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2.5D Modeling of Crustal Structures along the Eastern Cameroon and Western Central African Republic Derived from Finite Element and Spectral Analysis Methods

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Abstract

This study combines the finite element approach and the spectral analysis of Fourier's function, to investigate the eastern Cameroon and western Central African Republic. In this area, the signature of the gravity anomalies seems to correspond to the transition zone between the Congo Craton and the Panafrican Mobile Belt. Thus, a gravity interpretation based on the data obtained from four N-S profiles on the residual map is carried out using a 2.5D model. The residual anomaly map is obtained by using the finite element method (FEM) for data filtering. Spectral analysis is used to estimate the depth of the sources responsible of the observed anomalies. Our results demonstrated that the observed gravity anomalies in the region are associated with tectonic subsurface structures. This study suggests that the transition area, which comprises the northern margin of the Congo Craton (CC) and the southern border of the Mobile Zone of Central Africa (MZCA) known as the Pan-African Belt (area covering the geological Congo Craton limit (GCCL)), is a product of convergent collision. This collision has caused considerable overthrusting of the Pan-African Belt (PAB) units onto the Congo Craton. The models suggest the intrusion of magmatic rocks during the continental collision, which were later metamorphosed into granulites along and around the northern margin of the Congo Craton. The presence of deep granulite structures in the northern margin of the CC expresses a continental collision. Some sediment formations appear in the Central African Republic with variable thicknesses. The granulites (deeper parts of PAB) observed might come from the uprising of some materials of the upper mantle probably during the opening of the Atlantic Ocean. The probable geophysical limit of the CC in the upper crust is suggested on this study.

Keywords: Finite element, residual anomaly, spectral analysis, 2.5D modeling, Congo Craton, Pan-African belt, upper crust

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1 Introduction

The gravimetric method survey is used in this paper in order to show the structure of the upper crust in the study area which extends from south to north between latitudes 2°15' to 5°15'N, and from west to east between longitudes 13°44' to 16°10'E (Fig. 1). This zone under study is found in the eastern Cameroon and extends into the Central African Republic (Fig. 1). The study area is characterized by the contact between the Congo Craton (CC) and the Pan-African belt that are the major geological structures of that area (*Tadjou et al.,* 2009; *Shandini et al*., 2010). The gravity studies reveal an important tectonic structure along the 4°N parallel, which is not mentioned by geological facts, probably because it is located at depth (*Mbom-Abane*, 1997). This structure can be linked to the African Orogeny process. The interactions between the mobile domain (Pan-African Belt) and the Congo Craton are partially understood from geological studies, and yield to various and divergent tectonic models that broadly correspond to the collision between the CC and the Mobile Belt (*Poidevin*, 1983; *Nzenti et al.,* 1988; *Penaye et al.,* 1993; *Abdelsalam et al.,* 2002; *Toteu et al.,* 2006; *Shandini et al.,* 2010). The collision between the CC and the PAB led to the Pan-African units overthrusting onto the Congo Craton by about 50 to 150 km (*Manguelle-Dicoum*, 1988; *Shandini and Tadjou,* 2012). This work consists in the separation of Bouguer anomaly in regional and local scale components that result from a combination of different causes, in order to study and interpret them separately (*Parasnis,* 1997; *Ndougsa et al.,* 2007). While the regional component provides valuable information in interpreting deeper and large-scale structures, the residual local scale component often delineates mineral and hydrocarbon prospects at relatively shallower depths (*Sharma et al.,* 1999; *Erdem et al.,* 2005; *Ndougsa et al.,* 2007). The crustal structure of the study area is studied using the residual anomalies. The finite element method (FEM) in the framework of this study is used to separate at each node of the data grid the regional anomaly from Bouguer's in order to obtain the residual anomaly as recently developed by many authors (*Mallick and Sharma*, 1999; *Sharma et al.,* 1999; *Kaftan et al.,* 2005; *Ndougsa et al*., 2013). The residual anomaly map shows that the area is characterized by a long positive residual anomaly wavelength of about 270 km (Fig. 4). The anomalies trending mainly in the E-W direction can be identified on the residual map. This positive anomaly is located around the northern limit of the Congo Craton and might represent the intrusion of dense materials. The aim of this work is to use FEM filtering of observed gravity anomaly in one hand, and the combination of spectral analysis and 2.5D modeling in the second hand, to determine the shape, depth, thickness and the distribution of anomalous sources around the study area characterized by negative Bouguer anomalies. Then we present a model of the subsurface structure setting of the transition zone between the Congo Craton and the Pan-African belt in the study area using the existing gravity data.

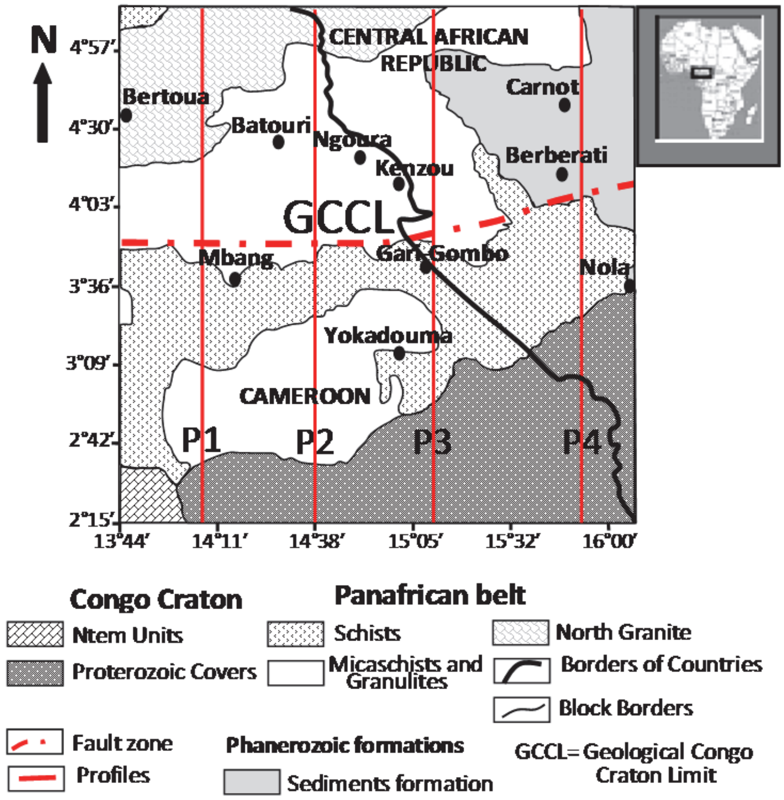

Fig. 1. Geological sketch map of the study area with profiles from *Tadjou et al*. (2009) modified.

2 *Geological and tectonic setting*

The summary of some applied geology works (*Cornacchia and Dars*, 1983; *Vignes Adler et al.,* 1991; *Nzenti et al.,* 1991, 1999) has laid out that the bedrock or the basement in Central Africa consists predominantly of Precambrian basement with magmatic and metamorphic rocks of different stages of the Precambrian outcropping from Cameroon to Sudan (Fig. 1). The outcropping rocks are principally rejuvenated granites and migmatites (*Ngako et al.,* 2003; *Mvondo et al.,* 2003, 2007). There are also volcanic and sedimentary rocks in relation with the opening of Atlantic Ocean from the Mesozoic and the Cenozoic. According to geochronologic study, Cameroon is made up of two principal structural zones (*Bessoles and Lassere*, 1977; *Bessoles and Trompette*, 1980; *Penaye et al.,* 2004; *Shang et al.,* 2004; *Ganwa et al.*, 2008): 1) the stable Congo Craton in the South and Central areas, meanwhile, the northern part corresponds to the 2) Mobile Zone of Central Africa (MZCA) known as the Pan-African belt of the Central Africa (*Penaye et al.,* 1993; *Nzenti et al.,* 1991, 1999). Those structural zones were formed during the Pan-African tectonic events that are related to the Pan-African orogeny (550 ± 100 Ma).

The Congo Craton, which is known as the Ntem Complex in Cameroon (*Maurizot et al.,* 1985), consists predominantly of Archean rocks with some reworked and resedimented material formed in the Paleoproterozoic era (*Tchameni*, 2001; *Pouclet et al.,* 2007). The Archean period is dominated here by Liberian orogeny (2700–2600 Ma), which began with the intrusion of magmatic rocks from which the greenstone belts were derived. The diapiric intrusion of Tonalite-Trondhemite-Granodiorite (TTG) followed the Greenstone belt formations between 2900 and 2800 Ma during the major tectono-metamorphic phase (*Tchameni et al., 2000; Tchameni, 2001*; *Tadjou et al.,* 2009). The metamorphism is dominated here by granulites facies rocks that ended with an important migmatisation event resulting in the intrusion of anatectic potassic granitoid. *Tchameni et al.* (2000) show that the paleoproterozoic evolution of the Ntem Complex is equivalent to the eburnean orogenic cycle that is characterized by intrusion of doleretic dykes; this cycle ended with a thermal or hydrothermal event about 1800 Ma. The Ntem Complex consists of metamorphic and igneous rocks which are amphibolites, gabbros, charnockites and granodiorites (*Ndougsa et al.,* 2002; *Caron et al.,* 2010). The metamorphism is restricted to the contact between the Ntem Complex and the Pan-African fold belts. The main Precambrian boundary between the Congo Craton and the Pan-African belt consists of metasedimentary rocks lying along the northern edge of the Congo Craton (*Nzenti et al.*, 1991, 1999; *Mvondo et al.,* 2005; *Mapoka et al.,* 2011). The main part of the Pan-African belt of Central Africa is characterized by crustal overthrusting of which *Poidevin*, (1983) represented the first schema. This schema supposed the thrusting to the south of the Pan-African structures onto the Congo Craton (*Ndougsa et al.,* 2002; *Meying et al.,* 2009). The Pan-African chain is situated between the West Africa Craton in the North West and the Congo Craton in the South. The Ayos, Mbalmayo-Bengbis, the Yokadouma and the Yaoundé series represent it in Cameroon. It mainly consists of continental sedimentary formations of the Precambrian and epizonal metamorphic rocks that are Schist and Quartzite (*Vicat,* 1998; *Ngako et al.,* 2003; *Olinga et al.,* 2010).

In general, the region has a complex and uneven tectonic structure. This tectonic seems to have given rise to a vertical movement of the basement with subsidence to the North and uplift to the South (*Manguelle-Dicoum*, 1988; *Shandini and Tadjou,* 2012). This basement movement must have provoked irregularities in the formations at depth, given rise to faults, horsts and grabens characteristic of the boundary between the Congo Craton and the Pan-African folds belt (*Shandini et al.,* 2010).

3 Gravity data

The gravity data used in this work were collected during two reconnaissance survey campaigns of Cameroon and Central African Republic, undertaken respectively by the ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer) and *Poudjom et al.* (1996). The first one is between 1963 and 1968, and the second one is done in addition to fill some of large gaps observed between the stations and to ameliorate the general cover of the area. The data set in general, consists of irregularly spaced gravitational acceleration values and corresponding geographical coordinates. *Louis* (1970) and *Poudjom et al.* (1996) have processed these data sets respectively. During the second survey (1993–1995), coordinates were obtained from a GPS 55 AVD instrument of Garmin International Inc., with approximate error of 100 m. Elevations in relation to sea level were obtained with Wallace & Tiernan (N°3b4) altimeter accurate to one meter. Base-stations were defined using the International Reference IGSN71 (*Poudjom et al.,* 1996). The space between stations varied from 1 to 4 km, depending on access facilities. The data sets were collected for all gravity stations including base stations (e.g. shown on figure 2a as dots), on available roads and tracks in the whole territory using Worden gravimeters (of n°313 and n°600 models) with a precision of 0.2 mGal. The gravity readings were corrected for drift and the gravity anomalies were computed assuming a mean crustal density of 2.67 g cm^{-3}. The calculation of terrain corrections was done after *Hammer* (1939), with a digital terrain model (*El Abbass et al.,* 1990). The maximum error in the Bouguer anomaly value for any of the stations due to the error in height determination was not expected to exceed 0.15 mGal (*Tadjou et al.,* 2009). The data set used in this study comprises 507 measurement points which were interpolated to a regularly space grid (x = 5 km and y = 5 km) using an appropriate software (Surfer 9.0) which permits us to obtain 2880 measurement points. The Bouguer anomaly values obtained by interpolation were then plotted to have a new Bouguer anomaly map (Fig. 2b), which is very similar to the one reported by *Poudjom et al.* (1996).

4 *Methodology*

4.1 *Finite element method*

Generally, data processing is very important in the potential field methods. The first and the most crucial step of this work is the removal of the effect of deep-seated structures from observed Bouguer gravity field, in order to enhance the signatures of shallow bodies (*Sharma et al.,* 1999; *Ndougsa et al.,* 2007). In this paper, we used the finite element method (FEM) developed by some authors recently (*Sharma et al.,* 1999; *Mallick and Sharma*, 1999; *Ndougsa et al.,* 2013) to filter the Bouguer anomaly into the regional and residual anomaly. The method allows the estimation of regional anomaly by considering, on one hand that, it is regular with a slope that slightly varies; on the other hand, we model it using an analytical regional surface (2-D modeling). The analytical regional anomaly is constructed using finite element approach, which is based on the concept and the properties of shape functions (*Mallick and Sharma*, 1999; *Ndougsa et al.,* 2013). According to this approach, the weighted sum of the variation of the analytical regional anomaly at any point (x, y) in the survey space can be expressed as series, which in fact, is the weighted sum of the values at the node of regional anomaly. It is as follow (*Sharma et al.*, 1999; *Mallick and Sharma,* 1999, 2001; *Ndougsa et al.,* 2013):

$$\mathrm{reg}(x, y) = \sum P_{\mathrm{i}}\,(x, y)g_{\mathrm{i}}\,,\ \ 1 \le \mathrm{i} \le \mathrm{n}\,, \tag{1}$$

with

$$P_{\mathrm{i}}\,(x, y) = \sum a_{\mathrm{ik}}B_{\mathrm{k}}(x, y) \quad 1 \le \mathrm{k} \le \mathrm{n} \tag{2}$$

The shape functions verify the following condition: $P_i(x_j,y_j) = \delta_{ij}$, where δ_{ij} is the Kronecker symbol and (x_j,y_j) are coordinates of j^{th} node. The final variations of the analytical regional anomaly are given by:

$$\text{reg} = \sum a_{ik}B_k(x, y)g_i\,, \quad 1 \leq \text{i, k} \leq \text{n} \tag{3}$$

where n is the number of nodes, g_i is the value of the regional anomaly at the i node, (x, y) is the coordinates couple of a point on the prospecting zone, $B_k(x, y)$ are vectors of n dimension basis that generate the n shape functions, a_{ik} are the element of regular matrix.

The residual anomaly is calculated by $\text{res}(x,y) = \text{bg}(x,y) - \text{reg}(x,y)$. The calculation of the Bouguer anomaly at each point of the prospecting area necessitates the availability of finite number of data at the border and inside of the study area. It uses the same finite element approach. In this paper, we have realized 72 finite elements in real space with eight nodes. The separated regional-residual data set is obtained by using the code elaborated by *Ndougsa et al.* (2013).

4.2 Spectral analysis

Spectral analysis as described by *Spector & Grant* (1970) is an interpretation technique based on the study of power spectrum properties. From the study of logarithmic power spectrum as a function of the spatial frequency, the mean depth of bodies responsible for the observed gravity anomalies can be estimated. The gravity data varies as a function of distance along a profile. The power spectrum is the magnitude of the discrete Fourier transform of the gravity. The average depths of the source bodies responsible of the observed gravity anomalies are determined by using the following expression (*Gerard and Debeglia*, 1975; *Nguimbous et al.,* 2010):

$$\Delta \log P = 4\pi H \Delta K \tag{4}$$

where $\Delta \log P$ is the variation of the logarithm of the power spectrum for a wavenumber ΔK (km^{-1}) and H (km) is the depth to approximate plane of density contrast. This relation is deduced from the power spectrum logarithm curve versus the wavenumber. On this curve, two straight-line segments can be identified and plotted by a least squares fitting on the data points. The high wave portion is due to shallow bodies. Deep-seated bodies cause the low wavenumber part. Two planes of density contrast are associated to these bodies and it is supposed that, the sources of gravity anomalies under study are mainly located between these two planes. The errors values have been obtained by considering that, each one is representing 5% of the mean depth value on each profile (*Nnange et al.,* 2000). The method is well established and proved its usefulness in schemes of interpretation in gravity (*Tadjou et al.,* 2009; *Shandini et al.,* 2010).

The data processing and interpretation was conducted through the following steps:

- ✓ The generation of a new dataset obtained by interpolating data from Fig. 2a in a 5 km x 5 km grid. This led to a new Bouguer's anomaly map (Fig. 2b);
- ✓ The Regional-residual filtering based on the FEM as done by many authors recently (*Sharma et al,* 1998*; Mallick and Sharma,* 1999, 2001*; Ndougsa et al,* 2013);
- ✓ The spectral analysis that enables, to determine depth to the sources responsible of the observed anomaly. In this step, curves are generated in MATLAB based on the Fourier equation cited above in formulae 4. The depth value is deducted based on the linear regression approach;
- ✓ The 2.5 D modeling is done, by using spectral analysis results and geological facts as constrains. The density contrast of rocks is obtained by making the difference between the earth's crust (d_0 = 2.67 g cm^{-3} and the various rock density (d_i). The strike length is fixed to 100 km, because of the immensity of the study area. The maximum depth window for the modeling of residual anomaly is not exceeding 10 km. For this modeling, the different types of rock are known as to belong to the CC or to PAB (*Nzenti et al.*, 1991, 1999; *Mvondo et al.,* 2005; *Mapoka et al.,* 2011).

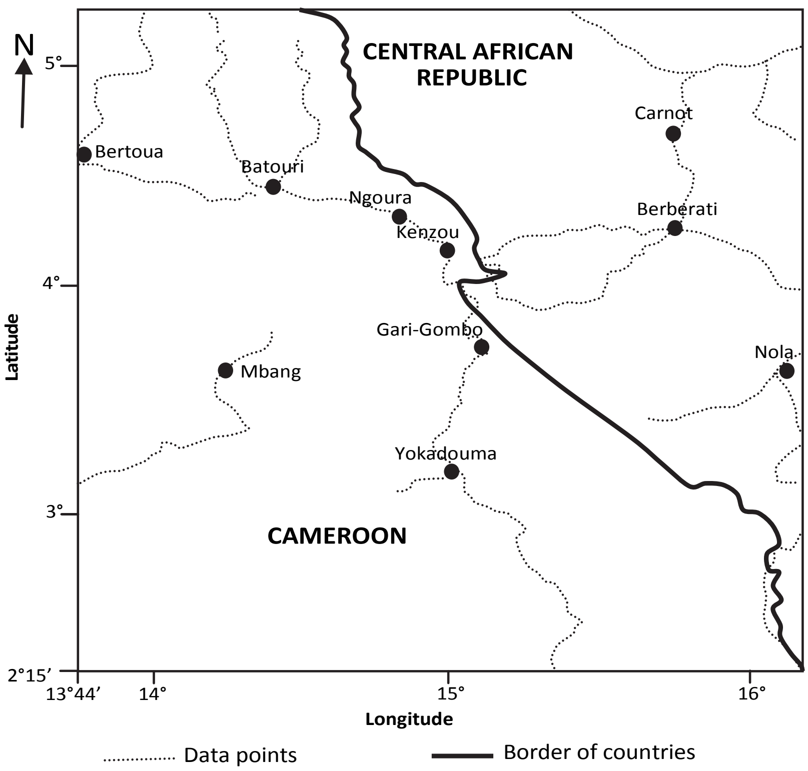

Fig. 2a. Gravity data distribution map of the study area.

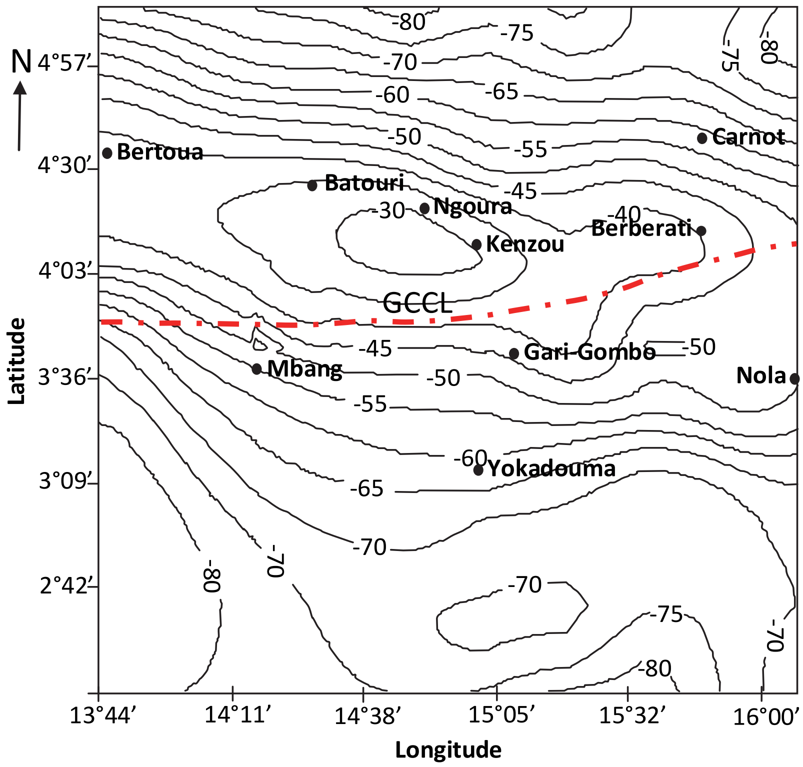

Fig. 2b. Bouguer anomaly map.

5 Results

5.1 Maps analysis

Bouguer Map

The Bouguer anomaly map (Fig. 2b) analysis shows that the region is characterized by a broad anomaly ranging from -65 to -30 mGal bounded by relative steep gradients around the 4°N parallel. This might indicate the contact between the Congo Craton and the Pan-African belt or a fault zone or both. The map shows a relative maximum around Batouri-Ngoura region. According to the geology, this maximum could be due to the intrusion of deeper materials or the uprising of some mantle materials. The relative maximum (amounting -50 mGal) at its eastern portion might also indicate the uplift of deeper mantle materials (granulites) overlain by sedimentary formations as shown on the geological patter (Fig. 1). At the South, there is a relative minimum of about -80 mGal that can be explained by the existence of lower density materials (granites). Some outflows on the geologic map have no effect on the Bouguer anomaly map; this might be due to their small thickness that does not cause much modification of the gravity field (*Kande et al.,* 2005).

Regional Map

The regional gravity anomaly map (Fig. 3) shows regional gravity field values ranging from -80 to -50 mGal with a regional maximum and this might probably represent the thinning of the upper crust due to mantle materials uplift. The gravity gradient and the structure of the contour lines on this map could also indicate that the basement of the region is homogenous.

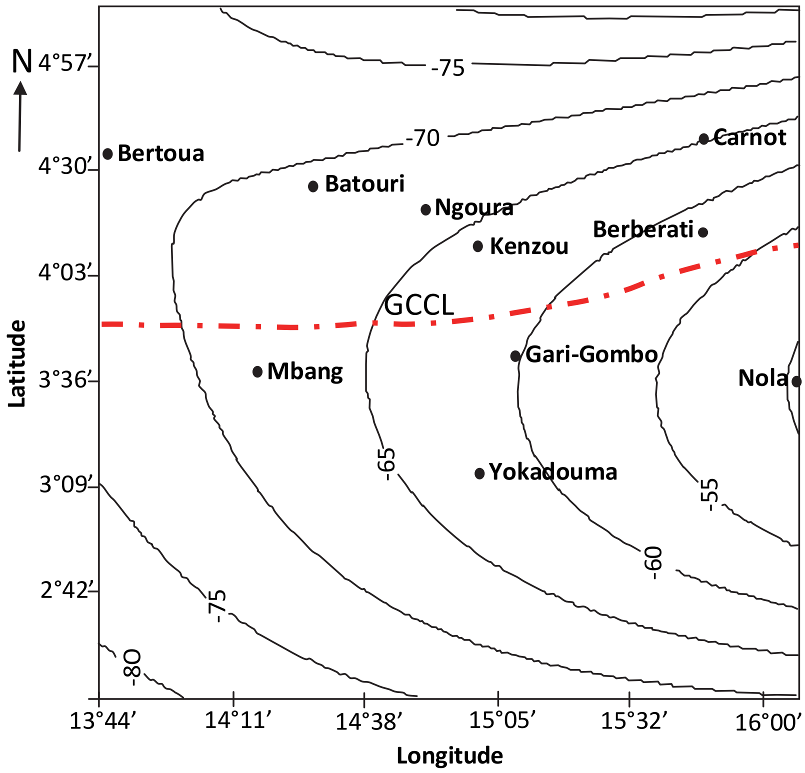

Fig. 3. Regional map.

Residual Map

The residual map (Fig. 4) has an important similarity with the Bouguer map. A long positive anomaly is identified with amplitude of about 40 mGal and trending mainly E-W. It shows a package of parallel isogals and presents a sharp positive anomaly of about 40 mGal around Batouri. This might indicate that the source responsible of the observed anomaly is relatively shallow. It could also indicate that the tectonic contact between the Congo Craton and the Pan-African belt is not very deep as assumed. In the Southeast, the residual anomaly map shows a relative minimum of about -20 mGal, this anomaly might be explained by the presence of the allochtonous rocks deposit as phanerozoic formations. The presence of a closed zero contour between the positive and negative package of isogals on this map could indicate the changing on structural formation in the basement. By correlating the local geology and the observed anomalies, four profiles were chosen on the residual anomaly map (Fig. 4) in order to model the structure of the upper crust in the area under study. The profile locations were chosen by considering different anomalies and the main trend of the significant anomaly on residual map that follows the boundary between CC and PAB. In order to cover all available information, the profiles are crossing completely the residual map area.

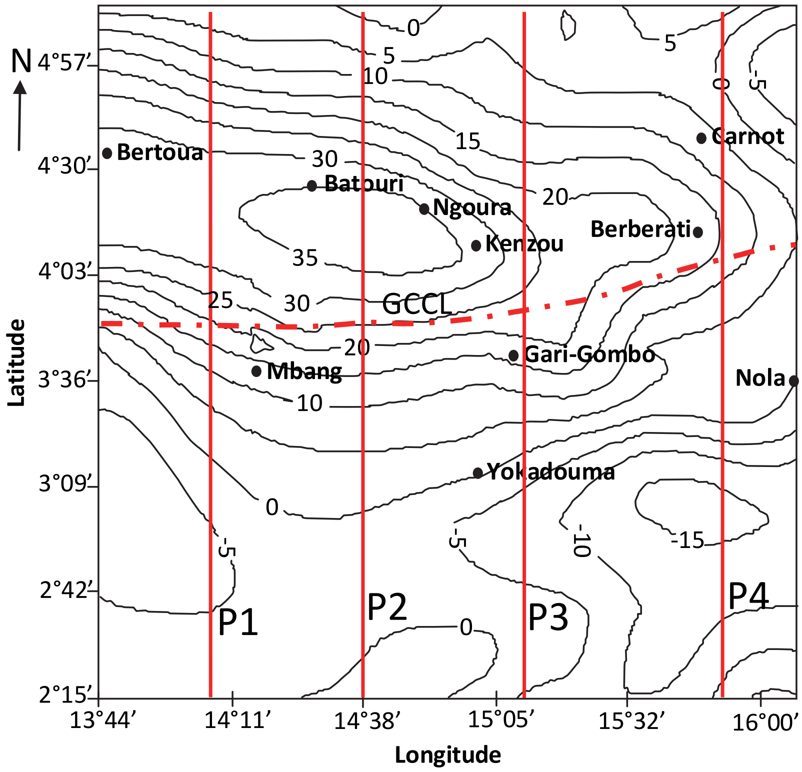

Fig. 4. Residual map with profiles.

5.2 *Spectral analysis results*

The application of spectral analysis on the four profiles plotted on the residual anomaly map is shown in Fig. 5. In this figure, the logarithm function of the power spectrum versus the wavenumber for each curve, presents approximately two linear segments. The high wavenumber portion is due to shallow bodies and deep-seated bodies cause the low wavenumber part. The depths 6.15 ± 0.31 km and 0.48 ± 0.02 km obtained from profile P1 are related to the contact between the basement of Pan-African belt and granulites. The block of granulites is an intracrustal formation beneath the PAB-CC transition zone and both depths represent the deeper and shallower discontinuities between high-density materials (granulites) and the basement in the Pan-African belt. The depths 6.43 ± 0.32 km and 0.48 ± 0.03 km derived from the profile P2 might represent respectively, the deepest contact between the granites formations and the CC basement, and the shallower contact between granulites and the basement around the northern margin of the Congo Craton. The thickness of this formation is less than the one obtained from profile P1. According to spectral analysis, the important discontinuities under profile P3 are located between 0.40 ± 0.02 km and 4.60 ± 0.23 km. Here the first depth might indicate the top of the contact between granulites and the basement in the Pan-African belt and the second one could show the deepest granulites-basement contact beneath the transition zone like it is shown on the model of profile P3. Sources of anomalies along profile P4 are located between 0.46 ± 0.02 km and 6.63 ± 0.33 km. The first depth could probably represent the interface between sedimentary formations (Pan-African belt) and the basement on the northern part of the Profile (Fig. 9). The second one materializes the contact between granites and the basement on the South (Congo Craton).

Table 1. Spectral analysis by profile.

Profile	Direction	H2 (km) Depth of the deeper discontinuity	H1 (km) Depth of the shallower discontinuity
P1	N-S	0.48 ± 0.02	6.15 ± 0.15
P2	N-S	0.48 ± 0.02	6.43 ± 0.32
P3	N-S	0.40 ± 0.02	4.60 ± 0.24
P4	N-S	0.46 ± 0.02	6.63 ± 0.33

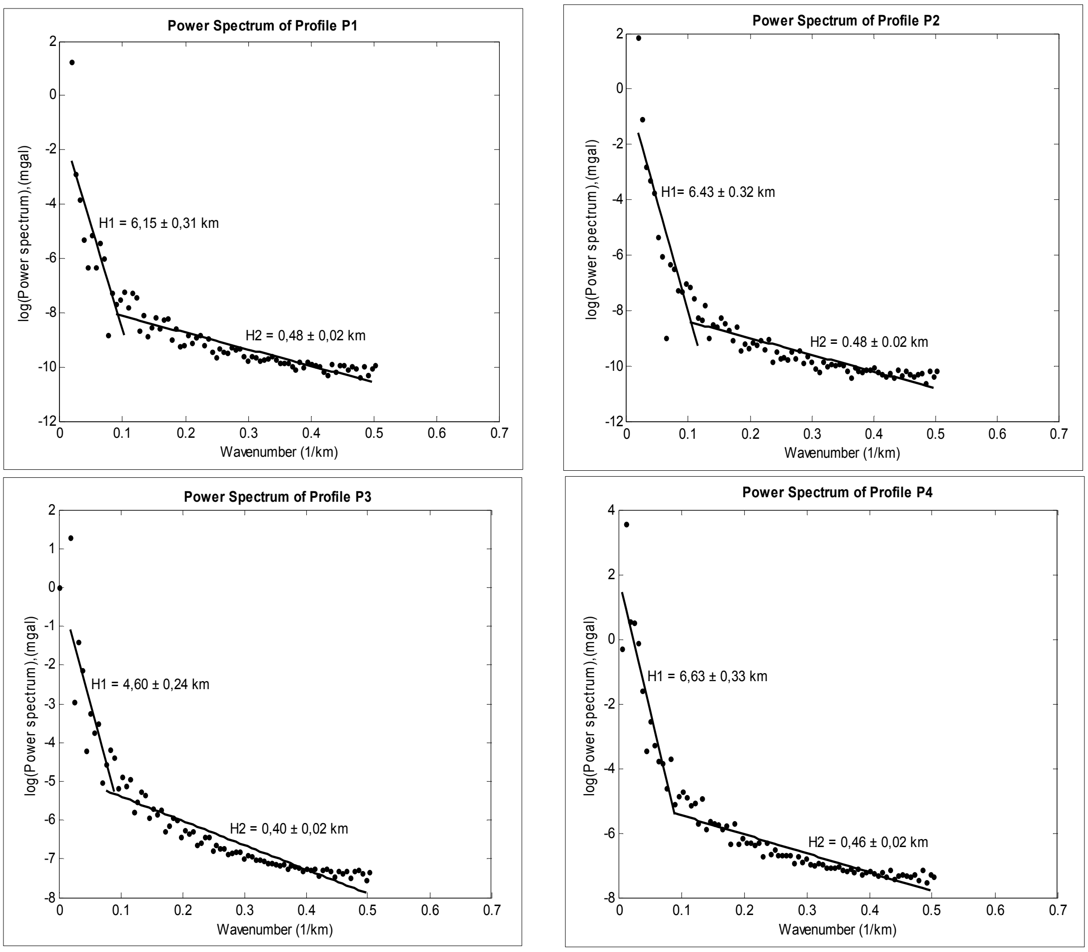

Fig. 5. Spectral analysis of profiles P1, P2, P3 & P4.

5.3 2.5D modeling

The 2.5D modeling program (*Cooper*, 2003) was used to infer the subsurface structure along four profiles in the study area. The program calculates the gravity anomaly due to the 2.5D bodies. It is based on the Talwani algorithm to calculate the gravity contribution of each body to the observed anomaly in an interactive way, so a change of a body does not require the recalculation of the whole model (*Nguimbous et al.,* 2010). The distances are measured in kilometers; the densities are in g/cm^3 and the anomalies in mGal.

The modeling consisted in fitting the observed anomalies and computed curves, based on bodies representing the possible geological units present in the subsurface. The initial depths of models were chosen according to the results of spectral analysis (*Tadjou et al.,* 2009*; Shandini et al.,* 2010). The density contrasts of rocks were calculated based on the difference between the mean density of the Earth's crust taken as 2.67 g cm^{-3} (approximately the same for CC and PAB) and the various rock densities. The mean density of granites, charnockites, granulites and sedimentary formations (sandstones and conglomerates) has been taken respectively as 2.60, 2.80, 2.85 and 2.57 g cm^{-3} in the study area (*Astier*, 1971; *Telford et al.,* 1990; *Parasnis*, 1997; *Tadjou et al.,* 2009; Shandini et al., 2010). All profiles P1, P2, P3 and P4, which are directed N-S, are drawn from 159 points of measure spaced from about 2 km. In all models, body 3 with the mean density of 2.67 g cm^{-3} represents at the same time the basement on the PAB and the basement on the stable CC**.** All the profiles have the same length of 324 km (Fig. 4).

The observed anomaly curve of the profile P1 has its maximum anomaly to be 40 mGal. The model comprises three bodies (Fig. 6). The body 1 has a density of 2.85 g cm^{-3} and corresponds to granulitic rocks (metamorphic formations), which are deeper structure of the PAB-CC transition zone with variable thickness reaching 5.5 km. The body 2 has a density of 2.60 g cm^{-3} and could be the granites under the southern crust of the Congo Craton. The body 3 has a mean density of 2.67 g cm^{-3} and represents the basement of the study area. The model approximately indicates the geometry of different formations. A good matching is observed between the observed anomaly and the model response.

Table 2. Densities assumed and corresponding rock layers [average densities of materials from *Astier*, (1971) and *Shandini et al*., (2010)].

Material	Mean Density (g/cm^3)
Basement	2.67
Granites	2.60
Granulites	2.85
Charnockites	2.80
Sandstone and Conglomerates	2.57

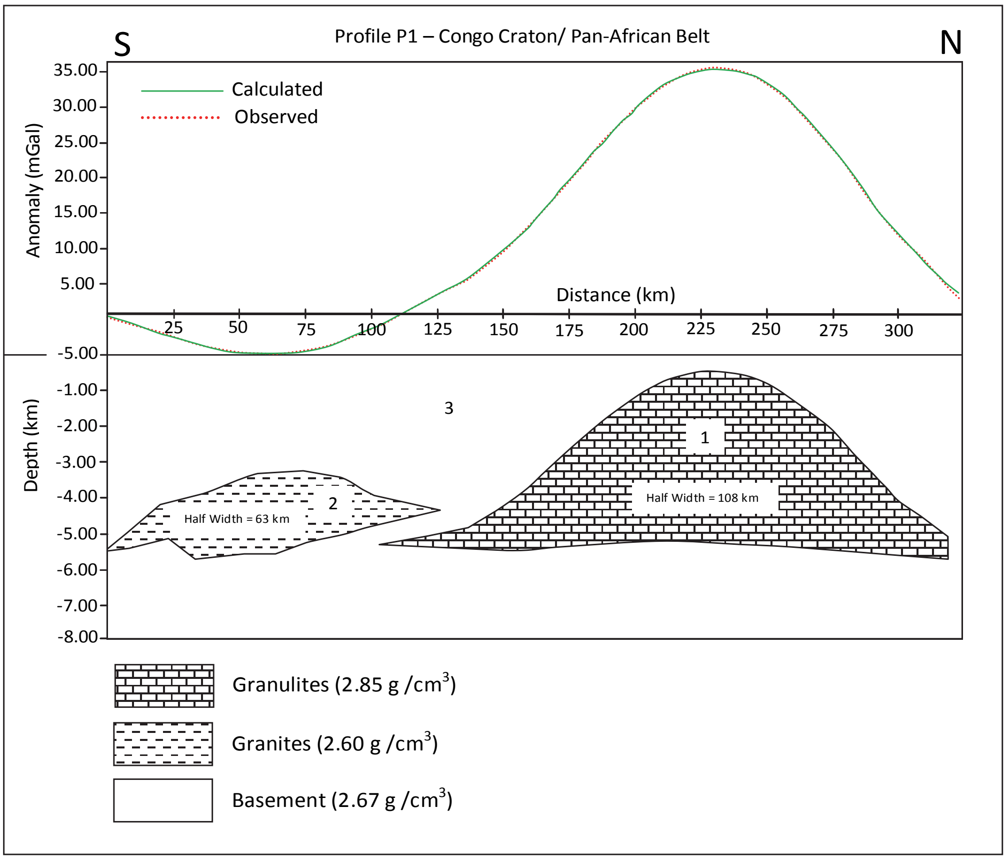

Fig. 6. Crustal model of profile P1.

The residual anomaly curve of the second profile (P2) presents the maximum of about 40 mGal that is caused by the uplift of dense materials in the crustal basement. Four bodies were associated to adjust the observed and the computed curves (Fig. 7). The body 1 has a density of 2.85 g cm^{-3} and might correspond to the granulites with variable thickness. The maximum thickness of this source is about 6 km. It is an intracrustal formation around the geological Congo Craton limit (GCCL). The body 2 with a density of 2.60 g cm^{-3} represents the granite formations shown on the model of profile P1, their maximum thickness is about 1.25 km. The body 3 with the mean density of 2.67 g cm^{-3} represents the granito-gneissic basement in the study area. The body 4 that appears in the start of the profile is particular with its density of 2.80 g cm^{-3}. This formation could be associated to the charnockites like proved by *Shandini et al.,* (2010). Charnockites are deeper structure of the CC. this formation with thickness of about 0.5 km is probably spreads southwards in the neighboring area of the study area.

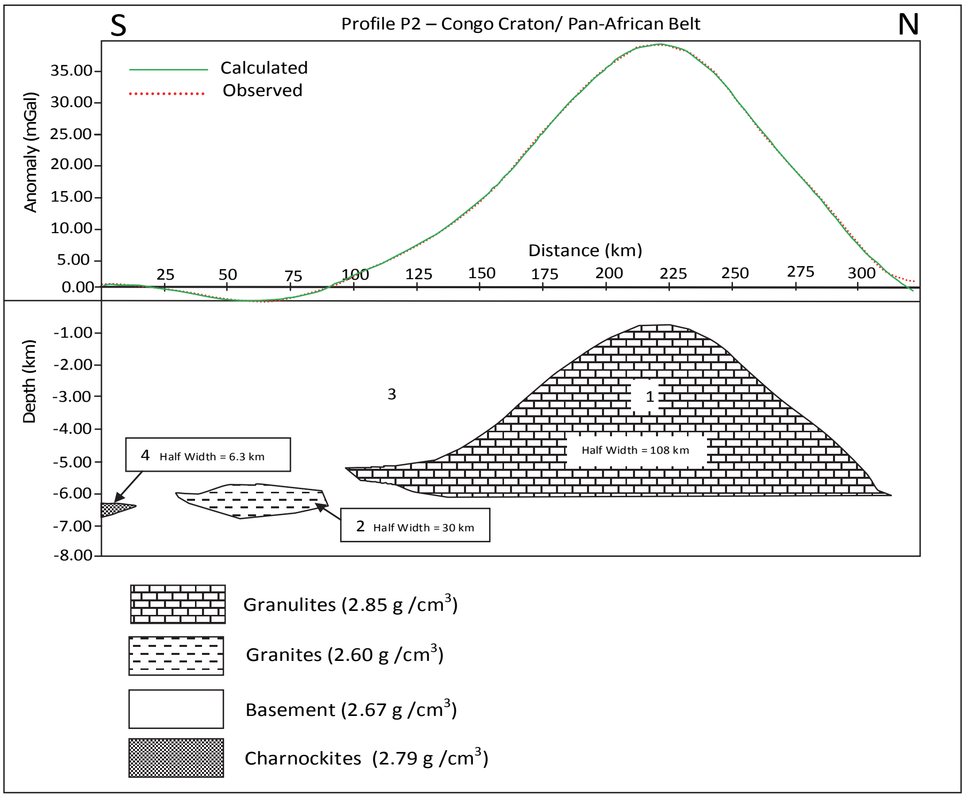

Fig. 7. Crustal model of profile P2.

The model of the third profile (P3) is very similar to the first one because, the number of its bodies, their shape and their density contrast are approximately the same; but the thicknesses of different sources (body 1 and body 2) are not the same between both first and third profiles (Fig. 8). The granulites and granites have the thickness of 4.15 and 3.85 km respectively.

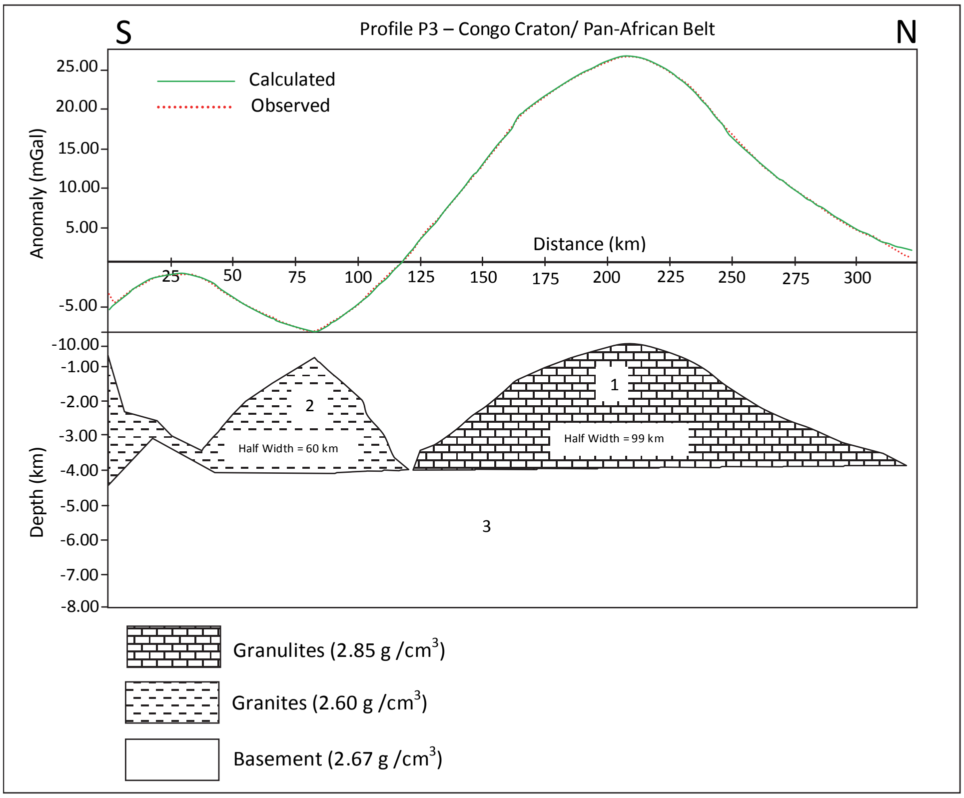

Fig. 8. Crustal model of profile P3.

The profile P4 with four bodies has a length of 324 km like all others (Fig. 9). All sources (body 1, body 2 and body 4) associated to that profile have a variable thickness. The body 1 with a 2.85 g cm^{-3} density is the same formation observed on the profile P2. It is a deeper intracrustal formation under the PAB-CC transition zone that can be associated to granulites. Their maximum thickness is about of 2.25 km. The body 2 inside the Congo Craton basement has a density of 2.60 g cm^{-3} and can be associated to granites with the maximum thickness of about 6.5 km. The body 4 is specific with the density of 2.57 g cm^{-3} and can be associated to sediments (phanerozoic formations). This body has a variable thickness with the maximum depth (about 1.5 km) at around Carnot in Central Africa Republic. The body 3 corresponds to the basement of the study area as described in all previous profiles. A good matching of observed and computed curves allows us to approximate the shape and the nature of the contact of different bodies.

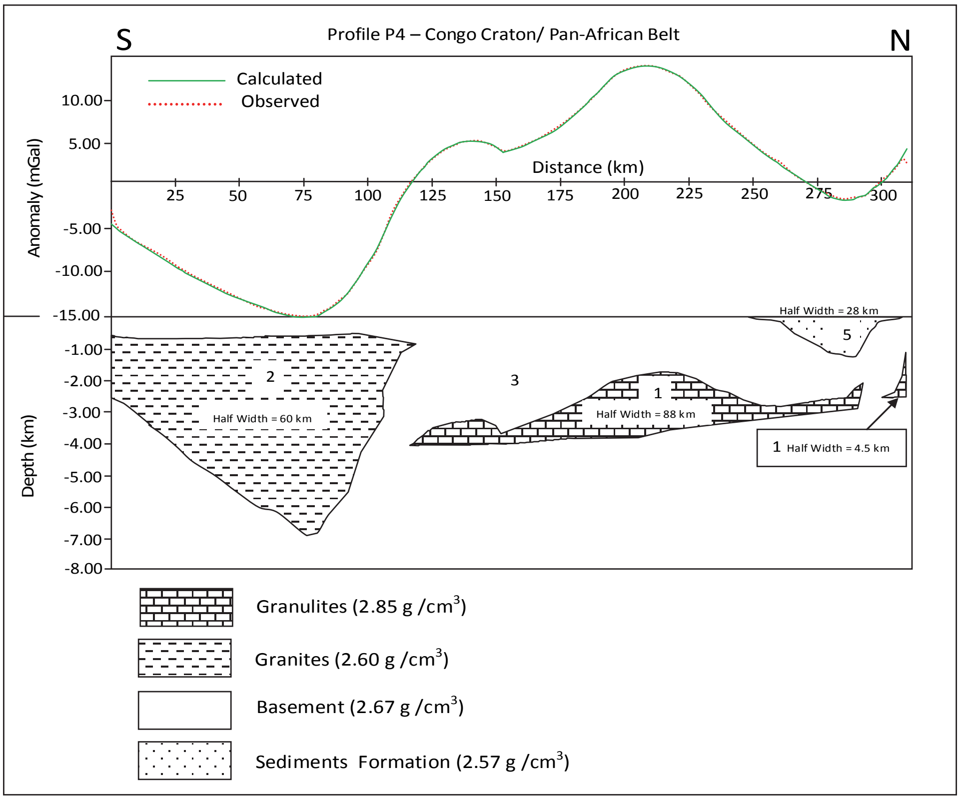

Fig. 9. Crustal model of profile P4.

6 Discussion

The comparison of FEM (finite element method) of separation and the polynomial filtering approach (*Njandjock et al.,* 2003) gives similar features at the first degree contrary to others degrees, and testifies that the residual map used in this paper is an appropriate one.

According to our 2.5D subsurface models, the structure of the study area presents many similarities in the composition of the upper crust when we pan from profile P1 to P4. In this study, we were supposed to show features of the different sources of anomalies and probably the intracrustal line of contact between the Congo Craton and the Pan-African belt within the area of study. This interpretation is not very easy because there is no coincidence between visible heterogeneities on the surface and the gravity anomalies; except on the profile P4 where the presence of sedimentary formations is clearly observed on the geological map, but we know that some outflows on this map have no effect on the Bouguer anomaly map; This might be due to their small thickness that does not cause much modification of the gravity field (*Kande et al.,* 2005). Some constraints have been adopted to build the model corresponding to each anomaly as such as the densities of anomalous masses have been considered to be superior or inferior to the enclosing bed density, which was supposed to have homogenous mean density of 2.67 g cm^{-3} for the CC and the PAB. The mean densities of some rocks like granites, granulites, charnockites and sediment formations were respectively supposed to be 2.60, 2.85, 2.80 and 2.57 g cm^{-3} (*Astier*, 1971; *Telford et al.,* 1990; *Parasnis*, 1997; *Tadjou et al.,* 2009; *Shandini et al.,* 2010). Obviously, none of the layers was expected to really have a homogenous density, because of both the presence of lithologic alterations and the natural increasing of density with depth. Granites and charnockites were known as the deeper structures of the CC and the granulites like deeper structure of the transition zone between the CC and the PAB (*Tadjou et al.,* 2009; *Shandini et al.,* 2010). The mean depths of mass sources were given by spectral analysis. All these constraints and other geological considerations linked with the tectonic features of the area were combined to build an accurate model for each profile. The important positive anomaly observed on the residual map at the transition zone between the Congo Craton domain and the Pan-African belt can be explained by the presence of granulitic rocks facies that were brought up tectonically to the surface during the Pan-African collision. These granulites come from magmatic rocks (granites eventually) metamorphosed after the continental collision between the CC and the PAB (Fig. 10). These materials lie near the zone where high residual gravity anomalies were observed, coupled with high gravity gradients that outline the tectonic boundary between the Pan-African units and the Congo Craton. Such intra-crustal bodies are usually interpreted as basal crustal rocks or mantle intrusion emplaced along a suture during collision (*Bayer and Lesquier*, 1978). This work reveals that the granulites rocks can be interpreted as the suture of a collision in the Pan-African belt as suggested by *Penaye et al*. (1993). These granulites have the maximum thickness around Batouri at profile P2 (about 6 km). The sediments mentioned on the geologic map are corresponding to the concerned layer (body 4) shown on the model of the profile P4 (Fig. 9). These sediment formations have variable thickness with the maximum (about 1.5 km) found around Carnot in the Central African Republic. The outflows of schist and micaschist in the study area as shown by the geological map confirm the hypothesis of significant tectonic movement around the northern edge of the Congo Craton. It is important to mention that, some outflows existing on the geological map are not represented on these models due to their small thickness that does not cause much effect on the gravity field (*Kande et al.,* 2005). This study could reveal that the top of the granulites formations corresponds approximately to the tectonic (geophysical) border between the CC and the PAB in the upper crust. In fact, we think that, during the collision, the regional stress field was very significant in the contact line between these two blocks, so the major uplift was following this border. This top is located around 225 km (about 4°16’) and testifies that the geological Congo Craton limit is relatively at the South than the geophysical limit. The deep contact between the CC and the Pan-African belt is displacing towards the northern part of the study area in the same order of the progression of the GCCL shown on the geological map. The deep structures of the upper crust along the four profiles are the same for the CC as well as for the PAB except on the profile P2 where some charnockites appears. The thickness of granulites is increasing from profile P1 to P2 and decreasing from profile P2 to profile P4, this could indicate that the uplift were most significant under profile P2 in this area. The shape of these granulites shows that the uplift was very important around the transition zone between the CC and the PAB. All the formations found in this study are outcropping in the neighboring west zone of the study area studied by *Tadjou et al.* (2009) and *Shandini et al.* (2010). The basement configuration and faults cannot be mapped directly using conventional field methods due to the blanket of Pan-African units whose thickness can be considerable in places (*Shandini and Tadjou*, 2012). Considering previous studies in the surrounding regions (*Manguelle-Dicoum et al.,* 1992; *Meying et al.,* 2009; *Tadjou et al.,* 2009; *Shandini et al.,* 2010; *Ndougsa et al., 2012*), and based on our modeling, we have proposed that there is a fault in this transition zone between the CC and the PAB. The overthrusting of Pan-African units onto the CC is not well shown in the models due to the limits of the conventional field methods; but the interval between the GCCL and the geophysical limit could represent the amplitude of the overthrusting at each model. Therefore, the granulites are deeper structure of the PAB on the geological point of view. The observation of the models shows that the source depths are in the range of 400 to 700 m; this is in agreement with aeromagnetic studies in a part of this study area (*Ndougsa et al.,* 2012). The changing on structural formation in the basement is confirmed by the presence of a closed zero contour between positive and negative isogal contours. The maximum depth observed in this work might represent the discontinuity between the upper crust and the lower crust in the region.

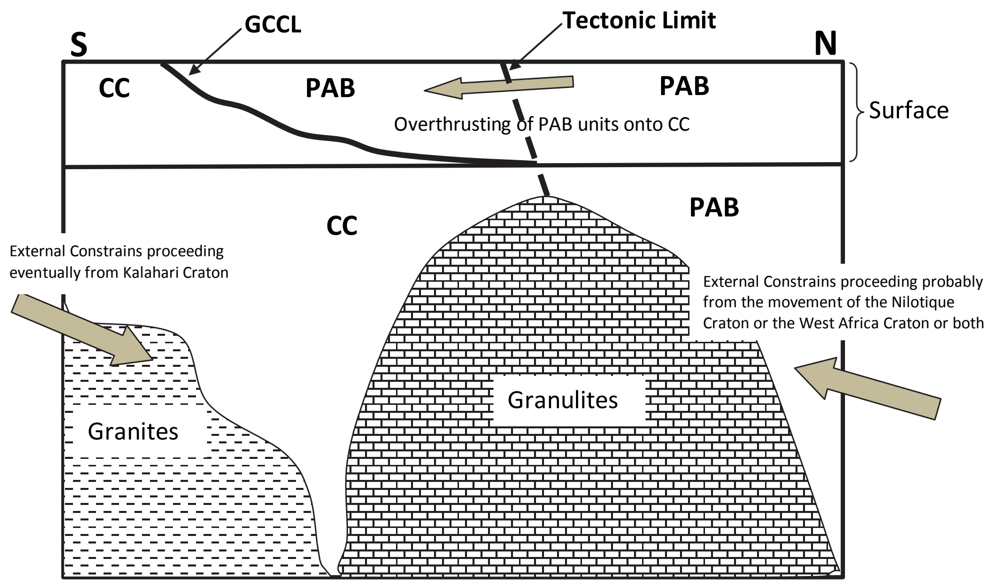

Fig. 10. Schematic model demonstrating the geometry of the collision process and location of rock types modeled.

7 Conclusion

The present investigation indicates that the upper crust geological models along the study area (particularly around the contact between Congo Craton and the Pan-African Belt) are similar. Metamorphic rocks are granulites located mainly around the contact of the two blocks. The important gradient observed on the residual anomaly map across the region might not be due only to the fault between Congo Craton and the Pan-African belt, but also to the tectonic uplift of dense materials (granulites) around and along the faulted zone. The spectral analysis permits us to determine the depths of shallower relative deep structures. The correlation of the 2.5D models obtained to the geology of the area has laid us to confirm the existence of two different blocks (CC and PAB) as shown by *Tadjou et al.* (2009) and *Shandini et al.* (2010). The gravity study also suggests that the northern margin of the Congo Craton is a product of convergent collision as has been suggested for the eastern margin of the West African Craton and the Pan-African belt (*Bayer and Lesquier*, 1978, *Tadjou et al.,* 2009). This collision that happened during the Panafrican orogeny cause considerable overthrusting of the Pan-African units onto the Congo Craton (Fig. 10); this overthrusting is not very well illustrated in the models due to the limits of conventional field methods and being in accordance with recent studies as *Toteu et al.* (2004) and *Shang et al.* (2004). In this paper, residual gravity anomalies and spectral analysis permit us to identify two main discontinuities beneath the upper crust. Synthesis of our data and literature also allows us to propose a gravity model that illustrates the structure of the subsurface along four profiles chosen by considering different anomalies and the main trend of the most significant anomaly on residual map of the study area.

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