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Research Article

3D Mafic Topography of the Transition Zone between the North-Western Boundary of the Congo Craton and the Kribi-Campo Sedimentary Basin from Gravity Inversion

Sévérin Nguiya,[1] Willy Lemotio ,[2] Philippe Njandjock Nouck,[2] Marcelin M. Pemi,[2,3] Alain-Pierre K. Tokam,[2] and Evariste Ngatchou[2]

[1]*Faculty of Industrial Engineering, University of Douala, P.O. Box 2701, Cameroon*
[2]*Faculty of Science, University of Yaoundé 1, P.O. Box 812, Yaoundé, Cameroon*
[3]*Department of Renewable Energy, Higher Technical Teachers' Training College (HTTTC), University of Buea, P.O. Box 249, Cameroon*

Correspondence should be addressed to Willy Lemotio; willylemotio@gmail.com

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The structure of the transition zone between the north-western boundary of the Congo Craton and the Kribi-Campo sedimentary basin is still a matter of scientific debate. In this study, the existing gravity data are interpreted in order to better understand the geodynamics of the area. Qualitatively, results show that the major gravity highs are associated with long-wavelength shallow sources of the coastal sedimentary basin, while large negative anomalies trending E-W correlate to low dense intrusive bodies found along the northern limit of the Congo Craton. For the delineation of the causative sources, the gravity anomalies have been inverted based on the Parker-Oldenburg iterative process. As inputs, we used a reference depth of 20 km obtained by spectral analysis and successively, the density contrasts 0.19 g/cm^3 and 0.24 g/cm^3, deduced from available 1D shear wave velocity models. The results reveal an irregular topography of the mafic interface characterized by a sequence of horst and graben structures with mafic depths varying between 15.6 km and 23.4 km. The shallower depths (15.6-17 km) are associated with the uprising of the mafic interface towards the upper crust. This intrusion may have been initiated during the extension of the Archean Ntem crust resulting in a thinning of the continental crust beneath the coastal sedimentary basin. The subsidence of the mafic interface beneath the craton is materialized by 2 similar graben structures located beneath both Matomb and Ebolowa at a maximum depth of 23.4 km. The intermediate depths (18-22 km) are correlated to the suture zone along the Pouma-Bipindi area. The location of some landslides across the area matches within the northern margin of the Congo Craton and suggests that this margin may also impact on their occurrence. This work provides new insights into the geodynamics, regional tectonics, and basin geometry.

1. Introduction

South Cameroon region is known to be an interesting area of mining research and oil exploration. All mining experts agree that the area is a hidden treasure in terms of the substantial mining resources it possesses. The use of spectral methods to investigate the crustal density structure in the south region of Cameroon remains among many mathematical tools the most employed approach in geophysical data analysis and the interpretation of tectonic structure. One such application is the spectral estimation of the depth to the bottom of the gravity sources due to the variation of crustal layers beneath the north-western margin of the Congo Craton [1–3]. The depth estimation of density interfaces from potential fields beneath the Congo Craton was done by means of the gravity power spectra [4], which showed that the slopes of logarithms of energy spectra are linked to the thickness of the anomalous gravity sources.

In order to explain the geodynamic process of density layers from the uppermost mantle to the lower crust, the fluctuation of the power spectrum function permitted [1–3] and Owona et al. [5] to delineate the frequency limits corresponding to the major crustal discontinuities; the mean depth results obtained for those authors reveal a crustal thickness around 45 km beneath the Congo Craton area and about 28 km thick for the continental part of the Kribi-Campo area. Despite a good correlation with the estimation of the crustal thickness within the transition zone between the Congo Craton and the Kribi-Campo subbasin derived from seismological studies [6], there is no consensus with the presence of the mafic composition for the lower crust [1, 3, 5]. Therefore, works of Tokam et al. [6], based on the joint inversion of the Rayleigh wave group velocities and P-receiver functions, reveal the presence of mafic formations that occupy almost the entire lower crust, with thicknesses varying from 10 km under the continental basin to nearly 25 km beneath the Craton. Moreover, results obtained by Owona et al. [5], by joining other geophysical data analyses, have pointed the similar conclusion.

This paper aims to provide a map showing the spatial distribution of the intracrustal mafic discontinuity in the transitional zone between the north-western edge of the Congo Craton (CC) and the Kribi-Campo area. In order to improve the knowledge of the mafic structure beneath the region, a 2D spectral analysis of existing gravity data is carried out. This spectral method is applied in a rectangular grid size of 157 km × 201 km expanded using the maximum entropy prediction which is useful in minimizing edge effects when working with data containing systematic high frequency [7–10]. Then, a code for 3D inversion of gravity data [11] has been used to obtain the 3D topographical image caused by the mafic interface density considering the density contrast between two media. The main purpose of this paper is to show the geodynamic implication of the intracrustal mafic discontinuity in the north-western portion of the Congo Craton based on the analysis and the gravity inversion constrained by seismic information and its implication to the occurrence of landslides across the area. Factors as faults, earthquake, volcanism, and geomorphology are known as potential triggers of landslides. By correlating the location of some observed landslides and the gravity data, new insights on the regional tectonic can be inferred.

2. Geological and Tectonic Settings

The study area lies between latitudes 2.32° and 4.20°N and longitudes 9.85° and 11.3°E (Figure 1); three major tectonic features characterize the region (Figure 2): the Kribi-Campo subbasin, located in the Gulf of Guinea, is the littlest coastal basin in Cameroon and constitutes the southern part of the Douala/Kribi-Campo basin [12], the north-western portion of the Congo Craton (CC), known in Cameroon as the Ntem Complex, is mostly composed of Archean rocks including intrusive rocks with a predominance of magmatic rocks, and metasediments and mafic-ultramafic intrusive rocks and the Pan-African Belt of Central Africa (CAPB), situated between the West African and Congo Craton, represent the Yaoundé group in our study area [13–17].

The region of interest bears traces of the different tectonic events that have marked the African continent. The more prominent tectonic feature is the north-western part of the Congo Craton which is known in Cameroon as the Ntem Complex. This complex is divided into two main structural units: the Nyong unit, to the northwest end, and the Ntem unit, in the south-central region [18, 19]. The Archean Ntem unit is dominated by gneisses intrusive complexes primarily consisting of Tonalite Trondhjemites and Granodiorites (TTG) suite rocks [20–22]. The intrusive rocks of the tectonic unit have a charnockitic character with predominance of granitic, tonalitic, and syenitic formations. The Archean terranes in the Ntem Complex are mostly formed of Horst and Graben tectonics linked to diapiric movements in the mid to lower crust [23]. The whole unit appears to have been coaxially strained [23]. Some authors reveal that the presence of dome and basin structures is the result of gravitational instabilities [24–27]. Thus, works from Owona et al. [5] confirmed this theory by proposing a 2D 1/2 gravity modelling showing that the interface separating the lower mafic crust and the upper crust is undulating. They supposed that the mafic layer also contributes to the variation of the gravity field along the gravity profile crossing the transition zone between the Congo Craton and the Kribi-Campo basin. The Ntem Complex is also marked by the past magmatic activities with several bodies of dense rocks such as amphibolites, gabbros, charnockites, and granodiorites [5, 6].

The last mafic event, dated at the period before 2.1 Ga, is marked by the rifting of the Archean Ntem crust [5, 28, 29] and has resulted in the emplacement of swarms of mafic doleritic dykes [5, 28–31]. The continental crust of our study area is mainly composed of Nyong unit formations. According to some geologist, the Nyong unit may be relict features from the collision between the Congo Craton and the Sao Francisco (Brazil) Craton in the lower Proterozoic [21, 32]. The Nyong unit also carries imprints of past magmatic event, which are characterized by the neoproterozoic intrusion of nepheline syenites in the sinistral shear zone [29, 33]. Apart from the Douala basin, the Kribi-Campo subbasin is the only sedimentary coastal basin in the south region of Cameroon. It constitutes the northern limit of the Gabo-Equato Guinean basin [34]. The Archean basement is mostly composed of green rocks belt, charnockites, and potassic granitoids [35]. Ntamak-Nida et al. [12] mentioned that the western limit of the subbasin appears to be widely defined by a major oceanic fracture zone, the Kribi Fracture Zone (noted KFZ) [36, 37]; the continental sector of the KFZ, known as the Kribi-Campo fault (KCF), is the major fault that crosses the transition zone between the Congo Craton and the Kribi-Campo area. The interpretation of geophysical model shows that this resulting suture may be assimilated to the thrusting of the central Africa mobile belt rocks onto the Congo Craton (CC) [5].

3. Data and Method

3.1. Data Acquisition. The data were collected during gravity campaign operated in Cameroon between 1963 and 1990 by various organizations and researchers [5]. The earliest data were those carried out by ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer); to these data have been added those acquired by [39], Société E.L.F. (Essences et Lubrifiants Français), IRGM (Institut de la Recherche Géologique et Minière) and University of Leeds (1984-1985 and 1986). Gravimeters Worden (N∘ 313, 600, 69, and 135) and

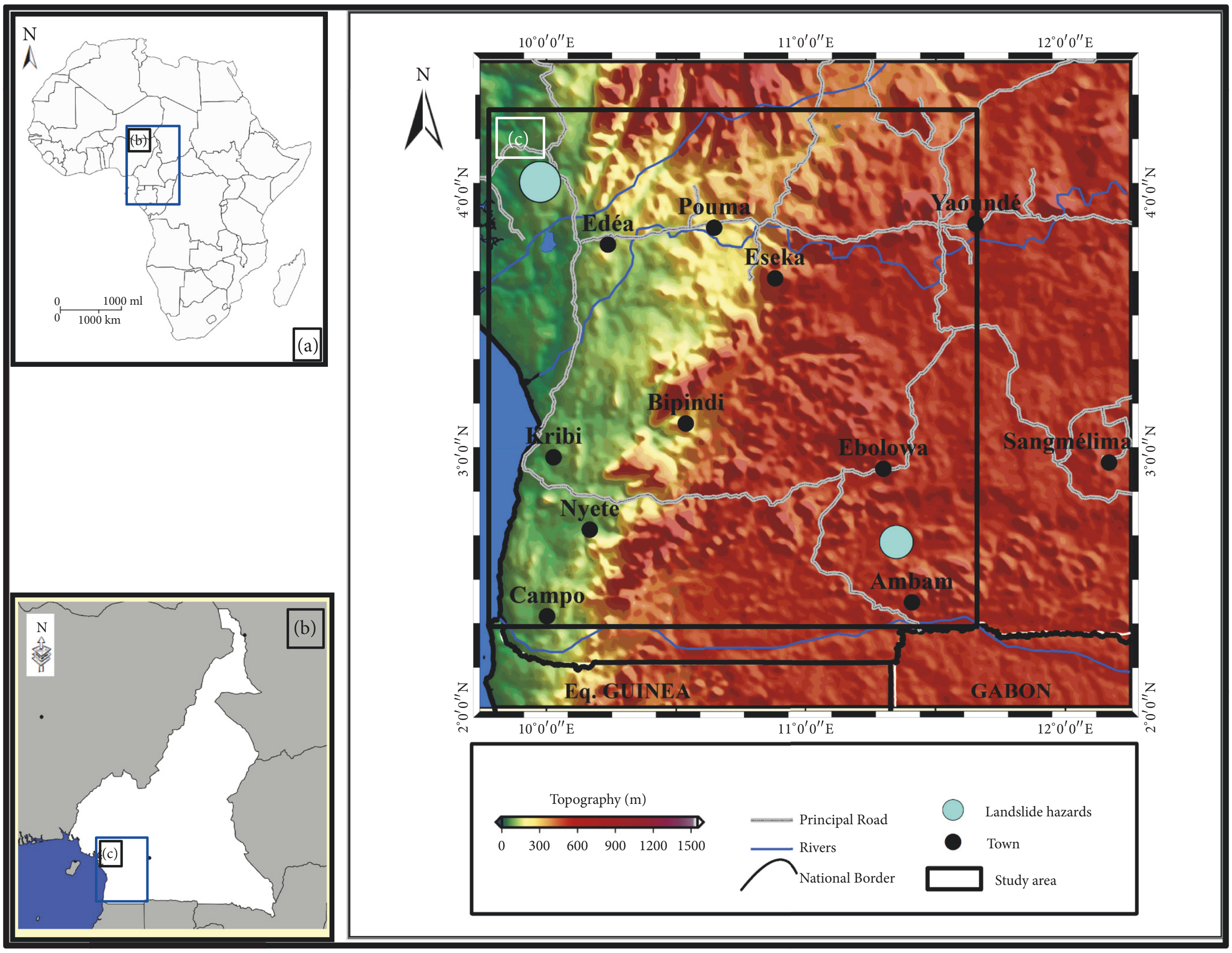

Figure 1: Topographic map showing the study area (landslide document is taken from Tchindjang, [38]).

Lacoste & Romberg (model G, N∘ 471 and 828) were used for the gravity measurement with a resolution of 0.01 mGal.

The gravity measurements were done along roads and trails and the space between stations varied from 4 to 5 Km including base stations. The coordinates of gravity stations have maximum error ranging between 200 and 2000 m and the measurement accuracy of gravity values was about 0.2 mGal. The data were uniformly reduced to Earth-tide effects and instrumental drift, free air reduction was also applied to the data, and a reduction density of 2,67 g/cm^3 was used for the Bouguer correction. The Hammer (1939) method [41] was used for the terrain corrections [42]. The available dataset used in this study derived from 256 gravity stations covering an area of about 157 km × 201 km size. The study includes only terrestrial data because of the difficulties to access data from the sea. The Kriging method was used in order to achieve a meaningful spatial distribution of gravity data within the region. The kriging interpolation process was executed using Surfer 13 software. The Bouguer values were then plotted to obtain the Bouguer anomaly map, with a grid spacing of 2,02 km giving a total grid size of 100 rows by 79 columns (Figure 3).

3.2. Method. To better characterize the mafic structure along the transition zone between the Kribi-Campo and the Congo Craton, the methodology along the paper is based on the 2D spectral analysis followed by the regional/residual separation and the 3D inversion of the regional gravity map.

3.2.1. Power Spectrum Analysis. The Fast Fourier Transform method was commonly used in geophysical studies for the depth estimation of the causative bodies. The power spectrum graph was obtained by a careful choice of the gravity profiles crossing the significant anomalies on the Bouguer anomaly map computed [3, 5, 43]. Herein, the 2D spectral analysis was applied to the gravity grid data and allows calculation of an average depth to a set of causative anomaly sources [10, 44, 45]. The method proves to be an appropriate technic where the calculation of the power spectrum should not be

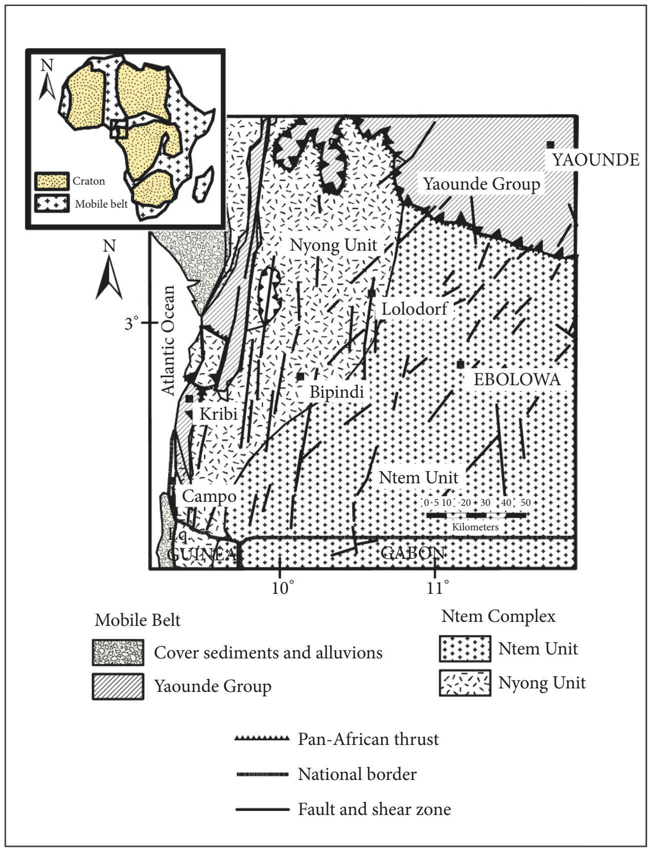

Figure 2: Simplified geological map of the South Cameroon showing the principal units and the main lithological formations (modified after Tchameni et al. [40]).

dominated by biases and it should be statistically meaningful [45–48].

The 2D power spectrum energy is obtained by averaging over the set of independent computed power spectra energy; then the current two-dimensional problem was transformed to one dimension, and we can compute the logarithm of the energy spectrum that provides the mean depth of density interfaces [45, 49, 50].

Prior to spectra calculation, data grids need to be expanded in order to avoid edge effects [7]. The maximum entropy method (MEM) is a powerful tool to minimize boarding effects. The MEM samples the original data near the grid edges to determine its spectral content. It then predicts a data function that would have the same spectral signature as the original data and computes the extrapolated data of the same nature and the real data adjacent to it. Furthermore, the predicted grid data will not significantly modify the energy spectrum that would result only from the original data. This process runs along lines in several directions and applied weighting along adjacent lines to eliminate line divergences.

Errors on the depth estimation of causatives sources increase with depth, but also depend on the size of the grid. Thus, for simple shape structures used for two-dimensional gravity models, Naidu [51] considers that the size of a grid must be 10-20 times greater in extent than the mean depth of the anomaly source sought. In our case, the Bouguer anomaly map has been expanded to a square grid of 225 km × 225 km by using the MEM (Figure 4). It is preferable to use a square grid to compute the radially averaged spectrum (this is to use the same frequency in both x- and y-directions, so the radial average spectrum is not biased by a frequency different from the other). For the determination of the mafic discontinuity, assuming a value of 16 to 20 km for its mean depth, our expanded grid has the required size for these estimates. The aim of spectral analysis is to determine the mean depth of the mafic discontinuity for the grid in order to study its spatial distribution in the crust. Once power spectrum is computed, the top depth of the density interface is estimated as half of the slope of the straight line adjusted to the natural log of energy spectrum versus the radial frequency by considering the theory of Spector and Grant [4].

3.2.2. Regional/Residual Separation. The observed gravity anomalies are the sum of gravity effects of density fluctuations at different depths in the basement half space. Before inverting the mafic density interface, the target anomalies should first be separated from the Bouguer anomaly map. In the literature, there are several filtering methods

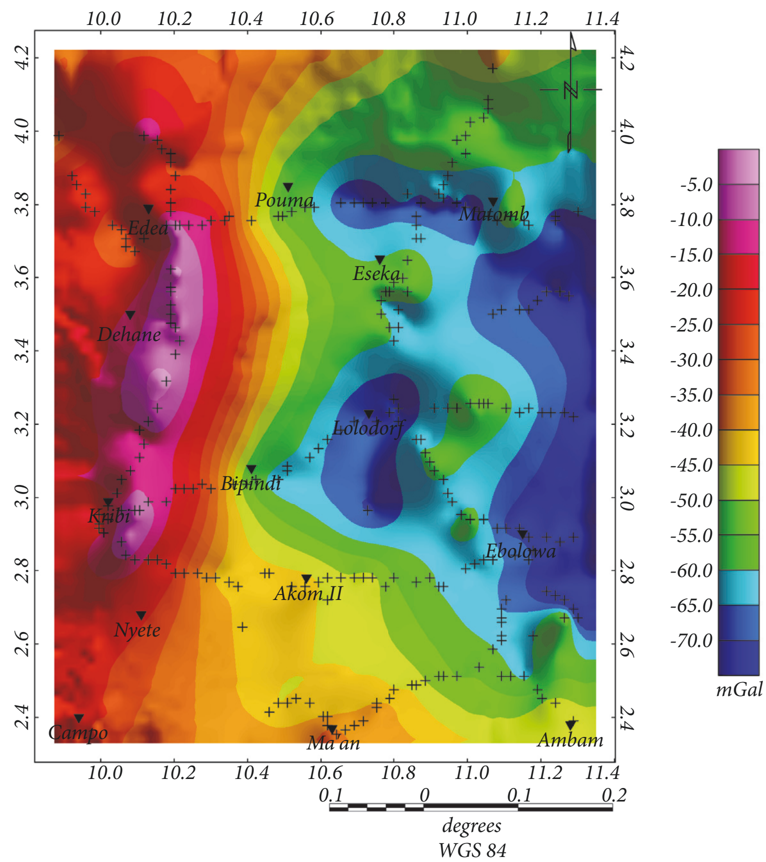

FIGURE 3: Gravity data distribution and Bouguer gravity anomaly map of the study area (Contour interval: 5 mGals; color-scale unit: mGal; projection: Mercator). Data are recorded at stations shown here as black cross and were collected following all available roads and tracks.

where regional/residual separation was performed [4, 52–54]. Herein, an Upward Continuation filtering method was used. It is the suitable method to dissociate the regional gravity anomaly resulting from deep sources from the observed gravity. The regional/residual separation by using the Upward Continuation method consists of selecting a height at which the continuation is most closely linked to the known regional anomaly at a standard observation. The spectral analysis permits us to get the average depth estimate at which the mafic discontinuity was located; the obtained depth will be taken as the optimum continuation height for the regional-residual separation [55, 56]. The upward continuation process by attenuating the shallow source anomalies allows a better accentuation of deeper anomaly sources with the increase of the upward continuation height [57].

3.2.3. 3D Gravity Inversion. At the aim of producing a full map showing the spatial distribution of the intracrustal mafic formation within the crust, a 3D gravity inversion will be performed on the regional gravity data. The method allows computing the geometry of a three-dimensional density interface from the gravity anomaly data. The inversion procedure is based on the Parker and Oldenburg iterative process [58, 59] and it can be established as follows:

$$F[h(x)] = -\frac{F[\Delta g(x)]\, e^{(-kz_0)}}{2\pi G\rho} - \sum_{n=2}^{\infty}\frac{k^{n-1}}{n!}F[h^n(x)] \quad (1)$$

where $F(\Delta g)$ is the Fourier transform of the gravity field, G is the gravitational constant, ρ is the density contrast between two layers, k is the wave number, $h(x)$ is the depth to the interface (considered positive downwards), and z_0 is the average depth of the density interface.

The relation (1) is the fundamental theory used by [11] that permits them to develop a 3DINVER MATLAB code for the computation of the depth interfaces related to the gridded gravity anomaly. By considering the mean depth interface, the density contrast between two media, and the input filtered gravity anomaly, the depth interface values are iteratively computed and the inversion procedure ends when the difference between two consecutive topography interfaces is less than a given error level used as convergence criterion or until a maximum of iterations is accomplished.

The instability of the inversion operation (1) due to high-frequency anomaly sources allowed Oldenburg [59] and Nagendra et al. [60] to introduce a high-cut filter $HCF(k)$ in order to achieve the convergence of series. Two other filter parameters WH and SH are used for the adjustment during the convergence process. The filter is defined by

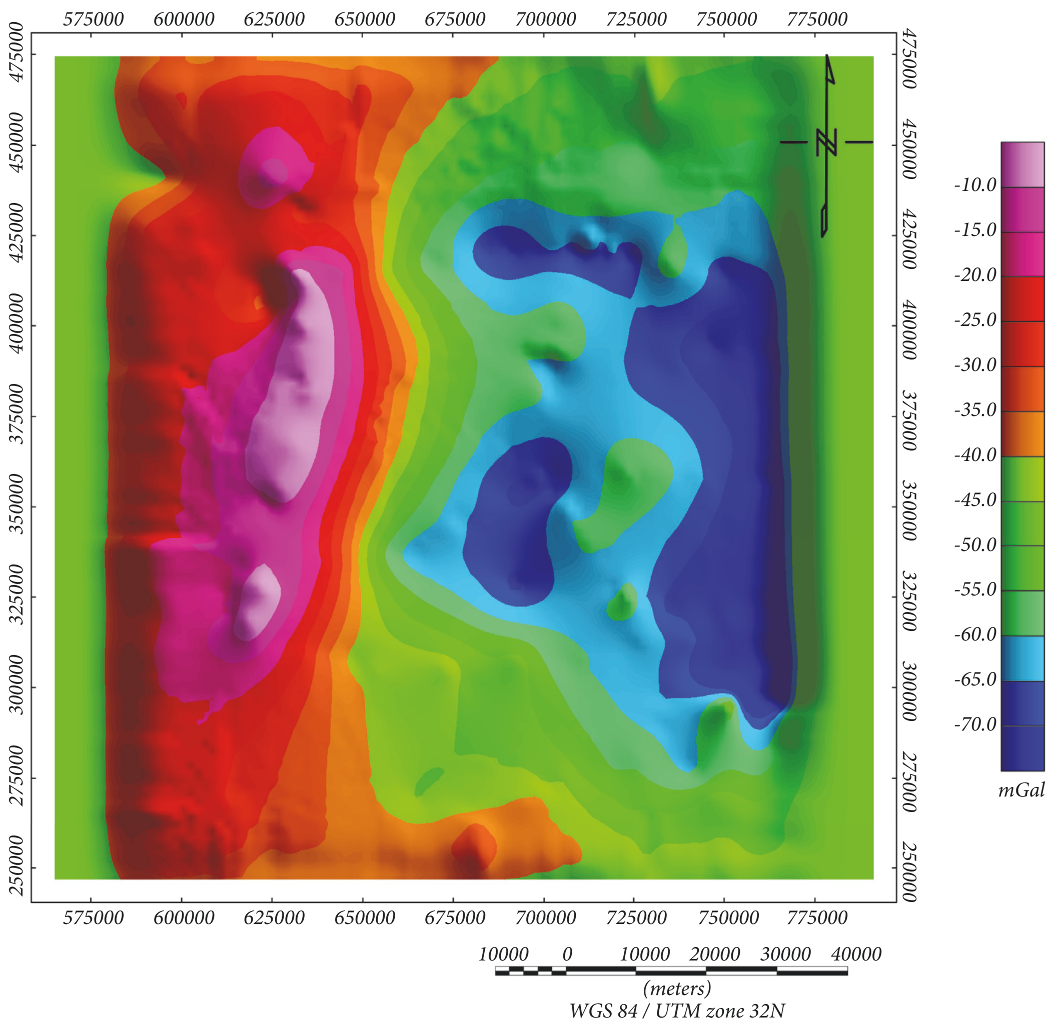

FIGURE 4: Grid map expanded using the Maximum Entropy Method (Burg, 1967) conserving the same spectral signature as the previous Bouguer anomaly map.

$$HCF(k) = \frac{1}{2}\left[1 + \cos\left(\frac{k - 2\pi WH}{2(SH - WH)}\right)\right] \quad (2)$$

For middle frequencies, there is a rectangular window with a value of 1 for low frequencies (WH) and 0 for high frequencies (SH) equivalent to a hamming window. k is the wavenumber expressed as $1/\lambda$, where λ is the wavelength in kilometers.

The MATLAB function 3DINVER performed by [11] was used in this paper to study the 3D geometry of the intracrustal mafic discontinuity in the area. So this study was carried out on a rectangular filtered gravity map with a size of 157 km × 201 km, made up of 256 gravity stations irregularly spaced. Before initiating the inversion procedure, it is recommended to expand the grid because the Fast Fourier transform (FFT) function introduces some edge effects during filtering, then invert the data, and finally remove the grid extension in order to retain only the original grid size. So any edge effects are removed from the study area. Herein, the previous original grid map was extended to a square grid size of 225 km × 225 km by applying the MEM [7]. Usually, a 10% expansion of the grid is enough to avoid boarding effects. Two other parameters are important for the inversion process: the mean depth reference of the interface and the density contrast across the interface. The iteration is at which the inversion process is stopped and the RMS is also displayed by the function. After convergence has been obtained, the best way to determine if the inverted interface is an acceptable solution is to compare the observed filtered gravity anomaly with the computed gravity data associated with the inverted interface. If the differences between both gravity maps are only a few mGal, the model can be validated; if not, some parameters of the inversion should be changed. The data processing was conducted by following the procedure summarized on the chart (see Figure 8).

4. Results

4.1. Analysis of the Bouguer Anomaly Map. The Bouguer anomaly map (Figure 3) reflects the combined effects of shallower and deeper crustal basement due to the lateral variations in the density of unknown subsurface materials. A global look of this map shows a couple of positive and negative anomalies delineated by strong NE-SW gradients. The appearance of these gradients could be associated with the fault network that occurs in the Precambrian oceanic area and extends to the continental domain crossing the Kribi Campo and the Congo Craton regions. This fault system, known as the Kribi-Campo Fault (KCF), resulted from the frontal collision between the two large structures, the Congo Craton (CC) and the Pan-African Mobile Belt (PMB) [61].

The Lolodorf zone and the Pouma-Matomb area are marked by long wavelength gravity anomalies with low amplitude of about -65 mGal. Both anomalies seem to be linked to the large gravity low observed in the eastern part of the Bouguer map with a minimum amplitude of -69 mGal and N-S trend. The gravity low seem to be caused by a downwarp in the basement and can be attributed to the crustal thickening due to the granitic intrusion with the low density contrast within the Northern portion of the Congo Craton [3]. This explanation corroborates well with the isostasy theory, in comparison with the topographic map (Figure 1), showing that elevated area is generally linked to the low anomaly sources constituting the crust. The Bouguer map shows a relative high (amounting to -10 mGal) around the Kribi-Edea region. The high values can be attributed to the intrusion of magmatic formations and their subsequent metamorphism (granulites body) or the uprising of some mantle materials (syenitic, mafic formations). Thus, geological studies indicate an important mafic magmatic activity during the rift extension [62]. The isoanomaly contours in the map going from the coastal area to the continental domain follow almost the NE-SW trend and reflect the onshore transition of the continental crust.

4.2. Mean Depth Estimation of Density Interfaces. The power spectrum graph of Figure 5 illustrates a sketch of the natural logarithm of the power spectrum versus the frequency. The graph is divided into three frequency domains. The first one, domain A, in the low frequency ranging from 0.02 to 0.22 km^{-1}, represents the deeper density interface with a mean depth of 20.01 ± 0.9 km. The second one, domain B, corresponds to the high frequency ranging from 0.25 to 0.75 km^{-1} and belongs to the shallower sources with a mean depth value of 5.7 ± 0.3 km. The final part of the power spectrum graph does not have a geological meaning and corresponds to the white noise. Depth estimates of 20.01 ± 0.9 km may possibly correspond to the intracrustal mafic interface beneath the transitional zone between the Kribi-Campo and the Congo craton area. This result is in good agreement with seismic studies from Tokam et al. [6] revealing that the crust is divided into several layers with a lower thick mafic layer at depth below 18 km beneath the region. The shallower sources' depths of 5.7 ± 0.3 km may be attributed to the dense mantle formations within the sedimentary coastal basin responsible for the observed positive gravity anomalies in the coastal area.

After identifying the main sources responsible for the observed gravity anomalies of the study area, the study will be now focused on the anomaly sources situated in the low frequencies associated with the deeper mafic formation. We will apply a filter to the Bouguer map to isolate the gravity signatures corresponding to the 20 km mean depth interface.

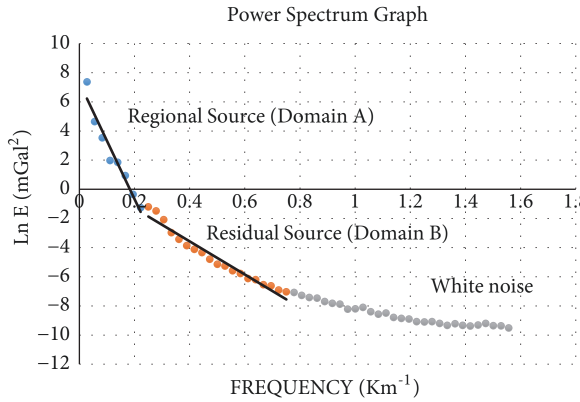

Figure 5: Power spectrum graph of the gridded Bouguer data showing 2 frequency domains. The first one with blue circles represents the regional source, the second domain with orange circles corresponds to residual source, and the gray circles represent white noise.

4.3. Regional and Residual Gravity Maps. The regional gravity map (Figure 6) shows anomalies ranging from -56 to -24 mGal; the anomalies consist of a western gravity high and an eastern gravity low almost oriented N-S and separated by strong gradients. The gravity highs are observed in the Kribi-Dehane area with a slight extension towards Campo and a maximum amplitude of -25 mGal. These anomalies are enclosed by gravimetric gradients which extend towards the Pouma-Bipindi area. The enhancement of these gradients on the central part of the regional map confirmed the presence of fault system in the area and also revealed that the major faults crossing the transitional zone between the Kribi-Campo and Congo Craton area had a deep origin and in the same way could explain the seismicity of the zone. The upward continued map also illustrates the change in anomaly character with a minimum value of -56 mGal along Ebolowa-Matomb axis. This can suggest that the lower crust formations are deepening towards the east of the region. As such, the 20 km upward continued data present a suitable regional map for gravity inversion studies to help define the basement characteristics of the mafic discontinuities and associated intrusive bodies from the Pan-African belt.

To highlight local anomalies, the regional component of the gravity anomaly field is commonly subtracted from the Bouguer anomaly map, generating a residual map (Figure 7) that shows exactly shallow density structures. The computed residual gravity map is characterized like the Bouguer anomaly map by a broad positive anomaly zone with a NE-SW orientation. This zone can be related to the shallow response of mafic rocks such as gabbros [5, 30]. Gravity lows with a ring shape observed at Pouma, Matomb, and Bipindi-Lolodorf area appear to be the signature of intrusive igneous

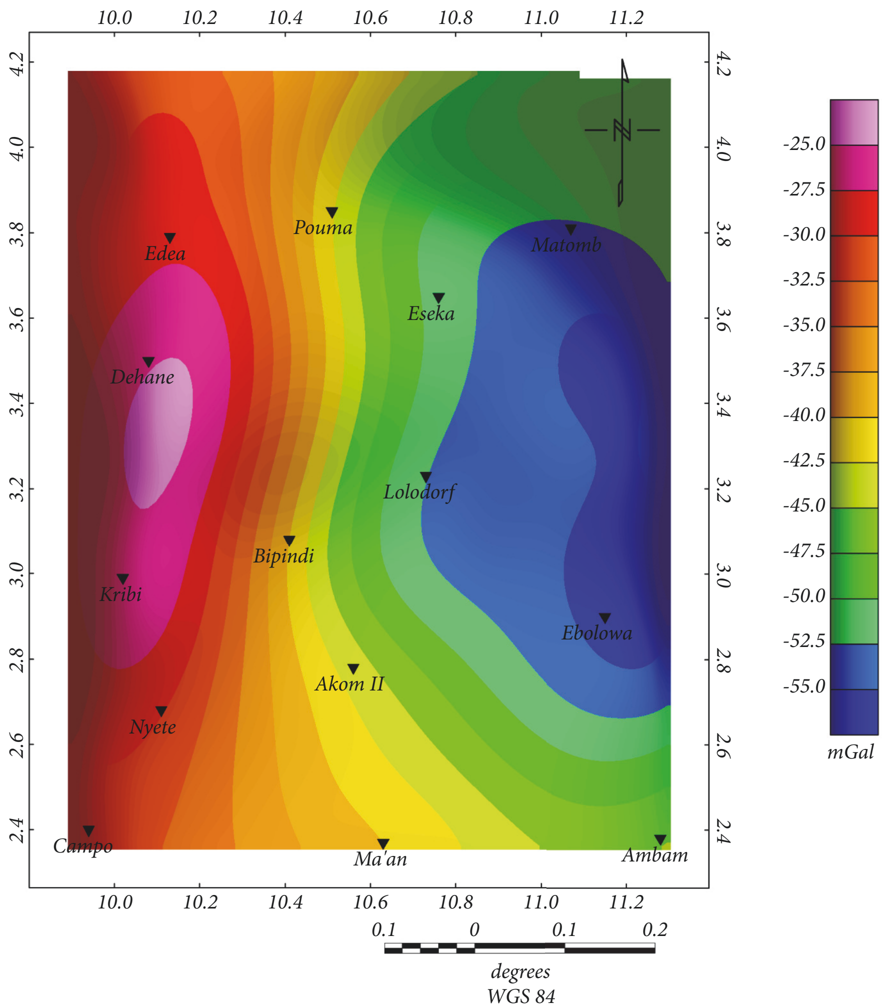

Figure 6: Regional gravity map obtained by applying the upward continuation filtering method to the Bouguer anomaly map (contour interval: 2.5 mGals; color-scale unit: mGal; and projection: Mercator).

rocks in the upper crust such as granits, syenites, and Tonalite Trondhjemites and Granodiorites (TTG) formations [30, 63].

4.4. 3D Topography of the Mafic Interfaces. Taking into account the importance of the inversion parameters such as the density contrast between the two media (the lower mafic crust and the upper crust) and the mean reference depth of the mafic interface, we considered a mean depth of 20 km derived from the results of the spectral analysis. We also made the choice to vary the density contrast depending on whether we are in coastal area or beneath the craton (Table 1).

For each density contrast, we compute the corresponding mafic depths in order to obtain the topography of the underlying mafic interfaces (Figure 9). The constraints from the shear wave velocity model [5, 6] helped to compute the density contrast beneath the Kribi-Campo area and within the Congo Craton. The convergence criterion was set at 0.02 km; the RMS errors between the two consecutive topography values and the iteration at which the inversion process is stopped are presented in Table 1. We denote that for both geological terrains the iterative procedure was achieved at the third iteration and that the change in density contrast does not significantly alter the depth variation of the mafic interface; this allows us to deduce that we are practically under the same tectonic unit. Regarding the mafic depth map, when increasing the density contrast from 0.19 to 0.24 g/cm^3, the magnitude of the upper crust thickness increases around 0.95 km within the coastal area, while it decreases about 1.68 km beneath the Congo Craton. The MATLAB function also displays the gravity anomaly associated with the inverted mafic interfaces and the residual error between the observed gravity anomalies and the computed anomalies (Figure 10).

This later appears to be very close to the input gravity signal with a residual error map revealing that the differences are minor and are in the range of -2.5 to 1.8 mGal. So we can rely on the estimate of the resulting inverted mafic interface.

The resulting mafic depth map represents the depth variations of the boundary between the upper crust and the lower mafic body. The upper crust thickness seems to increase

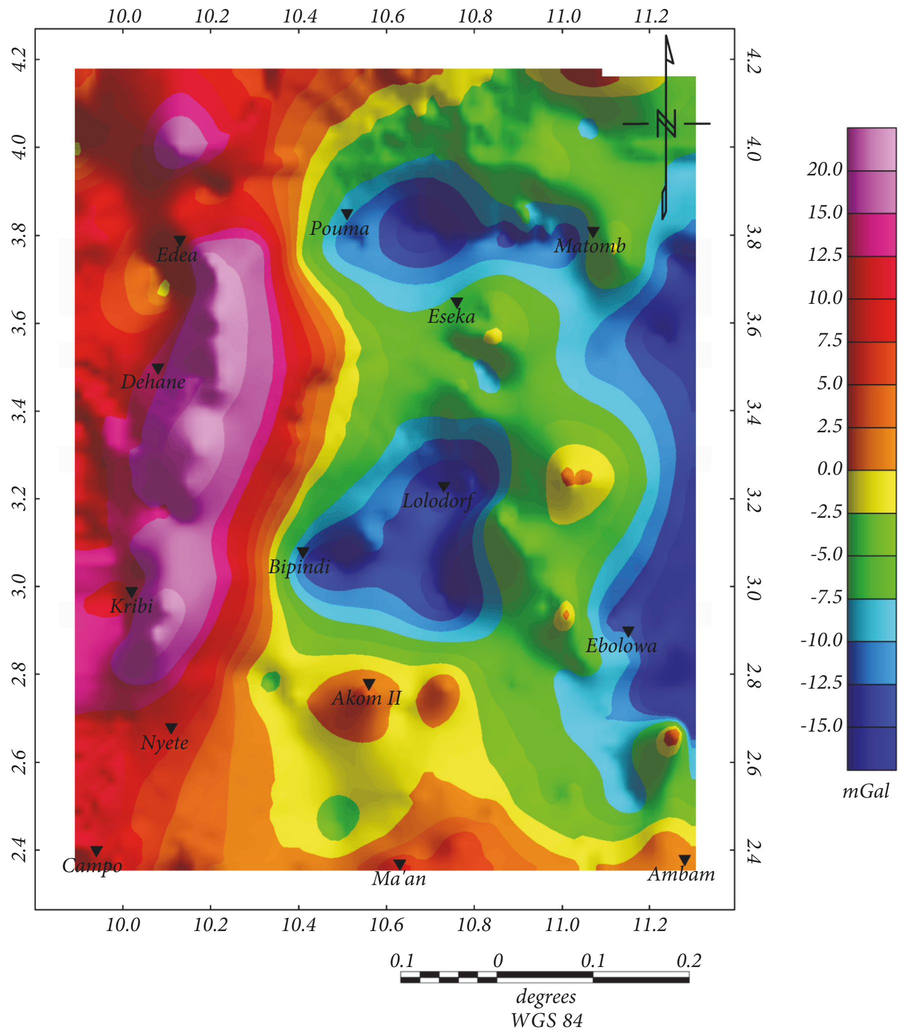

FIGURE 7: Residual gravity map of the study area obtained by subtracting the regional gravity map from the Bouguer anomaly map (contour interval: 2.5 mGals; color-scale unit: mGal; and projection: Mercator).

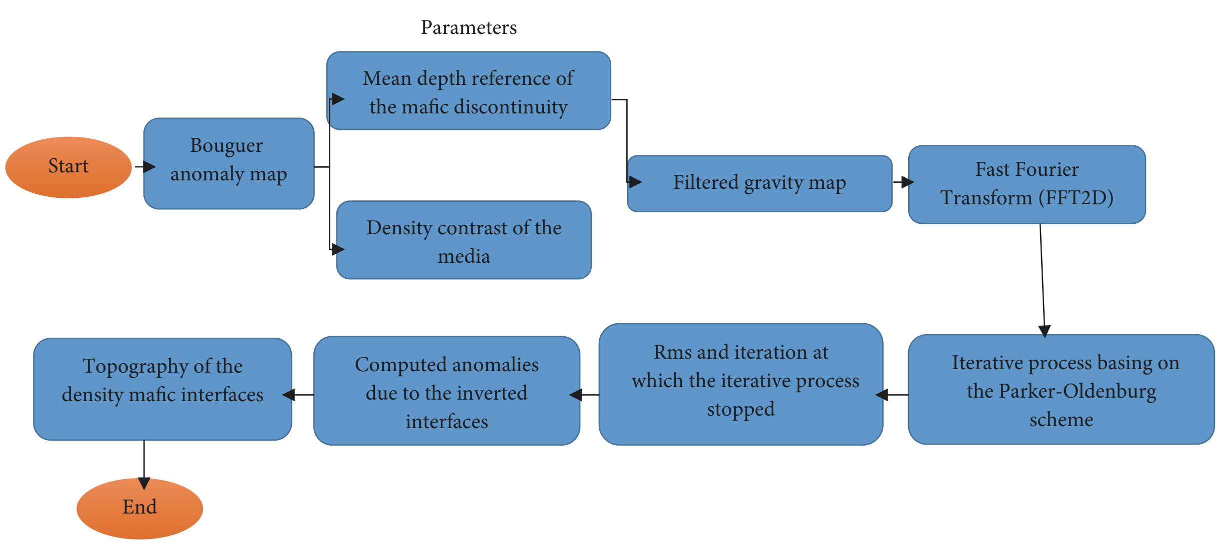

FIGURE 8: Summary of the 3D inversion process.

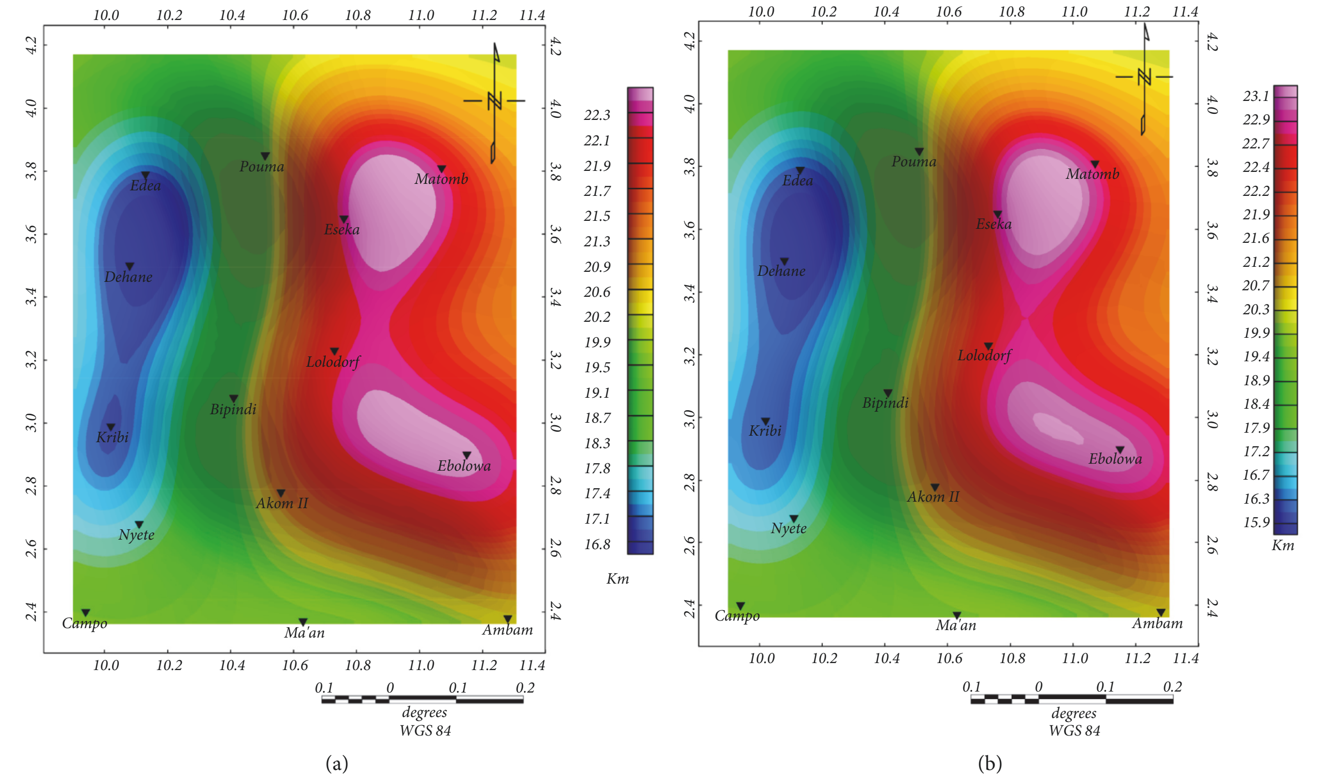

FIGURE 9: (a) Computed contour map of the mafic depth by using the 3D gravity inversion of the study area. Density contrast $\Delta\rho$ = **0.24 g/cm^3**. (b) Computed contour map of the mafic depth by using the 3D gravity inversion of the study area. Density contrast $\Delta\rho$ = **0.19 g/cm^3**, contour interval 0.1 mGal. Geographical coordinates.

TABLE 1: Inversion efficacy by geological unit.

Mean depth reference: Z_0	Density contrast	
Z_0 = 20 Km	Kribi-Campo terrain	Congo Craton terrain
	$\Delta\rho$= **0.19 g/cm^3**	$\Delta\rho$ = **0.24 g/cm^3**
	ITER=3	ITER=3
	RMS=0.0031 Km	RMS=0.0015 Km

eastwards from approximately 16 km (coastal sedimentary basin) to about 22 km (continental craton), with dominated N-S strong gradients that cover the Pouma-Bipindi area. The lower mafic depths are observed in the western part of the area precisely in the Kribi-Edea axis. This area is marked by dome structures with a minimum depth of about 15 and 16 km observed both in Dehane and Kribi regions. Despite the poor data coverage beneath the coastal sedimentary basin, the mafic depth distribution is in agreement with previous studies [5, 6]. The authors revealed a depth of 18 km for the mafic formations beneath the basin, while in this study, we find a depth varying from 15.6 to 17 km. The dome structures observed in some coastal regions show that the mafic discontinuity is uprising toward the upper crust (see Figure 11). The mafic interface becomes deeper from the center region to the eastern edge of the study area where a depth of up to 23 km is reached at Ebolowa and in the vicinity of Matomb. These collapse zones seem to describe two grabens structure of the same nature. Although the two depressions seem to be a bit similar in their shape, magnitude, and strike direction, it is difficult to link the two tectonic features because they could have been put in place at different geologic period. Furthermore, geological studies reveal that the Ebolowa sector is dominated by low Archean terrain with occurrence of low syenitic intrusion [24, 40, 64]. This Archean period of deformation can explain the presence of the large basin structure in the Ebolowa area and its gravitational incidence in our gravity model. At a first glance, the intermediate depth going from 18 to 22 km in the central part of the inverted interface map defines contours patterns identical to those of gravity anomaly derived from the computed data.

The linear characteristics, crossing the Pouma-Bipindi area, follow almost the N-S trend direction and correspond to the faults network which correlate well with the geological map. These faults features may be responsible of the subsidence of the lower mafic interface beneath the Matomb-Ebolowa area.

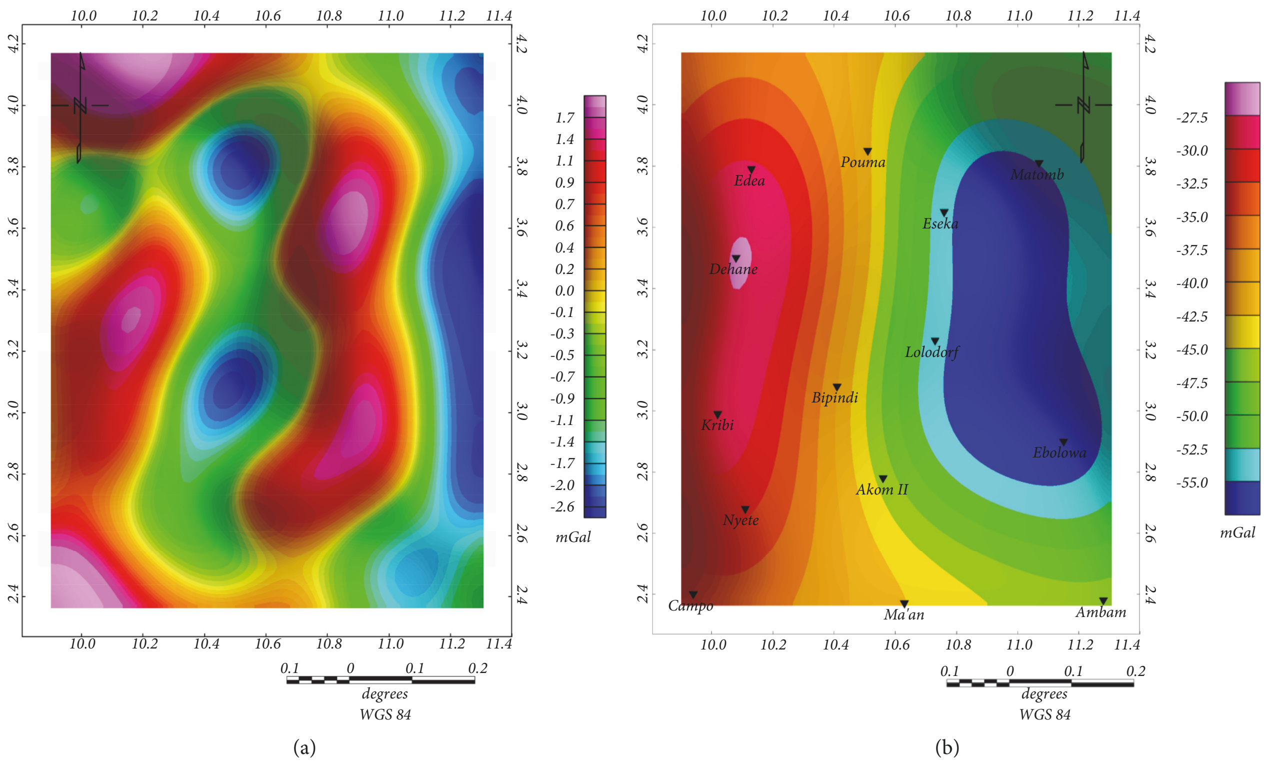

Figure 10: (a) Difference between the regional gravity map and the one due to the inverted mafic interface. Contour interval 0.1 mGal. Geographical coordinates. (b) Gravity anomaly map associated with the inverted mafic interfaces. Contour interval 2.5 mGal. Geographical coordinates.

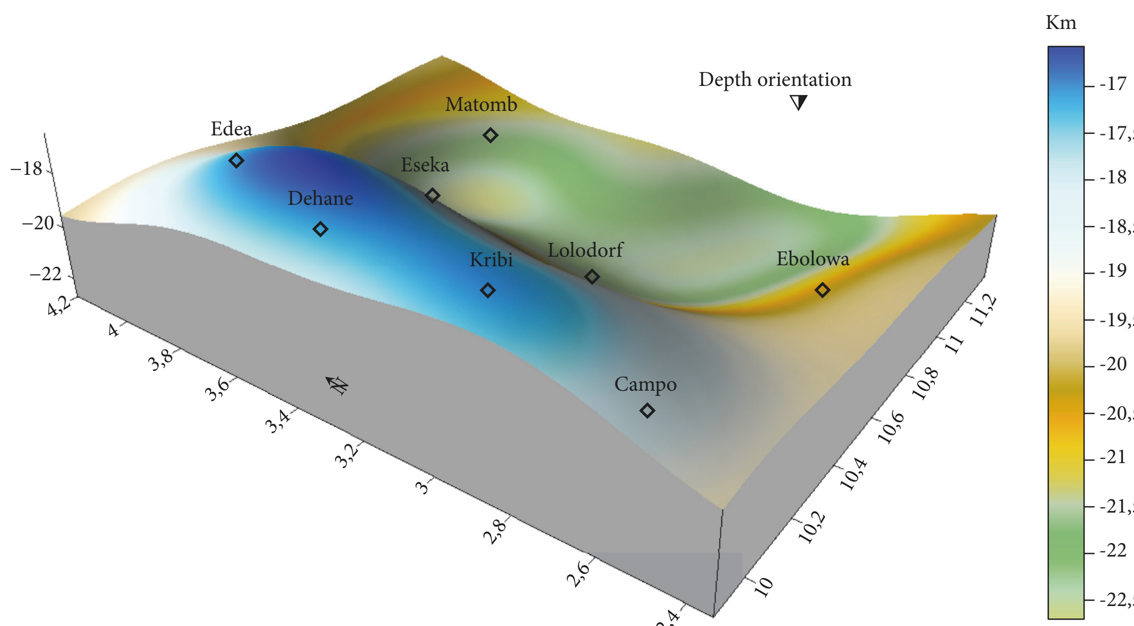

Figure 11: 3D view of the mafic depth showing the topography of the mafic density interfaces along the transition zone between the Kribi-Campo area and the Congo Craton.

5. Discussion

The investigation of the intracrustal mafic discontinuity beneath the transition zone between the Congo Craton and the Kribi-Campo area by using gravity data analysis and 3D gravity inversion method has allowed a better understanding of the mafic interfaces behavior within the continental crust. The results prove that the lower/upper crust boundary is not homogeneous and present discrepancies due to lateral density variation in Earth interior. To achieve this, a rectangular grid size of 157 km × 201 km was selected to perform the two-dimensional (2D) spectral analysis. Prior to this transformation, the gridded data was expanded to a square grid size of 225 km × 225 km to avoid side effects and to obtain more reliable source depth estimations. Poudjom et al. [1] used the same process to build the crustal thickness contour map of the West central Africa; they have selected 33 subgrids to estimate the crustal thickness (T_c) and studied its variation beneath the area by spectral analysis of the gravity data. The power spectrum graph allows us to identify two density domains: one situated in the high frequencies and a mean depth value of 5.7 km, another located on the low frequencies and an average depth of 20.01 km. The first estimate corresponds to dense formations within the Kribi-Campo subbasin. Tadjou et al. [65], by investigating the anomalous density structure beneath the Kribi-Campo sedimentary subbasin, have estimated the dense bodies in the same area at 6.5 km depth; so just a minor difference of 0.8 km was obtained; this can be explained by the permanent tectonic activity affecting the basin and the gravity effect of the other dense materials within the upper-crust layer. In order to elucidate ambiguities on the dense bodies origin and to bring out more explanation about the gravitational instabilities observed along the above transition zone, the 20 km mean depth interface attributed to the intracrustal mafic discontinuities was chosen as a fundamental parameter for the 3D gravity inversion. The inversion procedure constrained by seismic information was applied on the filtered gravity data with the aim to construct a mafic depth map. The mafic interface is uplifted in the Kribi-Edea area with the crust thinning beneath the continental basin where the Moho is found at about 28 km [5, 6, 65].

This result suggests that the observed dense materials have a mantle origin during the past magmatic event as Tadjou et al. [65] mentioned in their gravity studies, but our model reveals shallow mafic intrusion beneath the Kribi-Campo area which could be the consequence of the relamination process during the Archean subduction [66–68]. The mafic intrusion also influences the deformation of the sedimentary rocks and exhibits some control on the basin geometry. The mafic depth becomes deeper from the center map to the east with a slight extension in the Matomb-Ebolowa area. The computed topography contour map also reveals clearly a linear characteristic of N-S trend along the Pouma-Bipindi axis which approximately corresponds to the faults feature. Geological studies reveal that this area is characterized by a faulting deformation responsible for development of blastomylonitic shear zones [29, 30]. The resulting deformation may be interpreted from the model as the thrusting of mafic interfaces onto the east side of the Lolodorf region. The symmetric graben structure observed both in Ebolowa and in the vicinity of Matomb resulted from the subsidence of the mafic intrabasement with a major depth of 23.4 km, so 3.4 km below the reference depth. The fact that the south-central part of the Congo Craton is dominated by low-density Archean rocks could explain the presence of these graben tectonic structures. Our results also provide new insights concerning the geodynamic behavior of the top of the lower mafic crust along the transition zone. It appears to be shallower in the Kribi-Campo area and deeper beneath the Congo Craton. The same process was observed for the Moho discontinuity where seismic work of Tokam et al. [6] demonstrates that the Moho is shallower beneath the coastal basin and becomes deeper within the Congo Craton. In addition, the results of our gravity inversion correlate well with those obtained by Owona et al. [5], but we noticed some discrepancies. Indeed, our model integrates a thin upper/middle-crust layer in the Kribi-Campo domain where the lower limit is located at almost 15 km and a thicker upper/middle-crust layer~ 23 km beneath the CC. Otherwise, since our study was based on the processing of the long wavelength gravity signal; the undulation of the mafic interface going from the coastal plain to the Archean continental crust plays a crucial role on the gravity instability on the surface geology and its geodynamic process has been better highlighted in this study.

The high gravity gradient observed on the Bouguer map associated with the Kribi-Campo fault (KCF) is part of the lineaments known as Sanaga fault. Ngatchou et al. [69] analyzed broadband seismogram and determined the source mechanism of the March 19, 2005 Monatele earthquake. Their results show the evidence that the contact between the Congo Craton and the Pan-African Mobile Belt (PMB) is still seismically active. Moreover, Owona et al. [70, 71] also pointed out the existence of some other fault systems in the area that may be also active. The location of some historical landslides across the area [38] matches with the location of some major tectonic features within the area and suggests that this major tectonic element may control the occurrence of landslides in the study area.

6. Conclusion

By using a 3D gravity inversion program based on the Parker-Oldenburg method and developed by [11], we carry out a gravity data analysis, using seismic information as constraints [6], to build a Mafic depth map showing the spatial distribution of the mafic density interfaces beneath the transition zone between the Kribi-Campo and the Congo Craton. The inversion of the mafic structure generated by a standard density model was based on the approximating assumption that the density contrast between the layers above and below the interface takes a constant value. The study allows us to deduce that the gravity lows and highs of circular or semicircular nature observed on the theoretical gravity map were attributed to mafic intrusions in terms of basement uplifts and depressions, proving that the mafic interfaces have a great incidence on the gravity anomalies within the region. From a mean reference depth of 20 km, the 3D view of the mafic depth shows uplifts reaching over 15.6-17 km in both Kribi and Dehane regions and two symmetrical mafic depressions, while centre parts extend up to a depth of 23.4 km beneath both Ebolowa and Matomb areas. The flock of depth contours almost trending N-S direction has increased values towards the east in the vicinity of Lolodorf. It suggests the existence of fault systems controlling the subsidence of mafic interfaces beneath the craton subsurface and impacting the occurrence of landslides in the area. Thus, the gravity inversion by using the Parker-Oldenburg 3D inversion method proves to be a powerful tool for the gravity data analysis and the tectonic interpretation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors reveal that there are no conflicts of interest regarding the publication of this paper.

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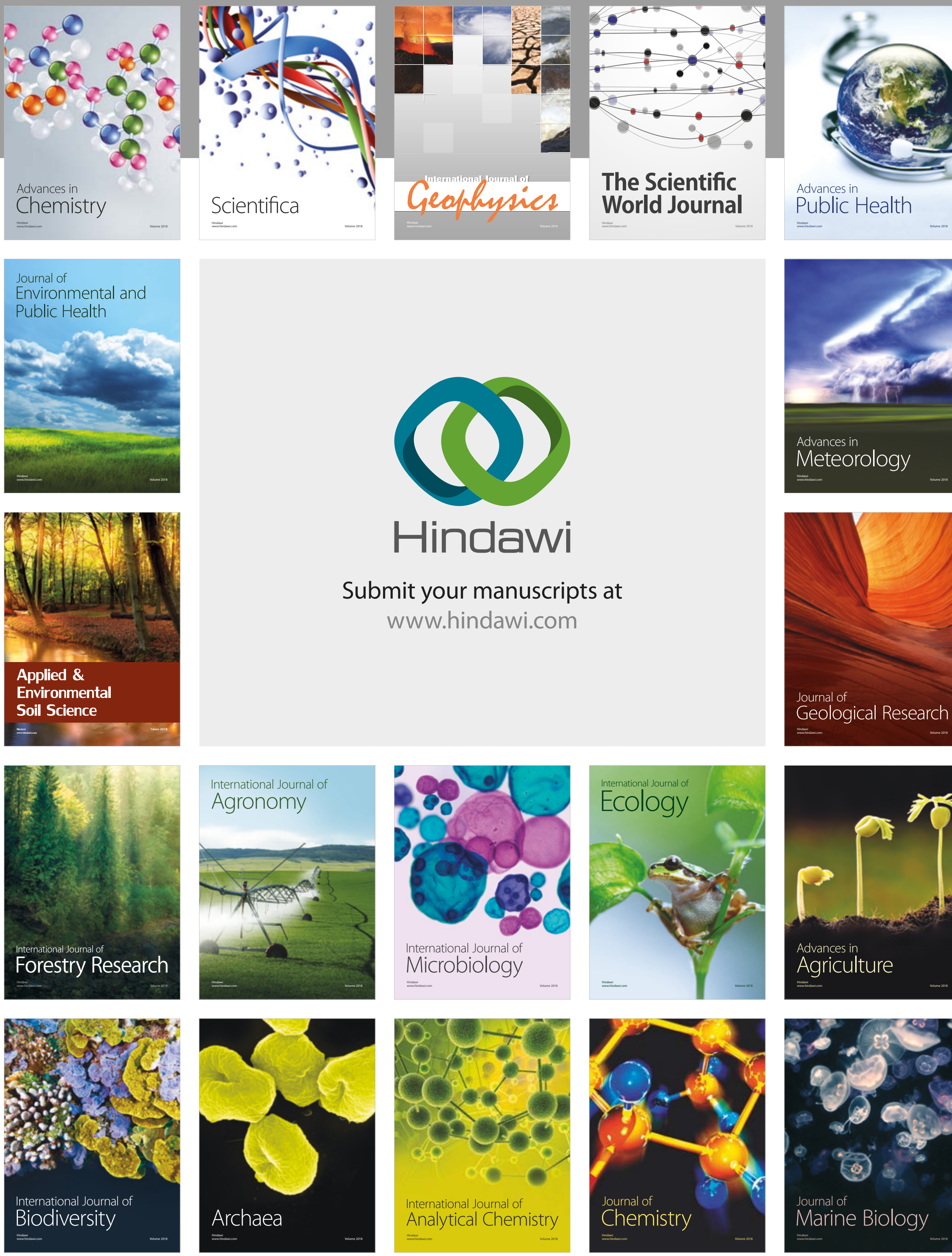
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