Benoit et al., J Geol Geophys 2018, 7:1
DOI: 10.4172/2381-8719.1000319

Journal of Geology & Geophysics
ISSN: 2381-8719

Research Article Open Access

Geophysical Signature Location in the South-West of Chad: Structural Implications

Diponbe Benoit[1]*, Nouayou Robert[1], Kenfack Jean Victor[2] and Momo Tonfack Christian[1]

[1]*Department of Physics, Faculty of Science, University of Yaounde I, Cameroon*
[2]*Department of Earth Science, Faculty of Science, University of Dschang, Cameroon*

Abstract

A Study is conducted in South-West of Chad with the goal of underlining the different lineaments of the region, which are entirely or partially hidden by the sedimentary cover. Different gravity data processing techniques including horizontal gradient of vertical derivative coupled with upward continuation and Euler's de-convolution are used. These methods revealed a number of lineaments describing gravity density discontinuities whose directions are N-S, NE-SW, ENE-WSW, and WNW-ESE at NNW-SSE. However, the predominant direction for major lineaments is WNW-ESE. The major lineaments associated to the faults are: F1, F2, F3, F6, F7, F8, F9, F10, F14, F21, F22, F23, F24 and F28. Euler's solutions indicate depths up to 9.2 km for the anomaly sources. Such lineaments are very useful for groundwater and oil exploration, but also for risk assessment.

Keywords: Bouguer anomaly; Upward continuation; Horizontal gradient; Euler de-convolution; lineament

Introduction

Chad corresponds to the mobile zone formed during the Pan-African orogenesis that occurred at Proterozoic between 830 and 665Ma [1]. This mobile zone is bounded to the south by the Congo Craton, to the West by the West African Craton and to the North-East by the metacraton of the Sahara. It appears that the whole of the Precambrian formations were marked by a strong imprint during the Pan-African events.

These Precambrian formations identified in Chad are distributed between the Tibesti massifs in the north, Ouaddaï in the east, Yadé (Mbaibokoum) in the south and the Mayo-kebbi in the South-west. They cover 15 to 20% of the surface of the national territory [2].

The secondary formations appear in the Erdis basin (Cretaceous Nubian sandstone) and the Mayo-Kebbi (Lower Cretaceous and Middle Cretaceous) basin. They also constitute the filling of several pits in Southern Chad (Lake Chad, Bousso, Doba, Salamat). They are sandstones of the intercalary continental and those of the Cretaceous with lagoon and marine features. The Pala- Lame basin located in Mayo-Kebbi, in the Southwest of Chad near the border with Cameroon, is part of the Yadé massif, a large outcrop of the Precambrian basement which extends to Cameroon, the Republic of Central Africa, Congo and Gabon, and includes the Congo Craton [3].

The region consists essentially of a large granite batholith (Mayo-Kebbi batholith), containing septa of metamorphites and two strips of volcano-sedimentary metamorphic epikeal formations similar to the greenstone belts [3,4]. The whole is intersected by a series of intrusive and vein rocks, ranging from alkaline granite to ultrabasic rocks.

Although the results of the various works cited above provided useful information over the study area, none of them proposed the cartography of the lineaments therein in a precise way. The latter is the objective of the present study. The Bouguer anomaly map of the study area has strong contrasts (gradients) that indicate discontinuities such as faults and flexures. In order to study these discontinuities, we conducted an analysis based on the horizontal gradient of the vertical derivative coupled with upward continuation and Euler's de-convolution. These approaches that have been successfully used in detailed studies, for example, [5-7] which have led to the delineation of the major geological structures and the mapping out of the different tectonic lineaments that affect the study area located between parallels 8° and 10° and the meridians 14° and 17° (Figure 1).

Geological Setting

Geological formations in South-Western of Chad are a prolongation of the massif of Central Chad towards the South-West [8,9]. The Mayo-Kebbi region is made up of Neoproterozoic formations (amphibolo-gneissics andthe Zalbi, Gouyegoudoum and Gong Djalingo series) and cover formations [10].

This massif is essentially made up with the major granitic batholith (the Mayo-Kebbi batholith), which contains septas, metamorphites and two hands of epimetamorphites and two bands of epitamorphites and two bands of epi-metamorphic volcano-sedimentary formation, analogous to belts of green rocks (the belts of Pala and Léré). A series of intrusive and vein rocks, ranging from alkaline granite to ultrabasic rocks, serve as intersections throughout the entire structure.

Secondary formations are represented in the region by lower Cretaceous with Wealdian features (the Léré series) and middle Cretaceous which is continental, with marine and lagoon intercalation (the Lame series) [11,12]. These were deposited during the cretaceous transgression which came from Cameroon and Nigeria through the Benue trough.

The ditches found in Southern Chad are grabens arranged in strings with a WSW-ENE alignment, which cut across the entire South of Chad and continue westwards to Cameroon, (the Mbéré ditch), the

***Corresponding author:** Diponbe Benoit, Department of Physics, Faculty of Science, University of Yaounde I, Cameroon, Tel: +237 222221320; E-mail: bdiponbe@yahoo.fr

Received November 27, 2017; **Accepted** December 07, 2017; **Published** December 15, 2017

Citation: Benoit D, Robert N, Victor KJ, Christian MT (2017) Geophysical Signature Location in the South-West of Chad: Structural Implications. J Geol Geophys 7: 319. doi: 10.4172/2381-8719.1000319

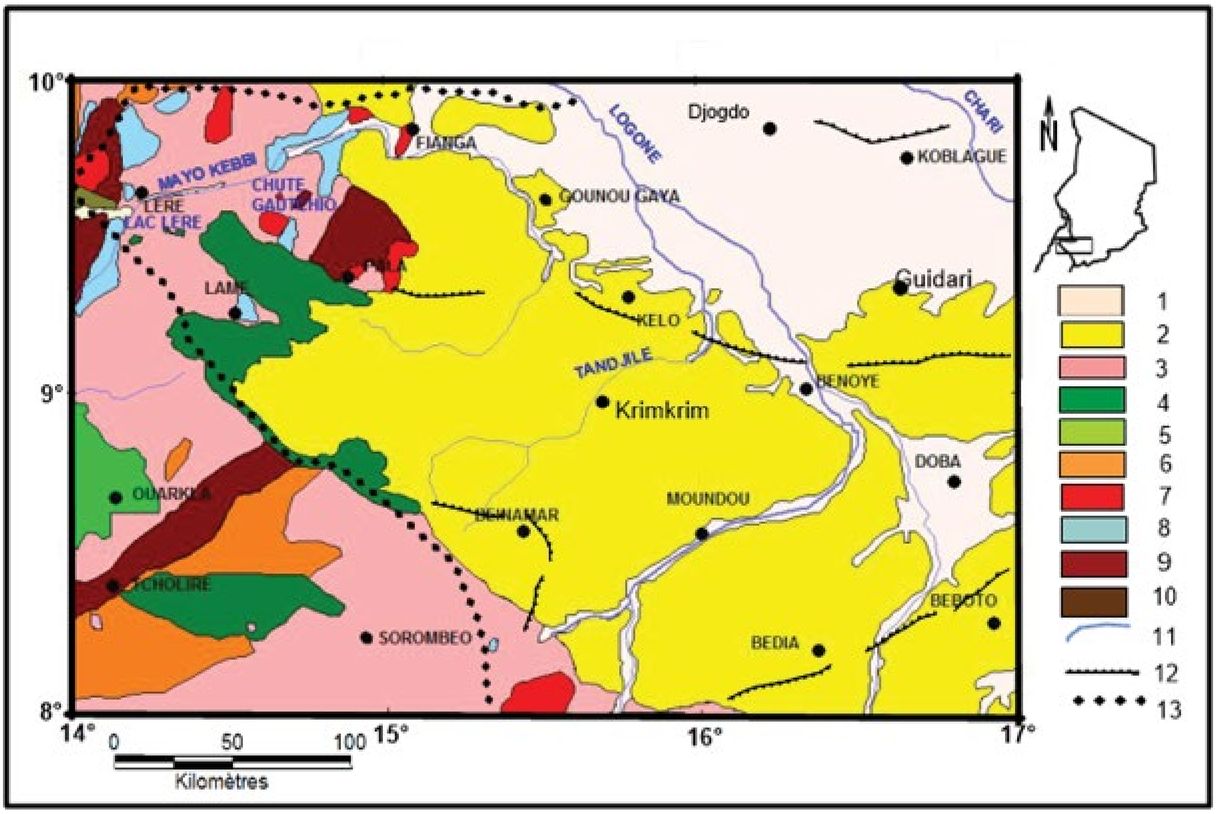

Figure1: Geological map of the study area ([16] modified).
1: Quaternary; 2: Continental terminal (paleogene-neogene); 3: Crystalline base; 4: Middle Cretaceous (Lamé series); 5: Upper Cretaceous (sandstones of Garoua); 6: Migmatites; 7: Post-tectonic intrusive rocks; 8: Gneiss-amphibolites; 9: Schist; 10: Lower Cretaceous (Léré series); 11: stream; 12: fault; 13: National boundaries.

Republic of Central Africa and eastwards to Sudan (the Birao and the Magara ditches) [13,14]. The lineaments on which they lie are probably those of the Panafrican base age (Adamawa lineaments). The Doba ditch, aligned in a WNW-ESE direction, is separated from the others by a high base zone along the Bogorop fault. The ditch of Bousso (or Bongor) is parallel to that of Doba and is situated to the north of the latter. These trenches were formed by a polyphase rifting linked to the separation of the crustal blocks of the African Cretaceous (130-98 Ma). They contain up to 7500 meters of deposits, essentially clastics, terrestrials of the cretaceous age, deposited on the Precambrian base with a covering of recent Miocenes. The Post-Cretaceous subsidence contributed in shaping the geometry of these basins. The mother-rocks are lacustrian shales of the inferior Cretaceous while the reservoirs are in the lower and upper Cretaceous [15].

In the Fianga and Laï regions, the geological formations are mainly sedimentary [16]. We however note the presence of the basement to the west of Fianga. Residual tables and shells of sandstone are located in the southern regions of Moundou and Mbaïbokoum. The formation of Kélo is attributed to Maastrichtien (sands of Kélo) which, over the first one hundred meters, alternates between white sand and grey or ochre clay with a continental, fluvial or lacustrian origin.

From a tectonic viewpoint, the formations are heavily pleated. The general directions are Northeast with significant dips, although horizontal movements lead to changes in direction (outcrops of the marbles of Teubara). The brittle tectonics is mainly made manifest by fractures which border the Precambrian against the Cretaceous sediments of the Chadian basin. The faults thus belong to the Jurassic or to the lower Cretaceous. The principal directions are NE-SW, E-W (boundary faults of the Léré basin) and NE-SW (boundary faults of the Mayo-Kebbi flow, east of Fianga) [10].

The Lame series is the less pleated than that of Léré, however, dips greater than 15° were observed at Baoré during a search for chalk. The dip is partly syn-sedimentary and partly post-turonian and ante-Oligocene, given that the formations of the continental terminal which are attributed to the Oligocene-Miocene, are only slightly (or not at all) affected by tectonic movement. The abovementioned volcanic phenomena are probably of the same age: syn-sedimentary, post-sedimentary and post-turonian. Some K/Ar analyses which have been previously carried out have yielded results which are spread between 45 and 85 Ma [3].

Data and Methods

Data

The gravity data used for this study were acquired during the gravity reconnaissance campaigns carried out by ORSTOM (Office de la Recherche Scientifique et Technique d'Outre-Mer) between the years 1960 and 1968. Measurements were taken every 4 km along the profiles in order to detect significant variations of geological features. The density of the data is about 220 stations per square degree and the localization of stations was done by means of topographical maps.

The elevation of stations was obtained with barometric records using the Wallace and Tiernan (or Thomnen) altimeters (type 3B4). The error margin on the position of stations around 200 m while the error on the altitude of the stations is about 10 m for the profiles located furthest away from the geodesic references. Practically however, it is less than 5 m. The variations of the gravitational field were measured using Worden (n°313, 600, 69 and 135), Lacoste and Rombert (model G, no. 471 and 828) and North American gravimeters. The accuracy on the values of the gravitational field is of the order of 0.2 mGal. The value of gravity at each station was corrected using the lunar-solar tide and the instrumental drift (correction density: 2.67 g/cm^3).

To carry out the processing at different levels, the Bouguer anomalies of the study area were interpolated by kriging on a regular scale with a square mesh of side 2 km.

Methods

Multi-scale study of gradient maxima: In this study, we used the multi-scale gradient analysis and Euler's de-convolution in order to identify the faults, their dip and their depth. [17,18] highlighted the usefulness of the maxima of the horizontal gradients of the gravity anomalies in the localization of zones which show abrupt density variations, which are interpreted either as faults or geological contacts, or as intrusive formations.

A quasi-linear disposition of several maxima corresponds to faults while a quasi-circular disposition shows the horizontal limits of intrusive bodies.

The multi-scale study of the horizontal gradient is a method which consists in coupling the horizontal gradient to the upward continuation at the different heights with the aim of characterizing the importance and the lateral extension of the structures responsible for anomalies and to determine the direction of dip of the localized contacts and faults.

On the other hand, a displacement of the maxima with upward prolongation indicates the direction of dip, but these maxima remain directly above the sub-vertical contacts [19]. Showed that on bringing several sources together, the superposition of their gravity effects on the Bouguer anomalies map and the horizontal gradient results in the delocalization of horizontal gradient maxima. These maxima will no longer be directly above the abrupt density contacts. This delocalization is further reinforced by the upward extension operations which generally smooth the iso-anomaly maps.

To reduce the effect of delocalization of the maxima, we made use of the vertical gradient maps which are quite able to minimize the effect of the interference of the gravity signatures of the sources [6,20,21].

Determination of the optimal altitude of the upward continuation of the gravity field and the depth of investigation: The upward continuation, which is a powerful low-pass filter, is equally used to determine the regional anomaly. However, this method equally has a shortcoming which stems from the difficulty to determine the appropriate extension in order to have the best approach for the said regional anomaly [22].

Indeed, [23] proposed a method of determining the optimal height for the upward continuation of the gravimetric field h_0. It consists of determining the altitude of the upward continuation of the Bouguer where the curve of correlation between the extended fields of the successive altitudes shows a maximum deflection. The process of data treatment in order to determine this altitude in our study area consists of: Carrying out several upward extensions to altitudes ranging from 5 to 125 km of the Bouguer anomaly map in 5 km intervals, then, using the relation (1) proposed by [24], calculate the correlation factors between the extended fields at two successive altitudes (g1 and g2).

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

where M and N are the numbers of data in the x and y directions respectively. Further, draw the graph showing the variation of the correlation factor as a function of the upward continuation altitude while matching each correlation factor to the lowest altitude, then draw the curve which gives the variation of the deflection C as a function of the upward continuation altitude. It has a maximum at the altitude h_0, corresponding to the optimal altitude of upward continuation of the Bouguer in the region. As such, the upward of the Bouguer to the altitude h_0 serves to eliminate the gravity related effect of the sources located beyond the altitude $h_0/2$ which is the depth whose anomalies constitute a residual field [25].

We applied this method to our study are in order to determine the optimal extension altitude of the gravity field and the limiting depth of study. It is worthwhile to note that [21,22,24] successfully used this method in their respective study areas.

Knowing that the Bouguer anomaly map results from the superposition of the effects of the regional geological structures and slightly extended local structures, it is thus necessary to separate the regional and the residual components [26,27].

The obtained optimal altitude of the upward continuation of the gravity field, h_0, effectively helps in the choice of the degree of the polynomial which should represent the regional anomaly and set the residual, while carrying out the polynomial smoothing using the method of least squares [22]. This method consists of performing a polynomial smoothing using surfaces of degree d, which vary from 1 to 10 and then applying it to the anomalies obtained from the upward continuation of the Bouguer at the altitude h_0. The appropriate degree of the regional polynomial is estimated from the point of discontinuity on the graph of the variance as a function of the degree of the polynomial.

Horizontal gradient of the vertical derivative: The horizontal gradient of the vertical derivative of the field at a given height h is calculated in the space domain by relation (2).

$$g_{DHDV} = \sqrt{\left(\frac{\partial g_{DV}}{\partial x}\right)^2 + \left(\frac{\partial g_{DV}}{\partial y}\right)^2} \quad (2)$$

Where g_{DV} is the vertical derivative at altitude h of the gravity field g as defined in relation (3), calculated in the space domain by the method of finite differences proposed by [27]. This operation enables to amplify the noise generated by data errors at the expense of the real signal as is the case where the calculation of the vertical derivative is done in the frequency domain [28]. The strength of this method lies in the fact that it uses upward continuation, is a stable filter which smoothes noise and enables the calculation of the vertical derivative at different altitudes [21]. Its expression is:

$$g_{DV} = \left(\frac{\partial g}{\partial z}\right)_h = \frac{g_{h+\Delta h}^{up} - g_h^{up}}{\Delta h} \quad (3)$$

where g_h^{up} is the upward continuation of the field at the altitude h and $g_{h+\Delta h}^{up}$ is the upward continuation at a slightly higher altitude $h+\Delta h$

Citation: Benoit D, Robert N, Victor KJ, Christian MT (2017) Geophysical Signature Location in the South-West of Chad: Structural Implications. J Geol Geophys 7: 319. doi: 10.4172/2381-8719.1000319

with $0.1 \le \Delta h \le 0.01$ as sampling step for the extension altitudes. It should be noted that the vertical derivative given by (3) should be referred to the altitude $h + \Delta h / 2$, but that Δh is smaller than h, this vertical derivative can be made to correspond to the extension altitude h [21,26].

The positions of the local maxima of the horizontal derivative are determined by the method of [29].

Euler's de-convolution: Thompson [30] developed a method based on the properties of the functions which govern potential fields. He noticed that these functions generally fulfill the criteria of Euler's homogeneity equation. [31] Generalized this technique to include the case of maps.

This method enables the precise localization of the sources of anomalies in the horizontal plane as well as the estimation of their depths. Euler's equation is then written in the following form:

$$(x - x_0)\frac{\partial g}{\partial x} + (y - y_0)\frac{\partial g}{\partial y} + (z - z_0)\frac{\partial g}{\partial z} = -NT(\mathrm{x}, \mathrm{y}) \qquad (4)$$

Where (x_0, y_0, z_0) are the coordinates of a gravity source, g is the intensity of the field measured at (x, y, z). N is the structural index which is linked to the geometry of the source [30,31] indicate that the choice of the structural index seems very important: for a number of considered structures, they established a structural index (N) which can take values ranging from 0 to 3. As such, they consider that the index N=1 is best suited for thin veins, dykes and faults with a small vertical rejection, the index N=0 for faults with significant rejection, and the index N=0.5 for intermediate cases.

Results and Interpretation

Analysis of gravity data

The Bouguer anomaly map: The processed data enabled the establishment of the Bouguer anomaly map (Figure 2) which shows anomalies stretched out in the major directions NNE-SSW to WNW-ESE and a secondary direction NE-SW. Zones of heavy anomaly are observed on one hand, with anomalies which are greater than the average of - 45 mGals, while on the other hand, there are zones of slight anomalies, where the values of the latter are less than the average. These domains are sometimes separated from the former by more or less significant horizontal gradients characterized by contracted iso-anomaly lines. We particularly note that the Northwest-Northeast part of the map, which goes from Léré through Pala, Lame, Gounou-gaya and Djogdo to Guidar is centered on a heavy zone characterized by anomalies greater than - 45 mGals. The general orientation of the iso-anomalies of this region coincides with geological structures of the crystalline base, post-tectonic intrusive rocks, gneiss-amphibolites, schist, and formations of the Quaternary and the Continental terminal. Similarly, the towns of Beinamar, Tcholire and Bedia are dominated by heavy anomalies with direction WNW-ESE, N-S and ENE-WSW, and coincide with the formations of the Continental terminal, schist and the crystalline base. The town of Doba is situated on a big panel of light anomalies with minima reaching - 85 mGals. This band, with orientation ENE-WSW covers the northern part of Bedia, the eastern part of Beinamar and extends up to Lame towards the West, passing through Krimkrim. This vast area coincides with the sedimentary formations of the Continental terminal, the Quaternary and the Middle Cretaceous of the Lame series.

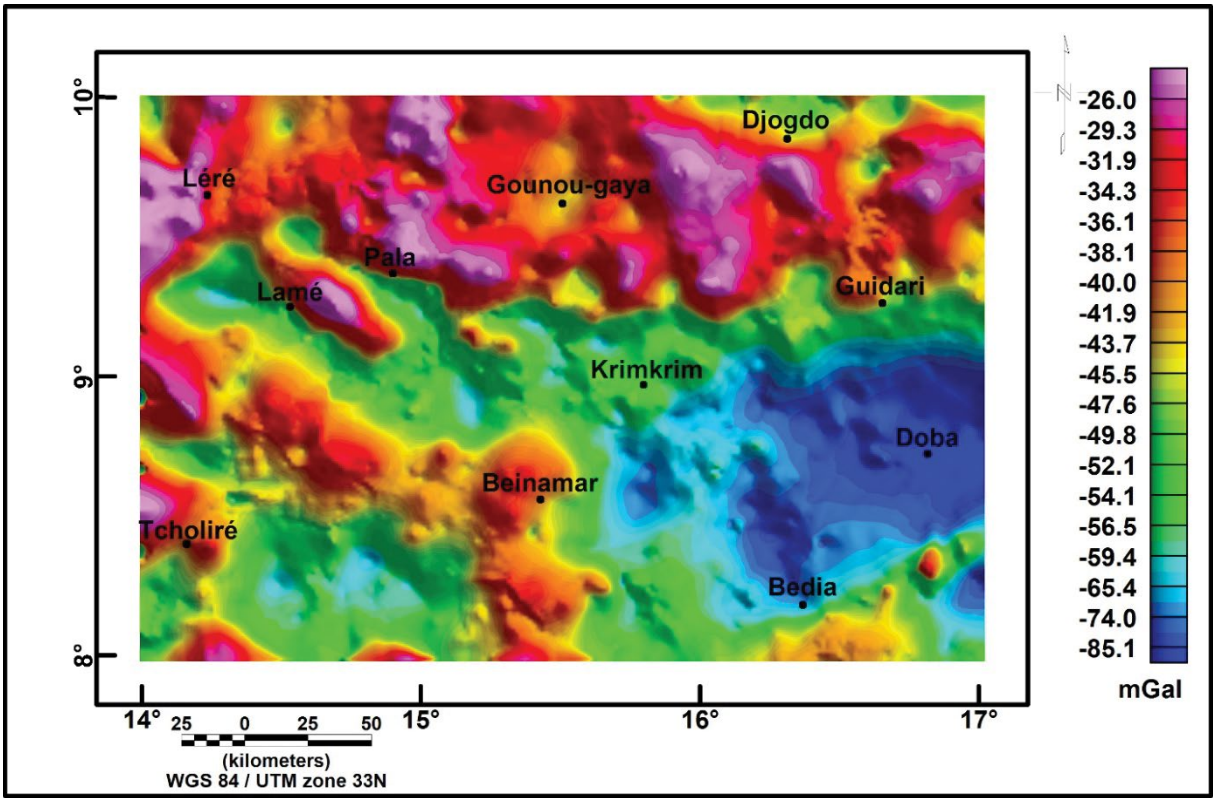

Figure 2: Bouguer anomaly maps.

Citation: Benoit D, Robert N, Victor KJ, Christian MT (2017) Geophysical Signature Location in the South-West of Chad: Structural Implications. J Geol Geophys 7: 319. doi: 10.4172/2381-8719.1000319

These anomalies, sometimes separated from the former by more or less significant horizontal gradients, indicate the presence of density discontinuities such as faults and the limits of intrusive bodies in the subsoil.

Residual anomalies: Residual anomalies (Figure 3) are obtained upon the subtraction of the regional anomaly from the Bouguer anomaly. They mainly represent the density variations in the upper crust, comprising of the variations of the thickness and density of sedimentary rocks which lie on the base rocks, but also the density contrasts induced by intrusive bodies. This map (Figure 3) highlights several positive and negative anomalies, which enables to efficiently correlate them with known geological structures. The positive anomalies located at the west of Léré (P_1), to the east of Lame (P_2), between Pala and Guidar (P_3,P_4,P_5) and the Beinamar–Bedia axis (P_6,P_7) could be due to rising of the basis. The positive anomalies of Tcholire (P_8,P_9) could be due to the intrusion of magmatic rocks in the subsoil. The principal negative anomalies are seen to occur in western part of the map, in the North and in the Southeast. A comparison of the geological map to the residual map shows that the negative anomalies (N_1, N_2, N_3, N_4, N_5, N_8, N_9, N_{10}, N_{11}, N_{12}, N_{13} and N_{14}) can be associated with sediments of Cretaceous basins which brought about the filling of the ditches in the South of Chad and the Nord of Cameroon.

Results of the multi-scale analysis of the gradient maxima

The vertical gradient map: The vertical gradient map (Figure 4) of the study area shows zones of positive gradient which stand out clearly from zones of negative gradient. Devoid of regional features, they also show a lateral separation of anomalies and an amplification of the gravity effect of superficial density contrasts to detriment of deep contrasts. The anomalies of Léré, Pala, Lame and the South of Djogdo stand out and are characterized by a positive gradient which locally reaches up to 2 mGal/km. The dispersions of these anomalies are in agreement with the dispersions of the geological distributions of the Precambrian which confirms the rising of the base. Similarly, the anomalies of Tcholire, Beinamar and the South of Bedia are characterized by a positive gradient reaching 1.8 mGal/km. The sedimentary basins of Pala, Doba and Bedia are characterized by a negative gradient reaching down to -2.3 mGal/km.

Analysis of the choice of optimalaltitude of upward continuation of the gravimetric field and depth of investigation for this study: With the aim of determining the depth of study, we used the upward continuation which is a powerful low-pass filter in order to first evaluate the optimal continuation altitude for the gravity field in the region (Figure 5).

Figure 5a shows the variation of the correlation factor as a function of the continuation altitude. It shows an increasing curve whose gradient however decreases as the continuation altitude increases. At a certain continuation altitude, there is a maximal deflection (denoted C on Figure 5b) determined by the gap between the curve of the correlation factor and the line joining the two extremity of the curve. We calculated the deflection C at several continuation altitudes of the Bouguer and drew the curve which gives the variation of C as a function of the continuation altitude (Figure 5b). This curve reaches a maximum at the altitude h_0 = 25 km, corresponding to the optimal upward continuation altitude. At this altitude, the gravity related effect of the sources found beyond the depth $h_0/2$ = 12,5 km, which is the limiting depth of study.

The polynomial smoothing with surfaces of degree d varying from 1 to 10, applied to the anomalies resulting from the upward continuation of the Bouguer to 25 km enabled to set the appropriate degree of

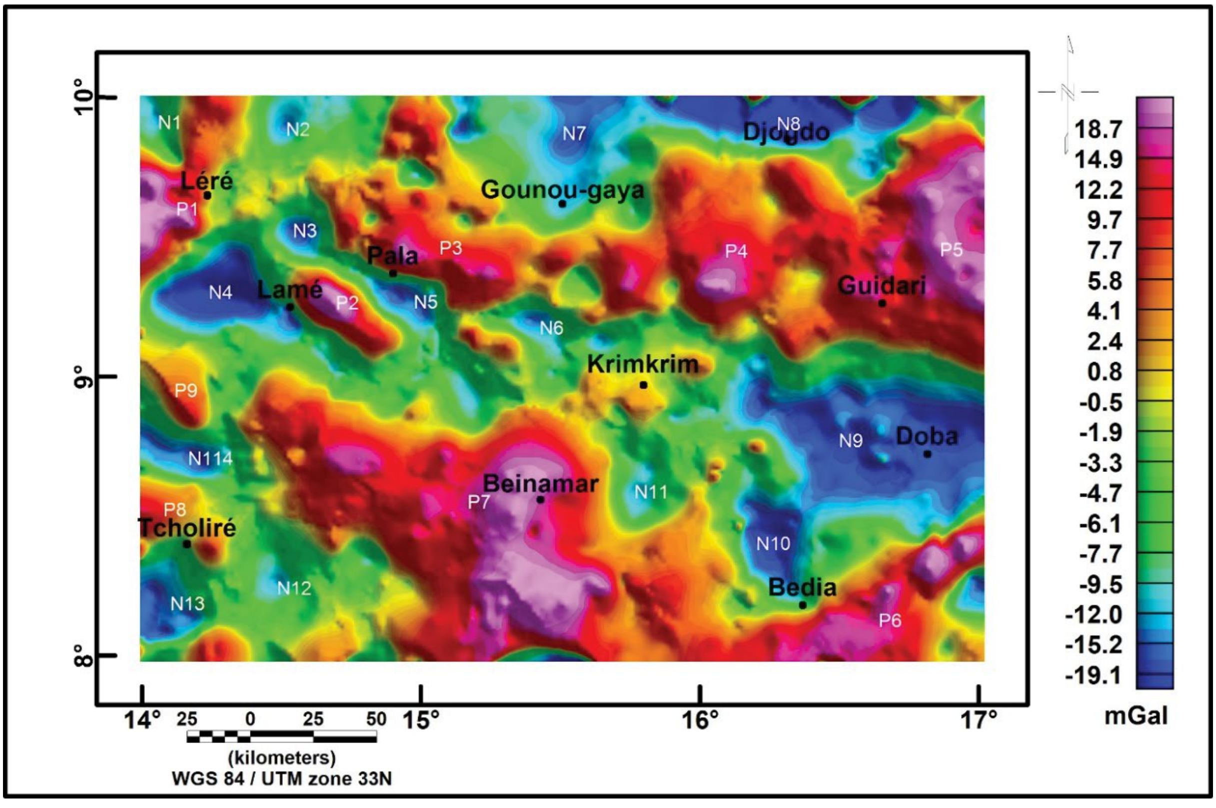

Figure 3: Third-order residual anomaly maps.

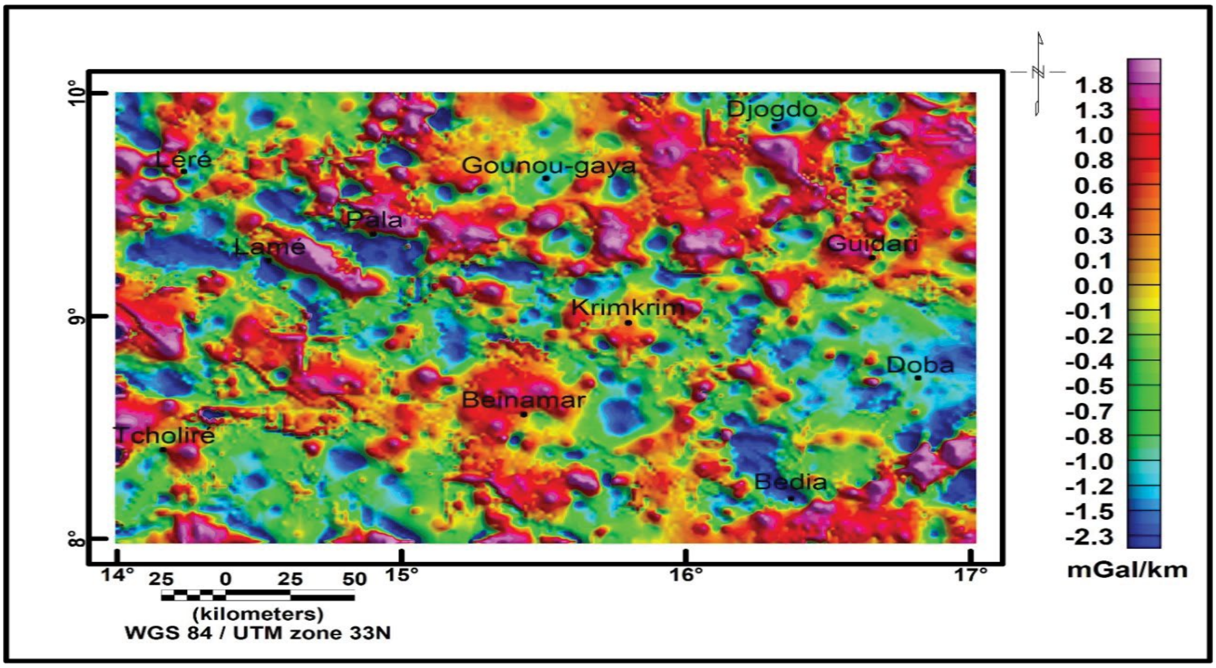

Figure 4: Vertical gradient map.

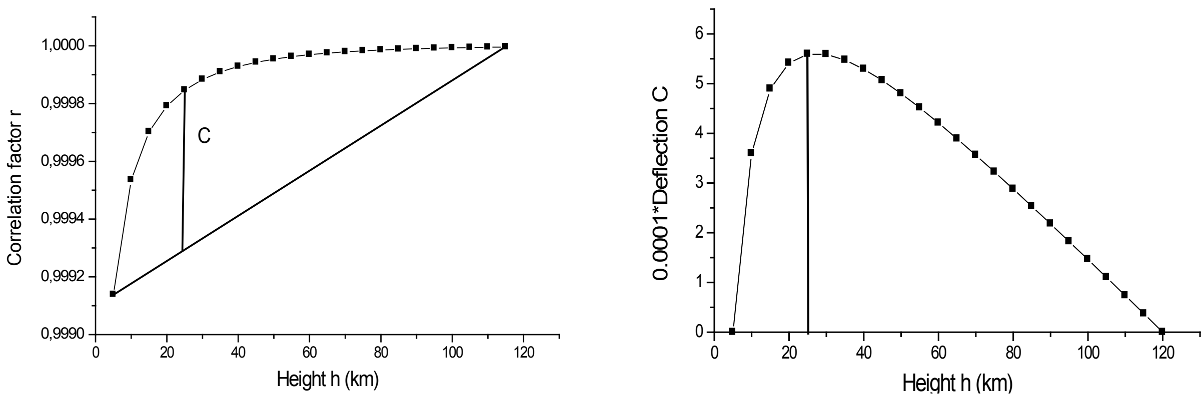

Figure 5: a) Correlation factor between the extensions of the Bouguer at two successive altitudes as a function of the continuation altitude in our study zone. b) Deflection, C as a function of the extension altitude of the Bouguer in the study zone. The optimal altitude of the upward continuation of the Bouguer is *ho* = 25 km.

the regional polynomial. The optimum degree of the polynomial representing the anomalies resulting from upward continuation at 25 km is 3 (Figure 6). The polynomial of degree 3 was thus used to carry out the smoothing of the Bouguer anomaly map with the aim of extracting the regional trends which would be linked to the undulations of Moho's discontinuity.

Consequently, in our study area, the residual gravimetric anomalies of degree n=3 highlights the gravity related effect of the structures situated at a depth less than 12.5 km (Figure 3).

Analysis of the results of the horizontal gradient of the vertical derivative coupled to the upward continuation: The map of the maxima of the horizontal gradient of the field derived follwing the vertical at different altitudes clearly highlights the different structural features present in the area of study, be they faults or intrusive structures.

The superposition of the local maxima of the horizontal gradient

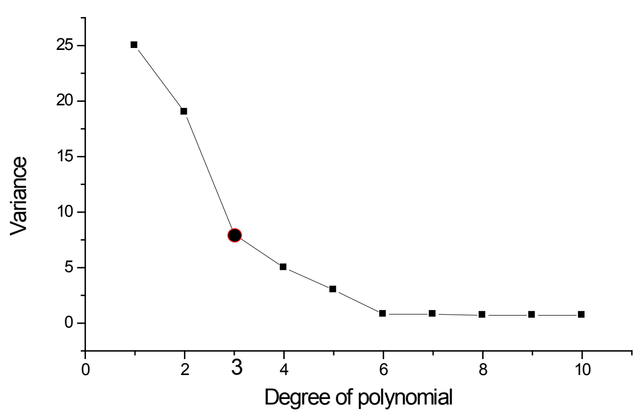

Figure 6: Graph of the variance as a function of the degree of the polynomial.

determined from the vertical derivative of the upward continuation of the Bouguer anomalies at different altitudes of 5,10,15,20 and 25 km enabled the drawing up of the map of (Figure 7). This map highlights the quasi-linear structures numbered 1 to 26, what can describe the quasi-circular faults or contacts. The quasi-circular contacts numbered A to E could correspond to the horizontal limits of intrusive bodies.

The directions of the quasi-linear contacts are WNW-ESE for (3), (4), (5), (6), (7), (9), (22), (24), (25), (27) ; ENE-WSW for (14), (18), (19), (30) ; NW-SE for (15), (16), (17), (20) ; NNE-SSW for (2), (8), (26); E-W for (21), (23) and N-S for (1), (13), (11). Basing the estimation of the limiting value of the depth of the roof of the anomaly source with respect to the height of continuation, the black maxima show that the effects of the sources situated above a depth of 2.5 km are eliminated.

This depth becomes 5 km for the green maxima, 7.5 km for the blue maxima, 10 km for the purple maxima and 12.5 km for the red maxima. This enables us to understand that the presence of black, green, blue, purple and red maxima on the same contact (Figure 7) shows that the depth is greater than 12.5 km. Similarly, the presence of black, green, blue and purple maxima on the same contact in the absence of red is an indication that the depth is situated between 7.5 and 10 km and lastly, the presence of black maxima on a contact in the absence of other maxima shows that the structure is most likely situated between 2.5 and 5 km.

On Figure 7, the presence of black, green, blue, purple and red maxima on the quasi-circular contacts A and D shows that the depth is greater than 12.5 km. The presence of black, green, blue and purple maxima on the contours C and E suggest that the depth is not uniform and is situated between 10 and 12.5 km. The absence of red, purple and blue on the contour B indicates that the depth would most likely be found between 2.5 and 5 km.

Contribution of Euler's de-convolution: Euler's de-convolution is applied on the Bouguer anomaly for the structural index SI=0.5, window W=10 × 10 and tolerance T=15% are represented in (Figure 8) with the aim of determining faults and to estimate the average depth of their roofs. Their alignment also shows the contacts obtained by the superposition of the maxima of the horizontal gradient of the vertical derivative of the new faults. The deepest accidents have as principal directions NE-SW to ENE-WSW and NW-SE, while their depths can range from 5 to 9.2 km. The NE-SW accident, situated to the North of Tcholire, which is absent on the superposition map of the maxima, is quite visible.

This accident is the continuation of one of the tectonic structures associated with the Adamawa plateau.

In addition to the linear contacts, Euler's de-convolution map helped to clarify and precise several geological contours with irregular depths. The network of contacts or superficial faults with depths varying from 2 to 4 km is quasi-present. These results approach the lineaments depth obtained by the upward continuation which vary from 2.5 to 12.5 km.

Structural map

The maps of the local maxima of the horizontal gradient of the vertical derivative calculated at different altitudes and Euler's de-convolution (Figures 7 and 8) enabled a structural map to be drawn (Figure 9), showing a good complementary relationship between the inferred faults. As such, four groups of faults were highlighted: N-S, NW-SE, E-W, NNE-SSW and SSE-NNW.

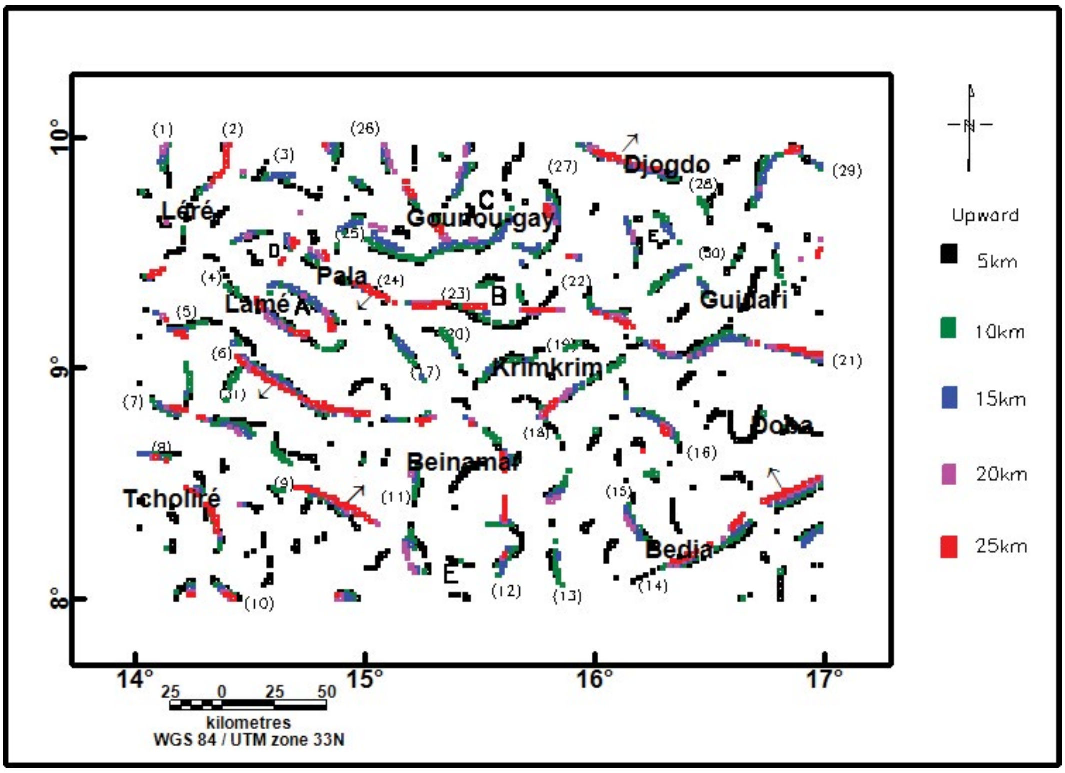

Figure 7: Localization of the horizontal gradient maxima of the upward extension of the vertical gradient, respectively at 5, 10, 15, 20 and 25 km.

Citation: Benoit D, Robert N, Victor KJ, Christian MT (2017) Geophysical Signature Location in the South-West of Chad: Structural Implications. J Geol Geophys 7: 319. doi: 10.4172/2381-8719.1000319

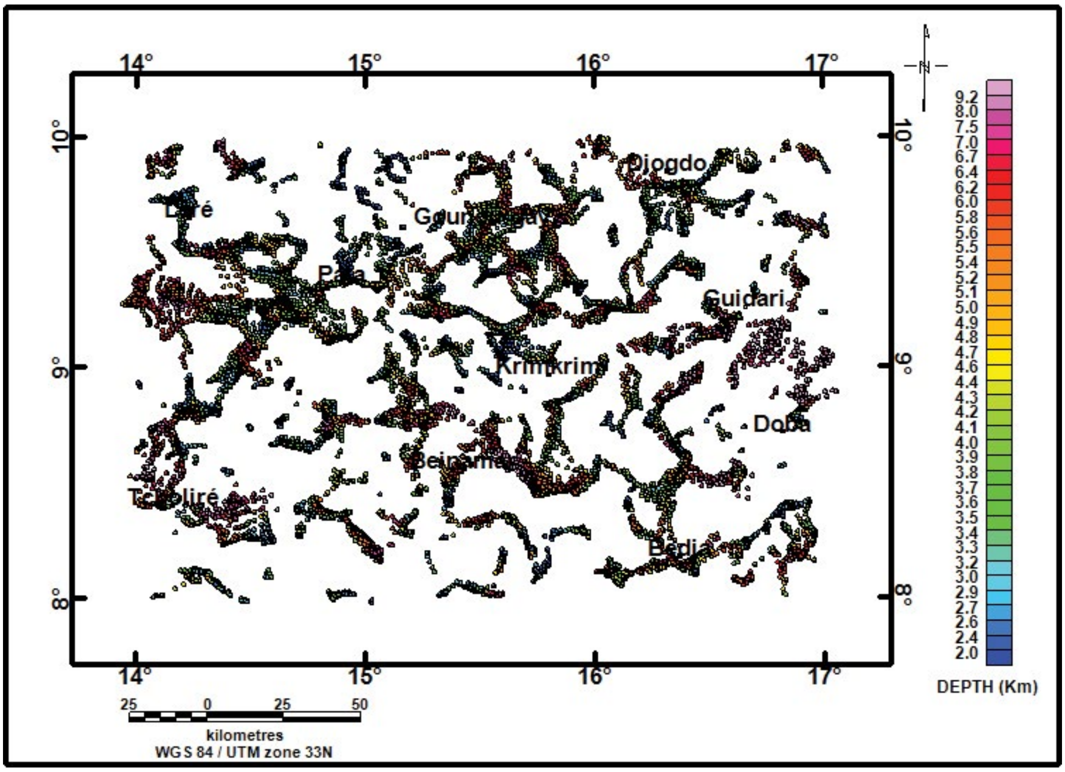

Figure 8: Map of Euler's solutions (IS = 0.5, T = 15% and W = 10 x 10).

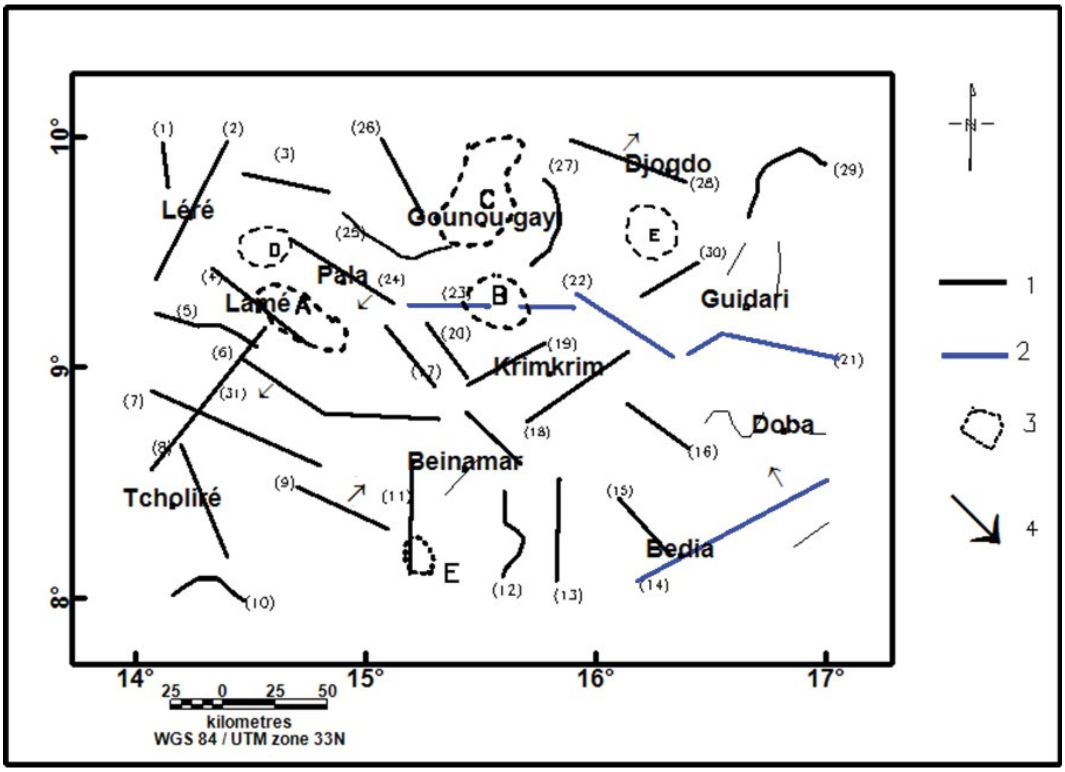

Figure 9: Interpretative structural map. 1: Newly identified faults or fractures; 2: Known faults; 3: Intrusive bodies; 4: Direction of dip.

Citation: Benoit D, Robert N, Victor KJ, Christian MT (2017) Geophysical Signature Location in the South-West of Chad: Structural Implications. J Geol Geophys 7: 319. doi: 10.4172/2381-8719.1000319

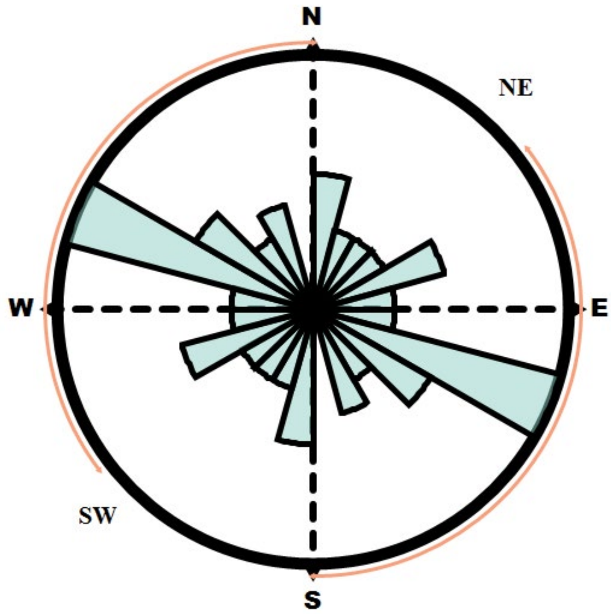

Figure 10: Rose window of the directions of fracture deduced from the gravity anomalies.

With the above, we were able to confirm several faults which were either observed or presumed by earlier studies and highlight a good number of deep or superficial accidents which were hitherto unknown. As such, lineaments which subsist on the map of the horizontal gradient of the vertical derivative upwards continued to an altitude of 25 km corresponding to the major accidents affecting the study area.

In the Western part of the map, the brittle tectonic is made evident by fractures which border the Precambrian base from the Cretaceous sediments. The faults F1, F2, F3, F4, F5, F6, F7, F8, F9, F24 and F25 with directions N-S, NNE-SSE, WNW-ESE and E-W are mostly located on the Precambrian base and denote the contact between the base and the formations of the middle Cretaceous, those of the upper Cretaceous and those of the Precambrian. These faults have depths varying from 5 to 12.5 km and a NE, SW, NW vertical and sub-vertical dip.

The faults F11, F12, F13, F15, F17, F19, F20, F21 and F27 which appear in the Southern part of Beinamar and continue to the center of the study zone have as directions N-S, NW-SE, E-W and ENE-WSW and are centered on the Continental terminal, while others mark the contact zones between the Continental terminal, the Quaternary and the base. They have depths varying from 2.5 to 7.5 km. The faults F11, F12, F13, F19 and F20 have a vertical dip, F15 and F17 have a SW dip and F27 has an E-W dip.

The fault F14, with a depth of 12.5 km, a NW dip and direction ENE-WSW runs across the Continental terminal right to the Quaternary. This fault clearly adopts the major tectonic direction in Cameroon, a direction which is marked by a series of faults, particularly the major fault at Mbéré. In Cameroon, this fault is marked by basaltic intrusions.

The faults F28 and F30 with a NE vertical dip have the respective directions WNW-ESE and ENE-WSW, with depths varying from 5 to 12.5 km, while the flexures F27 and F29 do not have uniform roofs. These four accidents are centered on the Quaternary. There are six intrusive bodies, denoted A, B, C, D, E and F. Body A, located around the town of Lame could be an intrusion of heavy rock, probably granite-

Nº	Orientation	Direction of dip	Nº	Orientation	Direction of dip
F1	N0ºE	Vertical	F15	N135ºE	Vertical
F2	N22ºE	Vertical	F16	N135ºE	Vertical
F3	N112ºE	Vertical	F17	N50ºE	Vertical
F4	N112ºE	Vertical	F18	N67ºE	Vertical
F5	N112ºE	Vertical	F19	N157ºE	Vertical
F6	N112ºE	SW	F20	N95ºE	Vertical
F7	N112ºE	Vertical	F21	N112ºE	Vertical
F8	N157ºE	Vertical	F22	N90ºE	Vertical
F9	N112ºE	NE	F23	N112ºE	Vertical
F10	N112ºE	Vertical	F24	N112ºE	SW
F11	N0ºE	Vertical	F25	N150ºE	Vertical
F12	N0ºE	Vertical	F26	N112ºE	Vertical
F13	N65ºE	Vertical	F27	N67ºE	Vertical
F14	N135ºE	NW	F28	N40ºE	NE

Table 1: Orientation of various linéaments.

gneissic into the sediment of the middle Cretaceous in the Lame series and is bounded to the West by the fault F4. Body B which shallower, lies on the known fault F23. Bodies C and D, located respectively in the western part of Pala and Gounou-gaya, confirm the fact that the batholiths of Mayo-Kebbi are a syn- or late-tectonic intrusion.

The principal directions of the identified lineaments are given in Table 1. The rose window of the directions (Figure 10) highlights a predominant direction: that consisting of the major direction NNE-SSW and the secondary directions E-W and WNW-WSE.

Discussion

With the processing of gravity data, this work has enabled to highlight now elements and thus, to improve our knowledge of the geological stuctures of the region. The discontinuities in the crust are essentially confined in the upper crust, up to 12.5 km.

The positive gravity anomaly seen in the the North of the Bouguer anomaly map and the residual map, coincides with the extension of the shearing zone in Tchollíré-Banyo, it agrees with the result which suggested it as a potential stitch zone between the Adamawa Yadé domain and the massif of the Mayo-Kebbi region [32,33]. The Talschists of the rocky belts of the Mayo-Kebbi region are associated to a peroditic type of protolith are aligned on on the prolongation of this anomaly. This observation agrees with the viewpoint of [23], according to which the positive Bouguer anomaly seen in this stitch zone corresponds to a closure of the oceanic basic in the Neoproterozoic.

The Westward opening of the Doba basin, marked by an anomaly of de -50 mGals right to the Lame basin observed on the Bouguer map (Figure 2) enables the establishment of a link between these two basins. This observation comes to confirm the idea according to which, during the Cretaceous, a connection existed between the Doba basin and and the Golf of the Benue through the Pala- Lame channel, which enabled the sedimentary filling of these basins [15,23].

The gravimetric lineaments suggest that the zone was subjected to a high pressure on the regional scale. This regional pressure, related to the major direction (Figure 10) of the gravity lineaments, is in line with the Panafrican faults which are similar to those observed at the edge of the West African crater and which are said to have played an essential role in controling the geodynamic evolution of the region région [34-36]. The tectonic evolution of this region leads to the understanding that the Precambrian was marked by the putting in place of great fractures which is the result of a compressive tectonic corresponding to the Panafrican orogenic. The period of fracture brought about belts of weakness on which dislocations occurred at the beginning of the Cretaceous and in turn, brought aboutthe formations of the basins of southern Chad.

Since the whole region contains a variety of rocks of different ages, it is not surprising that network of faults should be linked to different phases of tectonic activity [37]. The Cretaceous lineaments border the semi-grabens of the Cretaceous basins and are in agreement with the Guineo-Nubian lineaments which played several roles in different manners in the Cretaceous according to [38-40].

The analysis of maxima for investigation depth of the optimale upward continuation h_0 of Bouguer map help us to determinate the lineament depths of structurales map. These depths varies from 2.5 to 12.5 km and corrobore with Euler'solution whose depths giving varies from 2 to 9.2 km.

These highlighted lineaments will constitute a very important guide for the search of layers of underground water and mineral resources.

Conclusion

This work, based on the analysis of gravity data, enabled the highlighting of various geological structures present in the region, which sometimes are partially or completely masked by the sedimentary cover. The Bouguer anomaly maps establisehed here show the close connection, on one hand, between the positive anomalies and the rising of the base and also with magmatic structures, and on the other hand, between negative anomalies and basins. The principal directions are NNE-SSW, WNW-ESE and NW-SE. The superposition of the maxima of the horizontal gradient of the vertical derivative extended upwards to several altitudes up to 25 km in steps of 5 km, shows alignments which describe the contacts and provide information on their depths, of which the eepest one is estimated at 12.5 km with a strong dip. The structural map was drawn, it confirms the existence of four groups of faults with directions N-S, NE-SW, ENE-WSW and WNW-ESE at NNW-SSE which can generally be correlated with the Panafrican domain. The shear zone of Chad and certain faults would correspond to the boundary faults of the ditches of Southern Chad with Continento-Quaternary filling. Euler's de-convolution was used to determine the depths of the sources and their locations. The solutions are well grouped and are in correlation with several contacts previously deduced from the maxima of the horizontal gradient and their depths vary from 2.6 to 12 km. Lastly, the established structural map constitutes a reference document which could help in the choice of exploration sites for underground water layers and mineral resources,and also for the evaluation of natural risks.

Acknowledgements

The authors are grateful to the reviewers and the readership for their kind help in making the manuscript clearer, more correct and mature for publication.

References

1. Ngako V, Affoton P and Njonfang E (2008) Pan-African tectonic in Noethwester Cameroun: Implication for the history of Western Gondwana. Gondwana Research 14: 509–522.
2. Moussa I (2011) Neoproterozoic crustal growth and differentiation example of the Mayo Kebbi pan-African domain in southwestern Chad. Doctoral Thesis PhD University Nancy I: 107–117–332–338.
3. Kusnir I (1990) Strengthening the DRGM Activities and results PNUD/DRGM. Projet CHD/87/010 N'djamena 28.
4. Kasser M Y (1995) Precambrian evolution of the Mayo-kebbi region (Chad). A segment of the pan-African chain. PhD thesis: National Museum of Natural History of Paris: 217.
5. Khattach D, Keating P, Mostafa M L,Chennouf T, Andrieux T et al. (2004) Contribution of gravimetry to the study of the Triffa basin structure (North-East Morocco): Hydrogeological implications. CR Geosciences 336: 1427– 432.
6. Noutchogwe T C (2010) Geophysical investigation in the region of Adamaoua by gravimetric and magnetic methods: Structural and hydrogeological implications Theses Doct PhD Univ Yaounde I: 147.
7. Koumetio F, Njomol D, Tabod C T, Tatchum C, Noutchogwe T C, et al. (2012) Structural interpretation of gravity anomalies from the Kribi- Edea zone, South Cameroun : a case study. J of Geophy and Eng 9: 666–669.
8. Black R, Kasser M (1995) Mission in the Mayokbi. Mission report, DRGM N'Djamena.
9. Doumnang MJC, Pouclet A, Vidal M, Vicat JP (2004) Lithostratigraphy of the Pan-African lands of southern Chad (Léré region) and geodynamic significance of the magmatic formations. IGCP, Second annual field conference, 5-10th january 2004. Garoua Cameroun 8.
10. Doumnang MJC (2006) Geology of the neoprotorozoic formations of Mayo-Kebbi (South-West of Chad), contribution of petrology and geochemistry, implications on geodynamics in Pan-African. Thesis doct. Univ. Orleans pp. 234.
11. Gerard G (1958) Geological map of French Equatorial Africa at 1/200000. Explanatory note. Dir Geol Mines AEF Brazzaville pp. 198.
12. Wacrenier P, Vincent PM (1962) Explanatory note of the Mayo-kebbi geological map, Direction Mines and Geology. BRGM 3: 21-75.
13. Crenn Y (1955) Anomalies of gravity in Chad. ORSTOM Paris multigr 20.
14. Genik G J (1992) Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and Central Africa Republic (CAR). Tectonophysics 213: 169–185.
15. Tabe E (1980) Combined geophysical research methods for the study of the crystalline basement and the exploration of oil deposits in the sedimentary formations of the Doba and Bongor pits (Republic of Chad). PhD Thesis Moscow Lomonosov University pp.19–24.
16. Louis P (1970) Geological contribution to the geological knowledge of the Lake Chad Basin. Memoirs ORSTOM 42: 152–167.
17. CordellL(1979) Gravimetric expression of graben faulting in Santa Fe country and the espanola basin, New Mexico. New Mexico Geol Soc 30th Field Conference pp.59–64.
18. Cordell L, Grauch VJS (1985) Mapping basement magnetization zones from aeromagnetic data in the San Juan basin, New Mexico. Geophysics: 181–197.
19. Grauch VJS, Cordell L (1987) Limitations of determining density or magnetic boundaries from the horizontal gradient of gravity or pseudogravity data. Geophys 52: 118–121.
20. Marson I and Klingele EE (1993) Advantages of using the vertical gradient of gravity for 3-D interpretation. Geophys 58: 1588–1595.
21. Noutchogwe TC, Tabod CT, Koumetio F, Manguelle-Dicoum E (2011) A gravity model study for differentiating vertical and dipping geological contacts with application to a Bouguer gravity anomaly over the Foumban shear zone, Cameroon. Geophysica 47: 43–55.
22. Vanie LTA, Khattach D, Houari MR (2005) Contribution of gravimetric anomaly filtering to the study of the deep structures of eastern Morocco. Bull Inst Sci Rabat Sci section Earth 27: 32–33.
23. Zeng H, DeshuXu, Handong Tan (2007) A model study for estimating optimum upward continuation height for gravity separation with application to a Bouguer gravity anomaly over a mineral deposit, Jilin province, northeast China. Geophys 72: 145–150.
24. Abdelrahman EM, Bayoumi A, Abdelhady YE, Gobashi MM, El-raby HM, et al. (1989) Gravity interpretation using correlation factors between successive least squares residual anomalies. Geophys 54: 1614–1621.
25. Jacobsen BH (1987) A case for upward continuation as standard separation filter for potential-field maps. Geophy 52: 1138–1148.
26. Yalo N, Lawin AE, D'Almeida GAF, Gonçalves TP, Dagba GF, et al. (2013) Contribution of gravimetry to the study of the southern part of the onshore coastal sedimentary basin of Benin. Afr Geosci Review 20: 72–73.
27. FlorioG, Fedi M, Pasteka R (2006) On the application of Euler's deconvolution to the analytic signal. Geophy 71: 87–93.

28. Gunn P J (1975) Linear transformation of gravity and magnetic fields. Geophys Prospect 23: 300–312.

29. Blakely RJ, Simpson RW (1986) Approximating edges of source bodies from magnetic or gravity anomalies. Geophy 51: 1494–1498.

30. Thompson DT (1982) EULDPH: A new technique for making computer assisted depth estimates from magnetic data. Geophy 47: 31–37.

31. Reid AB, Allsop JM, Granser H, Millet AJ, Somerton W, et al. (1990) Magnetic Interpretation in three dimensions using Euler deconvolution. Geophy 55: 80–90.

32. Toteu SF, Penaye J, Deloule E, Van Schumus WR, Tchameni R, et al. (2006) Diachronous evolution of volcano-sedimentary basins north of the Congo craton: Insights from U–Pb ion microprobe dating of zircons from the Poli, Lom and Yaoundé Groups Cameroon). J Afr Earth Sci 44: 428– 442.

33. Penaye J, Kroner A, Toteu SF, Van Schumus WR, Doumnang JC, et al. (2006) Evolution of the mayo kebbi region as revealed by zircon dating: An early (ca. 740 Ma) Pan African magmatic arc in south-western Chad. J Afr Earth Sci 44: 530–542.

34. Njiel UO (1987) An albitophyre series (Poli Cameroun) an example of pre-orogenic non-ophiolitic volcanism, in sialic, but different from the hercynotype model. CR Acad Sci Paris 304: 515–520.

35. Ngako V (1999) The Precambrian basement of North Cameroon: An active neoproterozoic margin punched in the Pan-African. Geoenvironmental catastrophes in Africa (abstract). Geosc of Cameroon Yaounde University Press, Geocam.

36. Pouclet A, Vidal M, Doumnang-Mbaigane JC, Vicat J P, Tchamenie R, et al. (2006) Neoproterozoic crustal evolution in Southern Chad: Pan-African ocean basin closin, arc accretion and late to post-orogenic granitic intrusion. J Afr Earth Sci 44: 543–560.

37. Raimi J, Dewu BBM, Sule P (2014) Existence of a possible subsurface ring complex in the North-western part of the Nigerian younger granite province: A contribution from aeromagnetic and remote sensing data. Arabia J Geosci 8: 5057–5065.

38. Benkhelil J (1982) Structural map of the upper Benue valley. J Geol Mining 18: 140-151.

39. Guiraud R (1970) On the presence of dextral recesses in the Saharan Atlas: Megametric interpretation. CR Somm Soc Geol Fr 8: 316-318.

40. Guiraud R, Issawa B, Bellion Y (1985) Guinean-Nubian lineaments: A major structural feature across the African plate. CR Acad Sci Paris.