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Gravity Imaging Of the Crustal Structures beneath Southern Cameroon and Its Tectonic Implications

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---ABSTRACT---
In the present study, digital filters have been applied to gravity data in order to better understand and characterize the crustal structure of the Southern Cameroon. The approach is based on the qualitative and quantitative analysis of the Bouguer anomalies. Different filtering techniques (regional-residual separation, horizontal gradient method, vertical and tilt derivative, upward continuation and Euler deconvolution) were applied to the Bouguer anomalies. The quantitative interpretation of the Bouguer anomalies using the Euler deconvolution allowed to estimate the maximum depth of geological structures source of gravity anomalies beneath the study area at about 18 km. Furthermore, we identified lineaments mainly oriented East-West that allow to figure out the tectonic settings of the area. The interpretation of the extended Bouguer anomalies using upward continuation method for 5, 15, 25, 50 and 80 km depth helped to highlight the spatial distribution of anomalies in the deeper structures, and retrace the evolution of the Congo Craton as well as concluding that it has a mantle root underthrusting the Pan-African belt.

KEYWORDS *-Bouguer anomaly, Congo Craton, filter, Pan-African chain, tectonics*

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I. INTRODUCTION

The southern part of Cameroon is predominantly covered by the geological structure called Congo Craton. The Congo Craton was formed during the Precambrian and is one of the three main cratons found in Africa, the West African Craton and the Kalahari Craton being the other ones. In Cameroon, the northern edge of the Congo Craton has been identified and located by many studies [1, 2] and it is limited by the structures of the Panafrican Mobile Belt. Because of the potential mineral wealth of the southern Cameroon, the region continues to arouse the interest of many geologists and geophysicists. However, the layout and extension of the tectonic accidents that affect the region, as well as the geometry of the relevant basins cannot only be approached by the direct analysis. Therefore, we performed gravity investigations in order to identify the faults, their limits and their spatial distribution under the soil cover. To achieve this, we used the multi-scale analysis based on the coupling of the horizontal gradient method with the upward continuation [3, 4]. This approach, which has been proved effective in studies by [4], allowed highlighting the major geological structures and mapping the main structural lines that affect the study area. We are particularly interested in the transition zone between the Congo Craton and the Pan-African Chain. This area has been the subject of several previous investigations which all contributed to the understanding of the geological structures of the subsoil and delineating the Congo Craton limit. However, the majority of these works were conducted only on the western part of our present study area making the concluding statements about the structure of the northern margin of the Congo Craton incomplete. In fact, there is no definitive model for the evolution of the transition zone between the Congo Craton and the Panafrican Mobile Belt. Moreover, the major structural lines have not yet been characterized at the present scale. Therefore, a better knowledge of the crustal structure and the evolution of this transition will contribute to understand the setting of this major feature of the Cameroon geology.

II. GEOLOGICAL AND TECTONIC SETTINGS

The African continent crust is carrying the imprints of the various tectonic activities that affected it throughout the time. Most of the rocks of the continent are from the Precambrian period. In Cameroon, the geological exposures are dominated by Archean to Neoproterozoic rocks of the Congo Crfaton [5, 6] in the south, and the Panafrican Mobile Belt in the north. The major tectonic features identified across the country are: The Adamawa plateau (AF), the Kribi-Campo fault (KCF), the Sanaga fault (SF), the Tchollíré-Banyo fault (TBF), Cameroon Volcanic Line (CVL) and the Benue Through [7]. The present study area cover the transition zone between the Congo Craton and the Pan-African Mobile Belt where structural domains can be identified as Ntem complex (Congo Craton) and Yaoundé group (Pan African chain) as shown on the figure 1. The Congo Craton is represented by three units constituting the Ntem complex. These are the Ntem unit in the center, the Ayina unit in the east and the Nyong unit to the west; [8, 9]. The Ntem unit (Archean) includes a taped series, relics greenstone belts and intrusive complex. The intrusive complex is set up to 2.9 Ga [10–14]. The Nyong unit (Paleoproterozoic) corresponds to the western edge of the Congo Craton and is characterized by regional foliation plate and composite. It includes metasediments and meta-volcano sediments that could match the greenstone belts of relics, to gray gneiss migmatic composition [15]. The Ayna unit in the southeastern part of the Ntem complex is thought to represent a Paleoproterozoic sedimentary cover on the Congo craton. It consists of Yokadouma and Dja series [9].

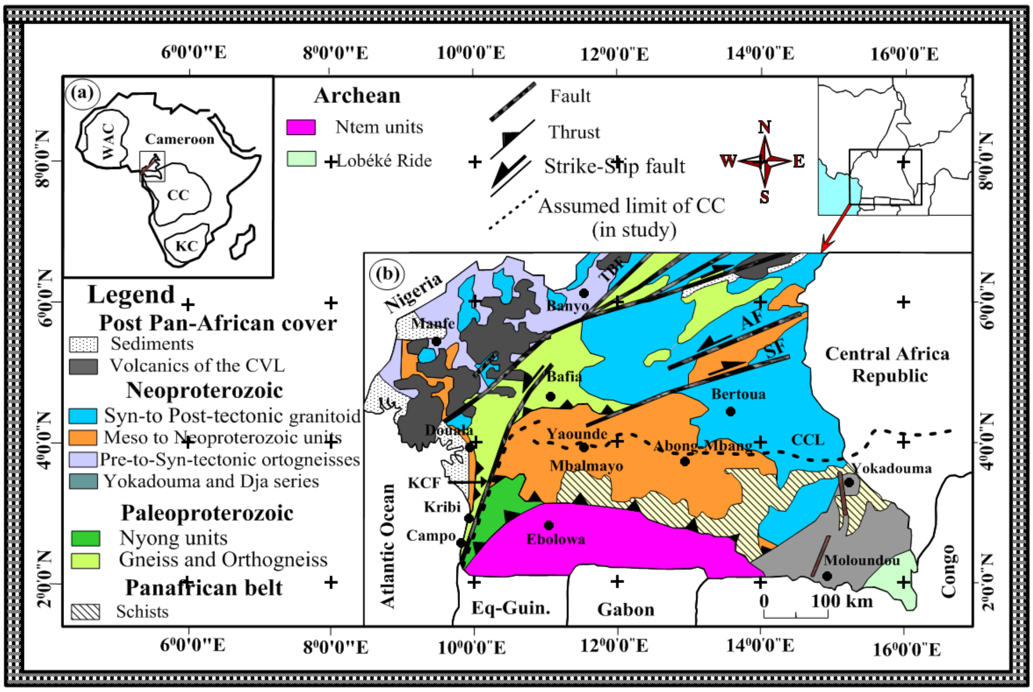

Fig. 1. Geological map of the southern part of Cameroon and surrounding zones showing major tectonic elements of the Precambrian basement.

III. DATA AND METHOD

3.1. Gravity data

The gravity data used in this work were collected between the longitudes 9,5^o and 17^o East, and the latitudes 2^o and 4,5^o North. The data were acquired during campaigns carried out by different organizations and researchers: ORSTOM (1960-1967), Hegberg (1968), and the ELF Company (1980). The dataset consisted of gravity measurements from 1173 stations irregularly distributed in the study area. Some areas are laking data due to inaccessibility. They were collected at 4 km intervals from all gravity stations including base stations, on all available roads and tracks in the area using Worden gravimeters (n°313 and 600) with a precision of 0,2 mGal. The gravimeter readings were corrected for drift and the gravity anomalies were computed assuming a mean crustal density of 2,67 g/cm^3 . The maximum error in the Bouguer anomaly value for any of the stations due to the error in height determination is not expected to exceed 0,15 mGal.

3.2.Method

The digital filters are mathematical tools used to modify the frequency distribution of a digital signal. They allow extracting from the raw data, useful information that can be processed to generate appropriate maps that can be useful for the geological interpretation. Several different filters were successively applied to the gravity data.

3.2.1. Regional and residual separation of gravity anomalies.

The Bouguer map superimposes the effects of both deep and shallow density contrasts, extensive and local (anomaly). Sometime the deep structure is masked by the effect of less interesting shallow structures. At each station, the magnitude of the observed gravity signal represents the sum of contributions from all shallow and deep structures including noises. Using band-pass filter coupled with the examination of the averaged power spectrum. In this regard, the features produced by the near-surface density variations are separated from those produced by more deep-seated ones.

3.2.2. Upward continuation method

The upward continuation process is applied to progressively remove the contribution of high-frequency, near-surface, shallow causative bodies from the gravity field, resulting in a smooth field reflecting the deeper causative bodies and/or density structures. We applied this operator on the Bouguer anomaly data to observe the variation of the high densities contrasts with the depth. The upward continuation acts as a low-pass filter that attenuates the high frequencies of the sources of superficial anomalies. It helps to observe, analyze and explain the geodynamics of main tectonic structures.

3.2.3. Horizontal gradient

The horizontal gradient allows to identify the lateral contacts between the media of different densities. It promotes the study of different areas of deep discontinuities in order to give their implications on tectonics. In the spatial domain, the horizontal or gradient derived horizontal (DH) of a field g (x, y) defined at different points (x, y) of the horizontal plane measurement, is given by the relation (1) [16]:

$$g_{\mathrm{DH}} = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \qquad (1)$$

where $\frac{\partial g}{\partial x}$and $\frac{\partial g}{\partial y}$are respectively the derivatives x and y of the field g.

The horizontal gradient is a good way to locate geological contacts in the basement, including the flaws by determining their path, dip and importance [4, 17]. The gravimetric anomaly over a vertical contact is represented by a curve having a minimum of side rocks low densities and the maximum of the rock side having high densities. Its hows the anomaly created by a contact and the horizontal gradient corresponding to a profile perpendicular to this contact as illustrated on figure 2 below.

3.2.4. Vertical derivative

The first vertical derivative applied to the potential field data is a useful method to distinguish the effects related to the presence of local masses included in regional data [18, 19]. It helps to identify the presence of regional anomalies while the second derivative can locate and accentuate the presence of anomalies related to relatively shallow sources [20]. The vertical derivative map, devoid of regional features, highlights positive gradient zones that stand out clearly from negative gradient zones. It also shows a lateral separation of the anomalies and an amplification of the gravimetric effect of the superficial density contrasts to the detriment of the deep contrasts.

3.2.5. Multi-scale Analysis of the horizontal gradient of Bouguer anomalies and vertical derivative.

The application of the horizontal gradient method coupled to the upward continuation allows the location of faults and the determination of their dip [21]. The method consists in creating series of analytical upward continuation of gravity data followed by the computation of the horizontal gradient for each step and their maxima. The maxima are superimposed to determine the dipping direction of the gravimetric lineaments as shown in figure 2 (b) below.

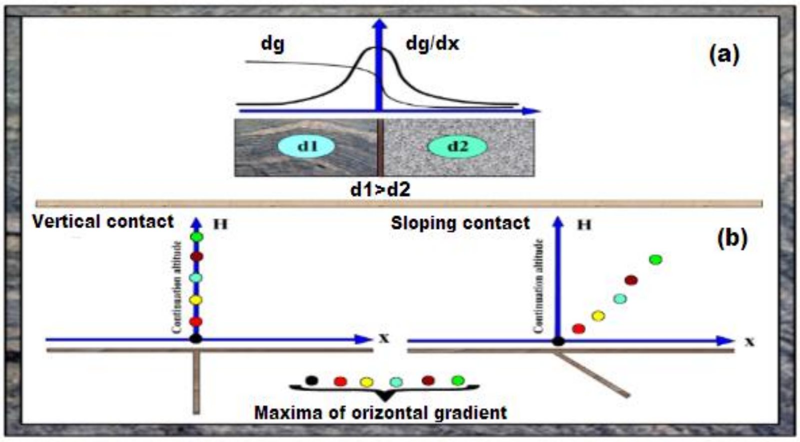

Fig. 2. (a) Map showing the variation of gravity data and horizontal derivative curve function of the distance to a contact; d_1 and d_2 are densities. (b) Maxima obtained for vertical, dipping and horizontal contacts. H is the vertical axis while X is the horizontal axis.

3.2.6. Tilt derivative

The tilt derivative technique is a data transformation method useful to highlight shallow bedrock structures and for some exploration purposes [24]. This transformation relates the ratio between the first vertical derivative (Z) and the total of horizontal derivatives (X and Y).

3.2.7. Euler deconvolution filter

The apparent depth to the gravity source is derived from Euler's homogeneity equation (Euler deconvolution). This process relates the gravity field and its gradient components to the location of the source of an anomaly, with the degree of homogeneity expressed as a "structural index". Euler's homogeneity relationship for gravity data can be written in the form given the equation (2) [21].

$$(x - x_0)\frac{\partial M}{\partial x} + (y - y_0)\frac{\partial M}{\partial y} + (z - z_0)\frac{\partial M}{\partial z} = \mathrm{N}(B - M) \quad (2)$$

where$(x_0, y_0\ and\ z_0)$is the position of the gravity source whose total field (*M*) is detected at position (x, y, z,) and *B* is the regional gravity field.

The Euler method has been applied to the Bouguer anomaly map using a 20 km × 20 km grid. This was done on the study area using the standard Euler 3D method of the Geosoft software package. The system uses the least squares method to solve the anomaly position, depth, and base level for a specific gravity source.

IV. RESULTS

4.1. Bouguer anomaly map

Figure 3 below displays the Bouguer anomaly map obtained from the gravity measurements. On this map, the interpolation process is done while limiting the confidence area around the points of measurements to a radius of about 20 km away from them.

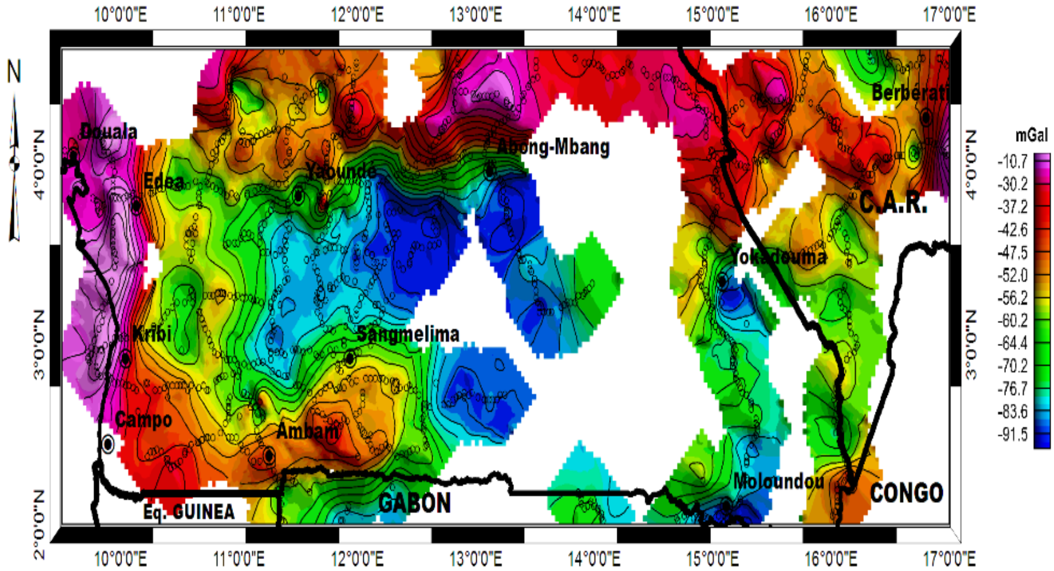

Fig. 3. Bouguer anomaly map of the study area. Small circles represent gravity measurement points.

Due to the irregular distribution of the gravity measurements, some areas of investigation do not have enough data, triggering lack of information as elucidated by white spaces on figure 3. To overcome this, a geostatistical tool (Kriging) is used to estimate data in blank areas. Therefore, a new Bouguer anomaly map made from 10260 regularly spaced points is obtained for the studied area with 5 mGal contour intervals as shown on figure 4. The new Bouguer dataset will be the basis of all subsequent interpretation in the following stages.

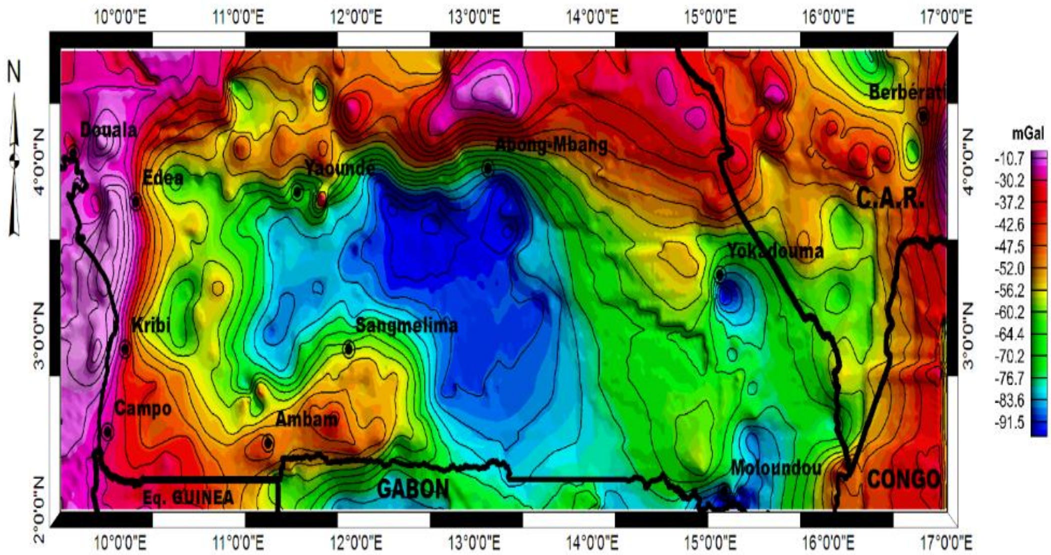

Fig. 4. Bouguer anomaly map obtained after the kriging interpolation.

4.2. Regional-residual separation of anomalies.

The separation of the anomalies into regional and residual is done after the gravity data have been transformed into the frequency domain. In this regard, the averaged power spectrum of the data is computed and the frequency window for the separation is interactively selected as illustrated on the figure 5 below.

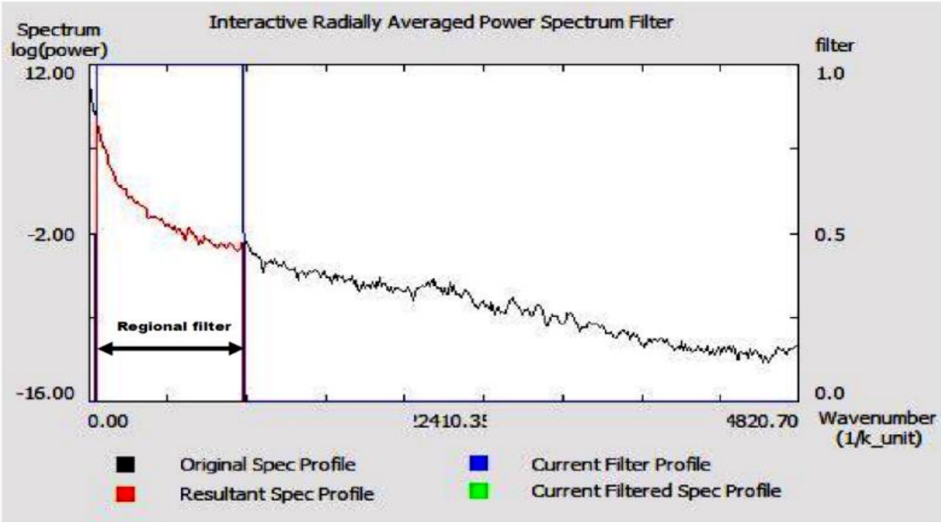

Fig. 5. Radially Averaged power spectrum of Bouguer gravity data.

The obtained regional anomalies (figure 6) are characterized by large negative anomalies center around Sangmelima with value reaching -91.5 mGal. At latitude 4°N, there is a gradient corresponding to the highest value of the anomalies in the area. This gradient corresponds to the transition zone between the Congo Craton and the Pan-African chain; these observations can be interpreted as the crust thinning towards the northern and western margins of the Congo Craton.

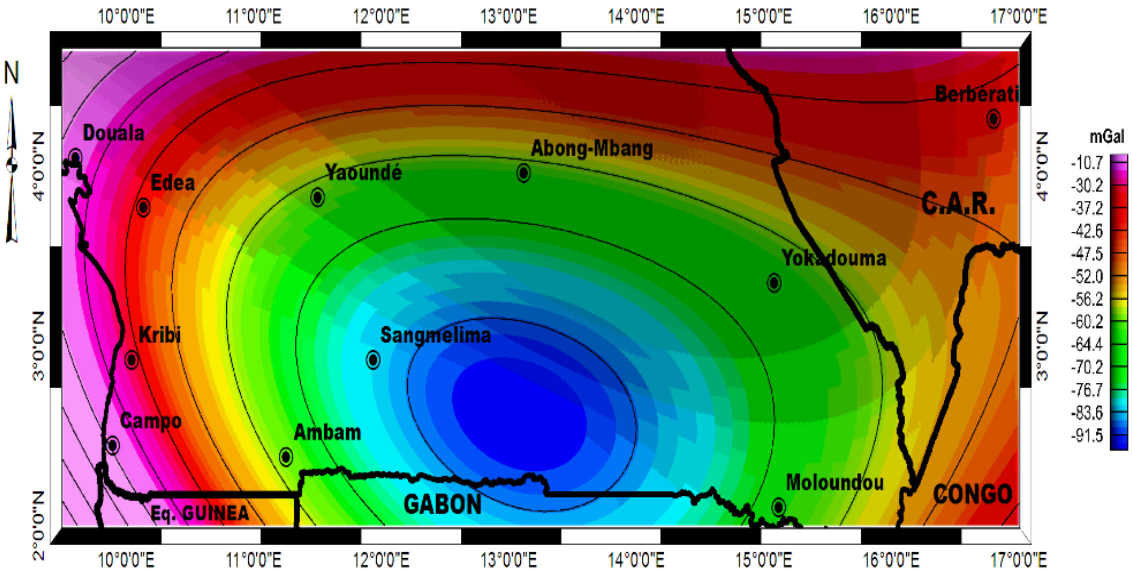

Fig. 6. Map of the regional Bouguer anomalies.

The residual anomaly map of the study area in the other hand was obtained by subtracting the regional anomalies from the Bouguer anomalies. They represent the effect of shallower features. Figure 7 shows the overall distribution of the residual anomalies along the study area. The map shows that thecenter of the stuiy area is dominated by negative anomalies ranging from – 90 to -60 mGal surrounding by zones of positive anomalies. We can observed shapes of contour lines on the residual map that are quite similar to the ones observed on the Bouguer anomaly map (figure 4**)**. However, the amplitude of the anomalies is not comparable. The comparison of the residual anomaly map to the geological map reveals that the negative anomalies correlate with the location of geological units ranging from mesoproterozoic to neoproterozoic. The positive anomaly trending SW-NE around Sangmelima, on the basis of geological considerations, can be interpreted in terms of the intrusion of igneous charnockites of the Ntem Unit.

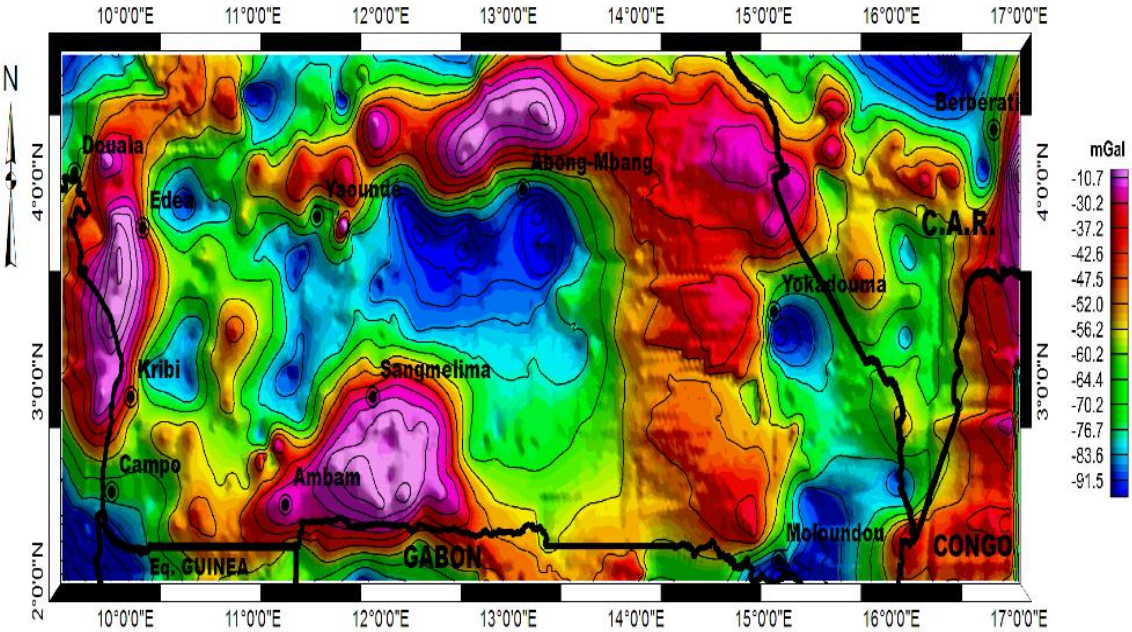

Fig. 7. Residual anomalies map of the study area.

In order to simultaneously interpret the signification of the Bouguer, Regional and Residual anomalies, the 3D representation of each anomaly map is placed on top of the corresponding 2D map, all displayed in three panels on figure 8. The large negative anomaly observed on the Bouguer, the regional, and slightly on the residual can be interpreted as the subsidence of the cratonic crust in the study area. The subsidence is probably resulting from the interaction between the Congo Craton and the Panafrican Mobile Belt.

4.3. Horizontal Gradient of Bouguer anomalies

The horizontal gradient map computed for the study area is shown on Figure 9. The map shows areas with high gradients that correspond to contact or fault structures [22]. The most relevant gradients are those observed at the western and Northern margins between the Congo Craton and the Pan-African mobile belt. The gradients around Ambam and Sangmelima may result to the presence of intrusive bodies [23].

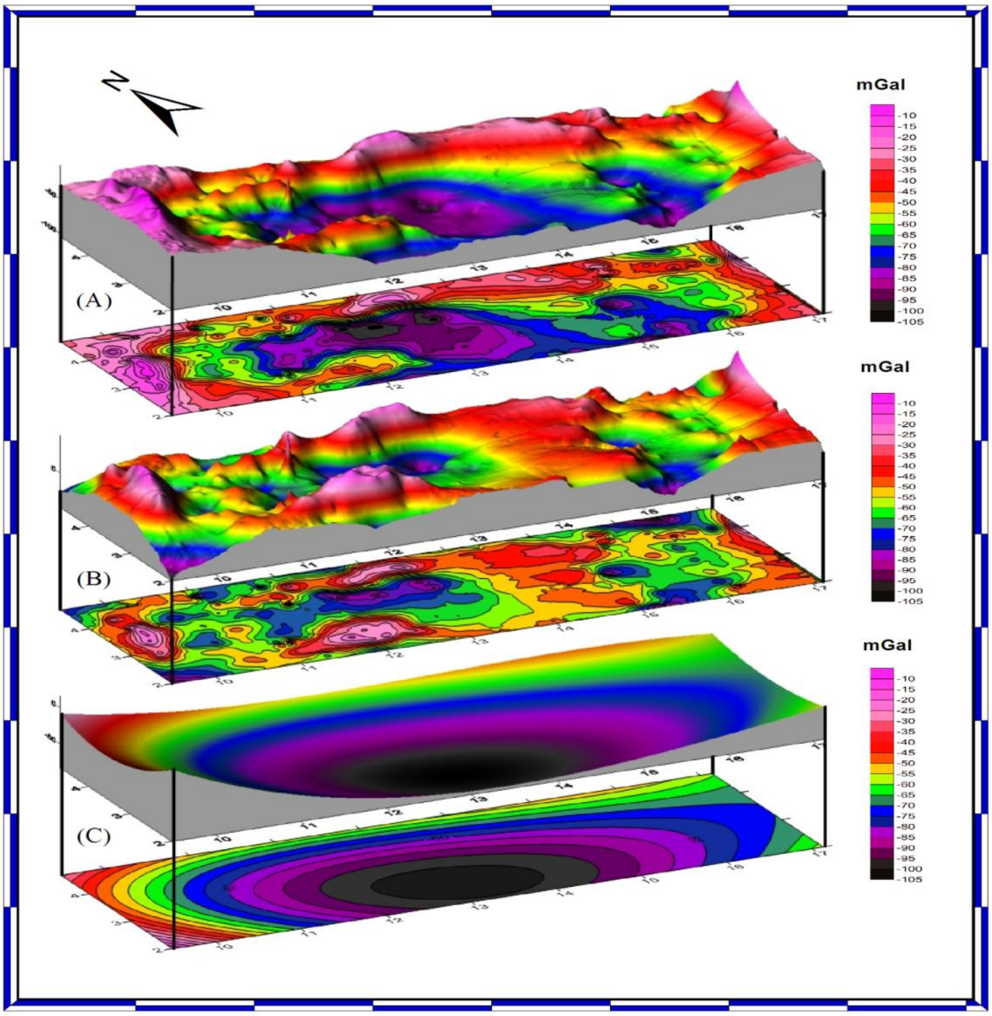

Fig. 8. Representation of Bouguer anomalies (Panel A), residual anomalies (Panel B), and regional anomalies (Panel C). In each panel, the upper part represents the 3D while the lower one is the 2D representation of the same anomalies.

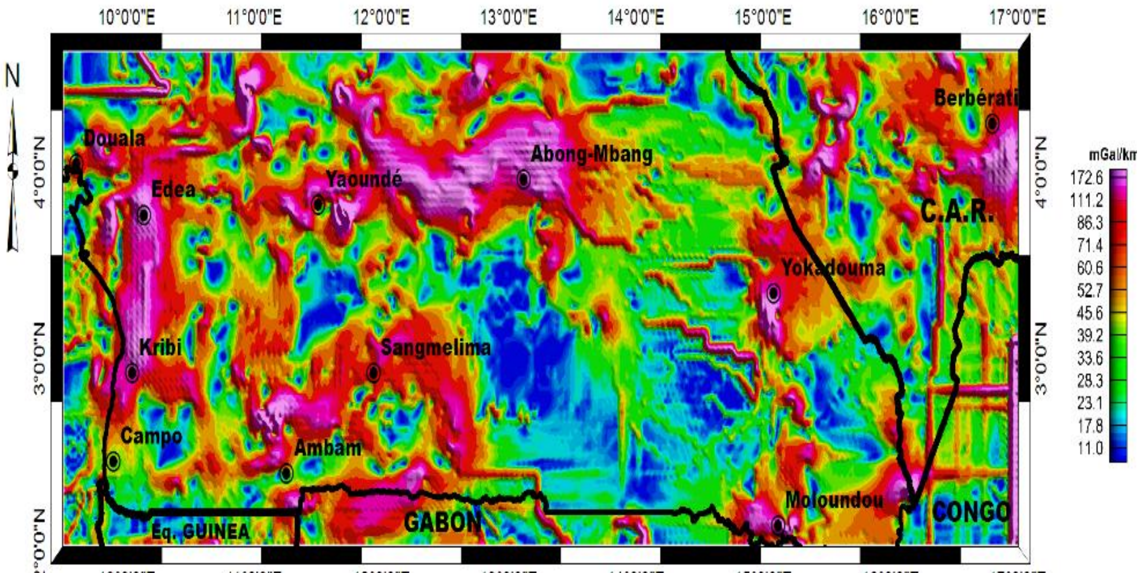

Fig. 9. Map of the horizontal gradient of Bouguer anomalies.

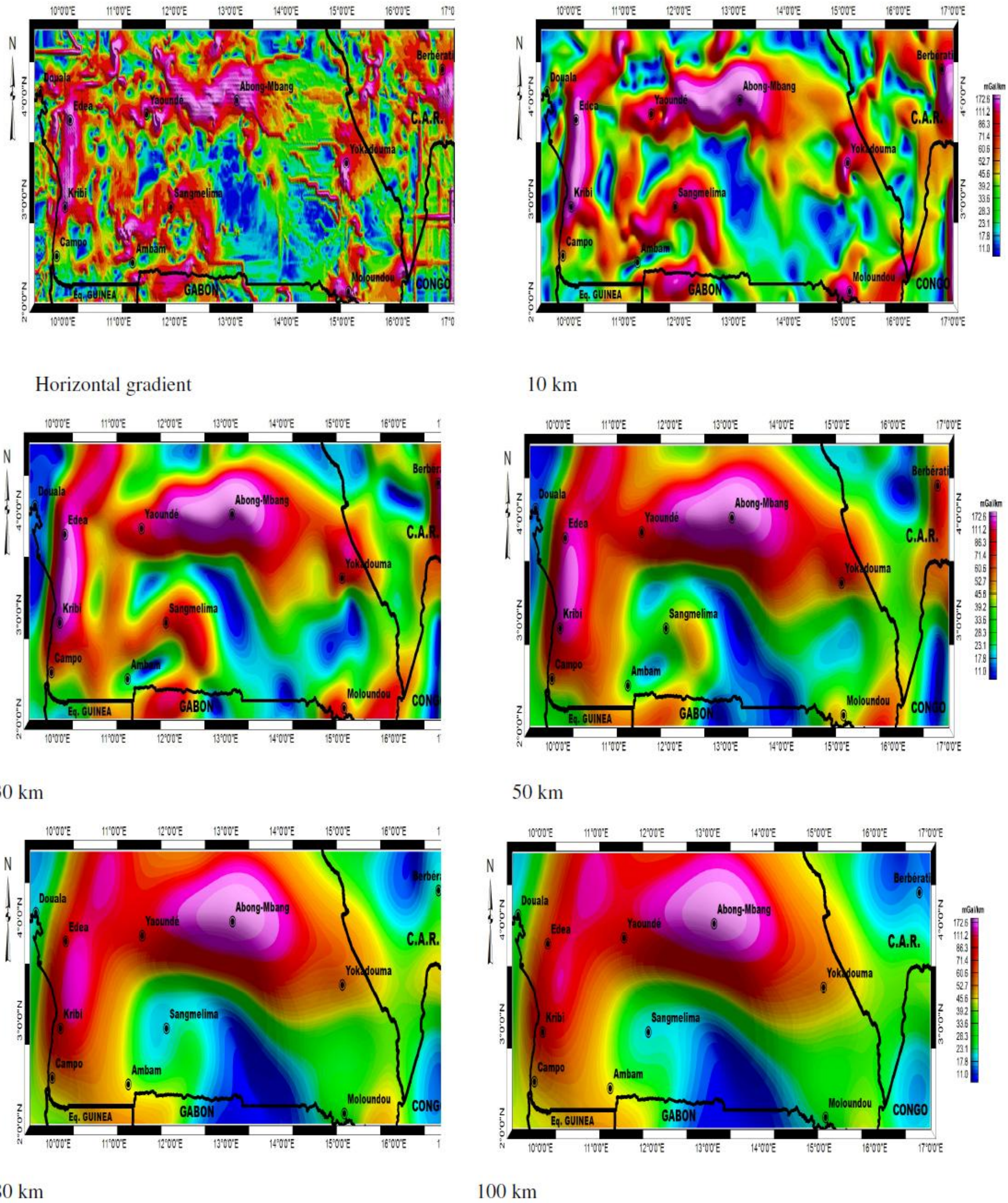

Fig. 10. Horizontal gradient maps of the upward continuation data for depths 0, 10, 30, 50, 80 and 100 km.

4.4. Upward continuation of the Bouguer anomalies

The upward continuation of the Bouguer anomalies has been performed for the depths 10, 30, 50, 80 and 100 km (figure 11). The effect of shallow structures are progressively vanishing with depth as the shape of the contour lines are becoming smooth and highlights regional features. We can deduce from the figure that the transition zone between the Congo Craton and the Pan African belt is covered by structures with high densities that are deeply seated up to depth 100 km.

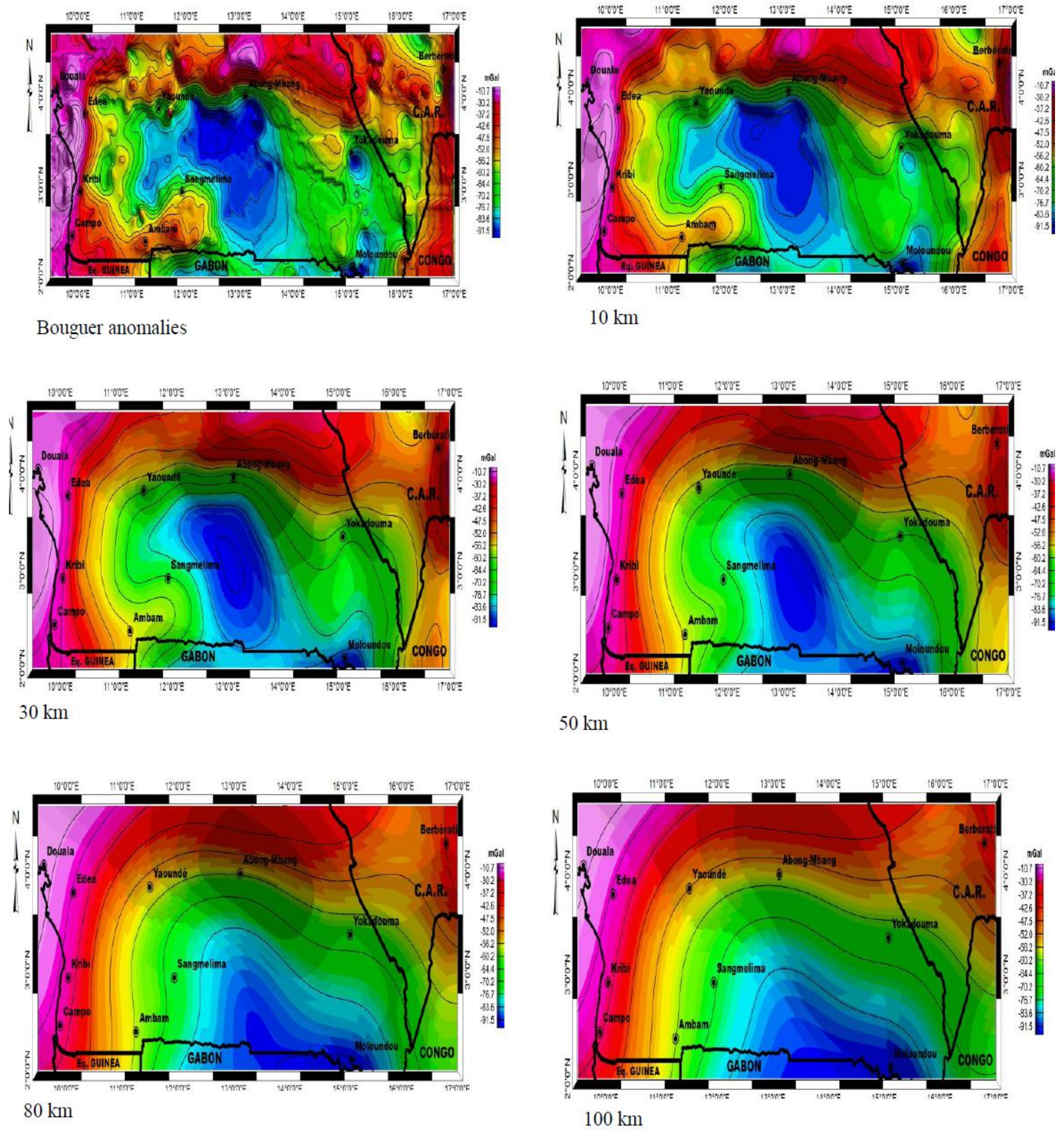

Fig. 11. Maps of the Bouguer (a) and the upward continuation of the Bouguer anomalies for depths 10, 30, 50, 80and 100 km.

4.5 Vertical derivative map

Figure 12 shows the vertical derivative map of the studied area. The analysis of this map reveals a sharp contrast between area of positive and negative vertical gradients. The positive gradients are mainly located along the northern margin of the Congo Craton surrounding a large area of negative gradients. We can also notice the proposed intrusion around Sangmelima and Ambam marked by the positive vertical gradients around these areas.

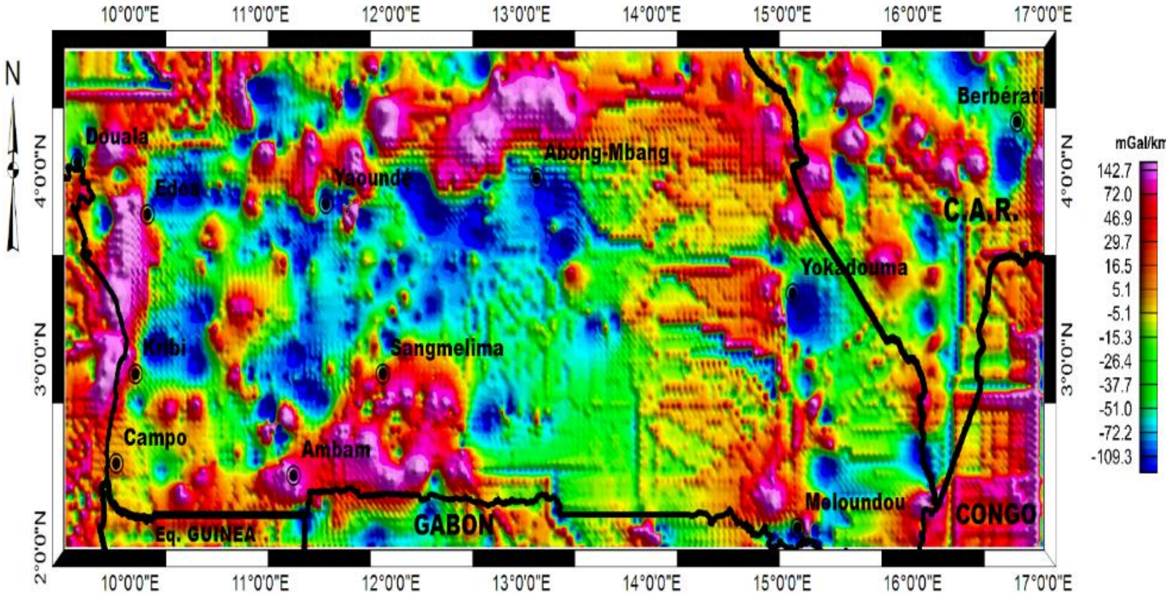

Fig. 12. First derivative map of the Bouguer anomalies.

4.6. Tilt derivative result

The tilt derivative map (figure 13) shows several features similar to those observed on the first vertical derivative map of the Bouguer anomaly (figure 12). Compared to the first vertical derivative, the anisotropies on the tilt derivative indicated from the high value tilt angle that the source of the causative bodies are deepest around the Congo Craton northern margin and some other areas as Ambam, Sangmelima and Yokadouma.

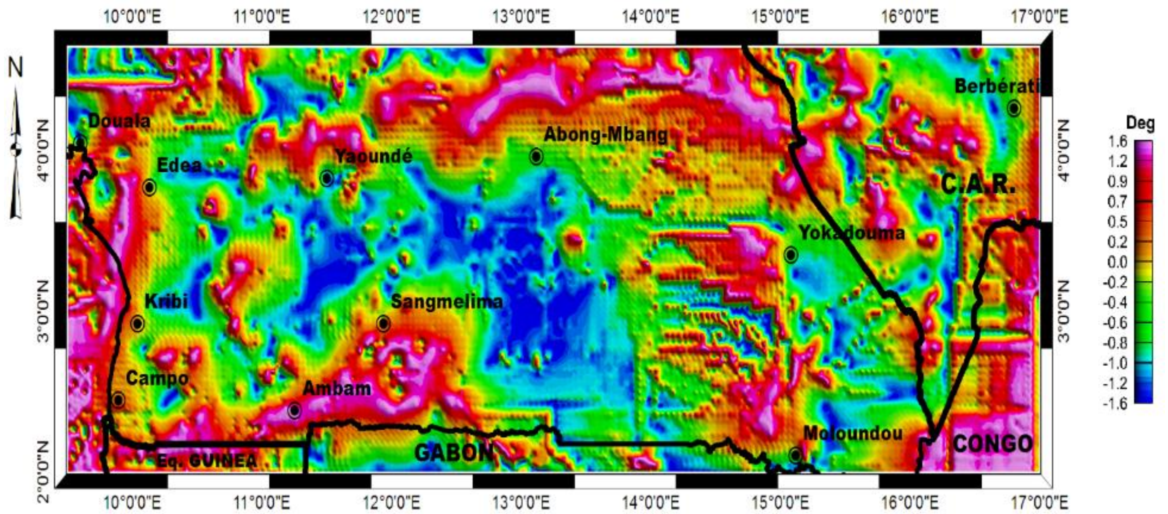

Fig. 13. map of the tilt derivative of Bouguer anomaly.

4.7. Depth of structures using Euler's Deconvolution

Several structural indexes have been tested for the Euler’s deconvolution method. For the structural index N= 1.0, the Euler solution has been found to provide the best solution for the present study. The map obtained from the deconvolution reveals new deep contacts and show that the solution are ranging from depth 2 to 20 km. The Euler deconvolution map (figure 14) shows that the geological structures worn by great depths are located on the western borders and between North Congo Craton and the Pan African chain, leading to the conclusion that the transition zone would be increased by abrupt variations of geological structures and high depth.

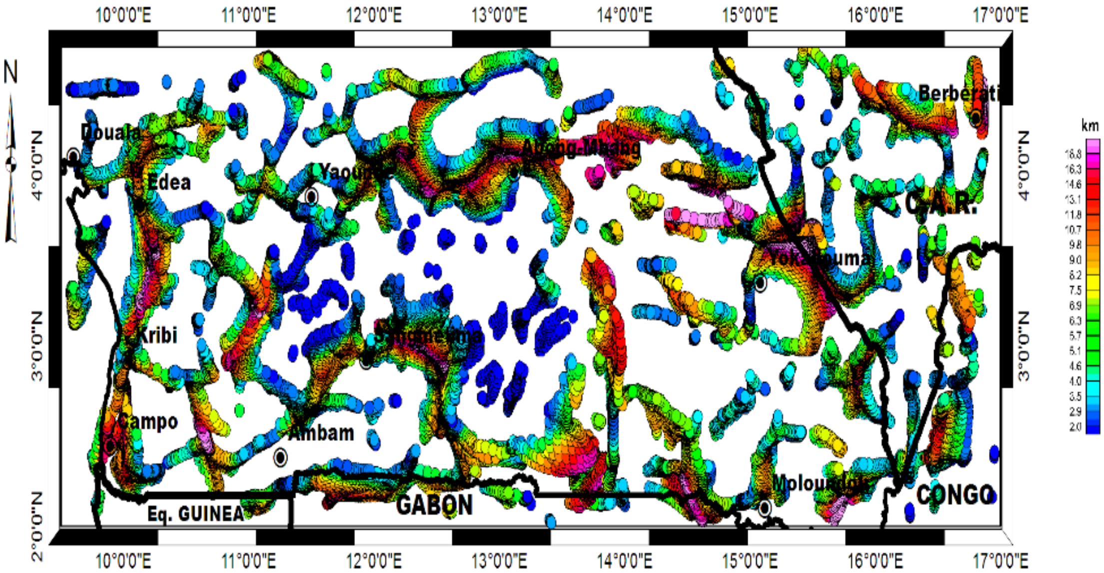

Fig. 14. 2D Map of Euler deconvolution.

4.8 Mapping lineaments

The superposition of the local maxima of the horizontal gradient determined on the Bouguer and vertical derivative extended a series of depth to 50 km, with a constant step of 5km is shown on Figure 15 and 16 below**.**A close look to the maxima horizontal map shows that the densification of maxima is a low over the study area, which may be the consequence of the irregular distribution of the gravity measurements as shown on figure 3. The alternate solution is to apply the vertical gradient technique to produce the map of the maxima of vertical gradients (figure 16).

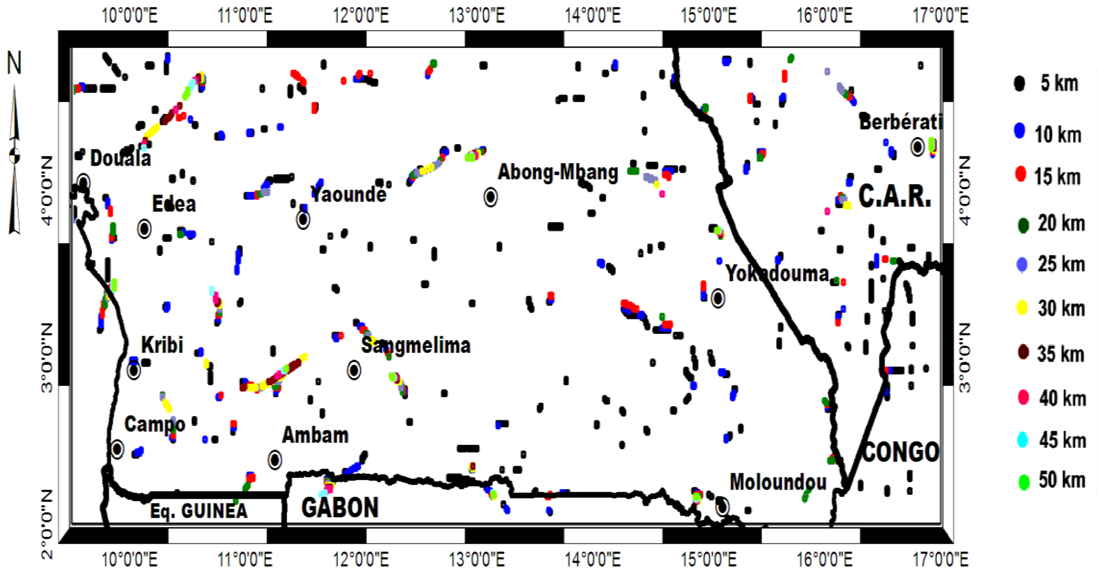

Fig. 15. Maxima horizontal gradient Bouguer anomalies map.

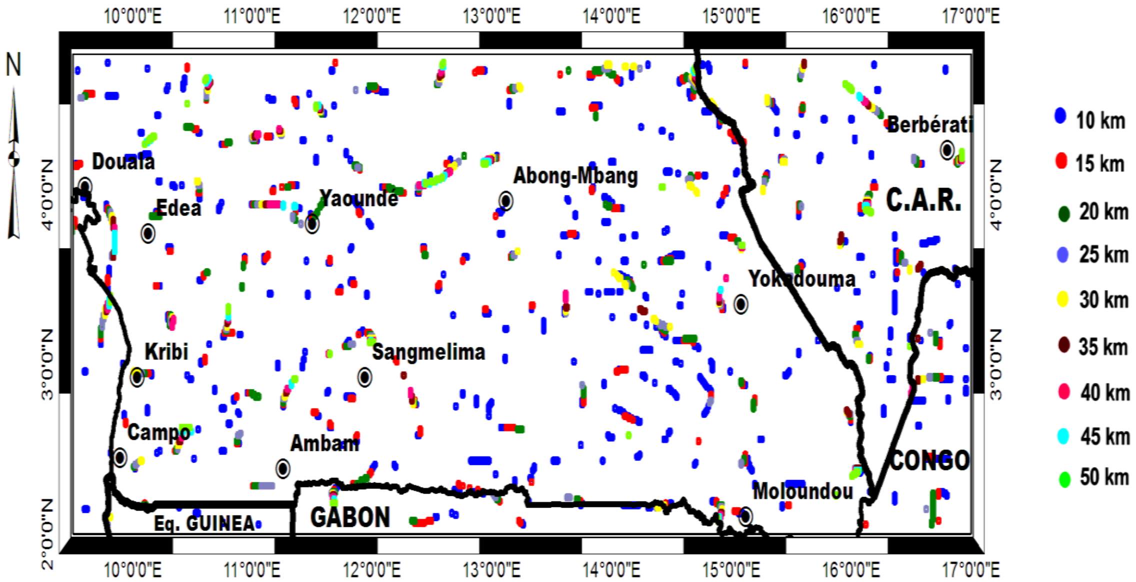

Fig. 16 Map of the maxima of the horizontal gradient of the vertical derivative of Bouguer anomaly.

We can observe on figure 16 that the densification of maxima is stronger in the northern and western parts of the study area. They can be considered as the fault veins and therefore are illustrative of the transition zone between the Congo Craton and the Panafrican Belt. The maxima points located near Sangmelima and Ambam are considered to be the zones of intrusion of geological structures. Therefore, the map highlights different structural features present in the area such as faults and intrusive structures. Another advantage of this representation is that it easily helps to determine the dipping direction of the contacts.

4.9. Lineaments map

The overlying of the main structural features observed on figures 14, 15 and 16 to the ones shown on horizontal gradient map of Bouguer anomaly (figure 9) is a way to identify the outlines of the geological structures in the study area as shown on figure 17. Black lines (numbered 1 to 45) are linear contacts corresponding to the lineaments of the major structural lines in the study area. From the Euler deconvolution analysis, these geological structures are buried up to depth of 18 km.

In addition, based on the multi-scale analysis carried out on the horizontal gradient map, it is evident that contrast gradient lineaments (13), (3), (44) and (45) become blurred on the extended horizontal gradient map at 50 km ; This may allow to conclude that these structural lines do not have an original mantle but crustal. Structural lines (2), (25), (4), (42) (40) (14) (17) (1), and (20). Illustrate the north and west borders between and the Pan-African Chain. The orientations of the 45 structural features have been determined as presented in the table 1 below.

Table 1. Identified faults and their orientation

N°	Orientation	N°	Orientation	N°	orientation	N°	orientation	N°	Orientation
1	N61°E	10	N128°E	19	N88°E	28	N118°E	37	N32°E
2	N09°E	11	N113°E	20	N73°E	29	N96°E	38	N72°E
3	N134°E	12	N83°E	21	N29°E	30	N126°E	39	N169°E
4	N49°E	13	N64°E	22	N52°E	31	N81°E	40	N0°E
5	N135°E	14	N78°E	23	N79°E	32	N163°E	41	N45°E
6	N109°E	15	N152°E	24	N151°E	33	N73°E	42	N178°E
7	N71°E	16	N25°E	25	N160°E	34	N25°E	43	N18°E
8	N83°E	17	N105°E	26	N106°E	35	N94°E	44	N04°E
9	N85°E	18	N13°E	27	N45°E	36	N45°E	45	N59°E

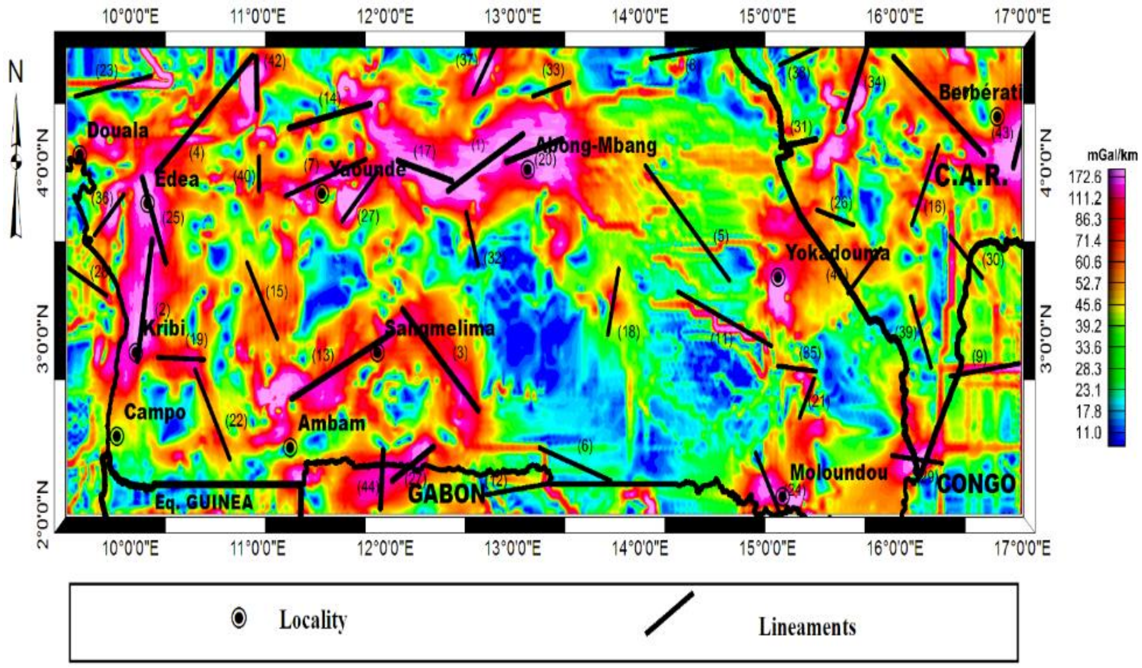

Fig. 17. Map of structural lineaments in the study area.

The rose of representative diagrams figure 18 below, show the directions of the large structural lines. The regional field stress associated with the predominant trending of gravity lineaments (figure 17) is in agreement with Eburnean orogeny trend [25] and would have played an essential role in the control of the geodynamic evolution of the region.

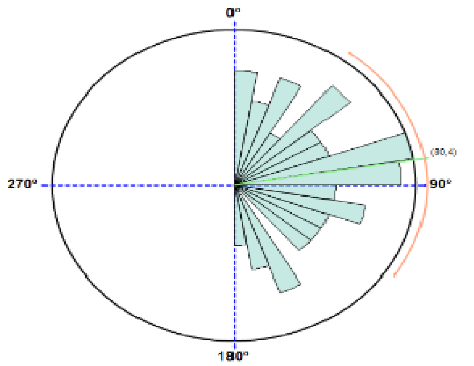

Fig. 18: Rose Diagram of identified lineaments.

V. DISCUSSION AND CONCLUSION

The Congo Craton has been subject of many past geophysical studies [22, 27–29]. In this work, we brought new elements for the characterization of large structural lines in the northern part of Congo Craton located in southern Cameroon and tried a new approach to understand the distribution of the gravity gradients at the transition zones between the Congo Craton and the Panafrican belt. The analysis of the map of lineaments in southern Cameroon by [22] helped to identify a number of structural features only in the western edge of the study area specifically in the NW margin of the Congo Craton where the interest of an extension much further east in this work.

The main results obtained in this study provide new insights thereby improving our understanding of the geological structure of southern Cameroon. The results provided by this work are as follows: 1) the collapse of the basement in the center characterized by negative anomalies and a rise of the basement to the east, west and south characterized by positive anomalies. 2) Strong gravity anomalies gradient contrasts located at the transition zones between the Congo Craton and Pan-African belt with mantle origins. 3) The gravimetric lineaments suggest that the area has been subjected to a major regional constraints. This could have played a key role in controlling the geodynamic evolution of the region.

The basis of variations in anomalies and high gradients localized, we can approach the geodynamic study hypothesis to admit that high gradients of contrasts at the transition zone between Congo Craton and Pan-African would have a mantle origin. The accidents highlighted to the north of the map are proof of the existence of a tectonic zone with a thrust zone through which the Congo Craton strikes under the Pan-African belt. The quantitative interpretation of the map of Bouguer anomalies from Euler deconvolution has allowed to estimate the depths of geological structures distributed throughout the study area where the depth can reach about 18 km. The deepest geological structures are located in the transition zones between the Congo Craton and the Pan-African Chain.

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REFERENCES

[1]. J. Kamguia, R. Nouayou, C. T. Tabod, J. M. Tadjou, E. Manguelle-Dicoum and H. L. Kande,Geophysical signature of geological units inferred from the analysis of geoid maps in Cameroon and its surroundings, Journal of African Earth Sciences, 52, 2008, 1-8.

[2]. J. M. Tadjou, R. Nouayou, J. Kamguia, H. L. Kande and E. Manguelle-Dicoum, Gravity analysis of the boundary between the Congo craton and the Panafrican belt of Cameroon, Austrian J. Earth Sci., 102, 2009, 71-79.

[3]. N. Archibald, J. P. Gow and F. Boschetti, Multiscale Edge Analysis of Potential Field Data Exploration, Geophysics,30, 1999, 38-44.

[4]. D. Khattach, P. Keating, M. L. Mostafa, T.Chennouf, P. Andrieux and A. Milhi, Contribution of gravity to the study of the structure of Triffa basin (northeastern Morocco): hydrogeological implications, C.R. Geoscience, 336, 2004, 1427-1432.

[5]. J. L. Feybesse, V. Johan, C. Triboulet, C. Guerrot, F. Mayaga-Mikolo, V. Bouchot and J. Eko Ndong, The west Central Africa belts: a model of 2.5-2.0 Ga accretion and two-phase orogenic evolution, Precambrian Research, 87, 1998, 161-216.

[6]. J. Penaye, A. Kroner, S.F. Toteu, W.R. Van schmus, J. C. Doumnang Mbaiggane, Evolution of the Mayo Kebbi region as revealed by zircon dating: an early (740 Ma) Pan-African magmatic arc in south-western Chad, Journal of African Earth Sciences, 44, 2006, 530-542.

[7]. S. F. Toteu, W. R. Van Schmus, J. Penaye and A. Michard, New U-Pb and Sm-Nd data from north-central Cameroon and itsbearing on the pre-Pan African history of central Africa,Precambrian Research, 108,2001, 45-73.

[8]. A. Nédelec, J. Macaudière, J. P. Nzenti andP. Barbey, Evolution structural et métamorphique de la série de Mbalmayo (Cameroun) : implications pour la structure de la zone mobile panafricaine au contact du craton du Congo, C.R. Académie des Sciences Paris, 303 (Série II),1986, 75-80.

[9]. J. Vicat, , J. Leger, E. Nsifa, J. Nzenti, R. Tchameni and A., Pouclet, Distinction au sein du Craton Congolais du Sud-Ouest du Cameroun, de deux épisodes doléritiques initiant les cycles orogéniques Eburnéen (Paléoprotérozoïque) et Panafricain (Néoprotérozoïque), C.R. Académiedes Sciences Paris, 323(série IIa), 1996, 575-582.

[10]. J. Delhal and D. Ledent, Data on the complex calcomagnésien geochronology of southern Cameroon, Mus. Roy. Afr. heat. Tervuren (Belg.), Rapp. Ann., 1974. 71-76.

[11]. M. Lassere et D. Soba, Age libérien des granodiorites et des gneiss à pyroxène du Cameroun méridional, Bulletin BRGM France, 2(1), sect. IV, 1976, 17 -32.

[12]. S. F. Toteu, W. R. Van Schmus, J. Penaye and J. B. Nyobe, U-Pb and Sm-Nd evidence for Eburnean and Pan-African high-grade metamorphism in cratonic rocks of Southern-Cameroon,Precambrian Research, 67,1994, 321-347.

[13]. C. Shang, M. Satir, W. Siebel, E. N. Nsifa, H. Taubald, J. P. Liegeoisand F. M. Tchoua, TTG magmatism in the Congo Craton; a view of major and trace element geochemistry, Rb-Sr and Sm-Nd systematics: case of the Sangmelima region, Ntem complex, Southern Cameroon, Journal of African Earth Sciences, 40,2004, 61-79.

[14]. C. Shang,M. Satir, E. N. Nsifa, J. P. Liegeois, W. Siebel and H. Taubald, Archean high-K granitoids produced by remelting of earlier Tonalite-TrondhjemiteGraondiorite (TTG) in the Sangmélima region of the Ntem complex of the Congo craton, southern Cameroon,International Journal of Earth Science (Geol Rundsch), 96, 2007, 817-841.

[15]. R. Tchameni, Géochimie et géochronologie des formations de l'Archéen et du Paléoprotérozoïque du Sud-Cameroun (Groupe du Ntem, craton du Congo), Thèse de Doctorat, Université d'Orléans, France, 1997

[16]. R. J. Blakely, Potential theory in gravity and magnetic applications, Cambridge Univ. Press, Cambridge, 1995

[17]. D. Khattach, H. Mraoui, D. Sbibih and T. Chennouf, Analyse multi-échelle par ondelettes des contacts géologiques: application à la carte gravimétrique du Maroc nord-oriental, C. R Geoscience, 338, 2006, 521-526.

[18]. R. J. Blakely and R.W. Simpson, Approximating edges of source bodies from magnetic or gravity anomalies, Geophysics, 51, 1986, 1494-1498.

[19]. B. H. Jacobsen,A case for upward continuation as a standard separation filter for potential-field maps, Geophysics, 52, 1987, 390-398.

[20]. E. A. Robinson and M. T. Silvia, Digital Foundation of Times Series Analysis, Holden Day, San Francisco, California, 1981.

[21]. A. B. Reid, J. M. Allsop, H. GranserA. J. Millett and I. W. Somerton,Magnetic interpretation in three dimensions using Euler Deconvolution, Geophysics, 55, 1990, 80-90.

[22]. A. Eshaghzadeh, Depth estimation using the tilt angle of gravity field due to the semi-infinite vertical cylindrical source, Journal of Geological Research, volume 2017, 2017, 1-10.

[23]. Owona Angue, M. L. C., Tabod, C. T., Nguiya, S., Kenfack, J. V. and Tokam Kamga, A. P. 2013. Delineation of Lineaments in South Cameroon (Central Africa) Using Gravity Data. Open Journal of Geology, 2013, 3, 331-339.

[24]. G. R. J. Cooper and D. R. Cowan,Enhancing Potential Field Data using filters based on the local phase, Computers and Geosciences, 32(10), 2006, 1585-1591.

[25]. D. B. Boukeke, Structures Crustales d'Afrique Centrale Déduites des Anomalies Gravimétriques et Magnétiques: Le Domaine Précambrien de la République Centrafricaine et du Sud Cameroun, Ph.D. Thesis, Université de Paris Sud, 1994.

[26]. J. P. Vicat, Esquisse Géologique du Cameroun: In Géosciences au Cameroun, Collection GEOCAM1, 1998, 3-11.
[27]. A. P Tokam, C. T. Tabod, A. A. Nyblade, J. Julia, D. A. Wiensand M. Pasyanos, Structure of the Crust Beneath Cameroon, West Africa, from the Joint Inversion of Rayleigh Wave Group Velocities and Receiver Functions Geophysical, Geophysical Journal International, 1183, 2010, 1061-1076. doi:10.1111/j.1365-246X.2010.04776.x
[28]. M. L. C Owona Angue, S. Nguiya, R. Nouayou, A. P. Tokam Kamga and E. Manguelle-Dicoum, Geophysical Investigation of the Transition Zone between the Congo Craton and the Kribi-Campo Sedimentary Basin (South - West Cameroon), South African Journal of Geology, 114 (2),2011, 145-158.

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