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Gravity Data Interpretation in the Northern Edge of the Congo Craton, South-Cameroon

Interpretação Gravimétrica na Borda Norte do Cráton do Congo, Sul de Camarões

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Abstract

Gravity data in the southern Cameroon are interpreted to better understand the organization of underlying structures throughout the northern edge of the Congo craton. The Bouguer anomaly maps of the region are characterized by an elongated SW-NE trending negative gravity anomaly which correspond to a collapsed structure associated with a granitic intrusion beneath the center of the region and limited by fault systems. We applied 3-D gravity modelling and inversion in order to obtain the 3-D density structure of the area. Our result demonstrated that observed gravity anomalies in the region are associated to tectonic structures in the subsurface. The resulting model agrees with the hypothesis of the existence of a major continental collision zone between the Congo Craton and the Pan-African belt. The presence of deep granulites structures in the northern part of the region expresses a continental collision.
Keywords: Bouguer anomaly; Congo Craton; Spectral analysis; 3D gravity modelling

Resumo

Um conjunto de dados gravimétricos, provenientes do sul de Camarões, foram interpretados para o melhor entendimento das estruturas em sub superfície na borda norte do Cráton do Congo. Os mapas de anomalia Bouguer desta região foram caracterizados por uma anomalia gravimétrica negativa de direção SW-NE, que corresponde a uma estrutura de colapso associada com uma intrusão granítica, abaixo do centro desta região, e que está limitada por um sistema de falhas. Foram utilizados métodos de modelagem gravimétrica 3 D e inversão, para se obter uma estrutura densa 3-D desta área. Os resultados demonstraram que as anomalias gravimétricas observadas na região estão associadas com estruturas tectônicas em sub superfície. O modelo resultado está em consonância com a hipótese de existência de uma zona de colisão continental principal entre o Cráton do Congo e o Cinturão Pan-Africano. A presença de estruturas granulíticas profundas na borda norte desta área indica uma colisão continental.
Palavras-chave: anomalia Bouguer; Cráton do Congo; análise espectral; modelagem gravimétrica 3 D

1 Introduction

A craton is a stable part of the continental lithosphere which has not been deformed for a longtime (Bates & Jackson, 1980). However, in collision zones, cratons can be partially reactivated giving rise to geological characteristics different from the cratonic quiescence as well as from the intense activity occurring in a mobile belt. This has been called metacratonic evolution (Abdelsalam *et al*., 2002).

The Congo craton is belted on its northern edge by a mobile pan-African domain. This mobile domain belongs to the pan-african belt in central Africa also known as Oubanguides (Pin and Poidevin, 1987). The interactions between this mobile domain and the Congo craton are partially understood from geological studies and yield to various and divergent tectonic models that broadly correspond to collision between the Congo craton and the mobile belt (Poidevin, 1983 ; Nzenti *et al*., 1984, 1988 ; Rolin, 1995 ; Penaye *et al*., 1993 ; Trompette, 1994 ; Castaing *et al*., 1994 ; Abdelsalam *et al*., 2002 ; Toteu *et al*., 2001 ; Toteu *et al*., 2004 ; Toteu *et al.,* 2006). The most relevant geophysical studies done in the transition zone between the Congo craton and the Pan-African belt includes audiomagnetotelluric investigations by Manguelle-Dicoum *et al*. (1992) and Mbom-Abane (1997), and gravity analysis by Tadjou (2004) and Tadjou *et al.* (2004). These studies were carried out in the area to determine the subsurface structures of the schist-granite contact and the Congo Craton boundary. Despite conclusions provided in these studies, there is no consensus on the evolution of the northern edge of the Congo craton since the position of the main suture zones and the character of the different tectonic units are still debate matters (*e.g*. Toteu, 2007).

In this study, we present a new look on the subsurface structure setting of the transition zone between the Congo craton and the Pan-African belt in southern Cameroon using the existing gravity data. The gravity data in the study area are separated into regional and residual Bouguer anomalies using an analytical technique based on polynomial fitting. Three-dimensional inverse gravity modelling was then applied to residual anomalies in order to obtain the 3D density structure model of the area. The major goal of this model is to contribute to an integrated understanding of the geodynamic features and processes of the northern edge of the Congo craton.

2 Geological Setting

The area under study lies in southern Cameroon, located in the transition zone between the Congo craton and the Pan-African belt of West Africa. Two structural domains can be distinguished in this study area: the Ntem complex (Congo craton) and the Yaoundé group (Pan-African belt) (Figure 1). The Ntem complex represents the north-western part of the Congo craton in Central Africa and is very well exposed in Southern Cameroon (Maurizot *et al*., 1985) (Figure 1). The complex is composed dominantly by younger intrusive complexes and by banded series composed of gneisses. Intrusive complexes are primarily constituted 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).

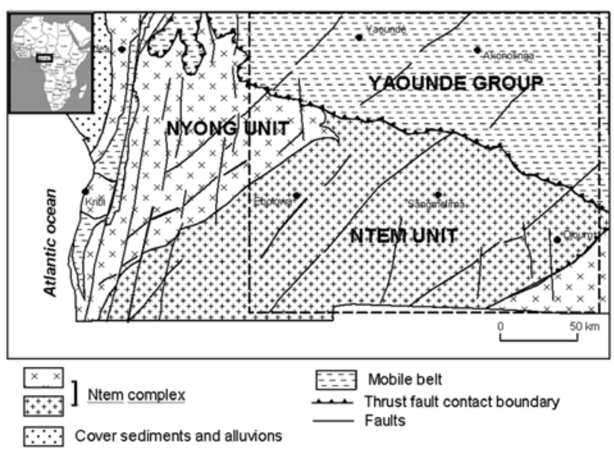

Figure 1 Schematic map of the south-western Cameroon. The Ntem complex consists of the Ntem and Nyong units. The study area is marked with dotted lines.

The different lithological groups include Archean greenstone belts, now only preserved as xenoliths of variable size in the younger intrusive complexes (Nsifa *et al.,* 1993; Tchameni, 1997). The tonalitic suite is essentially exposed to the north and is strongly mylonitized and retrogressed along the fault boundary with formations of the Yaoundé Group (Figure 2).

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The Yaoundé group is a huge allochtonous nappe thrusted southward onto the Congo craton. It comprises low- to high- grade garnet-bearing schist, gneisses and orthogneisses transformed under a medium- to high- pressure metamorphism reaching the granulite facies (Toteu *et al.,* 2004). In the study area, Yaoundé, group consists of the Mbalmayo-Bengbis series and the Yaoundé series known as "intermediate series". The Mbalmayo-Bengbis series are composed of schist and quartzites re-crystallized in the conditions of the greenschist facies (Vicat, 1998). The Yaoundé series consist of strongly deformed meta-sedimentary rocks and migmatites (Nzenti *et al.,* 1988). This series includes chlorite-rich schist, garnet- and (or) kyanite-bearing micashists, and garnet- and kyanite bearing high-grade gneisses thought to be derived from pelites and greywackes either in a continental basin or a passive margin environment (Nzenti *et al.,* 1988).

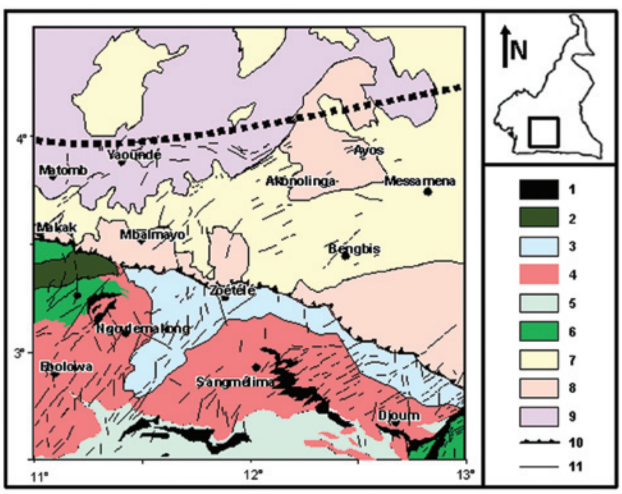

Figure 2 Geological sketch map of the study area (after Maurizot, 2000). 1. Iron formation; 2. Orthopyroxène bearing gneiss; 3. Tonalitic suite (TTG); 4. Charnockitic suite (TTG); 5. Banded series; 6. Biotite-horblende gneiss; 7. Micaschists (YS); 8. Epischist (MB); 9. Gneiss (YS); 10. Major thrust (Pan African); 11. Lineaments. The dashed line at the latitude of Yaoundé (4°N) is the assumed limit of the Congo craton (this study).

The structural data show a definite deformation on the surface, which is characterized by flat structures gently sloping to the North with a generalized tilting towards the South or South-West, indicating a significant overlap of intermediate formations on the basement of the Ntem complex. This deformation is seen by the presence of folds sloping to the North (Maurizot *et al.*, 1985). Generally, 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; Manguelle-Dicoum *et al.*, 1992). This basement movement must have provoked irregularities in the formations at depth, giving rise to faults, horsts and grabens characteristic of the boundary between the Congo craton and the Pan-African fold belt.

3 Gravity Data and Analysis

Gravity data consist of 617 Bouguer anomaly values (Figure 3) coming from the database of the Institut Français de la Recherche Scientifique pour le Développement en Coopération (ORSTOM) (see *e.g.* Creen, 1967; Collignon, 1968). The Bouguer anomaly values are the result of the Faye reduction referred to the ellipsoid, of the indefinite plate reduction with a constant reduction density of 2.670 g/cm^3 and of the topographic reduction. The gravity survey accuracy is estimated to be about 0.5 mGal

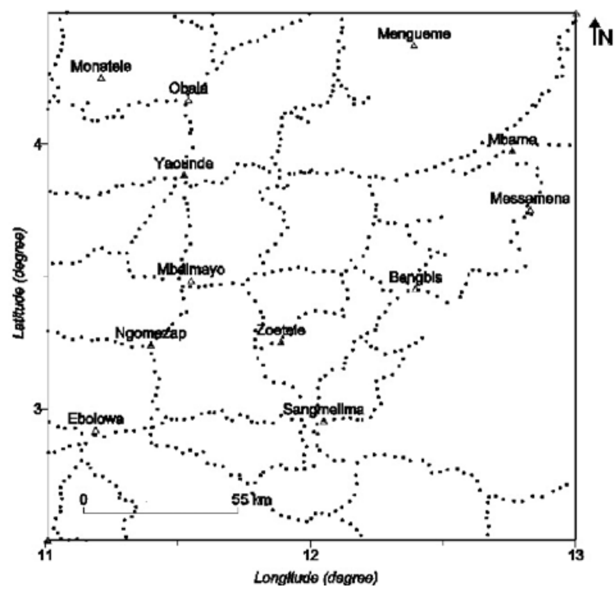

Figure 3 Study area map showing the gravity stations (dots).

In the study area, the Bouguer anomaly map (Figure 4) shows a predominant gravity low trending SW-NE to E-W and bounded by relatively steep gradients on the north and the south sides (Figure 2). The shape of this anomaly in the southern margin of the area on the Bouguer map is similar to that of the So'o granites in the geological map. In the north of this anomaly, a zone of small gravity highs,

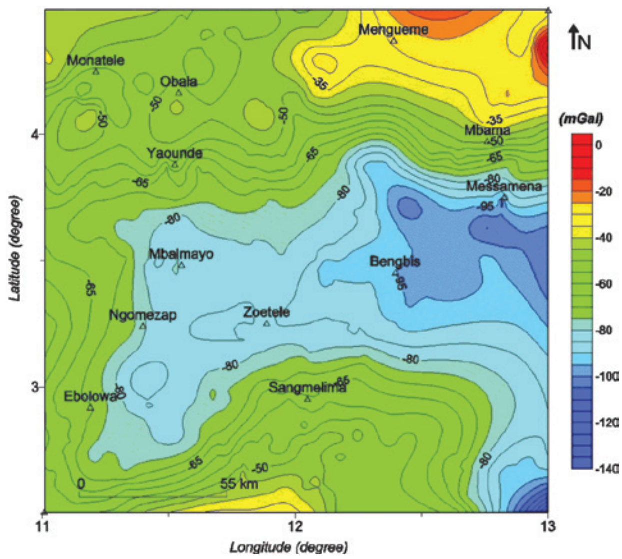

Figure 4 Bouguer anomaly map of the study area.

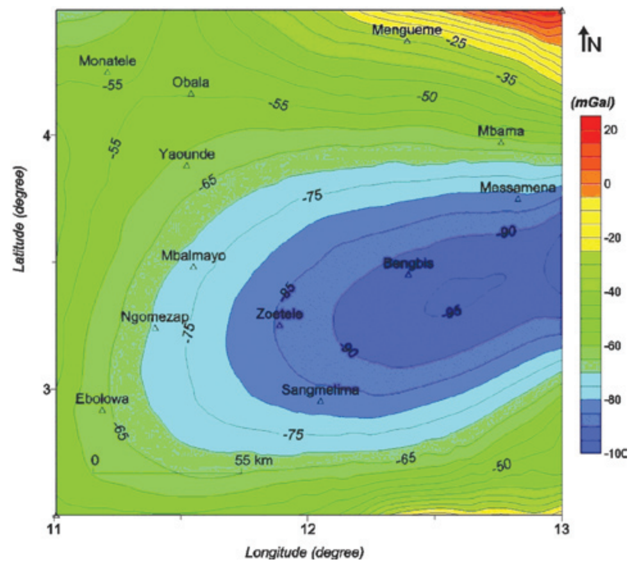

Figure 5 Third-order regional anomaly map of the study area.

bounded by relatively steep gradients, occur over or near higher metamorphic formations (granulites, migmatites and micaschists) and other granitic plutons. The presence of high gravity gradients, which occur over these basic intrusive rocks, suggests the existence of a suture zone between two blocks of the crust (Kennedy, 1984). The southern border of the area is characterized by a relatively positive anomaly trending SW-NE, which seems to represent a signature of the dense rocks (charnockites) in this zone.

The present study is based on qualitative and quantitative analysis of the gravity data to delineate both shallow and deep basement structures. The Bouguer gravity potential field data carries regional and local gravity effects, therefore isolation of regional and residual effect is made by polynomial fitting. The regional surface is expressed mathematically as a two-dimensional polynomial of an order that depends on the regional geology complexity. Inherent in this method is the assumption that all long wavelength gravity anomalies are derived from deep sources and constitute the regional gravity anomaly. While residual anomalies are due to the gravitational attraction of local or near surface geological structures having different densities and tectonic position.

The regional gravity field was separated from the Bouguer gravity field by developing polynomial of the 3th degree. The regional structure (Figure 5). is characterized by a broad negative gravity low with a minimum gravity of – 100 mGals in the center and by gradients increasing towards the east and the north. It may be inferred from these observations that the basement is deepening towards the center of the region thus indicating the crustal thickenning. Indeed, using spectral analysis of gravity data, Tadjou *et al.* (2009) obtained the crustal thickness beneath the northern edge of the Congo craton to vary from 25 km in the west to 32 km in the north and 47 km in the centre of the craton.

The residual gravity field is determined by subtracting the regional gravity from the Bouguer gravity and is shown in Figure 6. This is due to the gravitational attraction of local or near surface geological structures having different densities and tectonic position.

The residual gravity map is characterized like the Bouguer anomaly map by a large negative anomaly with a NE-SW trend. A comparison of the main negative anomaly of this map with the geological map (Figure 2) shows that it is centered on schist and quartzite formations. The southwest portion of this anomaly occurs over outcrops of the So’o granitic rocks in the Ebolowa area. This anomaly may be due to an intrusion of the So’o granite within the basement of the area, which has a low density contrast with respect to the surrounding rocks in the basement (Tadjou *et al.*, 2004, 2009).

The northern part of the residual gravity map is characterized by positive short wavelenght

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anomalies which are uncorrelated with surface geology. These anomalies may indicate a basement uplift and/or lateral difference in the density from causative rocks. The southern positive anomaly, which trends SW-NE at Sangmelima, on the basis of geological considerations, can be interpreted in terms of the intrusion of igneous charnockites of the TTG group.

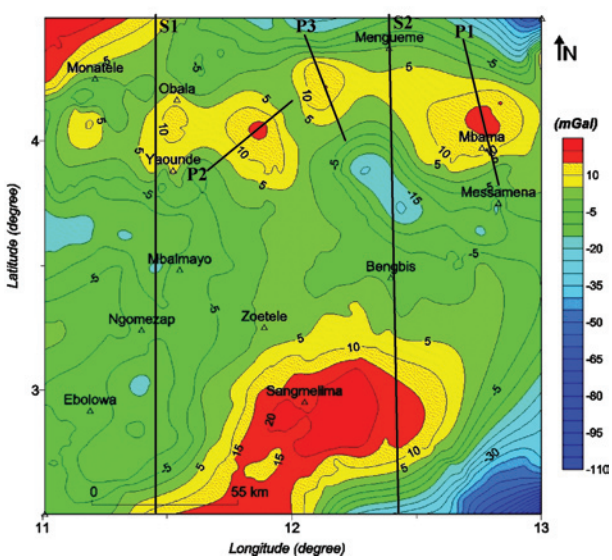

Figure 6 Third-order residual anomaly map of the study area (Intervals : 5 mGal) showing studied profiles (P1, P2 and P3) and selected 3-D density model cross sections (S1 and S2).

The residual anomaly data which represents the detected gravimetric effect of the shallower subsurface structures was used for modelling and inversion in order to obtain the 3D density structure of the study area.

4 Method

For three-dimensional gravity modelling and inversion, we used an interactive computer program for visualization and editing of large-scale 3D models (Bloxer) and a gravity modelling and inversion software (Grablox) based on a 3D block model (Pirttijärvi, 2004). The program Grablox uses two major inversion methods, namely, singular value decomposition (SVD) and Occam inversion (Hjelt, 1992). In each method three possible ways to parameterise the model (height, density and height + density inversions) are available.

However, gravity data inversion, has a non-unique solution as gravity anomalies result from the sum of all the gravity effects in the subsurface (*e.g.* Skeels, 1947; Chakraborty & Agarwal, 1992; Strykowski, 1998). The way to reduce the instability and to guarantee the uniqueness of the solution is to integrate geological and geophysical constraints into the forward modeling. The geological constraints (density values) used for the study area were determined from the density values published in some recent works (Mbom Abane, 1997; Tadjou *et al.*, 2004). Geophysical constraining focused on direct interpretation of the gravity field by power spectrum analysis method. The residual anomalies were studied by spectral analysis to constrain depth of perturbing bodies responsible of northern positive anomalies which are uncorrelated to surface geology. According to this method as described by Spector & Grant (1970), the depth of perturbing body source is obtained from the negative slope of the linear relationship between the logarithmic power spectrum and the gravity field wave number.

On the basis of the available constrains, a starting model was built up by approximate the region by 8 km x 8 km x 1km blocks. The initial density distribution was progressively changed by means of a trial-and-error procedure using Grablox program to compute the Bouguer anomaly of the model and to compare it to the observed Bouguer anomaly. When the best fitting between the observed and calculated gravity was made as good as possible, inversion was carried out using the singular value decomposition (SVD) inversion method in order to improve the fit to the observed Bouguer anomaly.

5 Results and Discussion

5.1 Spectral analysis

Three profiles P1, P2 and P3 were chosen according to the principal directions of the northern positive anomalies (Figure 6). The power spectrum curves obtained for the profiles are presented in Figure 7. On these curves, two straight line segments can be identified and plotted by a least squares fitting on the data points. The mean depth of density contrast plane is represented by h1 in the low frequency range associated to deep-seated bodies and h2 in the high frequency range caused by bodies at near surface.

The mean depth estimates for the deepest discontinuities obtained for profiles P1, P2 and P3 are 13.8 km, 14.2 km and 14.6 km respectively. These depths may be interpreted as inter-basement density variations associated with the northern margin of the Congo craton, or the upflit of the upper mantle in the northern part of the area. These results are consistent with those obtained by Nnange *et al.* (2000) who determined a major density discontinuity in the crust beneath the Congo craton area at depth 13 ± 1 km using spectral analysis of new gravity data in Cameroon. The shallowest depths obtained for the different profiles are 4.9 km, 4.7 km and 5.2 km respectively. These depths can be interpreted as mean depths of bodies responsible for the observed positive gravity anomalies in the northern part of the area.

5.2 Modelling and Inversion

The model obtained by means of inversion is shown in two vertical sections (S1 and S2) trending N-S (Figures 8 and 9). The general features of these sections are almost similar and have four principal bodies. Obviously, none of the bodies is expected to really have a homogenous density, because of both the presence of lithologic alternations and the natural increasing of density with depth. The main features modeled in the southern part of the model are lower density bodies (1) with densities ranging from 2.60 g/cm^3 to 2.65 g/cm^3. These bodies are correlated to granitic intrusion (So'o granites) in the upper crust which can reach 5 km and 7 km for sections S1 and S2 respectively. The granitic magma generation is related to crustal thickening of the region followed by the fracturing which must have leads to the collapse of large blocks of crust, with dimensions of several kilometres. Granitic magma was intruded along fractures in the upper, brittle, part of the crust. The negative Bouguer anomalies observed over the entire region can thus be attributed to the thickness of the crust associated with a granitic intrusion with a low density contrast beneath the center of the region. Our observations lead us to conclude that this granitic intrusion caused the subsidence of the basement along the northern border of the craton.

A layer with densities between 2.80 g/cm^3 and 2.90 g/cm^3 (2) was modeled as a basement high located in the southern area ; these formations

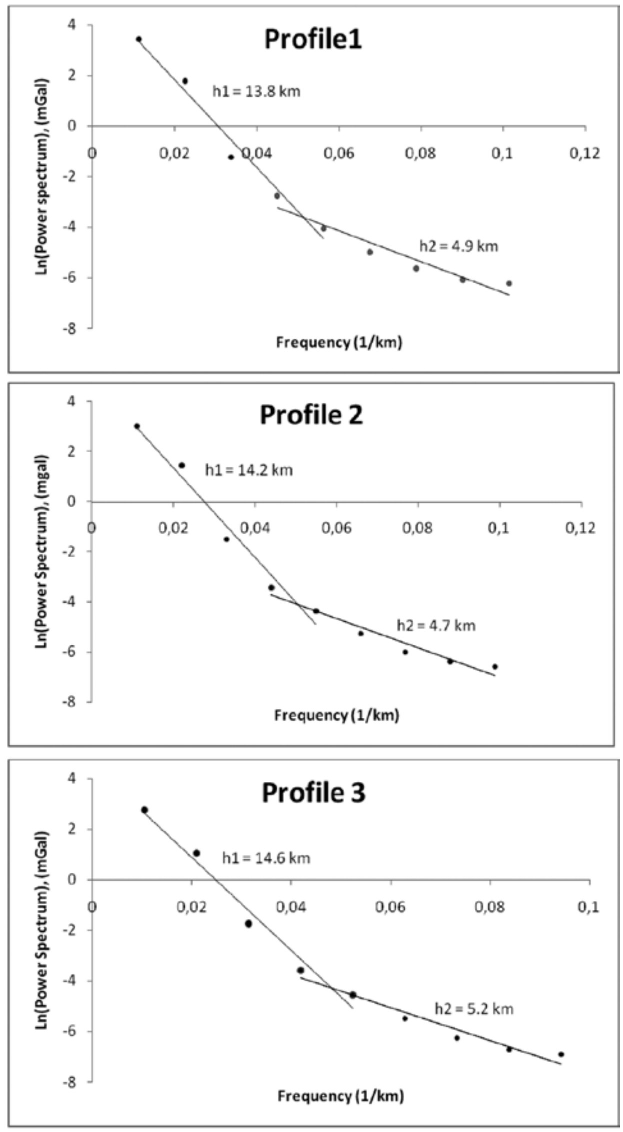

Figure 7: Plots of power spectrum versus the frequency for profiles P1, P2 and P3. h1: deep density contrast plane; h2: shallow density contrast plane

constitute the main pluton of the complex, and that it extends laterally at depth beyond So'o granites. It's structure follows the trend of a Bouguer gravity high in the southern part of gravity maps and represents charnockite formations. This body also penetrates under Pan-African formations (2) at depth of about 5000 m.

Pan-African formations (3) with densities between 2.65 g/cm^3 and 2.80 g/m^3 outcrop in the northern border of the model. These formations have a basin shape and overlay So'o granites. Beneath the Pan-African formations, constrained by spectral analysis results obtained for this work, 5 km deep high-density bodies (2.90 - 3 g/cm^3) (4) were added to the model to fit the observed Bouguer anomaly. These bodies underlie Pan-African formations and are deeply in contact with the charnockite bodies. These materials lie near the zone where high 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 intrusions emplaced along a suture during collision (Bayer & Lesquier, 1978). These bodies thus materialise the suture separating two blocks of different mean densities and can be interpreted as granulites rocks to have been put in place at the root of the collision zone.

The model for profile S1 puts the craton-belt boundary at 130 km (Figure 8) while profile S2 puts this boundary at 150 km distance (Figure 9); this suggests that the craton advances widely at depth toward the North-East, resulting in a SW-NE trending tectonic boundary between the Pan-African fold belt and the Congo craton in south Cameroon (Figure 2). Typically, craton-orogenic belt boundaries are marked by high gravity gradients but here this does not seem to be the case as the NW-SE trending thrust zone according to the geology maps (Figures 1 and 2) has no gravity expression. The interpretation suggests that there has been overthrusting of the Pan-African units onto the craton of about 50 to 150 km. The northern limit of the craton in the study area is concealed beneath Pan-African units (Figure 2) making gravity interpretation more appropriate tool for its delineation than surface mapping as it can delineate structural boundary where structural units have been overthrust.

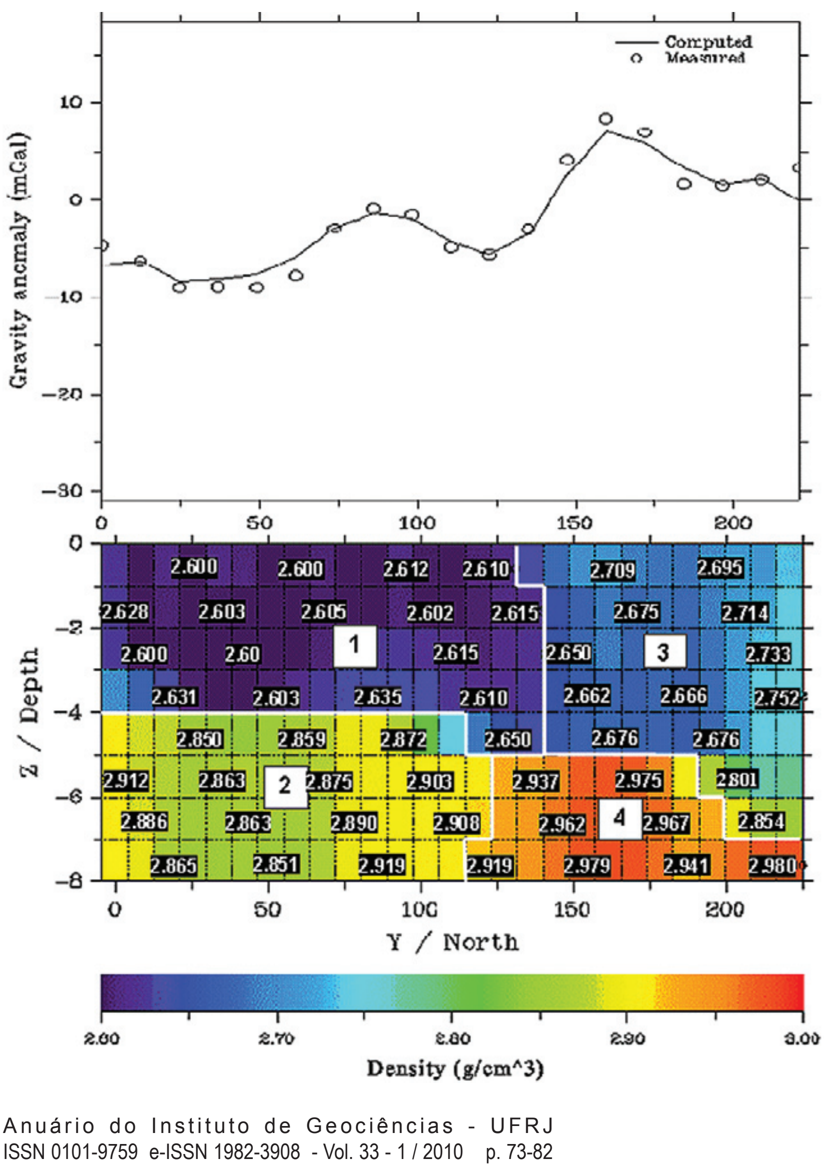

Figure 8 3D density model cross section (S1). **1**: So'o granites; **2**: Charnockites; **3**: Pan-African formations; **4**: Deep structures in Pan-African belt (granulites). In the upper box are shown the measured and calculated gravity anomalies.

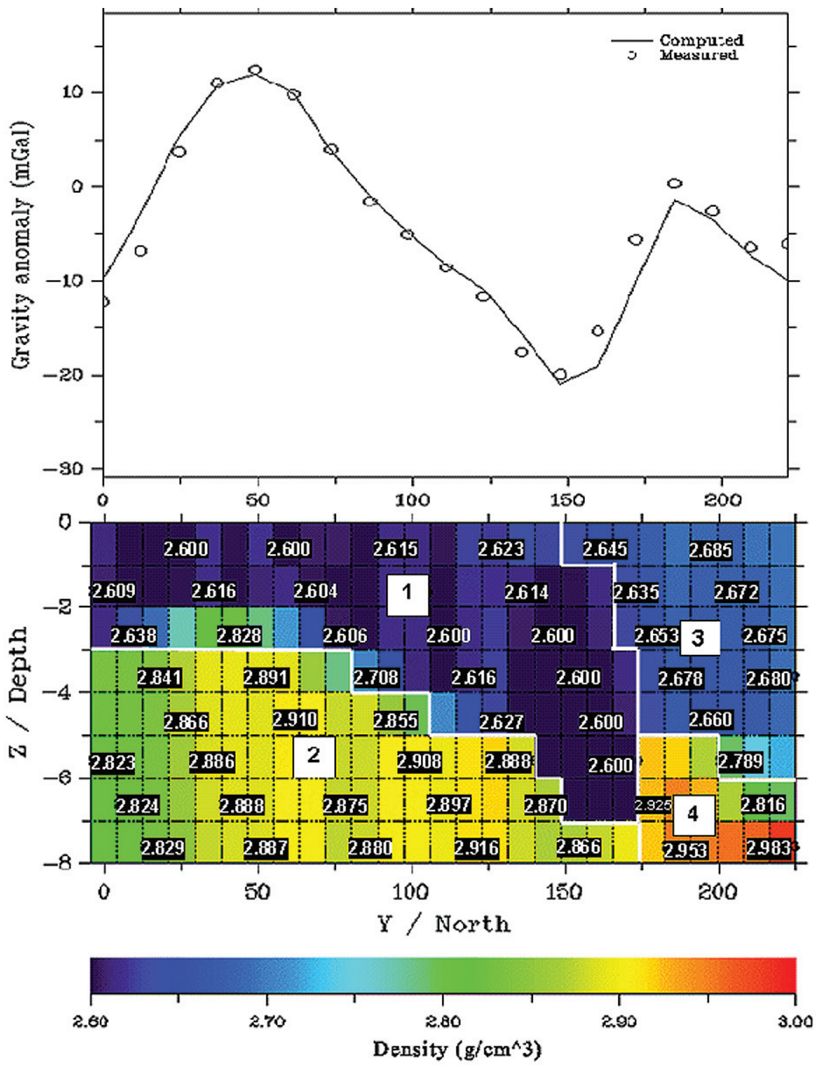

Figure 9 3D density model cross section (S2). **1**: So'o granites; **2**: Charnockites; **3**: Pan-African formations; **4**: Deep structures in Pan-African belt (granulites). In the upper box are shown the measured and calculated gravity anomalies.

The extension of the Congo craton under the Pan-African units was already suggested by previous geologic and geophysical studies (*e.g*. Nédelec *et al.,* 1986; Manguelle-Dicoum *et al.,* 1992; Tadjou *et al.,* 2004). This event marks the subduction of the Congolese craton under the Pan-African belt.

6 Conclusion

Gravity data interpretation in southern Cameroon shows that the observed negative Bouguer anomalies can be attributed to the subsidence of the basement along the northern border of the craton associated with a granitic intrusion with a low density contrast with thicknesses reaching 7 km. 3-D density modelling and inversion put into evidence in the northern margin of the Congo craton a deep structure corresponding to a classical model of collision suture as has been suggested for the western margin of the West-African craton and Pan-African belt (Lesquier & Louis, 1982; Bonvalot *et al.,* 1991). The resulting models lead us to agree with the previous geodynamical interpretations (*e.g.* Toteu *et al.*, 2004) that proposed a continent-continent collision involving the Congo craton and the Pan-African belt in central Africa.

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