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Automatic Extraction and Geospatial Analysis of Lineaments and their Tectonic Significance in South Cameroon Area using Remote Sensing Techniques and GIS

Extração Automática e Análise Geoespacial de Lineamentos e seu Significado Tectônico na Área Sul dos Camarões usando Técnicas de Sensoriamento Remoto e SIG

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Recebido em: 13/07/2020 Aprovado em: 14/09/2020
DOI: http://dx.doi.org/10.11137/2020_4_319_329

Abstract

This study investigates the dominant orientations of lineament features and the relationship between these trends and the spatial orientation of tectonic structures in the transition zone of the Congo craton and the Pan African belt in South Cameroon area. Landsat 8 OLI/TIRS and hill-shaded images, constructed from 30 m-resolution SRTM-DEM data, were used for automatically extracting and mapping geological lineaments. Lineament features were analyzed by means of azimuth frequency and length density distributions. Three major sets of lineaments trending W–E, ENE-WSW and WNW-ESE are identified in the South Cameroon area. These trends are probably related to repeated reactivation of pre-existing crustal structures during Eburnean and Pan-African tectonic episodes. The lineaments were formed under the compressional tectonic stress regimes generated during these tectonic events.
Keywords: *South Cameroon; Lineaments; Remote sensing*

Resumo

Este estudo investiga as características e orientações dominantes dos lineamento e a relação entre essas tendências e a orientação espacial das estruturas tectônicas na zona de transição do Cráton do Congo e do cinturão Pan-Africano na área dos Camarões do Sul. Imagens Landsat 8 OLI / TIRS e hill-shaded, construídas a partir de dados SRTM-DEM com resolução de 30 m, foram usadas para extrair e mapear automaticamente lineamentos geológicos. As características dos lineamentos foram analisadas por meio de distribuição de frequência azimutal e densidade de comprimento. Três conjuntos principais de tendências de lineamentos W–E, ENE-WSW e WNW-ESE são identificados na área dos Camarões do Sul. Essas tendências estão provavelmente relacionadas à reativação repetida de estruturas crustais pré-existentes durante os episódios tectônicos Eburnianos e Pan-africanos. Os lineamentos foram formados sob os regimes de tensão tectônica compressional gerados durante esses eventos tectônicos.
Palavras-chave: *Camarões do Sul; Lineamentos; sensoriamento remoto*

1 Introduction

The south Cameroon area is located in the transition zone between the Pan-African belt in central Africa (PAB) and the Congo craton (CC). The tectonic evolution of the south Cameroon area is described by various and divergent tectonic models that broadly correspond to the collision between the Congo craton and the mobile belt (Poidevin, 1983; Nzenti *et al*., 1988; Penaye *et al*., 1993; Castaing *et al*., 1994; Trompette, 1994; Rolin, 1995; Toteu *et al*., 2001; Abdelsalam *et al*., 2002; Shandini *et al*., 2010). The collision has yields to the thrusting of huge allochtonous nappe unit southward onto the Congo craton evolving several deformation phases which produced regional foliation trends resulting in structural discontinuities (lineaments) that have greatly influenced rocks of various geologic ages.

According to Adiri *et al.* (2017), lineament structural features may correspond to natural objects, including structural alignment, geomorphologic consequences, structural weakness, faults, fractures, dykes, granitic or porphyry intrusions, bedding planes and lithological boundaries separating different formations. Geological structural lineaments mapping plays a vital role in geological studies, especially in mineral exploration, mining, and petroleum industry. Detailed geological studies involve an understanding of lineament and subsurface geological information because they are often associated with mineral deposit emplacement and tectonic evolution processes (Meshkani *et al.,* 2013).

Several geological research works have been carried out to understand the tectonic framework of southern Cameroon area. These studies were focused mostly on the PAB (Penaye *et al*., 1993; Mvondo *et al*., 2003; Mvondo *et al.,* 2007; Olinga et *al*., 2010). Previous geophysical studies, based on magnetic and gravity data interpretation, have been carried out in the South region in order to delineate the tectonic lineaments (Shandini *et al.,* 2012; Ndougsa *et al*., 2012; Owona *et al.,* 2013; Akame *et al.,* 2014; Anaba *et al.,* 2019). As such, these interpretations do not encompass a precise cartography of the lineaments of the South Cameroon study area at a local scale which was the objective of the present study. Lineament mapping and analysis can provide essential clues about regional tectonic. However, the identification of lineaments at a regional scale would be extremely difficult if it is depended only on fieldwork. The availability of multi-spectral and high-resolution remote sensing data has enlarged the potential of using satellite data for fast identification, extraction, and mapping of structural lineaments (e.g., Sarp, 2005; Saadi *et al*., 2011; Argyriou, 2012).

This study aims to apply remote sensing and GIS techniques to morphological features extraction and analysis of lineaments over the South Cameroon area. Many methods of automatically extracting lineaments from digital data have been proposed, from satellite images and Digital Elevation Models (DEM) in regions where bed rock is exposed. These methods are mostly based on edge-detection techniques using spatial and morphological filters (e.g. Süzen & Toprak, 1998; Tripathi *et al*., 2000). An attempt was made in this work to automatically detect and map lineaments by integrating two types of satellite data: Landsat 8 OLI/TIRS and medium-resolution 30 m SRTM DEM images. These approaches have been successfully used in detailed studies, such as in reference and have led to delineation of the major geological structures and the mapping out of the different tectonic lineaments that affect the study area (e.g., Pike, 1991; Simpson & Anders, 1992; Jordan & Schott, 2004). Results of this study can contribute to fundamental knowledge of the neotectonics activity in the area to assess how the tectonics of the transition zone between PAB and CC is reflected in the morphology of the landforms.

2 Geological Setting

The study area lies in South Cameroon and is situated in the transition zone between the Congo Craton (CC) and the West African (PAB; Figure 1A). A simplified geological sketch map of the study area illustrating the main geological units is shown in Figure 1B. The Ntem complex represents the north-western part of the CC in Central Africa and is well exposed in South Cameroon (Maurizot *et al.,* 1986). This complex predominantly consists of younger intrusive complexes and banded gneisses series. Intrusive complexes primarily consist of TTG suite rocks (Nédélec et *al.,* 1990). The TTG unit is made up of three rocks types: the tonalitic suite (known as So'o granite), the charnockitic suite and the granodioritic suite massifs (Shang *et al.,* 2004). The tonalitic suite is exposed to the north and is strongly mylonitised and retrogressed along the fault boundary with formations from the Yaoundé Group.

The Yaoundé group is a huge allochtonous nappe thrust southward onto the CC. It comprises low- to high-grade garnet-bearing schist, gneisses and orthogneisses transformed in medium- to high-pressure granulite facies metamorphism (Toteu *et al*., 2004). The Yaoundé group in the study area consists of the Mbalmayo-Bengbis series (MB) and the Yaoundé series (YS) known as "intermediate series". The Mbalmayo-Bengbis series are composed of schist and re-crystallised quartzite in greenschist facies (Vicat, 1998). The Yaoundé series consist of strongly deformed meta-sedimentary rocks and migmatites (Nzenti *et al*., 1988).

The structural data show definite surface deformation characterized by flat structures gently sloping to the north

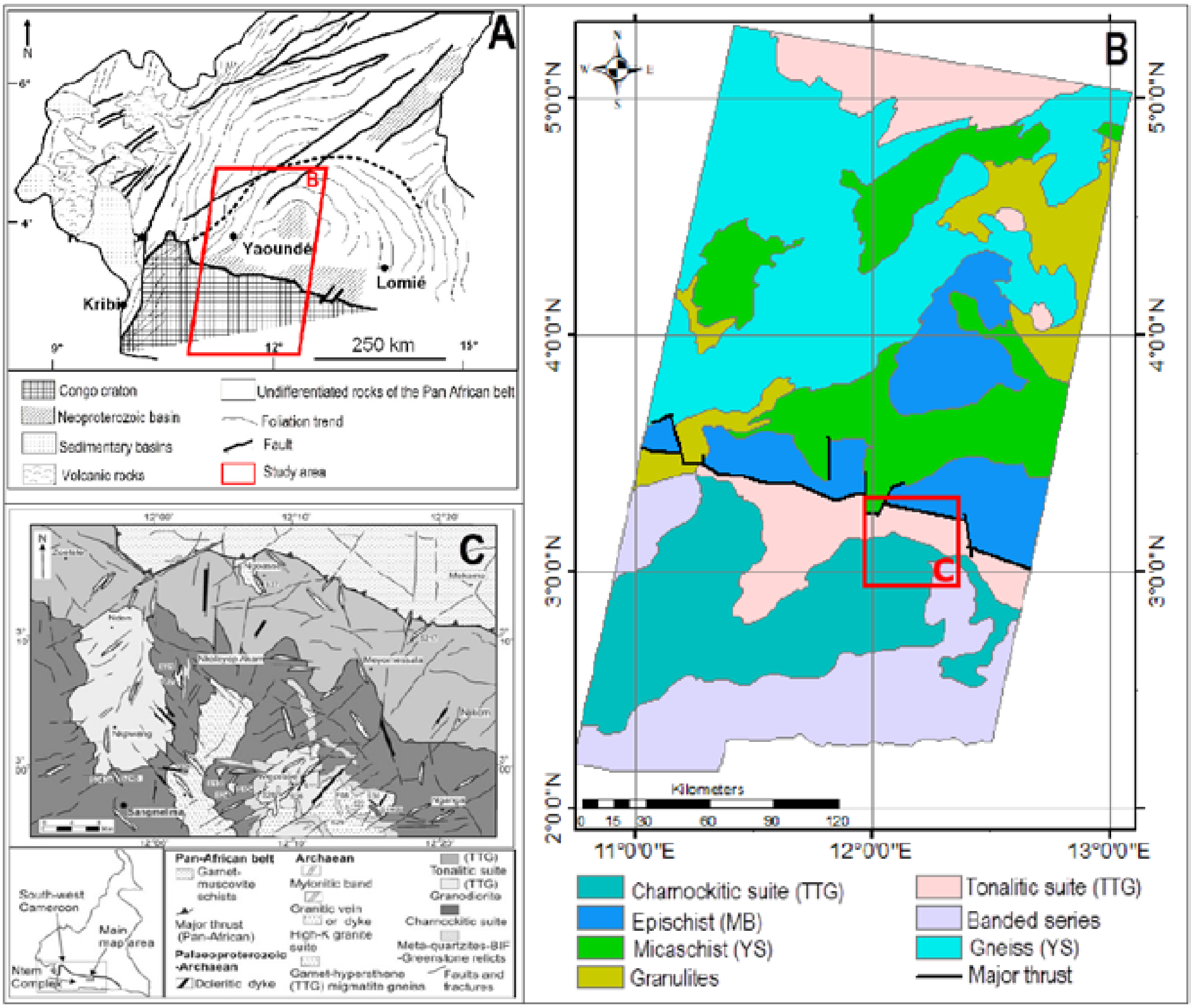

Figure 1 A. Tectonic map showing the foliation and lineation trends in southern Cameroon (Modified after Gazel *et al*., 1956); B. Simplified geological map of the survey area (digitized from Maurizot et al., 1986); and C. Geological map of Sangmelima area in South Cameroon (Shang *et al*., 2004)

and generalized tilting towards the south or south-west, indicating a significant intermediate formation overlap on the Ntem complex basement. Such deformation may be seen by the presence of northward sloping folds (Maurizot *et al*., 1986). The region has a complex and uneven tectonic structure.

The foliation trends derived from tectonic lines in south Cameroon (Gazel *et al*., 1956) result from the superposition of two or more phases of deformation which results from the deformation around the underlying CC (e.g., Toteu *et al.*, 2006; Mvondo *et al.*, 2007; Njiekak *et al.*, 2008; Mvondo *et al.*, 2009; Olinga *et al.*, 2010; Mbola-Ndzana *et al.*, 2014):

- the associated N110°–N140° stretching lineation, and rotational structures, inferred to as D1 deformation is interpreted as an early Pan-African nappe tectonic;
- the steep axial plane S2 foliation associated with the tight and upright folds and with syn-migmatitic conjugate shear zones may be explained by a West–East to WNW–ESE shortening during phase D2;
- The sinistral movement along the North–South to NE–SW shear zones (inferred to as D3) is consistent with NNE–SSW shortening direction;
- the WSW–ENE to SW–NE dextral one (inferred to as D4) is consistent with a WNW–ESE shortening direction.

3 Data Treatment and Methodology

The main objective of this research is to make an integrated interpretation of optical and elevation remote sensing satellite data in mapping structural lineaments structures in the South Cameroon area for tectonic framework interpretation.

The optical data are from the Landsat-8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS). The Landsat-8 Operational Land Imager (OLI) image consists of nine spectral bands with a spatial resolution of 30 meters for bands 1 to 7 and 9. The resolution for band 8 (panchromatic) is 15 meters (USGS, February 2014). Two Landsat 8 OLI/TIRS scenes covering the investigated area (Path: 185 and Row: 057 / Path: 185 and Row: 058) and acquired on 10 February 2020 were downloaded from the United States Geological Survey (USGS) portal (http://earthexplorer.usgs.gov/).The acquisition date was choose to ensure cloud-free images download. A mosaic of the Landsat images in natural color combination is shown in Figure 2A.

Altitude data used in this study were obtained from the Shuttle Radar Topographic Mission (SRTM) datasets. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60-meter long baseline (Kobrick, 2006). A description of the SRTM mission can be found in Farr & Kobrick (2000) and Farr *et al.* (2007). The SRTM DEM data for this study was downloaded and exported in GeoTIFF format from NASA's Earth Explorer website (http://www2.jpl.nasa.gov/srtm/) with geographic lat/long coordinates and a 1 arc-second (30 m) grid (Figure 2B). The raster file was later clipped to the extent of the survey area for post-processing. The methodology used in this research is summarized and shown in the flowchart in Figure 3.

Analytical hill-shading is applied to SRTM digital elevation model to produce shaded relief images with light sources coming from different directions. On hill-shaded images, linear features striking perpendicularly or obliquely to the look direction of the light sources are easy recognized,

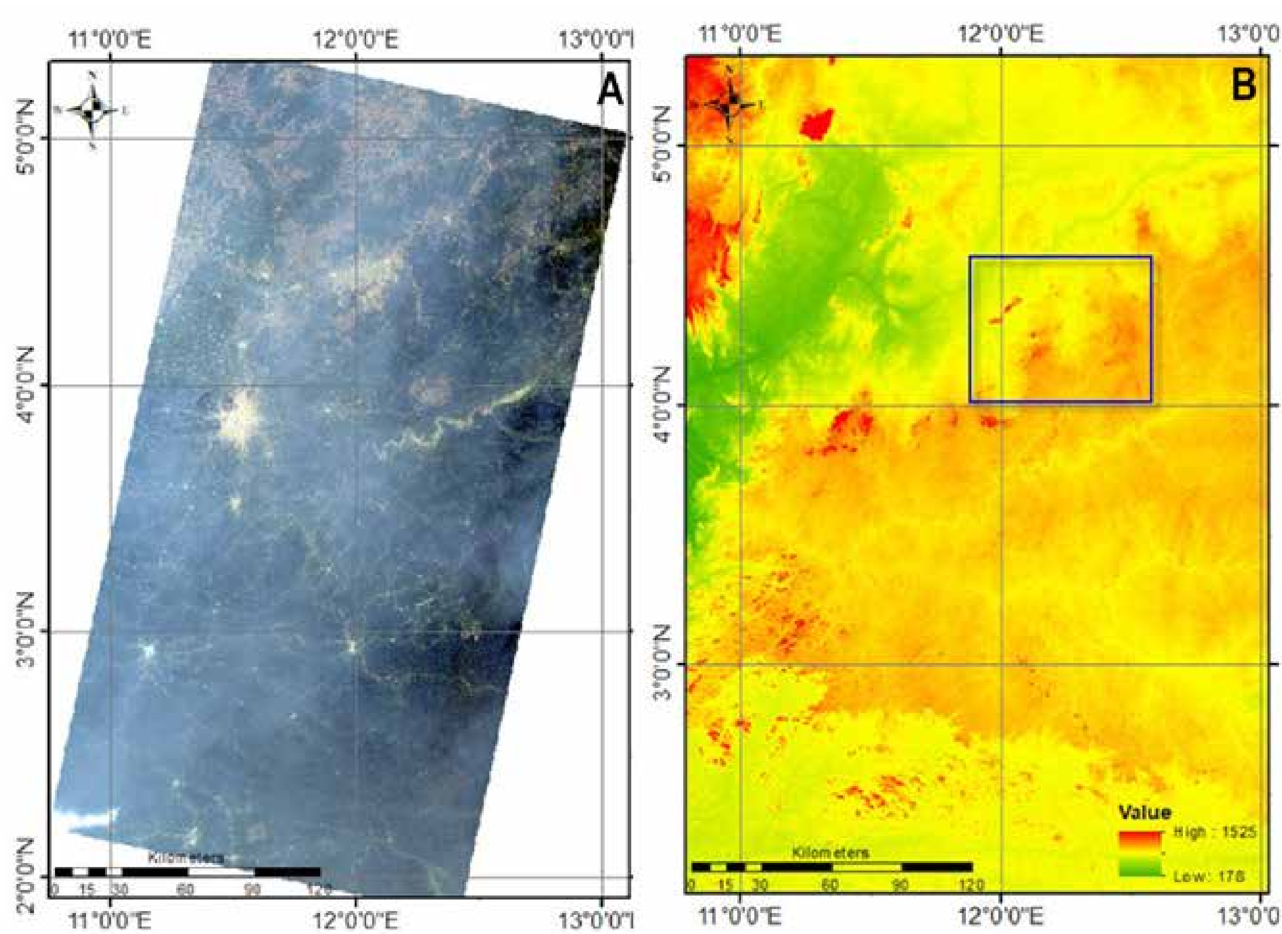

Figure 2 A. Mosaic of Landsat 8 OLI natural colour composite (RGB 321) of the study area; and B. SRTM digital elevation model for the study area

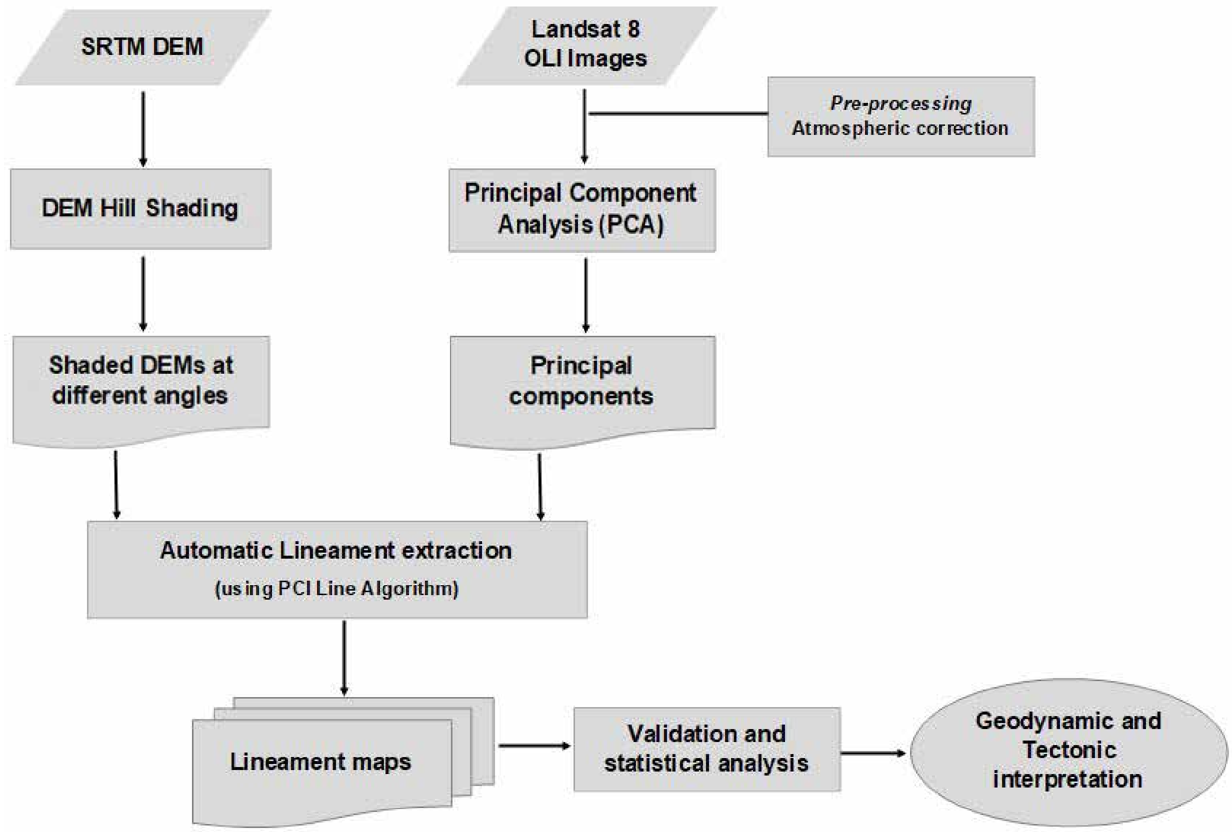

Figure 3 Summarized workflow of the research

whereas those parallel to the look direction are suppressed. Hill-shaded image transformation were derived from SRTM digital elevation model for the different lighting direction (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°) with the sun elevation angle of 45º using ArcGIS 10.5.1. software. Extracts of hill shading maps covering part of the study area are presented for illustration in Figure 4. The shaded relief images are combined to produce two images with multi - illumination directions using the overlay technique, with equal weights given to the individual directional hill-shaded images (Figure 5). The first multi-illumination hill-shaded image was produced by combining hill-shaded models illuminated from 0°, 45°, 90° and 135° light azimuths. The second multi-illumination hill-shaded image was produced by combining the other four hill-shaded models with light azimuth angles of 180°, 225°, 270° and 315°. Combine different lighting azimuth angles images into a single image provides valuable insight into the different spatial patterns of the linear features that would not be visible if only a single lighted hill-shaded image was used (Mark, 1992; Onorati *et al*., 1992; Loisios *et al*., 2007; Abdullah *et al.*, 2010).

Principal Component analysis (PCA) was applied to Landsat 8 corrected images. Principal Component Analysis is a linear transformation that reorganize the variance in a multiband image into a new set of image bands. The PC bands are uncorrelated linear combinations of the input bands. A PC transform finds a new set of orthogonal axes with their origin data mean, and it rotates them so the data variance is maximized. This transformation technique eliminates the data redundancy, isolates the noise in the latest principal component and then enhances the target information in the input image (Adiri *et al.,* 2017), which is lineament structures in this study.

The PCA was applied to the Landsat bands covering the study area (except thermal band 8) to produce new Principal Components (PCs). The eigenvalues were computed and analyzed to evaluate interdependency and correlation between PC bands. The PC1 covering the study area is characterized by the highest dynamic range (98.72%) followed by PC2 and PC3 (Table 1). Other PCs are characterized by very narrow dynamic range. PC image resulting from the first three PCs contains the majority of the information in the original imagery with unwanted image noises removed. Extract of RGB PC map covering part of the study area is presented for and compared to RGB true color of Landsat 8 raw image (Figure 6).

Hill-shaded and PC transform images were subsequently used for lineament mapping. The automated

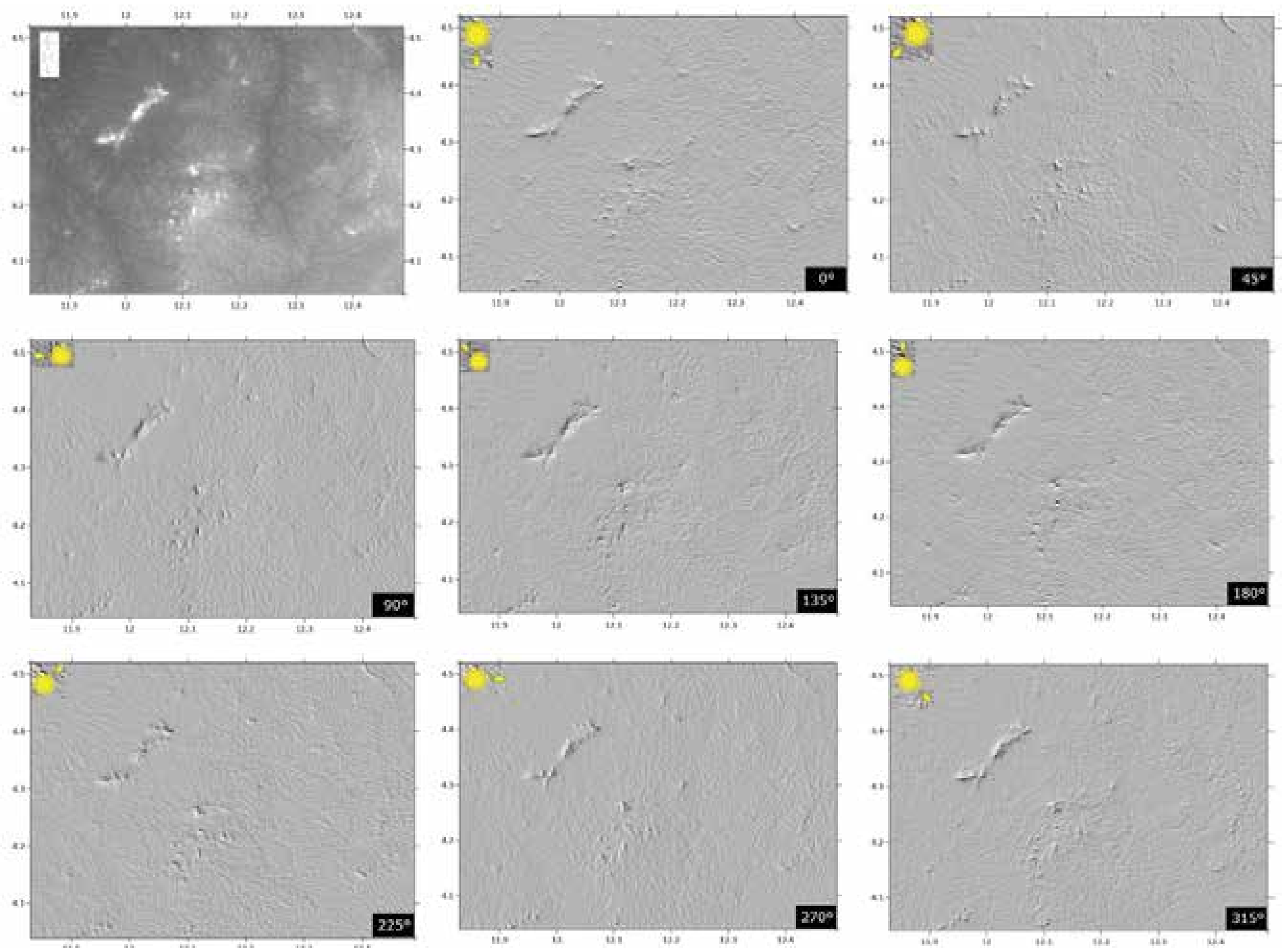

Figure 4 Hill-shaded images with a constant light dip of 45° and various light azimuths, covering part of the study area (blue rectangular box in Figure 3). The yellow arrows in each hill shaded DEM represent the direction of the Sun Azimuth.

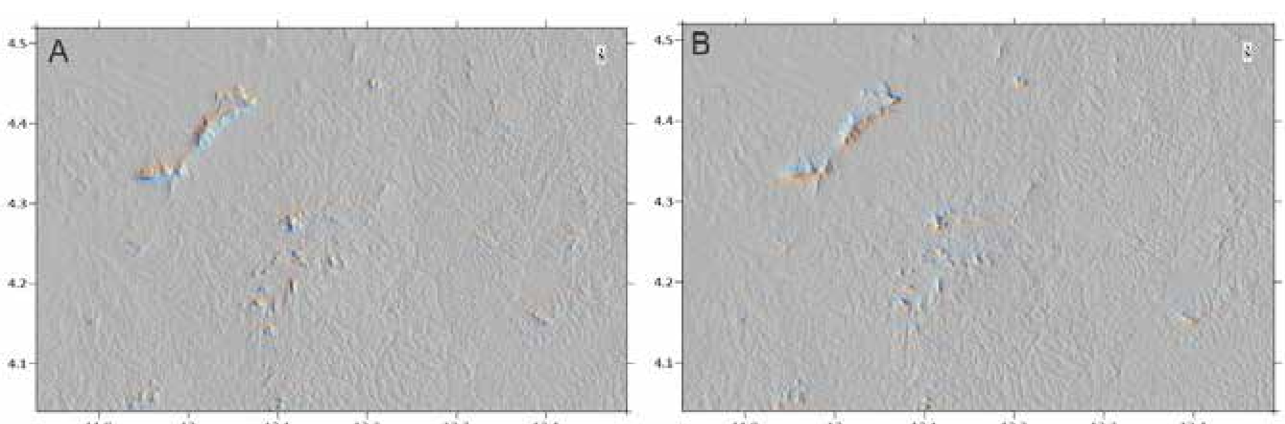

Figure 5 Two shaded relief images created by combining different shaded relief images; A. Combining four shaded relief images with sun angle of 0°,45°,90° and 135°; B. Combining four shaded relief images with sun angle of 180°, 225°, 270° and 315°.

lineament extraction was performed by the LINE module of PCI Geomatica software. The lineament extraction algorithm of LINE module consists of edge detection, thresholding and curve extraction steps. LINE module of Geomatica extracts linear features from an image and records the polylines in vector segments by using

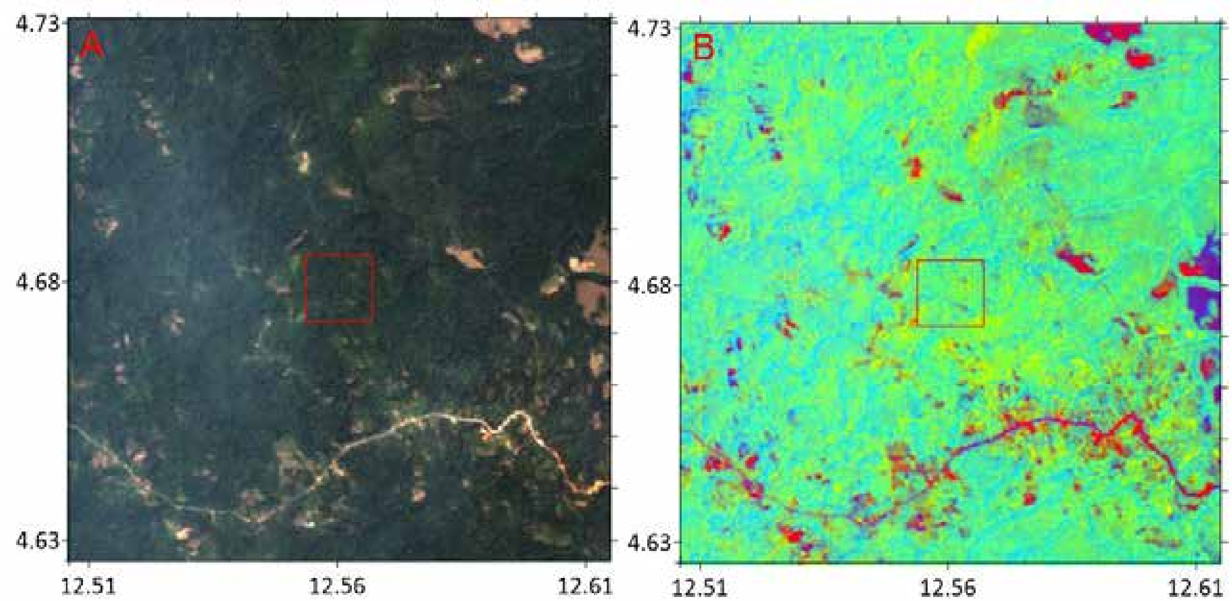

Figure 6 A. Extract of natural colour composite RGB 321; and B. Composite image of PC-1, 2, 3 as RGB.

Principal Component	Eigenvalues	Contribution rate (%)	Cumulative contribution rate (%)
PC-1	157772449.919473	98.72849	98.72849
PC-2	1565941.956616	0.979912	99.7084
PC-3	426540.851448	0.266914	99.97532
PC-4	27610.504485	0.017278	99.9926
PC-5	9792.165537	0.006128	99.99872
PC-6	1245.762542	0.00078	99.9995
PC-7	795.037280	0.000498	100

Table1 Eigenvalues and contribution rates of principal components after PCA

Name	Description	Values	
		SRTM	LANDSAT
RADI	Radius of filter in pixels	12	10
GTHR	Threshold for edge gradient	90	100
LTHR	Threshold for curve length	30	30
FTHR	Threshold for line fitting error	10	3
ATHR	Threshold for angular difference	30	30
DTHR	Threshold for linking distance	20	20

Table 2 Parameters values used in Line module

six optional parameters (RADI, GTHR, LTHR, FTHR, ATHR and DTHR). Multi-illumination hill-shaded images and RGB PC images were used for automatic lineament extraction using PCI Geomatica software. The identification of lineaments was also carried out on the panchromatic band 8 with a ground resolution of 15 m to improve the detectability of small features. LINE module parameters selection was based on several trials and visual assessment of the output. The parameters we selected are provided in Table 2. Extracted lineaments were statically analyzed using Rock works 16 software to determine lengths and create frequency weighted rose diagram for lineament population.

4 Results and Discussions

Lineaments extracted automatically from Landsat 8 (OLI) and SRTM DEM images were combined, and lineaments repeated more than once are eliminated to avoid repeating segments in the synthesis map. The lineaments derived from human activities and hydrographic network were also eliminated using GIS tools. 12442 lineaments were identified, ranging in length from 0.43 to 8.619 km, with a total length of 33419 km. Figure 7A shows a general view of lineaments mapped in the study area. The rose diagram (Figure 7B) shows a heterogeneous lineament with an ascendancy of the lineaments of W-E trend followed by two important families of orientations ENE-WSW and WNW-ESE. There are few lineaments that trend north-south.

The automatic extracted lineaments map from remote sensing images was compared with a published geological and structural map of Sangmelima region, part of the study area (Figure 1C). Orientation of the lineaments for all ground-based structural field datasets and automatic extracted lineament maps are compared using the rose diagrams (Figure 8). The dominant lineaments tend to run in the NE-SW, E-W and NW-SE directions. The two diagrams are differing but proves the existence of the dominant orientations of lineaments. The lineaments are highly concentrated on the automatic extracted map, while they are widely distributed in the thematic geological structural map.

The area was separated into different units according to the main lithologies and lineament orientations for each region were then plotted as frequency and length weighted rose diagrams (Figure 9). The different lithologies do not show the same orientation patterns. However, the extracted lineaments show similar general dominant lineament orientation pattern in the W-E direction and major orientations in the ENE-WSW and WNW-ESE directions, but at different angles in the datasets. This presumably reflects the orientation of pre-existing structures and differing preservation potentials of faults in these lithologies. The lineament networks of the Congo craton area and the Pan-African Mobile Zone are mostly supposable since their lineaments orientation seem comparable. The relative complexity of the lineament network in the Stable Zone is interpreted to be due to the coexistence of Eburnean and Pan-African fractures. Such a hypothesis leads to an

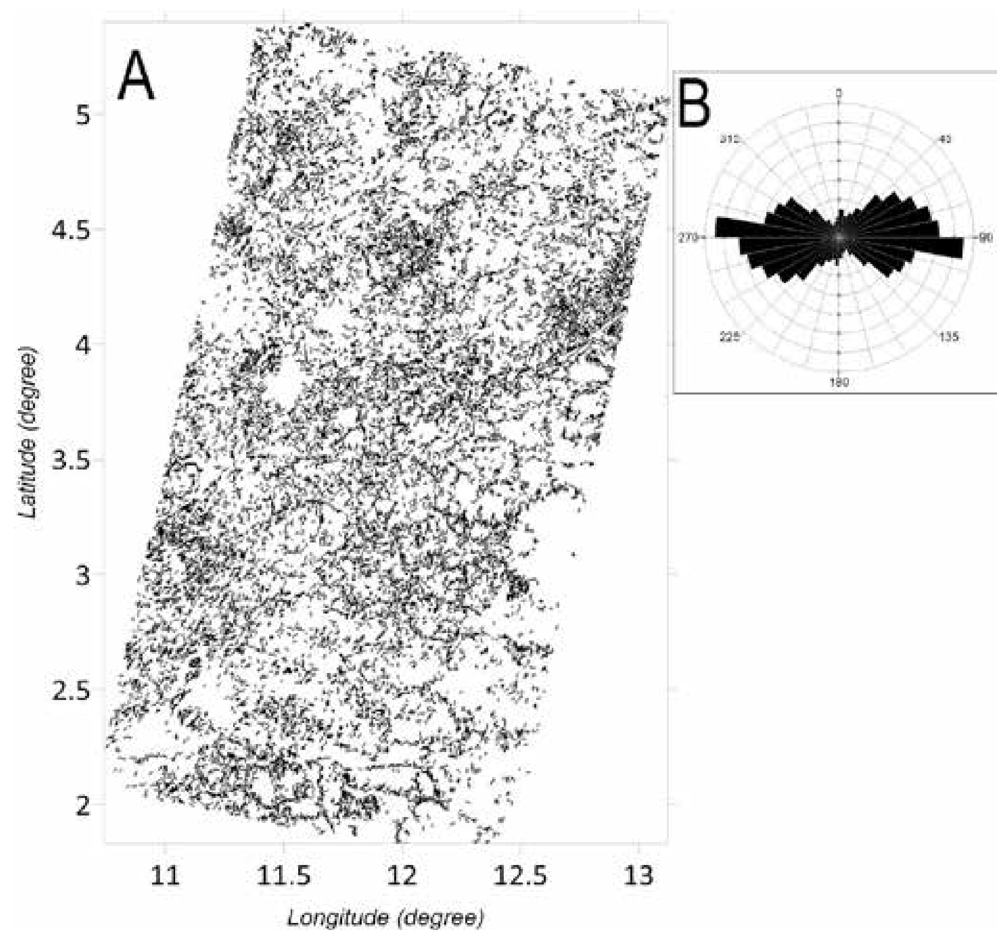

Figure 7 A. Automatic lineament map over the study area; and B. Rose diagram

Anuário do Instituto de Geociências - UFRJ
ISSN 0101-9759 e-ISSN 1982-3908 - Vol. 43 - 4 / 2020 p. 319-329

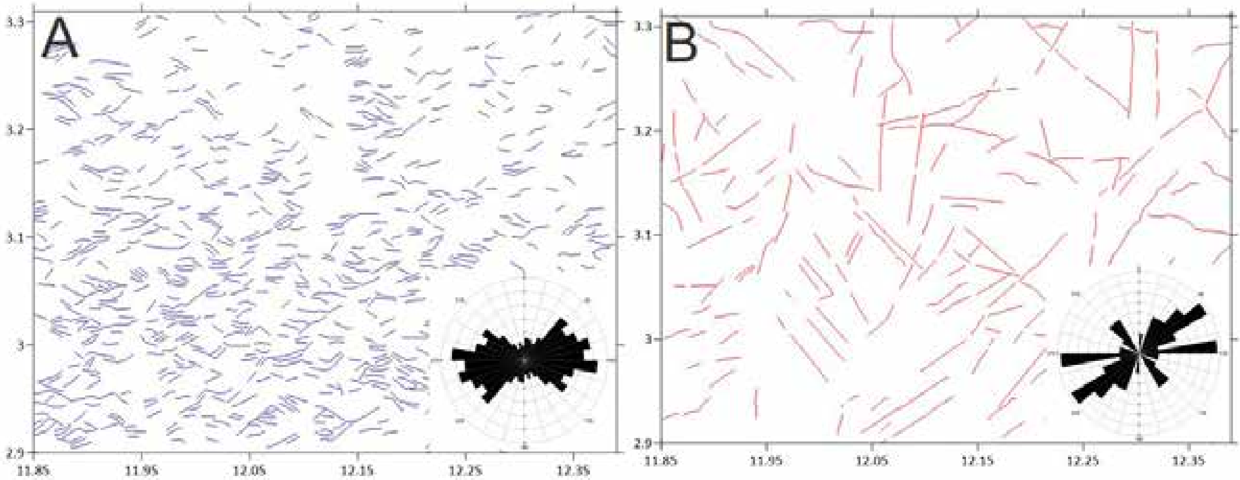

Figure 8 A. Lineament maps of Sangmelima area obtained from automatic extraction of remote sensing images; B. and compared to those extracted from the geological map (see Figure 1C)

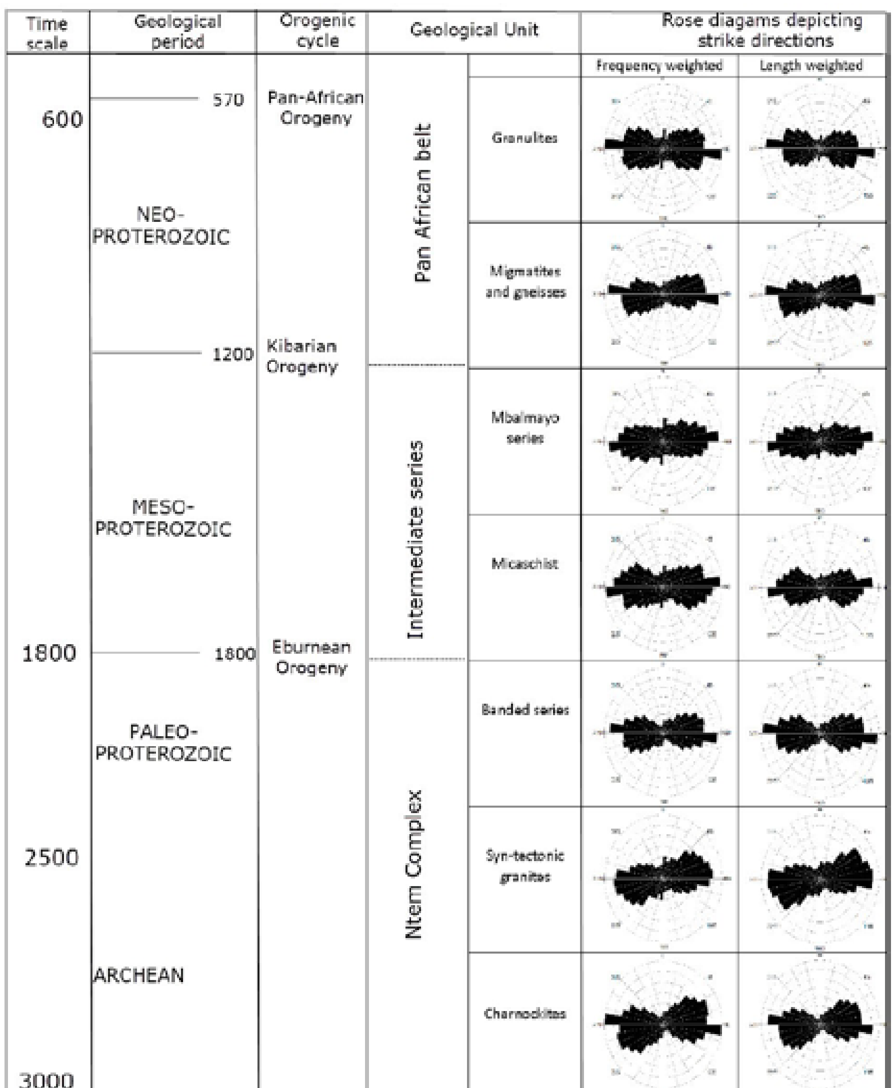

Figure 9 Temporal evolution of the lineament trends

inference that, in response to the Pan-African tectogenesis, the Eburnean cratonic basement and its cover records Pan-African fractures and that the Eburnean fractures were reactivated. It can be inferred that the W-E dominant direction of lineament result from an east-west regional shortening direction. Likewise, ENE-WSW and WNW-ESE lineament orientations can be attributed to NNE–SSW and WNW–ESE shortening directions respectively. These observations are consistent with tectono-metamorphic study of Toteu *et al*. (2004) who identified the principal changes of the regional shortening direction from W–E, WNW–ESE (D1–D2) to NNE–SSW (D3) and back to WNW–ESE (D4).

5 Conclusion

This study presents the combine use of remote sensing and GIS analysis techniques to extracts and analyse the geological lineaments at the transition zone between the Congo craton and the mobile Pan African belt in south Cameroon area. Hill-shaded images derived from 30 m resolution DEM data and Landsat 8 bands with different spatial resolutions were used to automatically extract linear features and analyse their tectonic significance in the study area. Three major sets of lineaments are affected the South Cameroon area trending W–E, ENE-WSW and WNW-ESE. These trends are probably related to repeated reactivation of pre-existing crustal structures during various Eburnean and Pan-African tectonic episodes. Ground-based structural field datasets for verifying the findings of the remote sensing analysis was performed. This result agrees well with the previous structural results studies in the sector of study. The methodology for lineament extraction used in this study delineates more lineament structures in the study area than the previously published structural map and thus provided an enhanced understanding of the structural and tectonic activities. Due to its multi-scale feature detection and representation ability, the remote sensing technique is capable of extracting lineaments tendencies in the large and unreachable areas. This methodology might potentially adopt for structural studies and their applications such as mineral exploration, ore-forming systems, nuclear energy facility settings, petroleum and groundwater studies, water resource investigations.

6 References

Abdelsalam, M.G.; Liégeois, J.P. & Stern, R.J. 2002. The Saharan metacraton. *Journal of African Earth Sciences*, *34*: 119–136.

Abdullah, A.; Akhir, J.M. & Abdullah, I. 2010. Automatic mapping of lineaments using shaded relief images derived from digital elevation model (DEMs) in the Maran – Sungi Lembing area, Malaysia. *Electronic Journal of Geotechnical Engineering*, *15*(1): 949–957.

Adiri, Z.; El Harti, A.; Jellouli, A.; Lhissou, R.; Maacha, L.; Azmi, M. & Bachaoui, E.M. 2017. Comparison of Landsat-8, ASTER, and Sentinel 1 satellite remote sensing data in automatic lineaments extraction: A case study of Sidi Flah-Bouskour inlier, Moroccan Anti Atlas. *Advances in Space Research*, *60*(11): 2355–2367. https://doi.org/10.1016/j.asr.2017.09.006.

Akame, J.M.; Mvondo, O.J.; Teikeu, A.W.; Owona, S. & Olinga, J.B. 2014. Apport des images landsat-7 ETM+ a l'etude structurale du socle archeen de Sangmelima (Sud Cameroun). *Revue Francaise de Photogrammetrie et Teledetection, 206*: 15-26.

Anaba, Q.M.F.; Basseka, C.A.; Lordon, A.E.D.; Eyike, A.Y. ; Shandini, Y. & Tadjou, J.M. 2019. Geophysical Data Processing for the Delineation of Tectonic Lineaments in South Cameroon. *Earth Science Research*, *8*(2): 1-16.

Argyriou, A. 2012. *A Methodology for the Rapid Identification of Neotectonic Features Using Geographical Information Systems and Remote Sensing: A Case Study From Western Crete, Greece.* School of Earth and Environmental Sciences, University of Portsmouth, Portsmouth, United Kingdom, PhD Thesis, 269p.

Castaing, C.; Feybesse, J.L.; Thiéblemont, D.; Triboulet, C. & Chèvremont, P. 1994. Palaeogeographical reconstructions of the Pan-African/Braziliano orogen: closure of an oceanic domain or intracontinental convergence between major blocks? *Precambrian Research, 69*: 327–344.

Farr, T.G. & Kobrick, M. 2000. Shuttle Radar Topography Mission produces a wealth of data. *American Geophysical Union Eos*, *81*:583-585.

Farr, T.G.; Caro, E.; Crippen, R.; Duren, R.; Hensley, S.; Kobrick, M.; Paller, M.; Rodriguez, E.; Rosen, P.; Roth, L.; Seal, D.; Shaffer, S.; Shimada, J.; Umland, J. & Werner, M. 2007. The Shuttle Radar Topography Mission. *Reviews of Geophysics, 45*, RG2004. doi: 10.1029/2005RG000183.

Gazel, J.; Hourcq, V. & Nickles, M. 1956. Notice explicative de la carte géologique a 1/1000 000 du Cameroun. Bull. DMG, Yaoundé, (2).

Kobrick, M. 2006. On the toes of giants: How SRTM was born. *Photogrammetric Engineering and Remote Sensing, 72*(3): 206-210.

Loisios, D.; Tzelepis, N. & Nakos, B. 2007. A methodology for creating analytical hill-shading by combining different lighting directions. *In:* Proceedings of the 23th International Cartographic Conference, Moscow, Russia, August 2007, p. 4–10.

Mark, R.K. 1992. A multidirectional, oblique-weighted, shaded-relief image of the Island of Hawaii. U.S. Geological Survey Open-file Report 92-422 (Version 1.0) http://pubs.usgs.gov/of/1992/of92-422/.

Maurizot, P.; Abessolo, A.; Feybesse, J.L. & Johan, L.P. 1986. Etude de prospection minière du Sud-Ouest Cameroun. Synthèse des travaux de 1978 à 1985. Rapport de BRGM 85, 274 p.

Mbola-Ndzana, S.P.; Mvondo-Ondoa, J.; Owona, S.; Sep-Nlongand, J.P.; Olinga, J.B. & Bilong, P. 2014. Evidence of the ~NE-SW extension in the Sa'a-Monatélé Region as in the Bafia and Yaounde groups within the Central Africa Fold belt (Cameroon): Implication for the Southern Cameroon Neoproterozoic extension. *Science, Technologie, Développement, 16*: 1–15.

Meshkani, S.A.; Mehrabi, B.; Yaghubpur, A. & Sadeghi, M. 2013. Recognition of the regional lineaments of Iran: Using geospatial data and their implications for exploration of metallic ore deposits. *Ore Geology Reviews*, *55*(C): 48–63. https://doi.org/10.1016/j.oregeorev.2013.04.007.

Mvondo, H.; Owona, S.; Mvondo, O.J. & Essono, J. 2007. Tectonic evolution of the Yaounde segment of the Neoproterozoic Orogenic Belt in South Cameroon (Central Africa). *Canadian Journal of Earth Sciences, 44*: 443-444.

Mvondo, H.; den Brok, S.W.J. & Mvondo O.J. 2003. Evidence for symmetric extension and exhumation of the Yaoundé Nappe (Pan-African Fold Belt, Cameroon). *Journal of African Earth Sciences*, *36*: 215–231.

Mvondo Ondoa, J.; Mvondo, H. & Den Brok, B. 2009. Pan-African tectonics in northwestern Cameroon: Implication for the history of western Gondwana. *Gondwana Research,* 16: 163–164.

Nédélec, A.; Nsifa, E.N. & Martin, H. 1990. Major and trace element geochemistry of the Archaean Ntem plutonic complex (South Cameroon): petrogenesis and crustal evolution. *Precambrian Research*, *47*: 35–50.

Ndougsa-Mbarga, T.; Feumoe A.N.; Eliezer Manguelle-Dicoum, E. & Fairhead J.D. 2012. Aeromagnetic Data Interpretation to Locate Buried Faults in South-East Cameroon. *Geophysica*, *48*(1–2): 49–63.

Njiekak, G.; Dörr, W.; Tchouankoué, J.-P. & Zulauf, G. 2008. U–Pb zircon and microfabric data of (meta) granitoids of western Cameroon: Constraints on the timing of pluton emplacement and deformation in the Pan-African belt of central Africa. *Lithos, 102*: 460–477.

Nzenti, J.P.; Barbey, P.; Macaudière, J. & Soba, D. 1988. Origin and evolution of the late Precambrian high-grade Yaoundé gneisses (Cameroon). *Precambrian Research*, *38*: 91–109.

Olinga, J.B.; Mpesse, J.E.; Minyem, D.; Ngako, V.; Ndougsa-Mbarga, T. &. Ekodeck G.E. 2010. The Awaé - Ayos strike-slip shear zones (Southern-Cameroon): Geometry, kinematics and significance in the late Panafrican tectonics. *Neues Jahrbuch für Geologie und Paläontologie - Abhandlungen*, *257*(1) :1-11.

Onorati, G.; Ventura, R. ; Poscolieri, M. ; Chiarini, V. & Crucillà, U. 1992. The digital elevation model of Italy for geomorphology and structural geology. *Catena*, *19*(2): 147–178. http://dx.doi.org/10.1016/0341-8162(92)90022-4.

Owona, A.M.L.; Tabod, T.C. & Nguiya, S. 2013. Delineation of Lineaments in South Cameroon (Central Africa) Using Gravity Data. *Open Journal of Geology*, *3*: 331-339.

Penaye, J.; Toteu, S.F.; Van Schmus, W.R. & Nzenti, J.P. 1993. U–Pb and Sm–Nd preliminary geochronologic data on the Yaounde series, Cameroon: a re-interpretation of the granulitic rocks as a suture of collision in the Central Africa, belt. *Compte Rendus de l'Académie des Science de Paris*, *317*: 789–794.

Poidevin, J.L. 1983. La tectonique panafricaine à la bordure nord du craton congolais: l'orogenèse des Oubanguides. In: Colloque on the African Geology, 12, Musée Royal de l'Afrique Centrale,Tervuren, Belgium. Abstract, p. 75.

Rolin, P. 1995. La zone de décrochements panafricains des Oubanguides en République Centrafricaine. *Comptes Rendu de l'Académie des Sciences de Paris*, *320*: 63–69.

Saadi, N.M.; Abdel Zaher, M. ; El-Baz, F. & Watanabe, K. 2011. Integrated remote sensing data utilization for investigating structural and tectonic history of the Ghadames Basin, Libya. *International Journal of Applied Earth Observation and Geoinformation, 13*(5): 778–791.

Sarp, G. 2005. Lineament Analysis from Satellite Images, North-West of Ankara. Middle East Technical University, MSc Thesis, 76p.

Shandini, N.Y.; Tadjou, J.M.; Tabod, T.C. & Fairhead, J.D. 2010. Gravity data interpretation in the northern edge of the Congo Craton, South-Cameroon. *Anuário do Instituto de Geociências*, *33*(1): 73-82.

Shandini, Y. & Tadjou, J.M. 2012. Interpreting gravity anomalies in south Cameroon, central Africa. *Earth Sciences Research Journal, 16*(1): 5 – 9.

Shang, C.K.; Satir, M.; Siebel, W.; Nsifa, E.N.; Taubald, H.; Liegeois, J.P. & Tchoua, F.M. 2004. Major and trace element geochemistry, Rb–Sr and Sm–Nd systematics of TTG magmatism in the Congo craton: case of the Sangmelima region, Ntem complex, southern Cameroon. *Journal of African Earth Sciences*, *40*: 61–79.

Süzen, M.L. & Toprak, V. 1998. Filtering of satellite images in geological lineament analyses: an application to a fault zone in Central Turkey. *International Journal of Remote Sensing*, *19*:1101-1114.

Toteu, S.F.; Van Schmus, W.R.; Penaye, J. & Michard, A. 2001. New U–Pb and Sm–Nd data from north-central Cameroon and its bearing on the pre-Pan African history of central Africa. *Precambrian Research, 108*: 45–73.

Toteu, S.F.; Penaye, J. & Poudjom Djomani, Y.H. 2004. Geodynamic evolution of the Pan-African belt in central Africa with special reference to Cameroon. *Canadian Journal of Earth Sciences*, *41*: 73–85.

Toteu, S.F.; Fouateu, R.Y.; Penaye, J.; Tchakounte, J.; Mouangue, A.C.S.; Van Schmus, W.R.; Deloule, E. & Stendal, H. 2006b. U-Pb dating of plutonic rocks involved in the nappe tectonic in southern Cameroon: consequence for the Pan-African orogenic evolution of the central African fold belt. *Journal of African Earth Science, 44*: 479–93.

Tripathi, N.K.; Gokhale, K.V.G.K. & Siddiqui, M.U. 2000. Directional morphological image transforms for lineament extraction from remotely sensed images. *International Journal of Remote Sensing*, *21*: 3281-3292.

Trompette, R. 1994. Pan, African – Braziliano aggregation of South America and Africa. *In:* Geology of western Gondwana 2000–500 Ma. A.A. Balkema, Rotterdam, The Netherlands.

Vicat, J.P. 1998. Esquisse géologique du Cameroun. *Géosciences au Cameroun*, *1*:3-11.