Structural Interpretation of Deep Structures of the Adamawa Plateau (Nord-Cameroon) from Combined Terrestrial Gravity Data and GRACE Model

Bouba Apollinaire[1], Mono Jean Aimé[2], Oyoa Valentin[3], Kamguia Joseph[4]

[1, 3]Department of Physics, Higher Teachers' Training College, University of Maroua, Cameroon

[2]Basical Sciences Teaching Department of Advanced Technical Teacher Training School, University of Douala, Cameroon

[4]Research Laboratory in Geodesy, National Institute of Cartography, Yaoundé, Cameroon

E-mails: boubaapollinaire[at]yahoo.fr; monojeanaime[at]yahoo.fr; voyoah[at]yahoo.fr, kjerryfr[at]yahoo.fr;
Corresponding author: boubaapollinaire[at]yahoo. fr

Abstract: ***In this study, a new structural map of the Adamawa plateau was produced. The multi-scale method of the horizontal gradient has been applied to the combined gravity data of the study area. These data are the combination of terrestrial gravity data and GRACE gravity ones computed from GGM02C model. Upward continuation at different heights was first applied to the dataset and horizontal gradient was later applied at each continuation height to issue a resultant grid which highlighted high gradients that corresponds to the lineaments. Our results confirm the existence of deep structures already recognized or assumed by the classic geological studies and highlights new accidents, an unknown geologically dense unit, never identified by any previous study. The structural map shows that the faults system of the Adamawa plateau is organized in NE-SW and NNE-SSW a direction which is associated to the Cameroon Volcanic Line.***

Keywords: Structural map, Multi-scale, Horizontal gradient, GGM02C, Upward continuation

1. Introduction

Located between latitudes 5° and 8°N and longitudes 13° to 15°E (Figure 1), the Adamawa plateau constitutes the Cameroonian part of the Pan-African North-Equatorial chain. Due to its hydrogeological and mineral richness, this region has aroused since several years the interest of many researchers [1], [2], [3], [4]. Despite the number of researches conducted in the study area and its surroundings, a new gravity campaigns has neither been carried out nor introduced into geophysical studies. The extention of accidents affecting the region has been approximated by using only terrestrial gravity data. These data are old and present many gaps and insufficiencies. In these conditions, the attempts of analyses and interpretations of gravity anomalies maps were mainly limited. They have not showed the real signatures of the geological features. Therefore, geophysicists should find complementary method in order to study the properties of the deep or near-surface structures. In this case, a global geopotential model can be a solution. This method permit to combine terrestrial gravity data to data computed from the GRACE gravity model. This approach permits to investigate the geological structures with high resolution. GGM02C was used to provide the most accurate representation of gravity anomalies in Adamawa plateau [5]. In this paper, the main objective is to show the capability of the densified gravity data to detect the deep geological structures of the Adamawa plateau. The obtained Bouguer anomaly map indicates strong gradients, marking the presence of discontinuities such as faults and flexures. These discontinuities are examined here based on the horizontal gradient maxima of the Bouguer anomaly map and its upward continuation at different altitudes, superimposed on the horizontal gradient. This processing has already been successfully used by [6]; [7] to delineate the major geological structures in eastern Morocco.

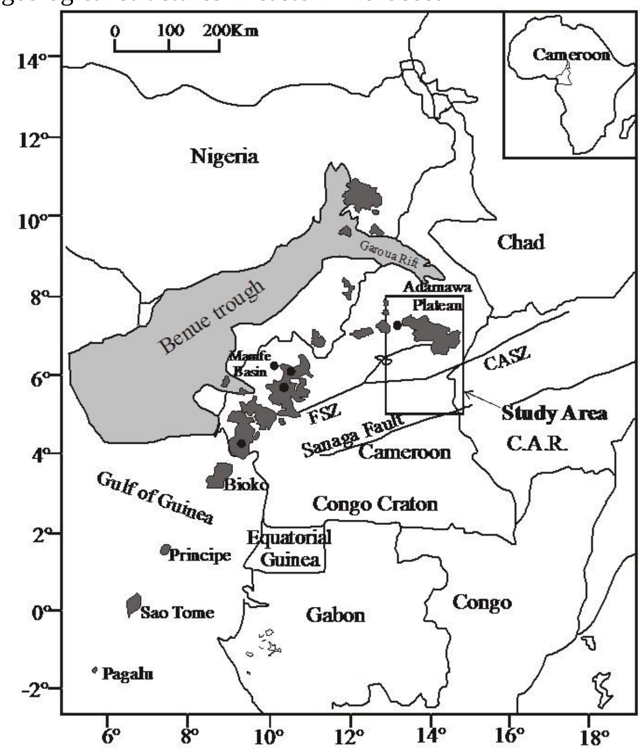

Figure 1: Location map of the Adamawa plateau modified after [8].

2. Geology and Tectonic Background

The Adamawa Plateau is one of the largest morpho-structural units of northern Cameroon.

Recent geological studies undertaken in this area [9]; [10], [11] have permitted to regroup the geological formations into two groups: The basement and cover formations (Figure 2). The basement is constituted by the Pan-African and Paleoproterozoic formations while the cover formations are represented by Cretaceous sedimentary series and basaltic formations. These formations have undergone intense volcanic activity leading to the establishment of the basin structure, covered by volcanic materials which reach the surface through deep fractures. These fractures are located at the base of major crustal lineaments [12], [5].

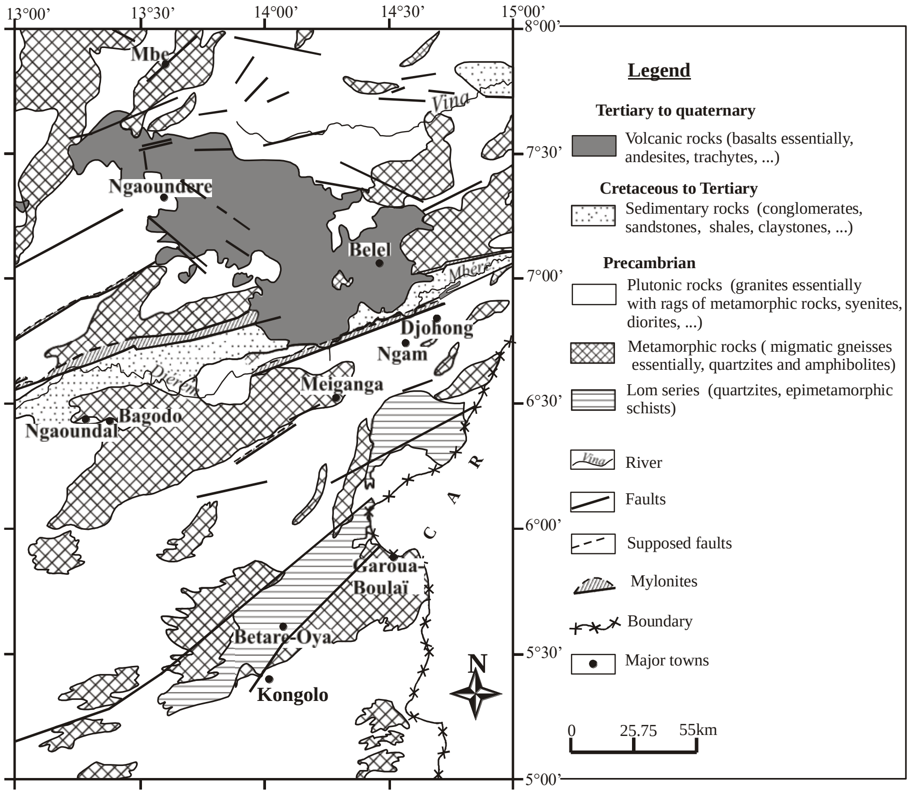

Figure 2: Simplified geological map of the study area showing major lithological and structural units modified after [13].

Three major tectonic structures are associated with the Adamawa Plateau: the Cameroon Volcanic Line (CVL), the South Adamawa Trough (SAT) and the Foumban Shear Zone (FSZ). The FSZ is a succession of major accidents that we follow from Sudan to Cameroon, where it disappears under the volcanic series. Structural studies [9] showed that the FSZ is a ductile accident, marked by numerous outcrops of granitoids [14]; [15]. Its structural evolution reveals two shear phases, one is dextral and the other is senestral. According to [9], the dextral phase is posterior to the senestral phase. The SAT is made up of the faults that border the southern part of the Adamawa plateau. It corresponds to a corridor about 300km long and 200 km wide [16]. It is constituted of the Cretaceous Mbéré ditch and the Djérem basin. Their filling is essentially constituted of continental formations: conglomerates, arkosic sandstones [13]. The CVL is a chain of intra-plate volcano shaped Y which extends from the island of Pagalu in the Atlantic Ocean west of Africa until about 2000km [17]. Along this line; there are several major volcanic centers that stretch from the Gulf of Guinea to Lake Chad. Among these volcanic buildings, only Mount Cameroon is still active and its last eruption occurred in year 2000. Several studies [18], [19], [8] showed that this line is due to a complex relationship between hot spots and lithospheric fractures.

3. Data Acquisition and Methodology

3.1 Data Acquisition

Gravity data used in this work come from two different sources. The first comes from terrestrial gravity data. Due to their insufficient coverage of the entire study area, the second source is obtained using grace gravity model.

The terrestrial gravity data used in this study comes from the BGI (Bureau Gravimétrique International) database for Central Africa. These data include the study area limited to the domain between longitudes 13° and 15°E and latitudes 5° and 8°N. The essential of measurements were carried out by ORSTOM (Office de Recherche Scientifique des Territoire d'Outre-Mer, now called IRD (Institute of Research for Development). The measurements were attached to the gravity bases of the network in Africa, known as Martin network [20]. In this study, the base is located at Ngaoundéré airport. The acquisition campaigns were carried out by car, along the roads or carossable tracks. Coordinates stations were determined on topographic maps and compass tracking. Elevation values were obtained with Wallace and Tiernan altimeters. The measurements were taken every 3km, the other measurements between 4 and

10km, and sometimes more. A total of 672 irregularly spaced measuring points were collected in the study area.

The second dataset were obtained by using Grace Gravity Model (GGM02C) [3]. This potential field model overcomes the absence and the sparseness of land or airborne gravity data [5]. It provides gravitational data with degree and order 200 and represents better the gravity anomalies in the Adamawa plateau [21]; [5]. According to [3], the Grace and terrestrial gravity data have the same precision; so they are stackable and can be superimposed. The free air correction was applied to the combined gravity net using an average rock density of 2.67gcm-3. Due to the presence of relatively smooth topography in the Adamawa plateau, no terrain correction was added. This dense gravity data has permitted us to draw a simple Bouguer anomaly map of the region (Figure 3) by using the Generic Mapping Tools [22].

3.2 Methodology

In order to delineate the lineaments associated with boundaries of rock units or faults, [23] proposed a new method which determines the maxima of the horizontal gradient applied on the upward continuation of Bouguer anomaly map. This method is a simple approach to estimate the locations contact and depth which change measures of field in x and y directions [24]. If dg/dx and dg/dy are the derivations of gravity field $g(x,y)$ in x and y directions, the horizontal gradient $HG(x,y)$ is given by:

$$HG(x,y) = \sqrt{\left[\frac{dg}{dx}\right]^2 + \left[\frac{dg}{dy}\right]^2} \quad (1)$$

In this case, lineated contacts correspond to faults, while the circular contacts are the limits of intrusive bodies [23], [11]. Some researchers applied this method successfully [6]; [25]; [26]. Thus, the highest levels of continuation correspond to the deepest contacts and vice versa. If we have a vertical structure, all the maxima overlap. These maxima reflect not only surface geology, edge of basins, but also tectonic discontinuities [7], [11]. To obtain the lineaments upward continuation at different heights was first applied to the combined gravity dataset. Horizontal gradient was then applied to the grid file at each continuation height and the resultant grid which highlighted high gradients was produced. The maxima of the horizontal gradient were finally applied on the grid file of upward continuation of densified Bouguer anomaly map.

4. Results and Discussions

The densified Bouguer anomaly map of the study area (Figure3) highlights two gravity zones. The first zone, located in Mbé, south of Kongolo, north of Djohong and west of Ngaoundéré is constituted of high anomalies. The amplitude values of these anomalies range from-60 to 35mGal. This variation illustrates the high density contrast in the crust. Based on the known geological features, it is possible to identify discontinuities related to the different underground structures on the map.

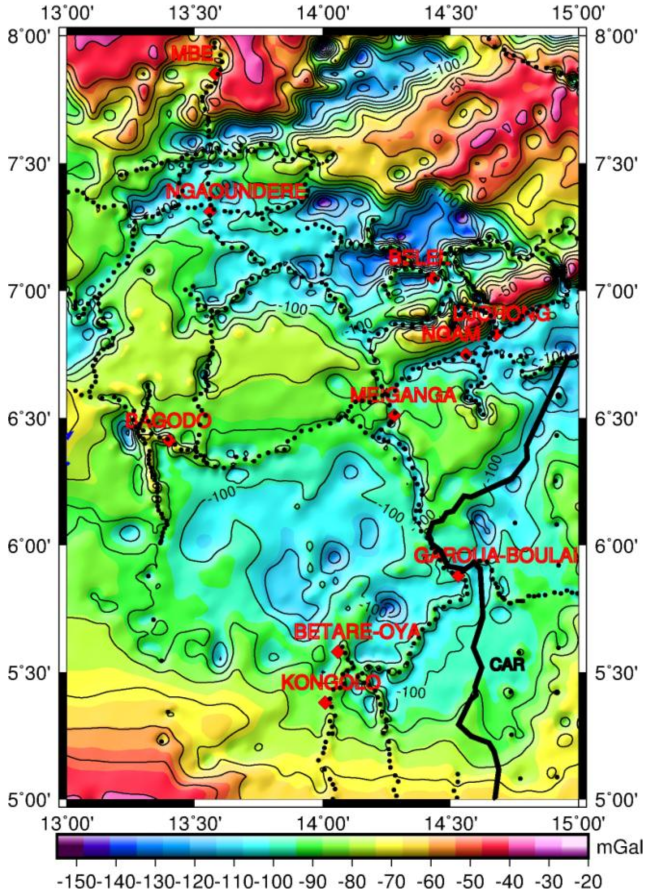

Figure 3: Densified Bouguer anomaly map of the Adamawa plateau (intervals: 10 mGal; color-scale unit: mGal). Black stacked line is boundary of countries (Cameroon and C. A. R). Red lozenges are localities. Black circle are measured gravity data and C. A. R stands for Central African Republic.

The second domain, located in the central part of the study area consists of a vast low area that goes from Bétaré-Oyoa to Djohong passing through Garoua-Boulai, Meiganga and Ngam, covers the cities of Ngaoundere and Belel. An overview of the configuration of these anomalies shows dominant direction ENE-WSW. This direction corresponds to the Cameroon Volcanic Line which extends from Foumban to the Mbere Ditch. The magnitude of these anomalies is approximately-100mGal with minimums reaching-120mGal. These anomalies can be interpreted to the signature of sedimentary basins or the presence of granites in the basement. These zones are separated by important gradients characterized by isoanomal lines. Their orientations permit to identify the structural directions of the region.

HGM was applied to upward-continued data at different levels to obtain the maps with gradient maxima (Figure 4). The horizontal gradient maxima for continuation heights 10km, 20km, 30km, 40km, and 50km were superimposed and the lines progressive migration of maxima presumed to indicate deep lineaments in the study area. Map of digitalization of horizontal gradient maxima produced a structural map of the study area (Figure 5). The rose diagram

(Figure 6) shows two main directions of fault and intrusive body.

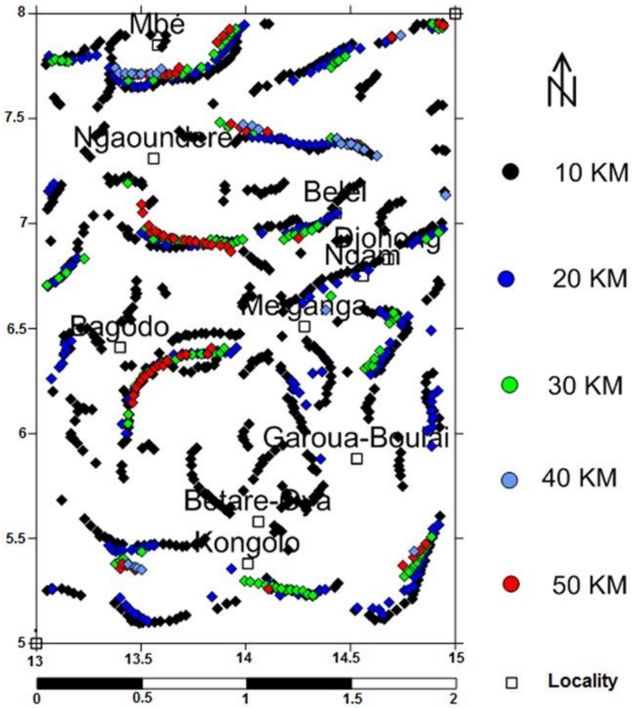

Figure 4: Maximum of the horizontal gradient of the Bouguer anomaly map and its upward continuation at different depths

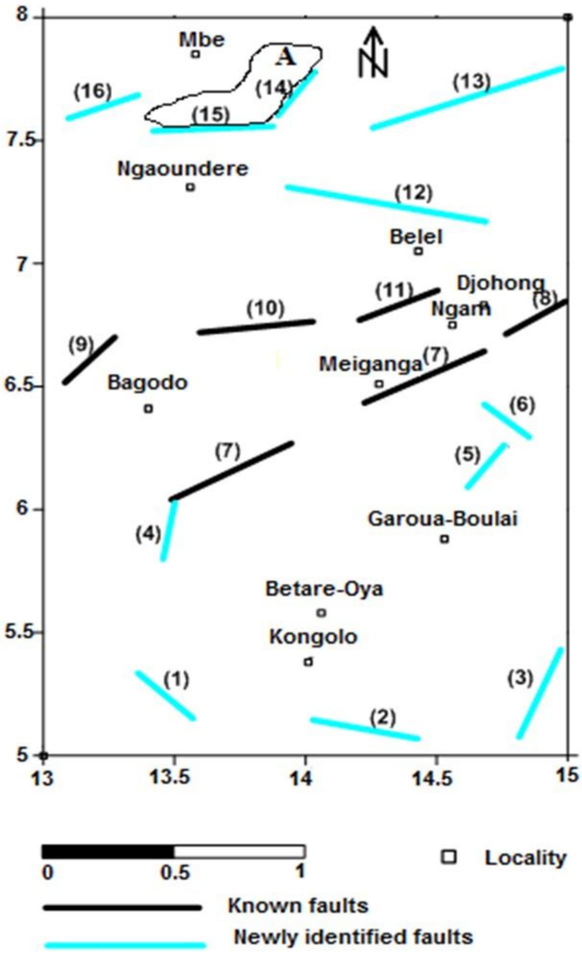

Figure 5: Structural map showing the distribution of interpreted gravity faults

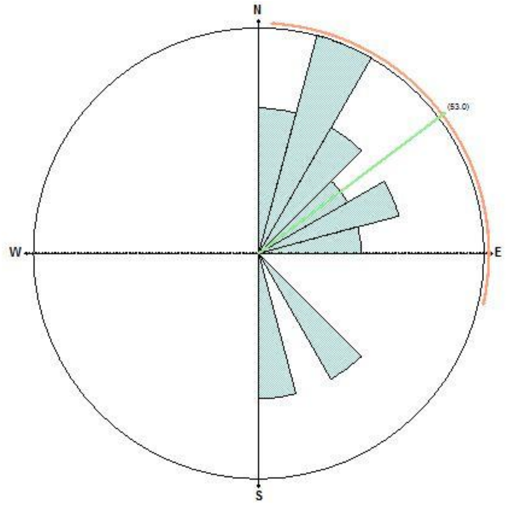

Figure 6: Rose diagram giving the direction of major faults and lineaments

The faults n° 7, 8, 10, 11, 13, 15 and 16 are oriented in the NE-SW direction. In this family, the faults n° 13, 15 and 16 are not underlined on the geological map of the study area (Figure 1). They could be blind faults probably hidden by basaltic formations, but lithospheric extension and constitute the limit of northern Cameroon and the Adamawa dome.

NNE-SSW direction is characterized respectively by faults n° 3, 4, 5, 9, and 14. The fault n°9 is already recognized in previous geological work. They were attributed to fractures that opened during the emplacement of the NE-SW Cameroon Volcanic Line and confirm the orientation of Adamawa Plateau.

The intrusive body denoted A, located in south of Mbe, is limited to the east by the fault n°14 and the south by the fault n°15. This body would be an intrusion, the one have high rocks probably basaltic in the granite-gneisses basement. These results corroborate with those obtained by [3] and are also compatible to the scheme proposed by [27] to explain the mechanism of magmatologic establishment of lavas in the Adamawa plateau. The direction of faults n°1 and n°2 has no geologic equivalent but probably correspond to the tectonic boundary between gneisses and migmatites of center region and granites of the study area.

5. Conclusion

In this work, the main objective is to determine lineaments (faults) associated with different discontinuities within the Adamawa plateau by using the Analysis of multi-scale maxima of horizontal gradients. The new Bouguer anomaly map obtained from the combination of terrestrial and Grace gravity data shows positive and negative anomalies. Positive anomalies are due to the uplift of basement while negative gravity anomalies are associated to the sedimentary basin or granitites formations. The resulting structural map shows the main tectonic accidents responsible for the structures of the study area. The two families of tectonics accidents NE-SW and NNE-SSW directions agree with the results of classical structural studies. These directions coincide with the geological and Panafrican structures. Other gravimetric lineaments such as 1, 2, 3, 4, 5, 6, 12, 13, 14, 15 and 16 were

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blind and therefore unidentified by the previous geological investigation. In addition an unknown geologically dense unit, never identified by any previous study, was detected near Mbe locality. These lineaments permit to understand the groundwater flow and provide information for the development of hydrodynamic model under the Adamawa plateau. For future investigation we will use some recent models from GOCE mission in order to improve the gravity analysis in the study area.

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Author Profile

BOUBA Apollinaire, Lecturer at the Higher Teachers' Training College of the University of Maroua, Cameroon. He received Doctorate/ PhD in Geophysics of the University of Yaounde I, Cameroon.