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ARTICLE

Crustal Structures Inferred from Combined Terrestrial and Earth Gravity Data beneath the Babouri-Figuil and Mayo Oulo-Lere Basins, North Cameroon and South Chad

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Abstract: In this work, the study of the crustal structure of the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins was carried out through the interpretation of gravity data. These data were obtained by combining the terrestrial gravity data obtained from the Earth Gravitational Model 2008. The analysis of the terrestrial Bouguer anomaly maps reveals both negative and positive anomalies. Negative anomalies, i.e., low-density signatures, are interpreted as specific rock types on the basis of the geological knowledge of the region while the positive anomalies are attributed to basaltic rocks underlying a generally granitic environment. The empirical method was used to distinguish anomalies due to deep structures from those due to near-surface structures. This method testifies that the residual map of degree 4 is appropriate. Six profiles are drawn on this residual Bouguer anomaly map and are interpreted using spectral analysis and 2D modeling methods. The results indicate that the mean depths of mass sources at the near-surface of the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins are located at 1.50 km and 1.55 km, respectively. Moreover, the Babouri-Figuil Basin is constituted of two formations while the Mayo Oulo-Lere Basin exhibits three distinct formations. These models also help clarify the geological structure of the study area as well as the thicknesses of the sedimentary basins.

Keywords: Earth Gravitational Model 2008; Bouguer anomaly; Empirical method; Spectral analysis; 2D modeling

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1. Introduction

The study area is located between longitudes of 13°–14°30 E and latitudes of 9°–10°30 N (Figure 1). It spans both the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins. The studies carried out in these basins have mainly focused on geological features [1–10]. These works have shown that the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins are two small Wealdian (lower Cretaceous) basins filled with continental sediments. These sediments are mostly siliciclastic and made up of an alternation of fine sandstones, siltstones, and indurated marls. However, from a geophysical point of view in general and gravimetry in particular, the infill of these basins is still poorly understood. The gravity data available in this area were obtained by ORSTOM (Office de Recherche Scientifique et Technique d'Outre Mer) during various reconnaissance campaigns. The studied profiles followed tracks, roads, and sometimes water courses. Despite these efforts, these data are very sparse and contain many gaps. A Bouguer anomaly map containing such gaps presents many insufficiencies, and its interpretation may lead to erroneous conclusions. To solve this problem, new gravity campaigns have been proposed to fill the gaps. However, gravity campaigns are very expensive. An elegant solution to this problem is to densify the measured gravity data by using the EGM2008 field model [11–13]. These data have been reduced by using a series of corrections to eliminate the non-geological causes of gravity variations. The obtained database allows us to establish a new gravity map of the region.

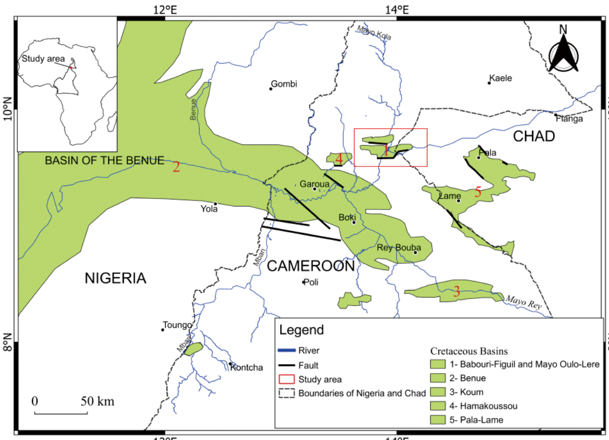


Figure 1. Location map of the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins.

Source: Modified after Besong [9].

The residual anomalies have been used to study the crustal structure of the study area. This residual local scale component often delineates mineral and hydrocarbon prospects at relatively shallower depths [14,15]. The method of Zeng et al. [16] is used to separate the regional anomaly from the Bouguer anomaly to obtain the residual anomaly as recently developed by many authors [17–19]. The residual anomaly map shows that the Babouri-Figuil Basin is characterized by low-value anomalies while the Mayo Oulo-Lere Basin is situated on high-value anomalies. These anomalies might represent the filling effect of the Benue sedimentary basin and the intrusion of dense materials, respectively.

The aims of this work include first using the "Zeng method" [16] to separate the regional anomaly from the Bouguer anomaly, and then second conducting a combination of spectral analysis and 2D modeling to determine the shape, depth, thickness, and distribution of anomalous sources beneath the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins. These methods have been used to isolate causative bodies by representing them as polygonal bodies in two dimensions [20]. Similar studies were used successfully to improve the subsurface structure of Algeria [21,22]. Such a type of study is capable of demonstrating the relationship between observed gravity anomalies and 2D gravity models.

2. Geological and Tectonic Setting

Cameroon has two types of sedimentary basins: coastal sedimentary basins located in the southwest of Cameroon and intracontinental sedimentary basins located in the northern part of the country. Many of the sedimentary basins situated in the northern part are connected to the Yola branch belonging to the Benue Trough. These include the Koum, Hamakoussoum, Babouri-Figuil, and Mayo Oulo-Lere basins. The Babouri-Figuil and Mayo Oulo-Lere basins are small sedimentary basins elongated in the EW direction. They are respectively located between latitudes 9°44'–9°50' and 9°39'–9°44' and longitudes 13°44'–14°02' and 13°43'–14°28' (Figure 2). These two basins are thought to represent Wealdian (lower Cretaceous) facies equivalents of the Bima Formation in Nigeria [10].

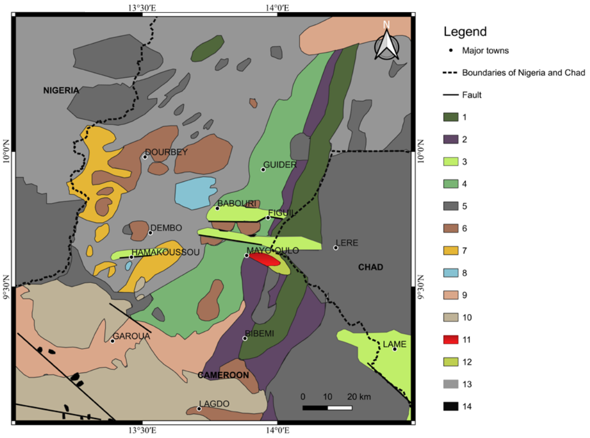


Figure 2. Geological map of the study area (modified from Abubakar et al. [23] and Abate Essi et al. [24]). 1: Mica schist. 2: Lower gneiss. 3: Sedimentary formations. 4: Embrechites Migmatite. 5: Old syn-tectonic granitoid. 6: Late syn–tectonic granitoid. 7: Anatexites granitoid. 8: Post–tectonic granitoid. 9: Quaternary alluvium. 10: Cretaceous Benue Sandstone. 11: Plio–Pleistocene sediments. 12: Conglomerates (sandstone and lavas). 13: Anatexites Migmatite. 14: Basalt.

The Babouri-Figuil sedimentary basin is the most northern of the small Cretaceous basins with continental sediment in north Cameroon. It is nearly 45 km long with a width ranging up to 1 km towards Figuil [4,10]. It is a basin dotted with mounds and basic sandstone. Its sedimentary pile locally reaches 1,500 m [25]. These sediments are constituted of fine sandstones, siltstones, and marls. Their presence testifies to sedimentation linked to the many uplift phases of the area [5]. Throughout the record of the basin, there is an abundance of flora as well as evidence of evaporation. A general swamp environment under a hot and humid climate is revealed by the abundance of Estherias whose egg dissemination is favored by drying seasonal periods [8].

The Mayo Oulo-Lere basin is > 50 km long and < 10 km wide. It extends towards the south of Chad in the Lere area. It is separated from the Babouri-Figuil Basin by granite complexes culminating at 800 m of altitude. It consists mainly of silts and hardened clays. Based on paleoflora study, the Mayo Oulo-Lere sedimentary basin is composed of small grabens [10,26]. These grabens, developed in a north-south-trending extensive context, are constituted with basaltic formations [5]. Microfossils collected from this basin are attributed to ante-Aptian sedimentation.

Tectonically, the Babouri-Figuil and Mayo Oulo-Lere basins have undergone intense volcanic activity leading to volcanic materials reaching the surface through deep fractures. These basins are associated with the Cameroon Volcanic Line (CVL). This major tectonic structure is a Y-shaped chain of intra-plate volcanoes extending from the island of Pagalu in the Atlantic Ocean west of Africa for ~2,000 km [27]. The first branch corresponds to the Benue Trough in Cameroon called the Yola–Garoua Basin, whereas the Babouri-Figuil and Mayo Oulo-Lere basins are connected and the second branch is situated in Nigeria. Volcanic rocks along this general line are composed predominantly of basalts. Their topographic expressions are accompanied by cracks, fractures lavas, and tuffs.

3. Data and Methods

3.1 Gravity Data

The gravity data used in this work are provided from two independent sources. One is derived from measured gravity data and the other is obtained from the Earth Gravity Model 2008 (EGM2008).

Terrestrial Gravity Data

The terrestrial gravity data used in this work were collected between 1960 and 1968 by the Office de Recherche Scientifique et Technique d'Outre–mer (ORSTOM) during various reconnaissance campaigns. These data were obtained between latitudes 9°00' and 10°30' N and longitudes 13°00' and 14°30' E. These data acquisition campaigns were obtained by car, along roads, crossable tracks, and sometimes water courses. Measurements were taken every ~3 km. Several gravimeters (Worden and Lacoste & Romberg) were used. The calibration of the gravimeters was carried out on stations of the Martin network defined in the Potsdam system which are attached to the international reference system IGSN71 (International Gravity Standardization Network, 1971). It is the reference system base of gravity measurements established in Africa [28]. The precision of the gravity values is on the order of 0.2 mGal. The location of the measuring stations was determined on topographic maps by compass tracking. The average error in the position of the stations is estimated at ~200 m. Altitudes were estimated using barometers and altimeters (Wallace and Thierman, Thommen). The accuracy of the altitude values depends on the climate, the difference in altitude between the reference station, the measuring point, and the distance from the stations. The error in the altitude of the stations can reach 10 m when the weather conditions are unfavorable, but is 3 m otherwise. The gravity readings were corrected for drift. The free air and the plate correction were computed assuming a mean crustal density of 2.67 g/cm^3. The calculation of terrain corrections was done after Hammer [29], with a digital terrain model [30]. 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 0.2 mGal [31]. The obtained Bouguer anomaly value is very similar to the one reported by Poudjom-Djomani [32].

The terrestrial Bouguer anomaly map presented in Figure 3 is plotted using the Generic Mapping Tools (GMT) [33]. This map shows two main types of anomalies: low and high anomalies. The low-anomaly zones are divided into two parts. The first part located in the northern part of the study area covers the towns of Hamakoussou, Dembo, Dourbey, and Guider and the entire Babouri-Figuil sedimentary basin. In this area, low anomalies are unevenly distributed (–65 to –35 mGal). This situation is likely due to the lack of terrestrial gravity data in the area. The second part located south of Lere is also constituted of low anomalies with a minimum that can reach –60 mGal. These anomalies are likely due to the filling effect of the Lame sedimentary basin in Chad. A high anomalies zone covers the southwest, covering the towns of Garoua, Lagdo, and Bibémi and the entire area of the Mayo Oulo-Lere Basin. The amplitude of these anomalies is around –25 mGal with a maximum of 0 mGal in the northern part of Bibémi and Mayo Oulo-Lere areas. These anomalies are likely due to either the upwelling of magmatic fluids through lithospheric fractures in the sedimentary zone or to denser rocks found on the surface [34].

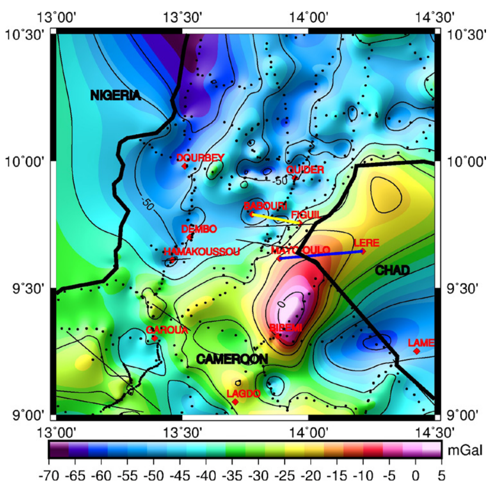


Figure 3. Bouguer anomaly map of the region obtained by using terrestrial gravity data. Black, yellow and blue lines represent the geological faults, Babouri-Figuil and Mayo Oulo-Lere sedimentary basins respectively.

Data from EGM2008

Gravity data were obtained using the Earth Gravity Model (EGM2008). This model provides more information on the Earth's gravity field for various geophysical applications [35,36]. Its utilization possesses the following advantages: (1) more information on areas without terrestrial gravity data; (2) the gravity data can be freely obtained; (3) the gravity data covers the entire Earth, with data obtained from disturbance analyses of satellite trajectories and data from satellite altimetry over the oceans [37]; (4) gravity constraints can be obtained by integrating gravity data of ORSTOM network base, marine, airborne and satellite gravity data; (5) contains degree and order 2159, and contains additional coefficients up to degree 2190 and order 2159 [37,38]; (6) good spatial resolution 2.5' × 2.5' [35,37] approximately 6 times higher than other models.

Comparison between EGM2008 and Terrestrial Gravity Data

A comparison between the terrestrial and EGM2008 gravity data justifies the approach undertaken in this study. Statistical standard deviations were calculated. Table 1 shows a prominent affinity between the mean and standard deviation values of the terrestrial and EGM2008 datasets average –41.25 and –41.79 mGal with standard deviations of 11.74 and 12.22, respectively. The mean and standard deviation of these datasets remain essentially the same. The differences in average are 0.54 and 0.48 mGal, respectively. This result shows that the terrestrial and EGM2008 gravity datasets have similar precision so they are stackable and can be superimposed. We conclude that the EGM2008 model accurately represents the gravity anomalies in our study area. This comparison agrees with the conclusions of previous work conducted by Eyike et al. [39], Abate Essi et al. [11], and Bouba et al. [12], who showed that EGM2008 gravity data offers continuous and reliable information about the Cameroon subsurface. This model has been also used in the exploration of coal deposits in India, in the mapping of cratons, and in the delineation of geological discontinuities in sedimentary basins [40]. In our study, data from the EGM2008 gravity model are combined with terrestrial gravity data. The Bouguer anomaly correction is obtained by taking an average density of 2.67 g/cm^3. The corrected gravity data thus obtained permits us to establish a new Bouguer anomaly map by joining points having the same anomaly value (Figure 4).

For the most objectivity, the Bouguer anomaly map is plotted by an automated algorithm using the Generic Mapping Tools software [33]. This map is interpreted as depicting two gravity anomaly zones.

Table 1. Comparison of Bouguer anomaly obtained from terrestrial and EGM2008 gravity data.

	Terrestrial Bouguer anomaly (mGal)	EGM2008 Bouguer anomaly (mGal)
Min	–66.43	–67.81
Max	3.68	1.66
Average	–41.25	–41.79
SD	11.74	12.22

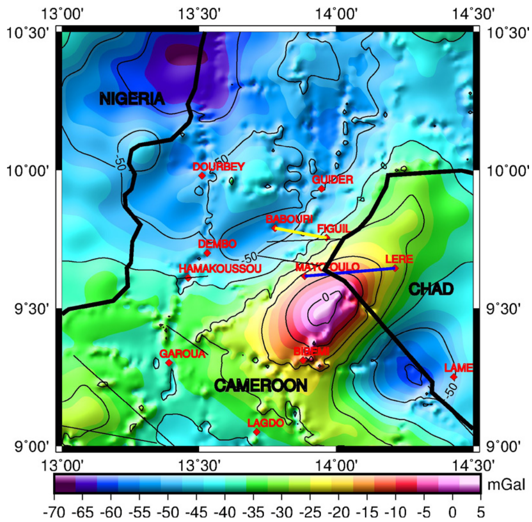


Figure 4. Bouguer anomaly map of the region obtained after combining terrestrial gravity data and the EGM2008 model. Black, yellow, and blue lines represent geological faults, and the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins, respectively.

The first zone located in the northern part of the study area, consists of a large low-gravity domain (–60 mGal) which is visibly more developed than on the terrestrial Bouguer anomaly map. It is in this area that the Babouri-Figuil sedimentary basin is located. This map shows that the minimum of the anomaly has a V shape that may suggest sedimentary infill, such as a lake basin where water courses brought their alluvium while the volcanoes have lava flows that spread. These anomalies may be due either to the collapse of a sedimentary block or to the local thickening of a sedimentary series generated by the depression of the basement roof. South of Lere, we observe a zone of negative anomalies (–60 mGal), which can be due to sedimentary deposits in this area.

The second zone extends from the town of Garoua to Lere in Chad and up to Bibémi. This zone includes the Mayo Oulo-Lere sedimentary basin. It is characterized by strongly positive anomalies. These anomalies could correspond to the intrusion of basaltic rocks under the sedimentary basin. However, the iso-lines of the anomalies do not coincide perfectly with the orientation of the basin. It suggests that the intrusion would have been favored by tectonic processes. The first and second domains are separated by a strong gradient, which could result from discontinuities between different crustal formations, such as faults, flexures, or contacts with intrusive rocks.

3.2 Method

Regional/Residual Separation

The harmonic degree chosen for a regional gravity survey is a value that reveals subsurface geological structures at different spatial wavelengths. When the regional degree increases, the wavelength of the residual anomaly decreases thereby revealing geological structures closer to the surface. In the Benue sedimentary trough, a degree 3 polynomial surface for imaging regional anomalies has been used [41]. Such a choice cannot, however, be difficult to justify when considering a detailed interpretation of the basement. It is therefore necessary to define criteria for choosing the regional surface which takes into account the variations of the gravity field in all directions. We used the empirical method of Zeng et al. [16] in order to isolate the regional components, and signatures of deep-seated geological structures from the higher frequency components that are characteristics of small, near-surface extended structures. This method allows one to determine the optimal degree of the polynomial surface, which gives the best degree of the regional trend from the Bouguer anomaly map.

Determination of the Upward Continued Field at Different Heights

The upward continuation is an operator that acts like an electronic filter by attenuating the short wavelengths thereby revealing the anomalies related to deeper structures. Consider $g(x, y, z)$ a function defined in the spatial domain in three dimensions; in two dimensions its Fourier transformation denoted as $G(k_x, k_y, z)$, where k_x and k_y are respectively the wave numbers following the x and y axes. Knowing the value of the spectrum for $z = 0$, we determine its value for $z = h$ by the relation:

$$G(k_x,k_y,h)=G(k_x,k_y,0)e^{-h\sqrt{k_x^2+k_y^2}} \tag{1}$$

The inverse transformation of $G(k_x, k_y, h)$ is $g(x, y, h)$. In this study, in order to calculate the upward continuation, we use the Fourpot program [42]. The maximum value of h must be equal to the optimum upward continuation height h_0 of the gravimetric field [17,18].

Determination of the Optimum Upward Continuation Height

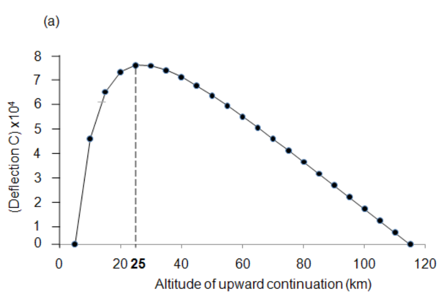
The data treatment steps carried out for the determination of the optimum upward continuation height in our study area are as follows.

- Upward continuation of Bouguer anomalies at heights from 5 to 120 km, by 5 km intervals.
- Calculation of correlation factors between the upward continued fields (g_1 and g_2) at two successive heights using the formula of Abdelrahman et al. [43]:

$$r_{g_1,g_2}=\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}g_1(x_i,y_j)g_2(x_i,y_j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}g_1^2(x_i,y_j)\sum_{i=1}^{M}\sum_{j=1}^{N}g_2^2(x_i,y_j)}} \tag{2}$$

where M and N are the number of sampling data along the x and y directions, respectively.

- The correlation factor is plotted as a function of increasing continuation height by making each correlation factor correspond to the lower of the two successive heights. The deflection denoted C at each height is presented in Figure 5a. This deflection is given by the gap between the correlation factor curve and the line joining the two ends of the curve. In Figure 5b, we plotted the curve giving the variation of the deflection C at each altitude as a function of continuation heights. This curve passes through a maximum altitude of h_0 = 25 km called the optimum altitude of upward continuation of the Bouguer anomaly and also corresponds to the depth of investigation in the region.



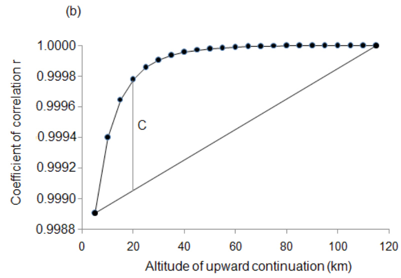


Figure 5. Optimum upward-continuation height by the method of Zeng et al. [16]. (a) Cross-correlation between two successive upward-continued heights as a function of the continuation height. (b) The deflection C of the cross-correlation curve.

Determination of the Degree of Regional Anomaly

For the choice of the degree of the regional anomaly, we calculated the coefficients of correlation between the upward continuation of the Bouguer map at 25 km and the regional anomaly maps for different degrees (Figure 6). We find that the upward continuation of the Bouguer map at the optimal altitude shows a maximum correlation with the regional anomaly map of degree 4. Thus, the residual anomaly map of degree 4 will essentially highlight the gravity effect of shallow structures in the study area.

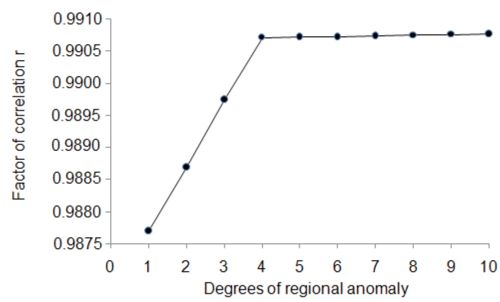


Figure 6. The factor of correlation according to the degrees of regional anomaly.

Power Spectrum Analysis

Spectral analysis is a method that can define the planes of separation between several structures of different densities. This method, which assumes a uniform distribution of block parameters, leads to a depth-dependent exponential rate of decay [44]. The dimensions and sample intervals of the data to be analysed should also be carefully considered [45]. When we plot the logarithm of gravity energy as a function of spatial frequency, the spectral curve has two slopes. The first slope located at low frequencies corresponds to deep structures. The second slope located at T high frequencies corresponds to near-surface structures. The average depths of gravity anomaly sources can be estimated from the relationship [46,47]:

$$h = \frac{\Delta\left(LogE\right)}{4\pi\Delta\left(n\right)} \tag{3}$$

where $\Delta(LogE)$ is the variation of the logarithm of the energy spectrum and $\Delta(n)$ is the interval of frequency. These depths permit constraining the 2D modeling and assimilation to the reality of the geological structures. The average error on each gravity profile is estimated at 5% of the obtained depth [12,48]. This means that there is no great difference between the depth estimations along the profiles for the two tectonic regions.

2D Modeling

The modeling of gravity data allows for the calculation of the theoretical anomaly from the simple shape of the structure of the model and to compare it to the observed anomaly. The best obtained model is that which corresponds to the structure whose calculated anomaly is assimilated to the observed anomaly by adjustment [49]. In this part, 2D modeling is obtained by using Grav2DC software based on the algorithm of Cooper [50] and Talwani et al. [51]. This modeling was carried out by taking into account the depths calculated by spectral analysis, the geology of the region, and the density contrast of the anomaly sources. The density contrast is calculated from the formula $C_i = d_0 - d_i$, where $d_0 = 2.65 g/cm^3$ is the average density of the granites, and d_i is the average density of the i^th^ formation [51].

4. Results

4.1 New Residual Bouguer Anomaly Map

The residual anomaly map presented in Figure 7 shows two anomaly types: positive and negative areas. The first area is located west of Garoua, northeast of the study area and east of Dourbey. The values of anomalies are between 0 to 15 mGal. It would be due to the presence of high-density rocks within low-density granitoid rocks. This map also shows another area of positive anomalies that extends from Bibémi to Lere in Chad and includes the Mayo Oulo-Lere sedimentary basin. The values of these anomalies reach up to 35 mGal in Mayo Oulo. These anomalies show that the Mayo Oulo-Lere Basin does not have the morphology of a sedimentary basin. It would therefore rather correspond to a lacustrine basin with dense rocks that are probably basalt.

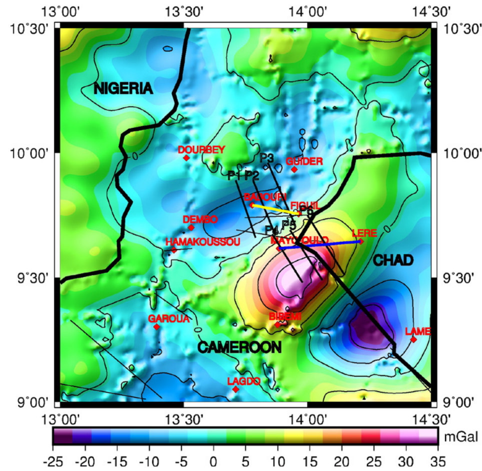


Figure 7. Fourth-order of residual Bouguer anomaly map of the region obtained after combining the terrestrial gravity data and the EGM2008 model. Black, yellow, and blue lines represent geological faults, and the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins, respectively.

The second area is constituted of negative anomalies. These anomalies are located south of Garoua and around Dourbey where the Babouri-Figuil sedimentary basin is located. The values of these anomalies are between –15 and –5 mGal. This range could correspond to the sedimentary deposits of the Garoua Trough in general and the Babouri-Figuil Basin in particular. This basin is constituted mostly of sandstone would be linked to the Benue trough. The map also shows another negative area located south of Lere near the Cameroon-Chad border. In this area: the minimum value of anomalies is –25 mGal. This would indicate the presence of weak formations compared to the surrounding formations.

4.2 Estimation of Mean Depth of Density Interfaces

In this part, we use spectral analysis to determine the depths of geological structure source anomalies. Six profiles (P1, P2, P3, P4, P5 and P6) have been traced on the residual Bouguer anomaly map. Profiles P1, P2 and P3 intersect the Babouri-Figuil sedimentary basin and profiles P4, P5 and P6 intersect the Mayo Oulo-Lere sedimentary basin. All these profiles are oriented perpendicular to the main elongation direction of the structure to be studied. When we plot the energy spectrum logarithm as a function of frequency, the spectral curve presents two characteristic slopes. The first slope located at low frequencies corresponds to deep structures. The second slope located at high frequencies corresponds to near-surface bodies.

In the Babouri-Figuil sedimentary basin, two major slopes have been obtained by spectral analysis of profiles P1, P2, and P3 (Figure 8). The first slope corresponds to deep structures with depths estimated at 4.70, 4.55, and 5.46 km respectively for profiles P1, P2, and P3. These depths could correspond to the crust-mantle interface (i.e., Moho). The second slope is associated with near-surface bodies (i.e., sediment and/or granite). The estimated depths are 1.48, 1.44, and 1.58 km respectively for profiles P1, P2, and P3. The average depth in this basin is ~1.50 km. This result agrees with that obtained by Ndjeng and Brunet [52]. According to those authors, the depth of the sedimentary series does not exceed 1.5 km. Therefore, the boundary between the lower crust and the upper crust beneath the Babouri-Figuil sedimentary basin would be shallow.

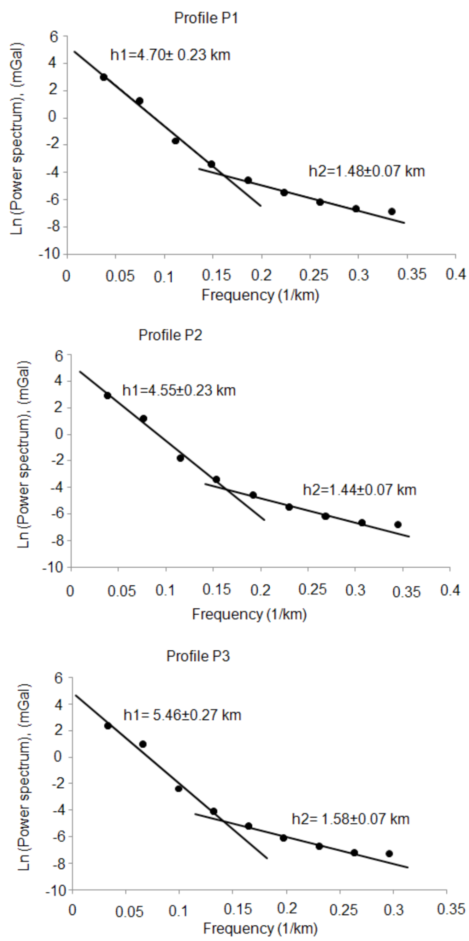


Figure 8. Power spectra of profiles P1, P2 and P3 of the Babouri-Figuil sedimentary basin.

In the Mayo Oulo-Lere sedimentary basin, two major slopes have been obtained for profiles P4, P5, and P6 (Figure 9). The first slope occurs at depths of 4.27, 4.62, and 5.32 km. These depths could correspond to the crust-mantle interface (i.e., Moho). The second slope occurs at depths of 1.48, 1.54, and 1.72 km. These depths are associated with intracrustal structures with an average depth of ~1.55 km. This depth probably corresponds to a near-surface layer. These results therefore indicate that the Mayo Oulo-Lere Basin should be slightly deeper than the Babouri-Figuil Basin.

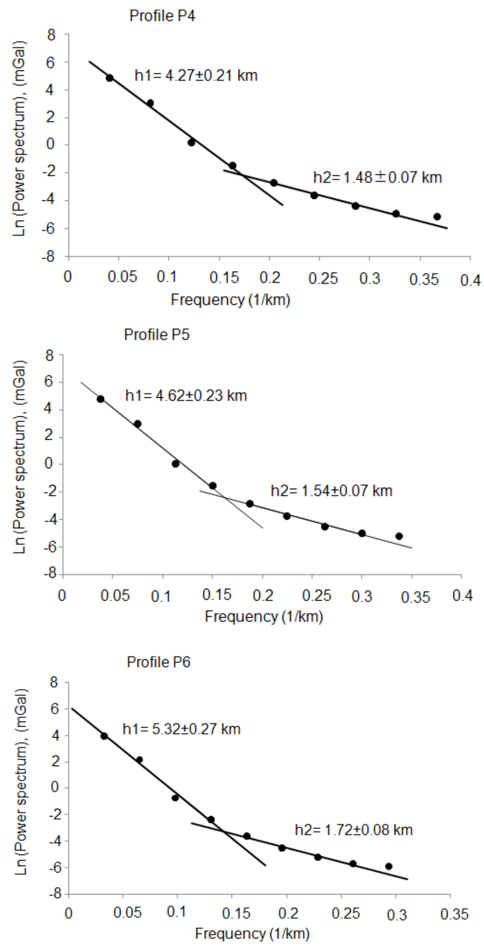


Figure 9. Power spectra of profiles P4, P5, and P6 of the Mayo Oulo-Lere sedimentary basin.

4.3 Density and Density Contrast of Structures

To determine the characteristics and shapes of geological structures of suspected bodies in the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins, six profiles were modeled. P1, P2 and P3 along a SE-NW direction were modeled in the Babouri-Figuil sedimentary basin and P4, P5 and P6 along an NW–SE direction were modeled in the Mayo Oulo-Lere sedimentary basin. The average densities of sediments, granites, and basaltic rocks present in the study area are respectively: 2.45 g/cm^3, 2.65 g/cm^3, and 3 g/cm^3 [53]. The corresponding density contrasts are respectively: −0.2 g/cm^3, 0 g/cm^3, and 0.35 g/cm^3. In the Babouri-Figuil Basin, we obtain three models of structures corresponding to profiles P1, P2, and P3. These models are constituted of two formations of different density contrast (Figure 10).

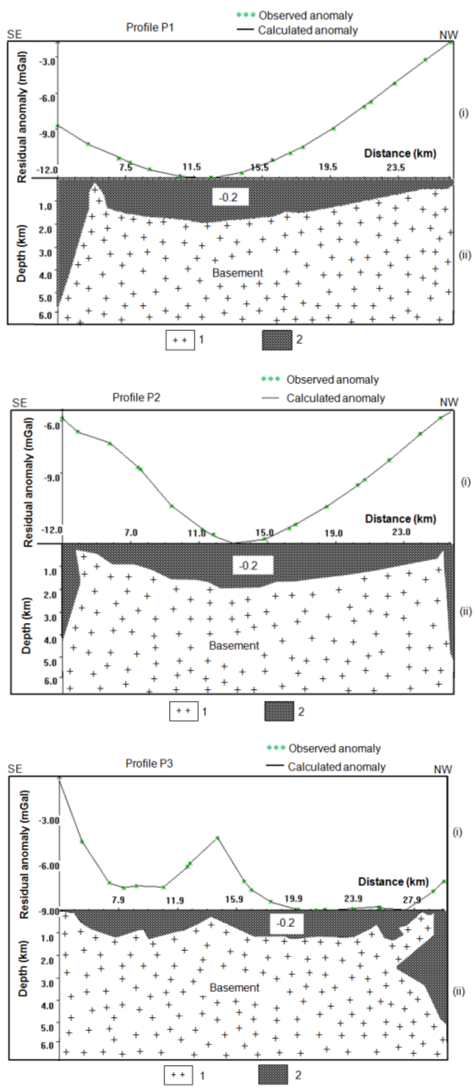


Figure 10. Crustal model of profiles P1, P2, and P3 of the Babouri-Figuil sedimentary basin.

The first formation has a density contrast and density respectively of –0.2 g/cm^3 and 2.45 g/cm^3. This formation is present throughout the profile. Its depth varies and reaches a value of 5 km, and this formation would probably be responsible for the vast zone of negative Bouguer anomaly observed in the sedimentary basin. The density contrast associated with this formation permits its identification. The second formation with a density of 2.65 g/cm^3 is most likely associated with granites. It constitutes the substratum of the basin and it is present as a rooted structure that extends to great depth.

In the Mayo Oulo-Lere Basin, we obtained three models corresponding to profiles P4, P5, and P6. These models are constituted of three formations of different density contrast (Figure 11).

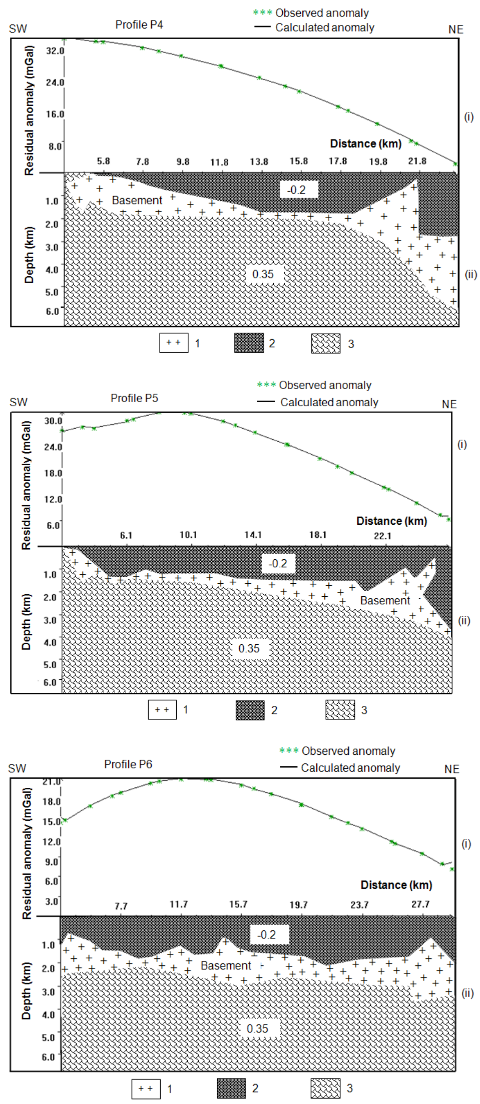


Figure 11. Crustal model of profiles P4, P5, and P6 of the Mayo Oulo-Lere sedimentary basin.

The first formation, with a density contrast of –0.2 g/cm^3, has an average density of 2.45 g/cm^3. It is associated with continental sediments. This formation is present throughout the profile. Its depth varies and reaches a maximum depth of 3 km. The second formation with an average density of 2.65 g/cm^3 is associated to granites. The depth is an extension of this formation and probably constitutes the substratum of the basin. The third formation, with a density contrast of +0.35 g/cm^3, has an average density of 2.95 g/cm^3. It is associated with basaltic rocks. To the SW of the profile, these basalts occur near the surface. The roof of this formation is decreasing and stabilizes at 1.5 km. This roof drops to a depth of 3 km to the NE of the profile. This formation most likely represents magmatic rocks formed at depth.

5. Discussion

In the Babouri-Figuil and Mayo Oulo-Lere basins of North Cameroon and South Chad, we determine a regional gravity anomaly, using the empirical method of Zeng et al. [16], that presents the best resemblance to the prolonged Bouguer anomaly at optimum altitude. This method testifies that the residual map of degree 4 used in this work is appropriate. The negative anomalies observed on this residual map are interpreted as due to the sedimentary cover while the positive anomalies can be explained by the presence of basaltic rocks that were tectonically uplifted to the surface. According to the spectral analysis, the depths of the negative anomaly (Babouri-Figuil Basin) and the positive anomaly (Mayo Oulo-Lere Basin) are quite similar. This is likely because the two basins are similar and shallow. The mean depths of the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins are 1.50 km and 1.55 km, respectively. These results agree with those obtained by Ntsama [10]. According to those authors, the Mayo Oulo-Lere and Babouri-Figuil basins are small shallow Cretaceous basins filled with continental sediments the depths of which do not exceed 1,600 m.

According to our 2D subsurface modeling, the structure of the Babouri-Figuil and Mayo Oulo-Lere basins presents many similarities in the composition of the upper crust such as in the profile P1 to P6. Some constraints and other geological considerations linked with the tectonic features of these basins were combined to build an accurate model for each profile. These constraints have been adopted to build the model corresponding to each anomaly such as the densities of anomalous masses. Densities are either higher or lower than the enclosing bed density, which was assumed to have a homogenous mean density of 2.67 g/cm^3 for the Babouri-Figuil and Mayo Oulo-Lere basins. The mean densities of the rocks present in the study area like granites, basaltic rocks, and sedimentary formations are respectively suggested to be 2.65, 3, and 2.45 g/cm^3 [54,55].

The interpretation of these models suggests the presence of granites, basaltic rocks, and sedimentary covers. The sedimentary formations have variable thicknesses with a maximum of ~5 km found in the Babouri-Figuil Basin and ~3 km in the Mayo Oulo-Lere Basin. The outflows of these sediments confirm the hypothesis gleaned from the geological map. Concerning the granite formations. They are very abundant in the study area and have important thicknesses in the Babouri-Figuil Basin. This contrast could indicate that the uplift of the granites is most significant in the Babouri-Figuil Basin. These models also suggest the presence of basaltic rocks to account for the observed positive residual anomaly. The origin of these rocks is found at great depths such as magmatic rocks cooled at depth. The magmatic body was also likely affected by faulting from extensional tectonics. These results are in accord with those of Kamguia et al. [41] which show that the relief of the study area generally preserves the imprints of tectonic faulting phenomena, and with those of Ndjeng et al. [4], which mention that in the Cretaceous, a strong extensional tectonic event occurred in the Babouri-Figuil and Mayo Oulo-Lere basins.

6. Conclusions

This work is based on the analysis and interpretation of combined gravity data from the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins of North Cameroon and South Chad. The newly obtained gravity anomaly map shows different geological structures partially masked by the sedimentary cover. This map depicts strong links between positive anomalies with basaltic rises and between negative anomalies with sedimentary deposits. For the choice of the residual anomaly, we used the empirical method of Zeng et al. [16]. This method shows that the residual Bouguer anomaly map of degree 4 is optimal for the interpretation of crustal structures. The spectral analysis carried out in the Babouri-Figuil and Mayo Oulo-Lere sedimentary basins permits the determination of major discontinuities. The mean values of 1.50 km and 1.55 km provide newly obtained depth estimates for future studies in these basins. The 2D modeling of the sources of residual anomalies suggests the structures have different densities or densities contrasts. The various models show that the Babouri-Figuil sedimentary basin is constituted of continental sediment deposited on a granitic basement. The Mayo Oulo-Lere sedimentary basin is constituted of sediments, basaltic rocks, and granitic basement. In our future investigations, we will explore a 3D inversion, Horizontal Gradient Analysis, and Euler deconvolution methods to improve and consolidate our results.

Author Contributions

Bouba Saidou (BS), Apollinaire Bouba (AB), Valentin Oyoa (VO), Kasi Njeudjang (KN), Joseph Kamguia (JK), Alidou Mohamadou (AM).

BS designed the study area and interpreted the gravity data by using various advanced processing techniques. AB established the objective, proposed the methodology and generated maps. VO contributed to the geological aspect of the paper. KN wrote the first draft of the paper and data supplier. JK performed critiques and improved the interpretation of results. AM supervised the work and revised the paper. All authors have read and approved the final version of the manuscript. All correspondence is addressed to Apollinaire Bouba.

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Data Availability Statement

The corresponding author guarantees the availability of the data used to carry out this study.

Conflict of Interest

The authors declared that they have no conflict of interest.

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