive deformational phase D₁ whose main markers are NNW-SSE to NW-SE S₁ foliation; (2) an early left-lateral deformational phase D₂ characterized by anticlockwise rotation of clasts and NE-SW sinistral transposition of early structures; (3) a NE-SW right-lateral deformational phase D₃ marked by clockwise rotation and dextral transposition of preexisting structures as well as the NE-SW S₃ foliation and (4) a late left-lateral deformational phase D₄ marked by the N-S transposition of NE-SW dextral D₃-related structures by late sinistral shear movement. This suggests a more complex tectonic history for the Pan-African Belt in Cameroon showing at least three shear phases, that is a right-lateral phase, sandwich by two left-lateral phases.

Keywords: Nlonako, Lineament, ring structures, tectonic reconstruction, Pan-African.

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I. INTRODUCTION

For many aspects of geological activities, remote sensing has been used as a valuable tool, as from the early days of “geologic remote sensing science” [1] to date. For regional mapping, structural interpretation and prospecting for ores and hydrocarbons, geologists have used space images [2]. Indeed, the advent of spatial technology, has greatly contributed to the improvement of the usual geological mapping methods, especially in developing countries where cartographic documents are incomplete or not updated due to some constraints [3] including the cost, accessibility to

dangerous or previously inaccessible sites, the heterogeneity of the information and the interpolation methods of traditional field-based lithological mapping [4]-[7].

Numerous Pan-African plutons such as the Ngondo pluton and Tertiary intrusions such as the Nlonako and Koupé plutons are marked by a dense forest environment and inaccessible sites, underlain by diversified geological formations in Cameroon. Rocks in these area outcrop sometime very rarely, discontinuously and usually highly altered. Therefore, traditional field mapping and tectonic studies are tedious, costly and may also lead to misinterpretation. This is the case of the Nlonako pluton for which round shape and N-S elongated shape are attributed

by [8] and [9] respectively. Therefore, the use of space images as landsat and Shuttle Radar Topography Mission (SRTM) is necessary to solve the problem of shape of this Tertiary complex. Indeed, data from the late images characterize the morphology, roughness and geometric shapes of the study area [10]. Field data, lineament analysis morphometric data from the Landsat 8 ETM+ and SRTM images were used in this study with the aim of definitely clarifying the shape of the NRC and suggesting the new tectonic history reconstruction of the study area.

II. GEOLOGICAL SETTING

The NAC is located in the south western part of the Cameroon Line (CL) and superposed on the N50E branch of the central Cameroon shear zone (Fig. 1, CCSZ). According to [11] this complex was emplaced as sill intrusive body during the Tertiary (45 - 35 Ma, [12]-[14]) in a Pan-African k-feldspars megacrysts granites and gneiss host rocks under fractures control consecutive to the late Cretaceous general extension. After its emplacement, the NAC experienced the cauldron subsidence of its summit, facilitated by the development of conjugated faults and the downward sliding of rocks along the NW-SE fault, leading to the formation of caldera at its summit [11]. The NAC is made up of syenites, biotite -pyroxene granite gabbro, rhyolite and basalt intruded in granite-gneissic basement [11]. Syenite, which represents the dominant rock type (about 90% of the rock types) of the NAC, displays porphyritic heterogranular texture made up of quartz, k-feldspar, plagioclase, pyroxene, zircon and opaque minerals. Biotite-pyroxene granites are composed of quartz, k-feldspar, plagioclase, biotite and opaque minerals. Gabbro consists of coarse heterogranular crystals to very fine grained matrix composed of plagioclase, olivine, pyroxene and opaque minerals in which some plagioclase, olivine and pyroxene occur as megacrysts. Diorite display tabular k-feldspar crystals and display very fine to medium grained texture, with plagioclase, k-feldspar and clinopyroxene as medium grained crystals. Rhyolite and basalt outcrop as dyke in syenite and gneiss and displays porphyric microlitic texture. More detailed petrographic data of the NAC are given by [9], [14] and [11]. According to [15], the megacryst granite basement rock of the NAC, is synkinematic granite whose emplacement was totally controlled by a N30° sinistral shear zone.

III. METHOD

The Landsat 8 satellite, whose image was used for the present studies, possessed a radiometer Enhance Thematic Mapper plus (ETM+) and has a spacial resolution of 30 m. The Landsat image used is from the sheet Landsat ETM+ LC 81860572017360 LGN00 of the 26 December 2017. The image was then projected to the WGS-84 datum and Universal Transverse Mercator Zone 32 N coordinate system. The method applied for lithology and structural features identification consisted of visual interpretations of the Landsat 8 ETM+ imagery and manual delimitation of features after textural analysis.

Fig. 1. Location of the study complexes redrawn from [16]. Lower right: age of the anorogenic complexes cropping out along the Cameroon Line. Alkali ring complexes: NA Nda Ali; K: Koupé; F: Fourougain; M: Mbafé; Mb: Mba Bitou; B: Biridjom; Mn: Mba Namboué; MD: Mayo Darley; Na: Nana; Ni: Hosséré Nigo; Nl: Nlonako; Nk: Nkongam; P: Pamsa; Pé: Pandé; P: Hosséré Poli; R: Roumpi; T: Hosséré Tchegui; Ko: Koukoumi; Mbt: Mboutou; GZ: Golda Zuelva; W: Waza. Syntectonic plutons: Ba: Bandja; Fo: Fomopéa; NgNgondo; Shear zones (SZ): BNMB = Buffle Noir- Mayo Baleo SZ; CCSZ = Central Cameroon SZ; GGSZ = Godé-Gormaya SZ; RLSZ = Rocher du Loup SZ; SSZ = Sanaga SZ; FKSZ: Fotouni-Kékem SZ.

Textural analysis consists in quantifying the different gray levels of the image in terms of roughness and distribution. From this contextual analysis technique an image dissimilarities or homogeneous zones can be highlighted on the map. Several methods of texture analysis methods are known. These include structural methods, statistical methods, methods based on the study of forms, spatio frequential methods and fractal [17]. The statistical approach known as Grey Level Co-occurrence Matrix (GLCM) proposed by [18] was adopted in the present study. This method allows the identification and selection of the parameters that enable the best definition the elements from the measurement of the gray tone distributions. Numerous authors developed topics on the application of the GLCM technique in synthetic aperture space images in geological applications [7], [19]-[24]. Executed in ENVI software environment the implementation of GLCM, using a 5x5 window and Pixel offset 1 on the Landsat ETM+ mono-band permitted the calculation and creation of normalized co-occurrence used for lineament investigations.

Lineaments are generally related to fractures and lithologic boundaries and in some cases to geomorphic relief, appear therefore on the image with a tonal difference. In geologic investigation, linear features on a satellite image regularly reflect the geological lineaments such as regional foliation, faults or fractures and hydrological structures such as river [25]. Several lineament detection algorithms exist in remote sensing, but those based on filtering techniques using

directional filters (Sobel) show good results [7], [26]-[33]. The filtering methods principle' main goal is the detection of neighboring pixels which suddenly change in gray level by the use of a differential operation. To extract lineaments, the Principal Component Analysis (PCA) was performed on the co-occurrence indices created. The de-correlation of the different bands and the reduction of the dimensionality of the resulting feature space enhancing the multiband image for structural interpretation purposes were performed using PCA. The main aim here was to use inter-band correlation, to compress textural information from the co-occurrence images to less, and to represent nearly the whole of the available information as applied by [34] and [35]. Directional filters were applied to the image at 0, 45, 90 and 135 for four principal directions (N-S, NE-SW, E-W and SE-NW) respectively, with 5 x 5 window to increase frequency and contrast in the image. The structure lines were then extracted manually in GIS software (Arcgis, for example). Structures clearly identified in the filter directions were considered as major while those observed not in all the directions were considered as minor structures. Major structures were named faults and minor structures named fractures after comparing with geological maps from [8] and [11]. A tentative validation of the results is provided based on SRTM image and our previous [8] conducted in the same area. The SRTM image is an altimetry data of 30 m to 90 m precision that facilitate supposed and demonstrated lineament extraction.

IV. RESULTS

A. Field data

Investigations during field works enable to identify features such as foliation (metamorphic and magmatic), folds, shear structures, veins and fractures.

Metamorphic foliation is observed in gneiss. It is characterized by quartz-feldspar rich clear and dark ferromagnesian alternative bands in Balondo Nlonako and Ngwa. This foliation displays NE-SW (N30E-N40E) trend, strongly dipping (65°-75°) toward the SE which was locally transposed into NW-SE (N143E-N158E) and the N-S direction (N10E-N165E) (Fig. 2a). This foliation is cut across by N165E, N70E and N40E quartz and k-feldspar rich veins (Fig. 2a, 2b) which itself, is affected by conjugated N85E and N125E sinistral shear planes.

Veins are observed in Enyokè, Balondo Nlonako and Singalngal. They are rhyolitic and basaltic in composition and display thicknesses varying from 7 to 13 cm in Enyokè vein. Veins are also Bt-Cpx granite in composition with thicknesses varying between 5 cm and 10 cm and outcrop in syenite and k-feldspar megacrysts granite in Balondo (Fig. 2c, 2d). In k-feldspar megacrysts granite, Bt-Cpx granite displays N20°E48°SE and N35E44NW conjugated planes whose directions are parallel to k-feldspar megacrysts. In Singalngal, N-S (N10E) and E-W (N95E) k-feldspar megacrysts granite veins with 15 to 45 cm thickness are observed in gneiss [11].

Fractures are mostly joints and observed in megacrysts granite and gneiss in Balondo Nlonako. This brittle

deformation fractured k-feldspar and cut cross one another or cross cut the foliation. Fractures display directions varying from N40E to N155E with strong dips towards SE or SW and grouped into two generations. The first generation (N40E-N80E) is cut across by the second generation N105E to N155E (Fig. 2). In k-feldspar megacrysts granite, fractures are oblique to k-feldspar megacrysts.

Fig. 2. Structural features. (a) Sinistral shear marked by quartz-feldspar rich vein along N85°E and N125°E plane. (b) Image redrawn from photo (a) showing sinistral shear movement. (c) and (d) Transposition of N30°E-N40°E foliation into NW-SE (N143°E-N165°E) in gneiss (c). (d) Image redrawn from photo (a).

B. Lineament Analyses

Sobel (5x5) filters applied on Landsat ETM+ image (Fig. 3) following the N-S (N0E and N160E), NE-SW (N45E), E-W (N90E) and NW-SE (N135E) enable the identification of lineament, but only those applied in N-S, NE-SW and NW-SE were used because there was a strong similarity between N-S and E-W filters.

In the filter applied in the NE-SW direction (Fig. 4), three lineament trends are observed: the NE-SW, the N-S and NW-SE directions. (1) The dominant NE-SW lineaments are cut across and sometimes affected by (2) the N-S sinistral thrust fault or lineaments. (3) These N-S lineaments are then cross cut by NW-SE lineaments. Detailed extraction of the lineaments (Fig. 4) shows that in CAN, the linear structures are generally oriented NE-SW. Nevertheless, some curvilinear structures are present and seem to indicate that the complex would be consisted of two rings.

In the filter applied in the NW-SE direction (N135E, Fig. 5), three lineament trends NE-SW, N-S and NW-SE are observed. However, the N-S and NE-SW lineaments are well represented. The NW-SE structures are presented in the NAC, although they are not well expressed as in the filter applied in the NE-SW direction. The circular structures observed in the NAC are more pronounced in this filter (Fig. 5). In addition, the organization of the Nlonako complex into two-rings is becoming more and more pronounced.

Fig. 3. Landsat ETM+ image of the study area.

Fig. 4. Extraction of lineaments on Landsat 8 ETM+ following the NE-SW direction (N45E).

In the filter applied in the N-S direction (N160E, Fig. 6a), four lineaments directions NE-SW, NNE-SSW, N-S and NW-SE are observed. The NE-SW structures are present only on the smallest rings of the complex, although is not well expressed as in the filter applied in the NE-SW direction. Circular structures (Fig. 6) are pronounced there as on the filters applied in the NW-SE direction (Fig. 4), as well as the occurrence of the complex into two rings.

Fig. 5. (a) Landsat 8 ETM+ image in monochromatic mode and (b) extraction of lineaments on Landsat 8 ETM+ following the NW-SE direction (N135E). (b) stereogram of directions. (c) stereogram of cumulative directions.

Fig. 6. Extraction of lineaments in the NW-SE direction (N160E).

The map of lineament synthesis presents three directions (Fig. 7a): (1) a NE-SW to ENE-WSW (N50E-N80E, averaged N60E-N70E) dominant direction (2) a secondary N-S (N170E-N10E) direction and (3) an accessory NW-SE direction. Also, NE-SW dextral shear markers are observed in the south of Eyimba and major N-S sinistral strike fault are identified at Ekomtolo and Makouma. Curvilinear and circular structures are observed in the NAC where two rings are identified: the largest and a smallest ring. The largest ring presents inner sub-circular steep slopes corresponding to the collapsed zone at the top of Mount Nlonako. On the Landsat image, the NE-SW and ENE-WSW lineaments are cut across and counter clockwise sheared by a N-S lineament in Makouma. These N-S lineaments are cross cut by the E-W to WNW-ESE lineaments.

Stereogram of the directions and the cumulative directions from the overall lineament data display (Fig. 7b, 7c): (1) a NE-SW to ENE-WSW (N50E-N80E, averaged N60E-N70E) dominant direction corresponding to the direction of the Adamawa fault whose extension to Fouban is known as the CCC; (2) a secondary N-S (N170E-N10E) direction, (3) a NE-SW (N30E-N40E) direction corresponding to the direction the N30E-N50E branch of the CCC and the southern part of the and (4) a E-W (N90E-N120E) to WNW-ESE (N120E-N140E) direction. On the Landsat images, the NE-SW and ENE-WSW lineaments are cross cut and counter clockwise sheared by the N-S lineaments. These N-S lineaments are cross cut by the E-W to WNW-ESE lineaments.

Fig. 7. Synthesis of lineament data. (a) Synthetic lineament map.

(b) Stereogram direction synthesis.

(c) Cumulative direction synthesis' stereogram.

V. DISCUSSION

A. Lineament distribution and contribution for the Nlonako complex shape determination

According to [9] and [14], NAC is a N-S elongated complex. However, the SRTM image (Fig. 8) indicates an egg-like intrusive body of about 10 km in diameter, oriented NNE-SSW from Ngalmoa to Balondo Nlonako [11]. In addition, data extracted from the Landsat 8 ETM+ image (Fig. 3) confirms this sub-circular shape. Moreover, field and petrographic data show that the NAC is a ring or annular complex (Fig. 15) slightly elongated in the NNE-SSW direction (Fig. 8; [11]), thus it can be called the Nlonako ring complex (NRC). The misinterpretation and miscorrelation for the determination of the annular or ring shape of the complex by [9] is likely due to the investigation techniques and the dense forest vegetation developed almost on the entire surface of the complex and, therefore, could not facilitate field investigations. For the present study, after field surveys, mathematical algorithms were applied to the Landsat 8 ETM+ image in order to remove vegetation before applying lineament extraction to the image. At the

end of the application of this method, two distinct rings were identified on the lineament map (Fig. 5, Fig. 6, Fig. 7a). The superposition of lineament map with field data, a geological map from [11] and unpublished geochemical data shows that they are composed of (1) syenite for the well expressed biggest ring (Fig. 7a) and surroundings (2) and gabbro for the poorly express smallest ring. This ring shapes support the fact that the NRC is a ring complex slightly elongated toward NNE-SSW as concluded by [11] instead of displaying N-S shape as proposed by [9].

Map of lineament synthesis (Fig. 7) and the SRTM image (Fig. 8) show NE-SW, N-S and NW-SE trend structures. (1) The dominant NE-SW trend mostly displays by structures in the NRC and its basement rock is parallel to (i) the main metamorphic foliation trend (Fig. 2c, 2d) and (ii) to the central Cameroon shear zone regional fault. This direction also corresponds to the trend of the Ngondo pluton elongation and the regional foliation and structures [11]-[15]. (2) The secondary N-S trend direction may correspond to the late deformational phase in the area. Indeed, these N-S-related structures transposed NE-SW structures towards a meridional direction in the NRC basement rock, as shown by SRTM image (Fig. 8). (3) The NW-SE trend corresponds to the direction of NW-SE fault cross cutting the NRC and may also corresponds to the trend of early structures such as foliation. Indeed, according to [36] and [37], NW-SE foliation is generally remnant in the Pan-African Fold Belt in Cameroon; this may explain their relative scarcity in the belt.

Fig. 8. SRTM image of the NRC showing its annular shape, slightly egg-like shape elongated toward the NNE-SSW and displaying circular structures. Note also the WNW-ESE, E-W; ENE-WSW and NNE-SSW faults networks, dextral NE-SW and N-S sinistral shear markers.

B. Contribution to Pan-African tectonic evolution

Three main tectonic deformational phases are generally recorded in the Central Pan-African Fold belt in Cameroon

[38]-[46]: (1) a Compressive deformational phase D_1 whose main markers are NNW-SSE to NW-SE foliation; (2) an early left-lateral deformational phase D_2 characterized by anticlockwise rotation and NE-SW sinistral transposition of early structures, and (3) a NE-SW late right-lateral deformational phase D_3 marked by a clockwise rotation and a dextral transposition of preexisting structures [35]. However, recent research works from [47] and [35] described a late sinistral shear phase transposing NE-SW dextral D_3 -related structures, suggesting a more complex deformation history for the Pan-African Belt in Cameroon. The NW-SE foliation recorded by gneiss corresponds to the S_1 , thus a D_1 -related structure during the compressive tectonic. This NW-SE foliation is sheared and transposed by a sinistral shear deformation (Fig. 2b). NE-SW foliation (S_2) still recorded in gneiss and the NE-SW magmatic foliation described in megacrysts granite from the Ngondo pluton by [11] and [15], are D_2 -related foliations. This NE-SW foliation also corresponds to the NE-SW D_3 trend deformational phase since D_2 and D_3 phase display the same direction but of different sense of motion, that is left-lateral and right-lateral respectively for D_2 and D_3 [37]-[42], [45]. This is evidenced by the clockwise structures observed on the SRTM image of figure 8. The relative absence of NE-SW sinistral shear markers on the SRTM image (Fig. 8) is probably due to the fact that they were overprinted by the NE-SW dextral shear phase structures [36]-[39], [42], [44]. The above deformational phases are usually described in the Central Pan-African Fold belt in Cameroon. In the study area, the SRTM image (Fig. 8) displays a N-S left-lateral movement overprinting and transposing the NE-SW right-lateral D_3 -related markers, suggesting a late N-S sinistral phase D_4 that follows the D_3 deformational phase. Indeed, some recent research works in the Central Pan-African Fold belt in Cameroon [46], [35] demonstrated the occurrence of a late N-S left-lateral movement overprinting the D_3 NE-SW right-lateral movement. The occurrence of sinistral N-S structure indicate that the tectonic history of the Pan-African Belt in Cameroon is more complex, and therefore display more than two shear phases but at least three, that is a right-lateral phase, sandwich by two left-lateral phase.

VI. CONCLUSION

The NAC is located in the south western part of the Cameroon Line and superposed on the N50E branch of the central Cameroon shear zone. Landsat 8 ETM+ and SRTM images were used for lineament interpretation and tectonic reconstruction. Lineaments extracted from Landsat 8 ETM and SRTM images indicate a sub-circular shape for the NAC. Results from the combination of the above data, field and petrographic data from [46] showed that the NAC is a ring complex, thus it is called Nlonako ring complex (NRC). The map of lineament synthesis and the SRTM image of the study area display: (1) dominant NE-SW trend structures mostly displayed by the NRC and its basement rock corresponding to the direction of regional foliation and structures; (2) a secondary N-S trend direction that may corresponds to the late deformational phase in the area, and (3) NW-SE trend structures corresponds to the direction of NW-SE

fault cross cutting the NRC and may also corresponds to the trend of early structures such as foliation. Four deformational phases were identified from field data, lineament from Landsat 8 ETM+ and SRTM images: (1) a Compressive deformational phase D_1 , characterized by NNW-SSE to NW-SE S_1 foliation; (2) an early NE-SW left-lateral deformational phase D_2 whose structures were overprinted by a dextral shear deformation; (3) a NE-SW right-lateral deformational phase D_3 marked by clockwise rotation and dextral transposition of preexisting structures and NE-SW S_3 foliation; and (4) a N-S late sinistral shear phase D_4 deformational phase which transposed the NE-SW dextral D_3 -related structures.

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