Gravity modelling along the northern margin of the Congo craton, South-Cameroon

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ABSTRACT

Gravity data over the southern region of Cameroon are modelled for a critical analysis of the deep structure in the area. The Bouguer anomaly maps of the region show a wide low anomaly zone in the middle part. The main negative anomaly displays a prominent west-east trend, which seems to be similar to that due to major basement structures. This suggests that the region might have been intruded by low-density granite structures. There is also good correlation between the residual anomaly map and the geology with the negative anomaly occurring over the areas underlain by low density rocks corresponding to So'o granites or calco-alkaline granites, which outcrops along the river So'o south of Mbalmayo. This formation is also found to the north-eastern part of Sangmélima. The structural models obtained show that these rocks extend in depth towards the northern margin of the region, and form the schist quartzite basement. They also overlay the charnockitic basement at a depth situated of about 3500 m. We propose models where the different crustal segments are welded together and we discuss the existence of a suture zone further north, below the migmatites. Numerous slopes and gravity discontinuities observed on those models reveal the great structural complexity of the region. This complexity confirms the hypothesis of continental collision models, between the Congo Craton and an active continental block in the north. This collision might have provoked an up throw of Pan African formation in the north over the Congo Craton formations in the south.

Key words : Bouguer anomaly, Craton, Panafrican, So'o granites, fault, density contrast, batholite, collision.

RESUME

Des données gravimétriques existantes au Sud-Cameroun sont modélisées pour une étude critique de la structure profonde de la région. La carte d'anomalie de Bouguer de la région met en évidence dans sa partie centrale une vaste zone d'anomalies légères (négatives) ; ces anomalies orientées presque W-E, semblent liées à l'effet de structures profondes. En accord avec les données géologiques, l'interprétation des données permet de les associer à l'effet de l'intrusion de roches granitiques légères. La corrélation entre la carte d'anomalies résiduelles et la géologie de surface permet de déduire que ces anomalies se situent à l'aplomb des roches de faibles densités, que nous assimilons aux granites de So'o ou granites calco-alcalins et qui affleurent de part et d'autre le long de la rivière So'o au Sud de Mbalmayo. Ces formations s'étendent aussi au Nord-Est de la région de Sangmélima. Les modèles de structures obtenus montrent que ces roches s'étendent en profondeur vers le Nord, constituant ainsi le substratum des schistes et quarzites ; elles reposent sur les charnockites à des profondeurs d'environ 3500 m.
Nous proposons des modèles où les différents segments crustaux sont accolés les uns aux autres, et nous discutons de l'existence probable d'une zone de suture plus au Nord sous les migmatites. De nombreuses ruptures de pentes et discontinuités qu'on observe sur les modèles reflètent la complexité géologique et structurale de la région. Cette complexité semble confirmer la thèse d'une collision continentale entre la marge septentrionale du Craton du Congo et une marge continentale active au Nord. Cette collision semble avoir provoqué un déversement des formations du panafricain au Nord sur celles du Craton au Sud.

Mots clés : Anomalie de Bouguer, Craton, Panafricain, granites de So'o, failles, contraste de densité, batholite, collision.

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Introduction

This paper presents gravity data and its geological interpretation, for a continental domain located in southern Cameroon. This region shows many geological features with different ages, which can be divided into cratonic and Pan-African domains. The cratonic domain belongs to the northern margin of the Congo Craton while the Pan-African domain consists of the intermediate series of the central African mobile zone (Champétier de Ribes and Aubague, 1956 ; Gazel and Giraudie, 1965). Given the complexity of the region, we have used this work to propose a crustal structural model for the region based on gravity study.

The study area is bounded by latitudes 2°25'N and 4°N, and longitudes 11°E and 13°E. The region is in the equatorial rainforest, characterised by a vast peneplain, with an average altitude of 700 m, dotted with inselbergs with average heights of about 1000 m. Previous geophysical work carried out in this region includes gravity investigation by Mbom-Abane (1997) and audiomagnetotelluric investigations by Manguelle-Dicoum (1988) and Mbom-Abane (1997). These studies were carried out to determine the subsurface structure of the region from which a further interpretation has been proposed. The main objective of this study is to propose a model of crustal structure by modelling the residual gravity field.

Geological setting

A geological survey of the region was first undertaken by Champétier de Ribes et Aubague (1956) and Gazel et Giraudie (1965). These studies were followed by recent structural and petrographical data by Nzenti et al. (1984) and Nédélec et al. (1986), which suggest intense tectonic movements during which the Pan African mobile belt was thrusted southwards over the Congo craton.

The region under study forms part of the Precambrian basement of southern Cameroon and is subdivided in two main petrographic and structural units as shown in Figure 1 (Bessoles et Lasserre, 1977) :

-To the south, there is a cratonic complex (or Ntem complex) of Archaen age which is the northern extension of the Congo Craton. It consists of

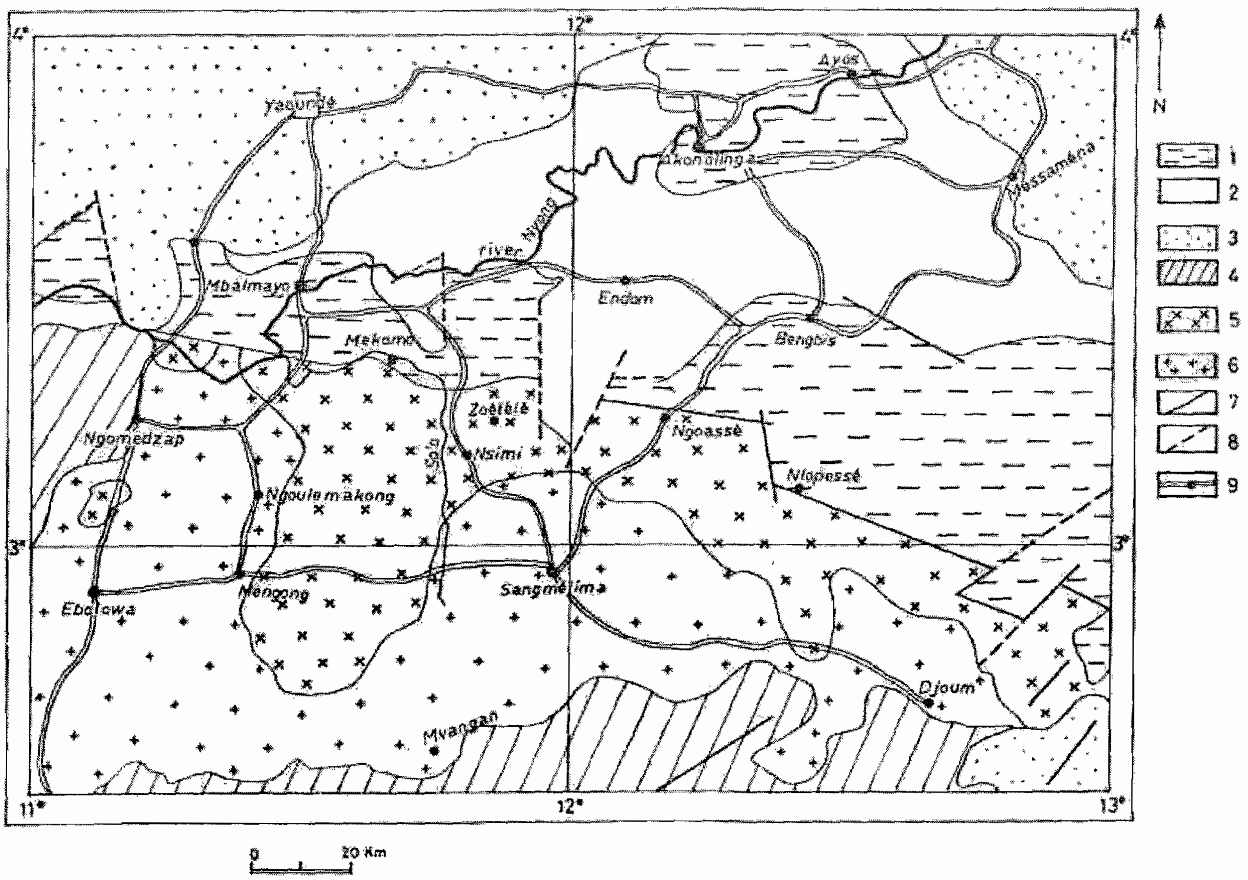

Fig. 1: Geological map of the region (After Champetier de Ribes, 1956)
1: Mbalmayo-Bengbis Schists or quartzites (Pan-African); **2** : Micaschists (Pan-African); **3** : Grenatiferous gneiss (Pan-African); **4** : Gneiss with pyroxene (Congo Craton) ; **5** : So'o granites (Congo Craton) ; **6** : Charnockites (Congo Craton); **7** : Observed fault ; **8**: Proposed fault; 9: localities.

intrusive rocks (So'o granites), charnockites and TTG (tonalites, trondhgnites and granodiorites).

-To the north of the craton, there is a Pan-African zone of proterozoic age called the Yaoundé group. It consists of overlying formations made up of beds composed of the Mbalmayo schists to the south, and occupies an E- W belt about 1500 km^2 in area (Champétier de Ribes and Aubague, 1956 ; Gazel et Giraudie, 1965). They dip to the north, and merge into the Yaounde grenatiferous gneiss to the north without any major lithological break. These include the micaschist and quarzite formations in Endom area (Gazel et Giraudie, 1965 and Nedelec et al., 1986).

The region generally has a complex and uneven tectonic structure. This tectonic structure seems to have given rise to a vertical movement of the basement with subsidence to the North and uplift to the South. This movement of the basement must have provoked irregularities in the formations at depth. These irregularities give rise to faults and grabens. This zone is interpreted as an extensive domain situated in the northern margin of the Congo craton (Nzenti et al., 1984). The geodynamic and geological setting of the area is that of an intra-continental basin (Nzenti et al., 1984 ; 1998).

Table 1: Origin of Gravity data in Cameroon (after Legeley-Padovany et al., 1996)

Periods	Organisations or institutions
1960 - 1967	ORSTOM
1968	University of Princeton
1980	ELF
1982	University of Leeds
1984 - 1988	IRGM – University of Leeds

Gravity data

Gravity data for this work were collected firstly between 1963 and 1968 during a detailed gravity survey of Cameroon and Central Africa undertaken by ORSTOM (Collignon, 1968) and secondly between 1980 and 1990 by other organisations (table 1). The data were collected at 4 km intervals at all gravity stations including base stations, on all available roads and tracks in the area, using Worden gravimeters (n°313 and 600) with a scale precision of 0.2 mgal/division. The gravimeter readings were corrected for drift and the anomaly values, each 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. The resulting Bouguer anomalies were then plotted to obtain a Bouguer

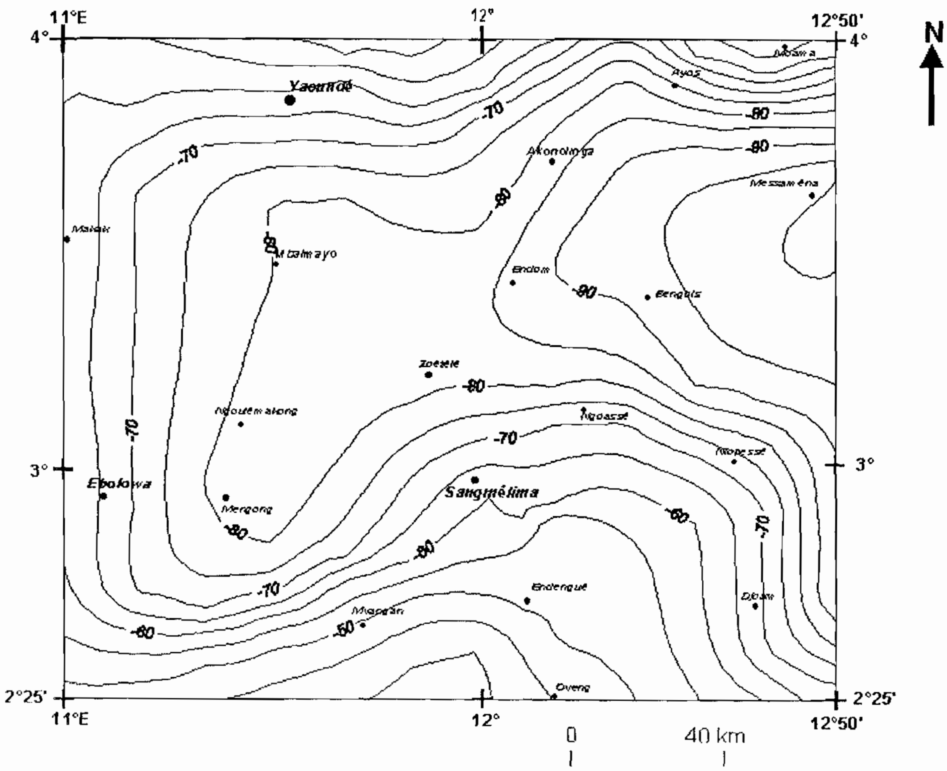

Fig. 2: Gravity Anomaly map of the area

anomaly map (Fig.2) with contoured interval of 5 mgal. This map which is broadly similar to those reported by Collignon (1968) and Legeley-Padovani et al. (1996) based on the same data, was obtained using the minimum curvature interpolation technique (Inoue, 1986); an appropriate software computer program for carrying out minimum curvature interpolation procedure (Golden software Inc. 1993) was used to grid data in this study.

- *Description of the Bouguer anomaly*

The main feature of the anomaly field on this map is the belt of highly negative anomalies with E-W trends. A close look at the Bouguer anomaly map (Fig. 2) shows that in general low gravity anomalies prevail in the centre of the area. These anomalies are not related to any surface geologic structure. A comparison of the main features of this map with the geological sketch map (Fig. 1) shows that this central negative anomaly, with minimum amplitude of approximately –100 mgal in Messamena zone, is entirely located on the Mbalmayo-Bengbis schist and quartzite formations. It is pertinent to mention that 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. The northern border of this anomaly is characterised by very high S-N gravity gradients and the anomalies in the region are positive relative to those of the immediate surroundings. These anomalies occur over or near higher metamorphic formations (granulites, migmatites and micaschists) and other granitic plutons. The observed zones of high gravity gradients, which occur over these basic intrusive rocks, suggest the existence of a suture zone between two continental blocks. The southern border of the area is characterised by a relatively positive anomaly trending E-W.

Table 2: Average densities of rocks in the area (after Mbom-Abane, 1997)

Rocks types	Sample range g/ cm³	Mean density g/ cm³
Granites	2.5 - 2.8	2.6
Gneiss	2.6 - 3	2.8
Metamorphic rocks	2.4 □3.1	2.74
Quartzites	2.5 □2.7	2.6
Charnockites	2.9 □3.1	3
Migmatites	2.6 - 3	2.8
Schistes	2.4 □2.9	2.64

- *Separation of gravity anomalies.*

The Bouguer anomaly includes the effects from deep sources, shallow sources and from lateral inhomogeneities. The anomalies coming from very superficial sources having been removed during the preliminary smoothing, the regional-residual separation helped to isolate the anomalies due to deep sources, from those due to less extensive and lower density contrasts. Be-

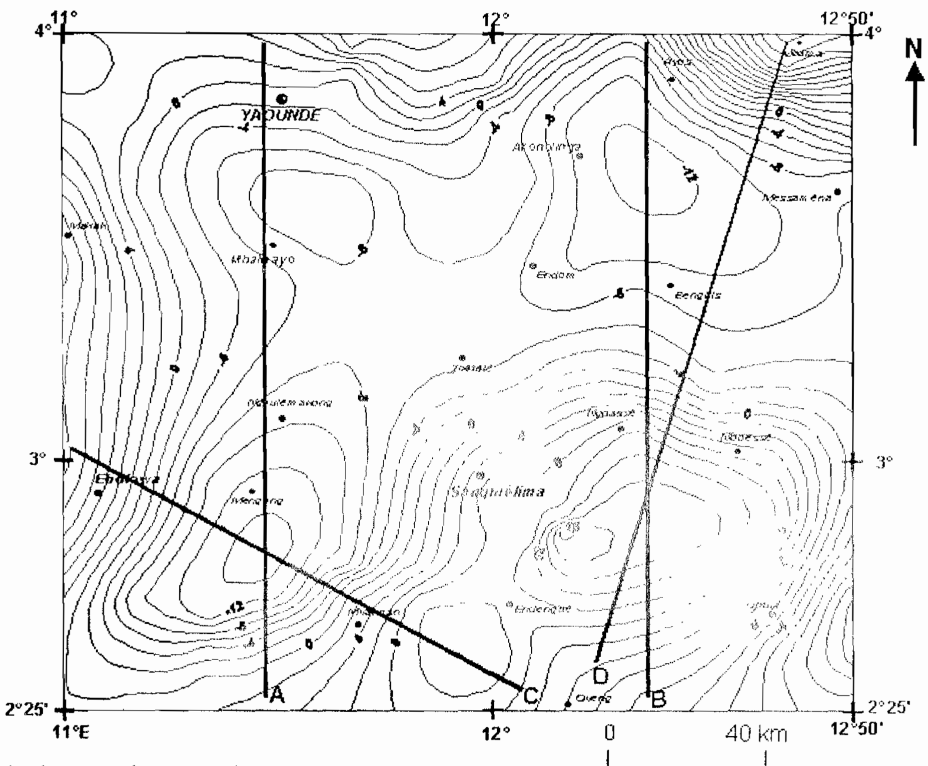

Fig. 3: Residual anomaly map ot area
A : interpreted profiles

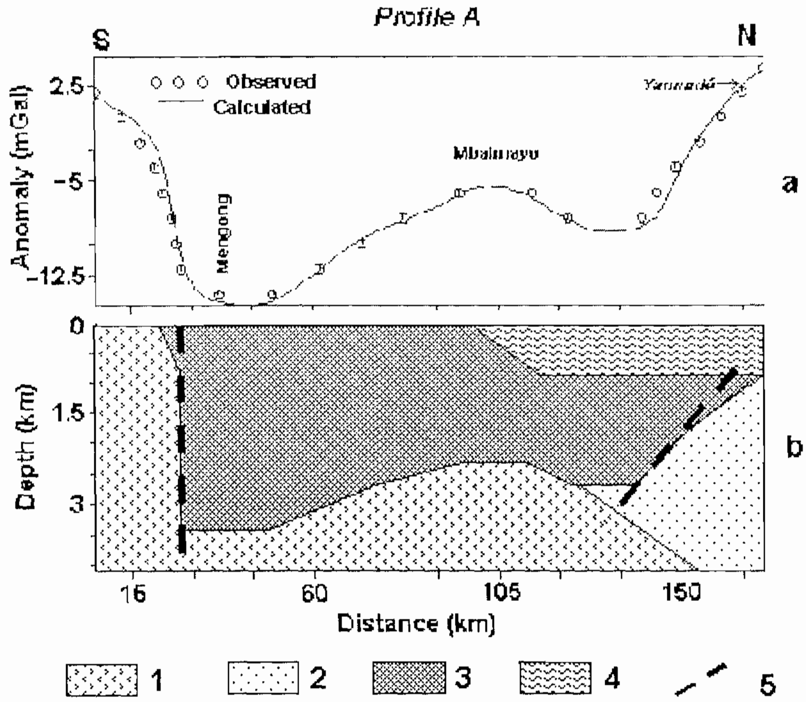

Fig. 4: Profile A:
a: Residual Anomaly Profile
b: Interpreted model (**1**: Charnokites; **2**: Migmatites; **3**: So'o Granites; **4**: Pan-African formations; **5**: fault)

fore being interpreted, the observed data are separated into regional and residual anomalies. The method used in the separation is one of the most flexible analytical techniques, that of polynomial fitting. The observed data are used to compute, by least-squares method, the mathematical surface giving the closest fit to the gravity field that can be obtained within a specific degree of details (Skeels, 1967). This surface is considered to be the regional gravity anomaly. The residual is obtained by subtracting the regional field thus

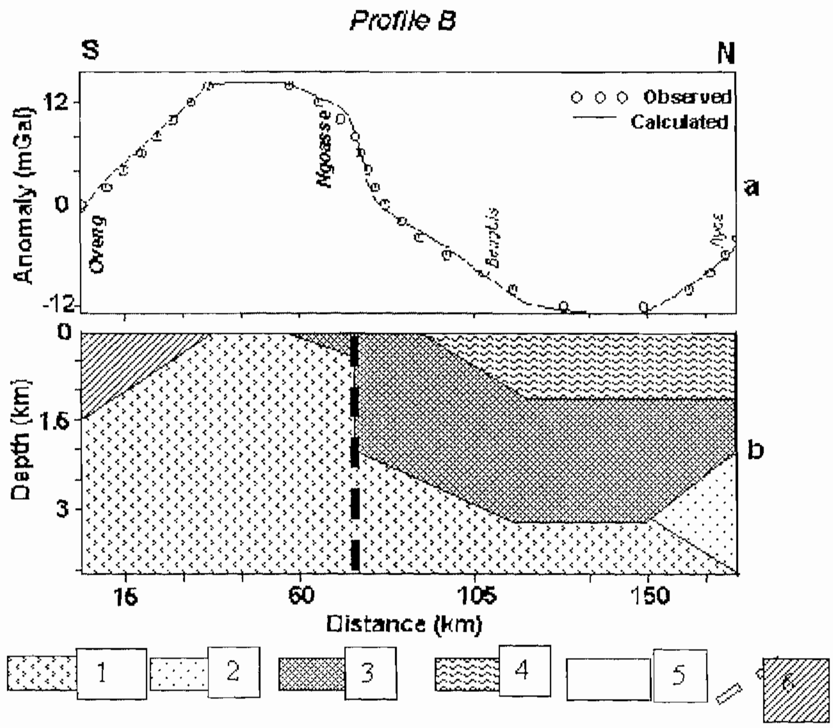

Fig. 5: Profile B:
a: Residual Anomaly Profile
b: Interpreted model (**1**: Charnokites; **2**: migmatites; **3**: So'o Granites; **4**: Pan-African Formations; **5**: gneiss formations; **6**: fault)

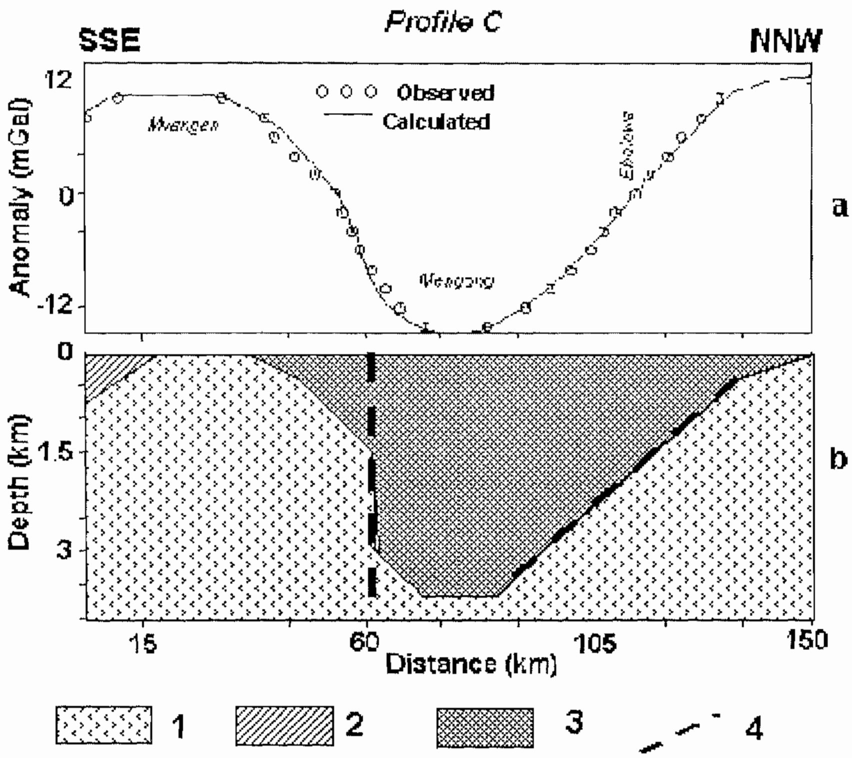

Fig. 6: Profile C:
a: Residual Anomaly Profile
b: Interpreted model (1: Charnokites; 2: gneiss formation; 3 So'o Granites; 4: fault)

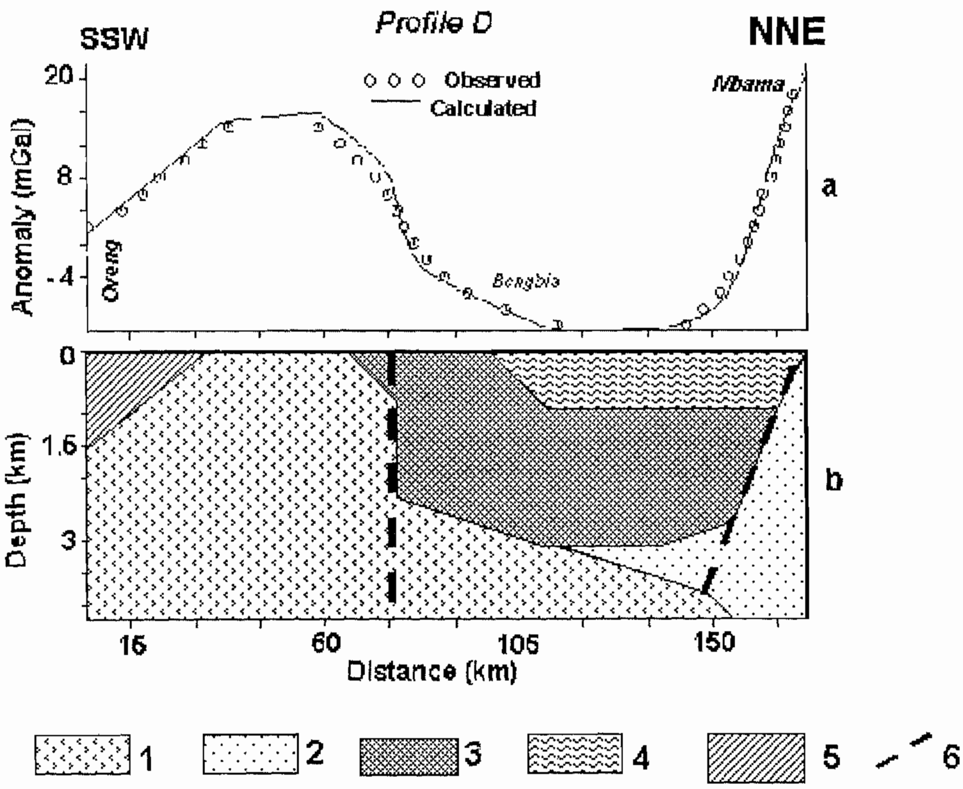

Fig. 7: Profile: D
a: Residual Anomaly Profile
b: Interpreted model (1: Charnokites; 2: migmatites; 3: So'o Granites; 4: Pan-African Formations; 5: gneiss formations; 6: fault)

determined from the observed gravity field. The regional surface is considered in practice as a two-dimensional polynomial and the order of this polynomial depends on the complexity of the geology of the study area. The method of polynomial fitting (Radhakrishna et al., 1990) was used in deriving the regional anomaly in the area. Using data uniformly sampled over the entire Bouguer anomaly map of the region, a second order surface gave the best model to the residual anomaly. The defect of this type of separation is that the effect of the thinning of the crust along the central axis is not reflected in the regional map. This has affected the thickness of the intrusion inferred in the central part of the region as shown in figure 3. This figure shows the resulting residual anomaly map of the area; the main feature of this map is similar to that of the Bouguer map of figure 2. This feature shows a large central negative anomaly with a NE-SW trend; with amplitudes of approximately –14 mgal in Mengong and –12 mgal in Ayos. The pattern of the contours of this anomaly indicates that to the north and northeast, beyond the mapped area, this body extends laterally at depth. A comparison of the main anomaly of this map with the geological sketch map (Fig. 1) shows that it is centred on schist and quartzite formations. The southwest portion of the negative anomaly occurs over outcrops of the So'o granitic rocks in the Mengong area. This anomaly may be due to an intrusion of the So'o granites within the basement of the area, which has a low negative density contrast with respect to the surrounding rocks in the basement. It should be recalled that although the density of granites is between 2.50 and 2.80 g/cm^3, the So'o granite seems to have a density in the lower limit of this interval. These granites extend in depth up to the north of Mbalmayo, subsiding below the schists and quartzites.

Interpretation

A quantitative interpretation of gravity anomalies was made, using the IGAO 2.5D interpretation software of Chouteau and Bouchard (1993), along four selected profiles trending approximately perpendicular to gravity contours in the residual map (Fig. 3) and geological structures. Four 2-D crustal models derived from the gravity signatures are shown in fig.4, 5, 6 and 7. The models are extremely simple and assume a cratonic block and a Pan-African block. Density contrast was established between host rock basement and granitic intrusion. In the absence of any measured density, we considered the average density of rocks samples in the area (Table 2). The So'o granites consisting of intrusive rocks have a density of 2.60 g/cm^3; the charnokites consisting of both basement and extrusive rocks are remarkably consistent in density varying from 2.90 to 3.10 g/cm^3; the migmatites show great density variation with a mean value of 2.80 g/cm^3; the Pan African formations and other metamorphic sediments are considered to be of minor importance, and their presence causes only local inhomogeneities in the basement. The density contrast between cratonic block and So'o granites varies from 0.22 to 0.30 g/cm^3; this contrast varies from 0.23 to 0.26 g/cm^3 between Pan-African formations and So'o granites. Based on these contrasts, the models of structures obtained show the bodies at their minimum possible depths for a good fit between the observed and computed (Geldart et al., 1966; Bhaskara et al., 1990). Hence, the minimum depth estimate for the negative anomalies is also the minimum depth estimated basement in the immediate neighbourhood.

Profile A (Fig. 4) trends N-S and runs across the major NE-SW trending central negative anomaly. This profile also bisects the outcrop of the major rock units. The geologic map of Fig 1 shows that this profile cuts across charnockites and So'o granites in the south, the Mbalmayo-Bengbis schists and quarzites at the centre, the grenatiferous gneiss in the northern border of the area and the unconformable contact between the Congo craton and the Pan African. The model of structure obtained from this profile consists of three layers of which the layer (**3**) is responsible for the observed negative anomalies in the area. This layer belongs to So'o granites, which underlies the schist and quartzite formations. This model shows that the So'o granite formations extend in depth up to the north of the area; their thicknesses are about 3500 m in Mengong zone (Fig. 4) and Ayos zone (Fig. 5), and 3000 m in Mbalmayo zone. The models also suggest that charnockites (**1**) is the main pluton of the complex, and that it extends laterally at depth beyond So'o granites. This body also penetrates under the Pan African formations (**2**) at depth of about 5000 m. In the southern part of this profile, the contact of charnokites with the So'o granites is inferred to dip inwards at 70° to depth of 1000 m, and then becomes vertical to reach the maximum depth. The vertical thickness of the Pan African formations (**4**) is inferred to be 1500 m. These formations, which outcrop in the northern border of the profile, have a basin shape and overlay migmatites and So'o granites.

Profiles B and D (Fig 5 and Fig. 7) which trend N-S and NNE-SSW respectively also have a graben shape

75 km wide, with a depth of about 35000 m. This graben consists of So'o granites (3), which is responsible for the low gravity anomaly in the area. They have in their southern part a horst which is the main pluton of the complex, with a density contrast of about 0.23. It can be associated to a charnockitic body. The maximum gradient occurs at the contact of charnokites and granites intrusion and is interpreted to indicate the presence of an intragranitic fault (Manguelle-Dicoum, 1988). In the northern part of Fig.5, the relatively positive anomaly that occurs is explained by masses of migmatites (2). Their density contrast (0.23 g/cm^3) is responsible for their shallow depth extends. The contact between migmatites and other formations represents a normal fault. In the northern part of profile D (Fig 7) the gravity anomaly reaches a steady value and does not begin to increase until it is over the migmatites. This zone is supposed to be the contact between the granite intrusion and other formations. The southern border of these profiles shows a graben, which is inferred to gneiss formations (5). The Pan African formations (4) in the northern border have a basin shape with depth of about 1200 m.

Profile C (Fig. 6) which trends NNW-SSE between Mvangan and Ebolowa, has a graben shape which is 30 km wide, with a depth of about 3500 m in Mengong area, which is also the thickness of the So'o granites within the zone. The gravity low at the centre part of this profile has a magnitude of -14 mgal, and it is associated partly with a postulate granite intrusion within the area. The steep gradient on the southern flank of this low anomaly is inferred to overlie the continuation of the fault observed in the south part of the others profiles, while the gradient in the northern flank is interpreted to indicate the presence of a second fault. The So'o granites are dipping south from 70° to 90°, and reaching the maximum thickness of about 3500 m.

The contact between the So'o granites and charnockites represents a normal fault with dip of about 90° on all profiles. The fault, which was also found in the Mbalmayo zone with magnetotelluric method (Manguelle-Dicoum, 1988; Manguelle-Dicoum et al., 1992), is an intragranitic fault. On all profiles studied here, the craton subsides to the north of the study area. In the north, we observed an overthrusting contact between the Pan-African formations and the So'o granites (Nzenti et al, 1984; Nedelec et al, 1986).

DISCUSSION

All the N-S gravity profiles show a graben shape in their middle parts. The interpretation of these profiles has established that the So'o granites, which are responsible for the negative anomalies in the area, are less dense than the basement rocks. The maximum vertical thickness of the rocks is estimated to reach 3500 m under the Ayos zone consisting of schists and quartzites, while the Mengong zone consists of So'o granites and charnockites. On account of two dimensionality, this value may be slightly under estimated; if the true density is more than the adopted density of 2.60, the depth will increase. It can be noted that the maximum thickness of the Pan African exceed 1500 m, so we suppose a migmatite formation of about 3000 m thick, under the metamorphic rocks, of which the grenatiferous gneiss, schists and micaschists may be an exposed part (see Fig. 4, 5 and 7). The thickness of those formations cannot be deduced with precision from gravity modelling, because of lack of density contrast between the So'o granites and them.

Interpretation presented in figures 4 to 7 supposes that the So'o granite formations, which are the most extensive, were put in place beneath the surface by a combination of subsurface subsidence and piecemeal stopping. The intrusion presumably represents a magma chamber, with high-density materials. The role played by this area during the Pan African episode of volcanicity is recorded at the surface by outcrops of charnokites and granites in the south, and by plutonic rocks (migmatites) within the fracture zone in the north. The limited vertical thickness of the So'o granites suggests that it may be produced by subsidence entirely within the basement.

An analysis of the structural section from the modelling profile shows that the width of the granitic intrusion increases with depth from the surface. In this light, the So'o granites certainly constituted a batholith, which is broader at depth than at surface. This granite (So'o granite) extends in depth up to the North of Mbalmayo, subsiding below the schists and quartzites. This confirms one of the conclusions of audiomagnetotelluric prospecting (Manguelle-Dicoum, 1988; Manguelle-Dicoum et al, 1992) and geological observations of (Nzenti et al, 1984 and Nedelec et al, 1986). According to these authors, the granite basement is found both to the South and the North of Mbalmayo, and seems to have been uplifted due to intrusion of highly conducting rocks embodied in them. Probably this granitic batholith is responsible for the low anomalies observed in the region. This granitic intrusion must have provoked the subsidence of the basement along the northern border of the Craton and this subsidence could have been responsible for the creation of the Nsimi-Zoétélé basin in the northern area of Sangmélima.

Gravity gradients along the flanks of the area are high. As a result of these high gravity gradients at the margins of the area and coupled with the fact that the anomaly within the area is negative relative to that of the immediate surrounding areas, the anomaly is interpreted to be due to a graben. The gravity data also suggests that the bottom of the graben slope towards the east. An elongated positive anomaly to the Southeast of the central negative anomaly, with a NE-SW trend and amplitude of 16 mgal occurs over outcrops of the charnockite formations. The positive anomalies observed in the northern border of the region, coupled with gravity gradients are supposed to be the effect of plate suture (Bayer and Lesquier, 1978).

There are two main fractures in the area: one at the northern margin and the other at the southern margin of the granite intrusion. These fractures are both inferred to normal faults. The southern fault in addition to its obvious strike-slip displacement, has a vertical component downthrowing to the north, while the more northerly fracture is inferred to have a downthrow to the south, south east and south west, enclosing a wedge-shape trough (Mbom Abane, 1997). The two faults may form a complementary system.

The positive anomalies observed in the south are associated with gneiss and charnockite at the southern border of the region. These charnokites represent a deep-rooted structure, which occupies the basement of the region and a massive body (gneiss) is in the South. Along the whole length of the profiles, the schists overlie the Craton. The model structure of the region presents an evolution of the roof of the granite basement, which is responsible for the observed anomaly. These roofs represent charnockite formations. This basement seems to have been affected by folding movement that characterises the transition zone between the stable craton and the Pan-African Mobile Zone (Poidevin, 1983). This basement downthrusted in the north and north east of the area at depth of 3500 m. In the north, the positive anomaly of the Pan-African series can be indirectly linked to the outcrop of allochtonous rocks within the fault belt. The extensive linear form of the anomaly coupled with the consistent nature of gradients along its flanks suggest the presence of two crustal blocks of different mean density and thickness separated by a suture formed by plate collision. The high gravity anomalies that outline the boundary are probably the gravity expression of north dipping mafic rocks, reflecting a Pan African suture. The proposed suture line is a tectonic boundary between the Pan African and the Congo craton, and marked by a major density discontinuity penetrating the crust. This margin may have been a product of intra continental collision.

The interpretation also suggests thicker Pan African formations than the adjacent Craton, and the presence of dense allochtonous rocks (migmatites) along the Pan African fold belt. Perhaps the strongest geological data in support of the subduction origin of the boundary is the presence of these allochtonous rocks, which may have been detached from descending oceanic plate wedged against the Pan African plate (Kennedy, 1964).

CONCLUSION

In conclusion, two general observations were made concerning the anomalies in this zone: firstly the residual anomalies within the area except the south-eastern and the northern parts are negative relative to residuals in the adjacent zone; secondly various anomalies are separated by high gravity gradients, which suggest faulting along the boundaries. Based on these observations, the zone is probably a subsided or rifted area in which the subsidence might have been accompanied by intrusion of low-density granitic rocks (So'o granites), with a thickness of about 3500 m. This intrusion has provoked a north or south trending faulting. The block faulting might have resulted in the formation of the graben; this is limited in its southern border by a broad horst. The detailed interpretation shows that magmatism existing within the zone approximately occurs at the margins of fault blocks. This magmatism was probably a direct consequence of block faulting of the basement rocks in the area. The geophysical study also suggests that the northern margin of the Congo craton is a product of an active collision margin as has been suggested for the eastern margin of the West-African Craton and Pan African belt (Bayer et Lesquier, 1978; Black et al., 1979b; 1985; Lesquier et Louis, 1982; Emenike, 1989). These collisions have provoked considerable overthrusting of the Pan-African formations onto the Congo craton formations.

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Received: 10/05/2003
Accepted: 14/02/2004