The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 04 || Series II || Pages || PP 01-07 || 2020 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Contribution of satellite gravity data (EGM2008) for structural characterization of the Goulfey-Tourba sedimentary basin (Northern Cameroon)

Kamto Paul Gautier[1,2,*], Nkoungou Gregory José[1,3], Tchato Sandra Céleste[1,2], Lemotio Willy[1,2], Atangana L.A. Aimé[4], Kamguia Joseph[1,2]

[1] Laboratory of Geodesy Research, National Institute of Cartography, Yaounde, Cameroon
[2] Department of Geophysics, Faculty of Science, University of Yaounde I, Yaounde, Cameroon
[3]Department of Earth sciences, Faculty of Science, University of Yaounde I, Yaounde, Cameroon
[4]National Agency of Radiation Protection, Yaounde, Cameroon
**Corresponding author, Kamto Paul Gautier*

Abstract: *In this study, the Goulfey-Tourba sedimentary basin has been structurally characterized using satellite gravity data derived from the global geopotential model EGM2008. The interpolation of these data was firstly carried out by applying the Krigeage algorithm using the Oasis Montaj software. The Bouguer anomaly map obtained has values ranging from -54.1 to 15.4 mGals. This map is divided into two main domains: a domain of negative anomalies characteristic of upper Tertiary sediments and a domain of relative positive anomalies probably caused by an uplift of basement rocks. Then, the horizontal gradient method was coupled with the upward continuation technique at several depths to highlight the position, direction and dip of major lineaments. A set of 11 lineaments (L1 to L11) from different directions have been listed. The two major lineaments identified have a NE-SW direction. The Euler deconvolution method was also applied to the Bouguer anomaly map with a structural index SI = 0.1 and a window of size 5. This method allowed us to highlight the position and orientation of 14 faults as well as their vertical extension. The position of several faults coincides with the lineaments identified using the horizontal gradient maxima. The structural map could be used to better understand circulation and formation of hydrocarbons. It could also help to update the geological map of our study area.*

Keywords: *Satellite gravity data, Structural map, Horizontal gradient, Euler deconvolution method, Goulfey-Tourba sedimentary basin*

Date of Submission: 11-02-2020 Date of Acceptance: 27-04-2020

I. INTRODUCTION

The Goulfey-Tourba sedimentary basin (northern part of the Logone-Birni sedimentary basin) represents a part of the large Chad sedimentary basin. This latter is a vast regional depression located between Cameroon, Chad, Nigeria and Niger. It has an approximate area of 27,000 km^2 and is part of the West and Central African Rift System (WCARS). The Goulfey-Tourba sedimentary basin has the topographic shape of a plain. In the northern and center-western parts of the Goulfey-Tourba basin, we meet the Bornu-Termit trough system. Significant hydrocarbon resources have been discovered in some sedimentary basins of the WCARS. Isiorho et al. (1991) have also identified this basin as being of interest for hydrogeological investigations. In addition, the Goulfey-Tourba basin and its surroundings have already been the target of several geophysical studies (Poudjom et al. 1996, Nguimbous-Kouoh et al. 2010, Nguimbous-Kouoh et al. 2017). These studies were made with terrestrial gravity data whose resolution should be improved. Therefore, the global geopotential model EGM2008 is a good alternative because it offers gravity data with a high spatial resolution. In addition, these satellite gravity data are available free of charge. Several geophysical studies have already been carried out with this satellite model on Cameroon (Eyike et al. 2010, Ngatchou et al. 2014, Marcel et al. 2016). So, they can be easily used to study lithospheric crust structure.

The aim of this work is to bring out structural and tectonic parameters of the Goulfey-Tourba basin from multi-scale analysis of satellite gravity data derived from the EGM2008 model. This method allows us to get some information on the position, orientation and dip of faults and lineaments of the study area. These structural parameters give us a good knowledge on the sedimentary basin architecture and a better control on fluid circulation and potential hydrocarbon resources. So, this study is crucial in the identification of suitable areas for future oil and mining explorations.

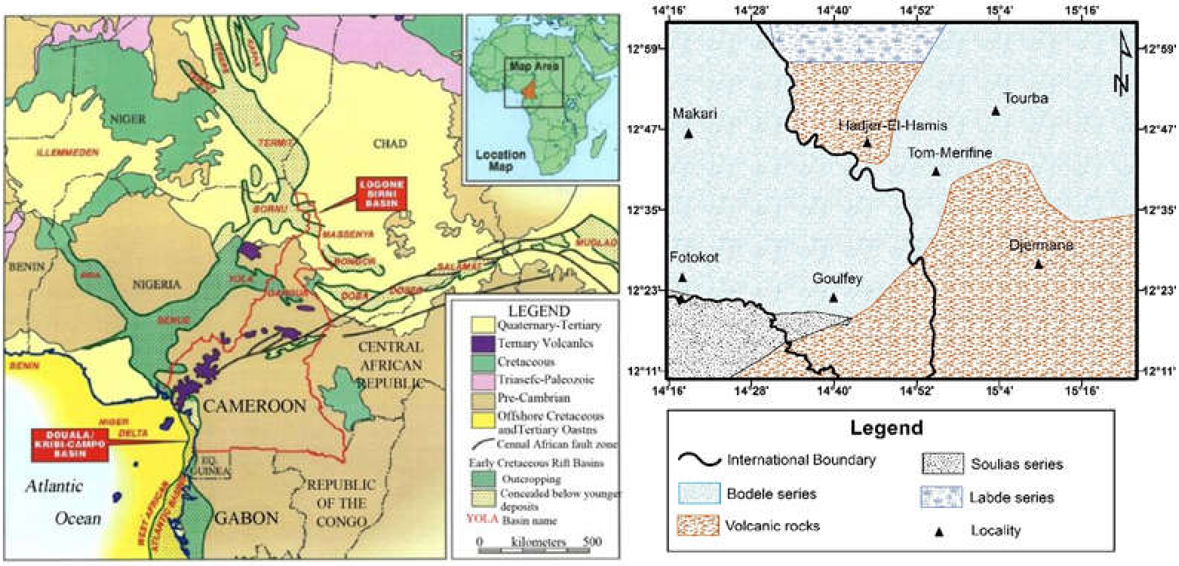
II. GEOLOGY AND TECTONICS

The Goulfey-Tourba sedimentary basin is located between the Central and West African Rift Systems (WCARS) as shown on Figure 1.a. It is directly connected to the Bornu and Termit sedimentary basins. The study area was affected by tectonic activities ranging from Precambrian to Quaternary (Burke and Dewey 1974, Durand 1982). Several faults and lineaments were generated during Pan-African Orogenesis (750-550 million years). Our basin is also characterized by many terrains inversions. The geological history of the study area is linked to the formation of the Chad basin. The Chad basin is an extension of the Central and West Africa plates during the Lower Cretaceous era. The sedimentary cover of the Chad basin has an average thickness of 600 m. This is the consequence of two main factors: the Lake Chad transgression during wet periods and the lacustrine transgressions during arid periods (Schuster 2003). These transgressions are marked by aeolian erosion which contributes to the degradation of material deposits.

The Goulfey-Tourba sedimentary basin has the topographic shape of a plain. It has been covered by deposits of sandy clayey alluvium during the Quaternary era. The low altitude of this basin exposes it to frequent flooding caused by the Lake Chad and the Chari River. The sediment covering of the Goulfey-Tourba basin consists of alluvium, wind sediments and lacustrine deposits. This basin presents three main geological series (Mathieu 1976):

- The Bodele series made up of sediments from the Upper Tertiary. It is composed of sand and clay with some clay intercalations. This geological series dates from the Pliocene and is mainly fluvial.
- The Soulias series from the Upper Pleistocene. It is made up of Aeolian sand and lacustrine silts.
- The Labde series dating from 2400 years to now. It contains a thin layer of alluvial deposits.

  The different series are underlained by some basement rocks such as granite, gneiss and migmatite, located at different depths.



(a) (b)

Figure 1: (a) Simplified geological map of Cameroon and its surroundings (modified from Genik 1993). This map shows us the lateral distribution of the different sedimentary layers. We also note the location of the Logone-Birni sedimentary basin. (b) Simplified geological map of the study area (modified from Nguimbous-Kouoh et al. 2010).

III. DATA AND METHOD

2.1 Data

The gravity data used in this study are derived from the Earth Gravitational Model EGM2008 (Palvis et al. 2008, 2012), an improved version of the terrestrial gravitational model EGM96. The EGM2008 model was released by the EGM development team of the National Geospatial-Intelligence Agency (NGA) of the United States of America. This geo-potential model contains spherical harmonic coefficients up to degree and order 2159

and some additional coefficients which extend up to degree 2190 and order 2160. The EGM2008 global model presents a complete database with a good resolution (2.5 'x 2.5'). It contains terrestrial, marine, airborne and satellite gravity data. This model is therefore available in hard-to-reach areas and could solve the problem of poor resolution of terrestrial gravity data. This gravity database has been validated by some researchers. They have compared the results of their studies with those obtained from other sources of geophysical data (Eyike et al. 2010, Ngatchou et al. 2014, Marcel et al. 2018). These authors suggested that gravity data from the EGM2008 model could be used to fill the lack of terrestrial gravity data in some areas.
Bouguer anomalies derived from EGM2008 model were obtained after applying Bouguer plate and topographic corrections on free air anomalies. The digital terrain model ETOPO1 (Amante and Eakins 2009) and a crustal density of 2670 kg/m^3 were used to make these corrections.

2.2 Method

In sedimentary basins, faults and fractures are very important structurally. They offer a better understanding of basin architecture and permits to have a good control on potential sites rich in hydrocarbons (gas, oil, etc.). However, sedimentary cover limits the structural mapping of basin by conventional field methods. In this case, we therefore use indirect methods such as the horizontal gradient and the Euler deconvolution method.

Maximum horizontal gradient / Upward continuation

The horizontal gradient is a good method to delineate structural features of the lithospheric crust. We use horizontal gradient maxima of a gravity field to highlight different lineaments such as faults, fractures or geological contacts of a given area (Grauch and Cordell 1987; Philips 1998). This method has the advantage of being very stable when faced with noises in a gravity field. For a gravity field$G\ (x, y)$, the horizontal gradient magnitudeHGM is given by the following expression (Philips 1998):

$$HGM = \sqrt{\left(\frac{\partial G}{\partial x}\right)^2 + \left(\frac{\partial G}{\partial y}\right)^2} \quad (1)$$

In addition, the combination of horizontal gradient maxima with the upward continuation technique is used to highlight the different lineaments as well as their evolution in depth (vertical or oblique). This technique consists of producing several maps upward continued at increasing depths and applying the horizontal gradient to each of these maps. The superimposition of the maxima of each map allows a better evaluation of lineaments direction and dip (Blakely and Simpson 1986).

Euler deconvolution

Euler deconvolution is a method used to obtain position and apparent depth of gravimetric or magnetic anomalies sources (Thompson 1982; Reid et al. 1990). This method consists in making the link between the components of a gravity field and the position of anomalies sources with a degree of homogeneity called "structural index". Euler's deconvolution equation (Thompson 1982) is written as follows:

$$(x - x_0)\frac{\partial g}{\partial x} + (y - y_0)\frac{\partial g}{\partial y} + (z - z_0)\frac{\partial g}{\partial z} = -N(B - g) \quad (2)$$

where x_0, y_0, z_0 are the coordinates of the gravity anomaly source$g\ (x, y, z)$, N is the structural index which represents the measure of the fall-off-rate of the gravity field with the distance to the source, B is the regional gravity field.
In geology, the depths obtained by Euler's deconvolution represent the stratigraphic or structural transitions encountered in geological formations. So, these Euler solutions appear where there are lithological discontinuities.

IV. RESULTS AND DISCUSSION

3.1 Interpretation of the Bouguer anomaly map

Figure 2 shows the Bouguer anomaly map for the study area. This map is obtained following interpolation of satellite gravity data derived from the EGM2008 model. The interpolation was carried out by applying the Krigeage algorithm with the Oasis Montaj software. The Bouguer anomaly map (Figure 2) shows values ranging from -54.1 to 15.4 mGals. Nguimbous-Kouoh et al. (2017) also established a Bouguer anomaly map over the study area using terrestrialgravity data and obtained a measurement ranging from -54 to 14 mGals. Thus, thiscontributes to validate our satellite gravity database. The Bouguer anomaly map (Figure 2) reflects lateral variations in density of shallow and deep geological units of the Goulfey-Tourba basin. The most negative anomalies are located around the localities of Goulfey, Tom-Merifine, Tourba and Makari. The negative anomalies of theMakari locality have not been highlighted by the previous work ofNguimbous-Kouoh et al. (2010) due to a lack of terrestrial gravity data in this part of the basin. These peaks of negative anomalies would be the signature of the Bodele geological series made up of sediments from the Upper Tertiary (Louis 1970, Cratchley et al. 1984). The Bouguer anomaly map of the study area is also characterized by the presence of relatively large anomalies around the localities of Hadjer-El-Hamis and Djermaya. These anomalies are thought to be the cause of an uplift in the bedrock due to magmatic intrusions of dense rocks such as rhyolites (Louis 1970, Cratchley et al. 1984).

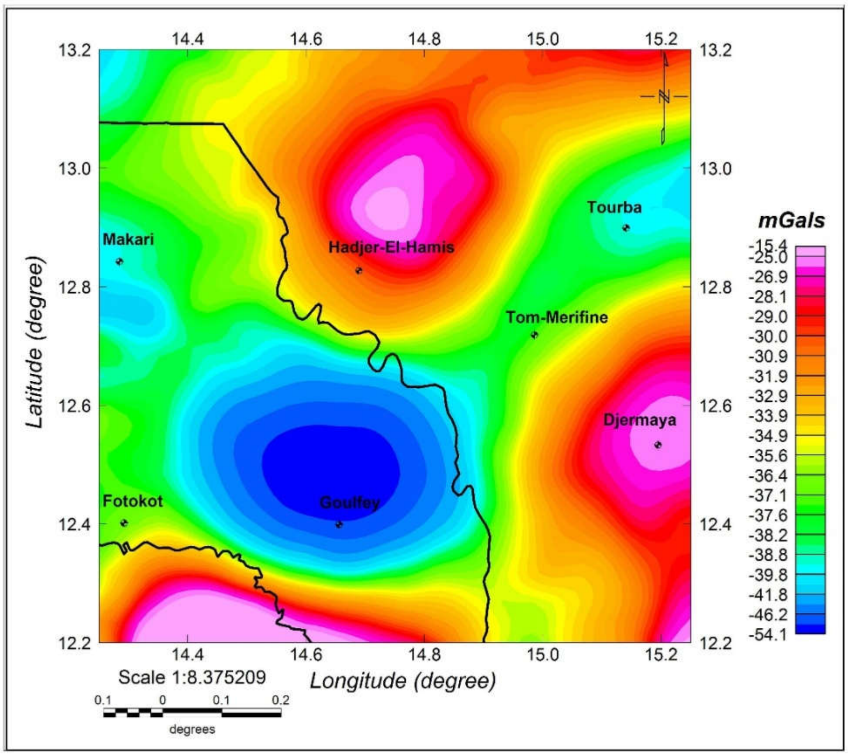


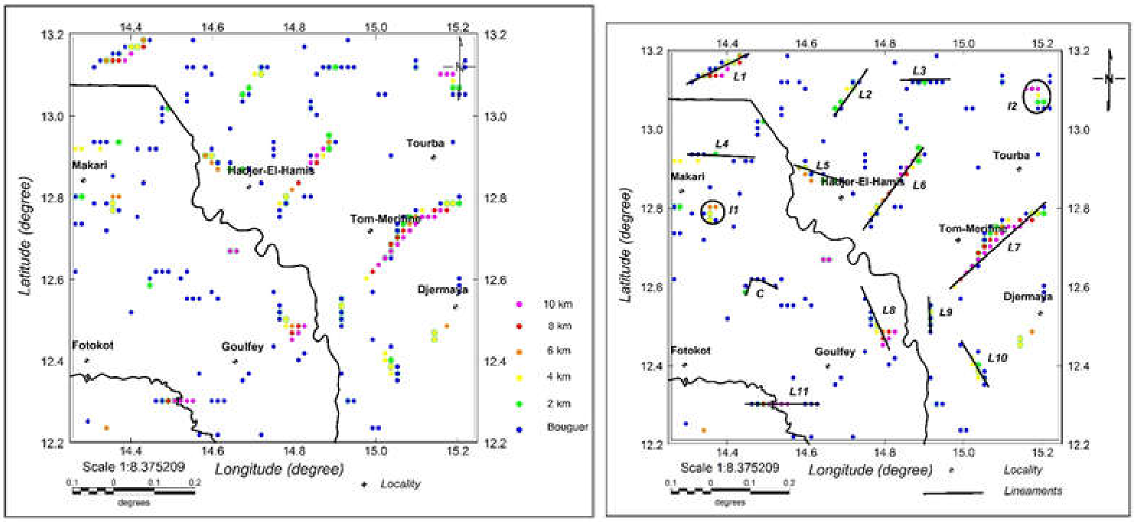
Figure 2: Bouguer anomaly map of the study area

3.2 Structural map and tectonic implication

Maxima of horizontal gradient coupled with upward continuation technique

The horizontal gradient method was applied to the Bouguer anomaly map (Figure 2). Then, the horizontal gradient map was upward continued to different depths ranging from 0 to 20 km. The maxima of each upward continued map have been determined and superimposed to obtain the map presented in Figure 2.a. The horizontal gradient maxima map helps us to highlight areas of abrupt density changes. The couplage of the maxima map of the horizontal gradient to with upward continuation at different depths shows the vertical extension of different anomalous structures. The quasi-linear arrangement of several maxima is simply the signature of a fault or a geological contact; on the other hand, a quasi-circular alignment of these maxima would correspond to the horizontal limit of an intrusive body (Koumetio et al. 2014). The different maxima shown on this map (Figure 2.a) show the direction, orientation and vertical extension of the lineaments of the study area.

The digitalization of the horizontal gradient maxima map allowed us to have a structural map on the study area (Figure 2.b). The structural map shows the distribution of some lineaments (faults, fractures and intrusion) that were generated during tectonic activities on the Goulfey-Tourba basin. A series of 11 lineaments (L1 to L11) of different directions have been listed. These lineaments are thought to be the cause of tectonic activities dating from the Precambrian to the Quaternary in the study area (Burke and Dewey 1974, Durand 1982). The two major lineaments are L6 and L7 with a NE-SW direction and a quasi-vertical extension. The work of Loule et al. (2013) and Nguimbous-Kouoh et al. (2017) also showed that the study area would have undergone tectonic activity in the main NE-SW direction. The interpretation of the structural map allows us to say that the basement of the study area would have been slightly affected tectonically. Nevertheless, the identification of the lineaments L6, L7 and L8 would allow a better control of hydrocarbons circulation.



(a) (b)

Figure 3: (a) Map of the horizontal gradient maxima upward continued at different depths. (b) Structural map showing the distribution of lineaments in the study area.

Solutions obtained by the Euler method

The Euler deconvolution method was applied to the Bouguer anomalies with a window size of 5 km x 5 km, a maximum tolerance of 15% and a structural index of 0.1. This structural index was chosen because it allows to better stand out from the different contact zones and underground faults. Figure 10 presents structural solutions obtained by applying the Euler method on the Bouguer anomalies. This method gives us information about the position, orientation and depth of gravity anomalies sources. We note that the study area is affected by a network of 12 shallow faults whose depth varies from 2 to more than 11 km. This explains why the origins of lineaments and faults in the study area are diverse. The main faults affecting the sedimentary basin, as well as their direction and depth, are classified in Table 1. The majority of the faults tend towards the NE-SW direction. This direction correlates very well with the two major lineaments orientation (L6 and L7) previously highlighted by the horizontal gradient maxima. In addition, the faults F6, F3 and F7 in Figure 4 and the lineaments L6 and L7 in Figure 3.b have the same position and direction parameters. This information on the orientation of shallow and deep faults is important because it allows a better control of the direction of fluids circulation inside the sedimentary basin. The various faults identified in the basin would be the response of a deep tectonic activity (Burke and Dewey 1974, Durand 1982) or even an intrusion of metamorphic rocks inside the sediment layers (Louis 1970, Cratchley et al. 1984).

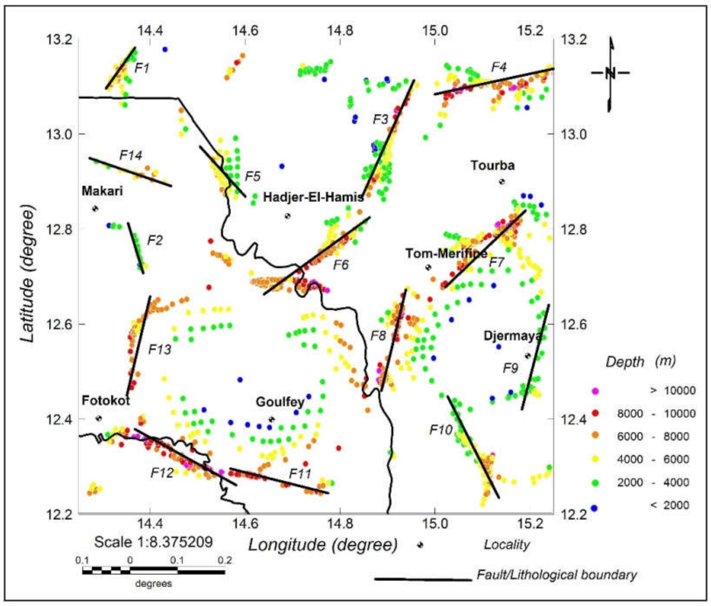


Figure 4: Structural interpretation map of Euler solutions for N = 0.1

Tableau 3: Directions and depth of faults identified by the Euler method

Fault ID	Direction	Depth range (km)
F1	SW-NE	2-6
F2	NNW-SSE	2-4
F3	SSW-NNE	4-8
F4	WSW-ENE	6-8
F5	NW-SE	4-6
F6	SW-NE	6-8
F7	SW-NE	4-10
F8	SSW-NNE	6-10
F9	SSW-NNE	2-4
F10	NNW-SSE	2-6
F11	WNW-ESE	6-10
F12	WNW-ESE	6-10
F13	SSW-NNE	6-8
F14	WNW-ESE	2-6

V. CONCLUSION

The main objective of this work was to make a structural characterization of the Goulfey-Tourba sedimentary basin using satellite gravity data (EGM2008). The calculated and interpolated Bouguer anomalies were able to show us gravimetric signatures which correlate very well with the previous works carried out on the study area. However, new signatures not identified in the previous works show that satellite data is a good alternative for areas without terrestrial gravity data.

The coupling of the horizontal gradient maxima with the upward continuation technique at several depths allowed us to highlight the lineament map of the study area. Some lineaments have been identified. This shows that the study area has undergone a slightly tectonic activity in the pass. The two major lineaments L6 and L7 with a NE-SW direction give us additional information on the tectonic history of the Goulfey-Tourba sedimentary basin. The Euler's deconvolution method has also been applied to the Bouguer anomaly map to highlight additional structural features (faults, fractures). A series of 14 faults have been identified. Many of them coincide with the position of the lineaments identified previously. A great part of the identified faults also tend towards the NE-SW direction. This allows us to appreciate the structural features identified in this work. The shallow and deep faults identified would greatly contribute to know the sedimentary basin architecture and therefore to have a better control of the hydrocarbons circulation (oil, gas).

REFERENCES

[1]. Isiorho, S.A., Taylor-When, K.S. and Corey, T.W. (1991) Locating groundwater in Chad Basin using remote sensing technique and geophysical method (Abstract): *EOS (Transactions of the American Geophysical Union), 72*, 220-221.

[2]. Poudjom, D.Y.H., Legeley-Padovani, A., Boukeke, D.B., Nnange, J.M., Ateba-Bekoa, AlbouyY. and Fairhead, J.D.(1996)*Levésgravimétriques de reconnaissance-Cameroun. Orstom*, France, 30 p.

[3]. Nguimbous-Kouoh, J.J., Ngos III, S., Mbarga, T.N. and Manguelle-Dicoum, E. (2017) Use of the polynomial separation and the gravity spectral analysis to estimate the depth of the northern LogoneBirni sedimentary basin (Cameroon*). International Journal of Geosciences*, 8, 1442-1456.

[4]. Nguimbous-Kouoh, J.J., Mbarga, T.N.,Njandjock-Nouck, P., Eyike, A., Campos-Enriquez, J.O. and Manguelle-Dicoum, E. (2017) Use of the polynomial separation and the gravity spectral analysis to estimate the depth of the northern LogoneBirni sedimentary basin (Cameroon*). International Journal of Geosciences*, 8, 1442-1456.

[5]. Eyike, A., Werner, S.C., Ebbing, J. and Manguelle-Dicoum, E. (2010) On the use of global potential field models for regional interpretation of the West and Central African Rift System. *Tectonophysics*, **492**, 25-39. http://dx.doi.org/10.1016/j.tecto.2010.04.026

[6]. Ngatchou, H.E., Liu, G., Tabod, C.T., Wang, Y., Kamguia, J., Nguiya, S., Tiedeu, A. and Ke, X. (2014) Crustal structure beneath Cameroon from EGM2008. *Geodesy and Geodynamics*, **5**, 1-7. http://dx.doi.org/10.3724/SP.J.1246.2014.01001

[7]. Marcel, J., Abate, E.J.M., Njandjock, P.N., Ngatchou, H.E., Oyoa, V., Tabod, C.T. and Manguelle-Dicoum, E. (2016) Structure of the crust beneath the south western Cameroon, from gravity data analysis. *International Journal of Geosciences*, **7**, 991-1008. http://dx.doi.org/10.4236/ijg.2016.78075

[8]. Genik, G.J. (1993) Petroleum geology of Cretaceous-Tertairy rift basins in Niger, Chad and the Central African Republic. *Bulletin of American Association of Petroleum Geologists*, 77, 1405-1434.

[9]. Schuster, M., Duringer, P. Ghienne, J.F. Vignaud, P. Mackaye, H.T. Beauvilain, A.and Brunet, M. (2003) Discovery of coastal conglomerates around the Hadjer el Khamis inselbergs (western Chad, central Africa): a new evidence for lake Mega-Chad episodes. *Earth Surface Processes and Landforms*, 28, 1059-1069.

[10]. Mathieu, P. (1976) Évolution géologique récente du bassin du Tchad. Orstom, Paris, 12 p.

[11]. Pavlis, N.K., Holmes, S.A., Kenyon, S.C. & Factor, J.K. (2008) An earth gravitational model to degree 2160: EGM2008. *Presented at the EGU General Assembly*. Vienna Austria, April, 13-18.

[12]. Pavlis, N.K., Holmes, S.A., Kenyon, S.C. and Factor, J.K. (2012) The development and evaluation of the earth gravitational model 2008 (EGM2008). *Journal of Geophysical Research*. **17**, Article ID: B04406. http://dx.doi.org/10.1029/2011jb008916

[13]. Amante, C. and Eakins, B.W. (2009) ETOPO1 1 Arc Minute global relief model: Procedures, data sources and analysis. *NOAA Technical Memorandum NESDIS NGDC-24*.

[14]. Grauch, V.J.S. and Cordell, L. (1987) Limitations of determining density or magnetic boundaries from the horizontal gradient of gravity or pseudogravity data. *Geophysics*. **22**, 359-383. https://doi.org/10.1190/1.1442236
[15]. Philips, J.D. (1998) Processing and interpretation of aeromagnetic data for the Santa Cruz Basin-Patahonia mountains area. South-Central Arizona. U.S. *Geological Survey Open-File Report. Arizona*. pp 02-98.
[16]. Blakely, R.J. and Simpson. R.W. (1986) Approximating edges of sources bodies from magnetic or gravity anomalies. *Geophysics*. **51**, 1494-1498.
[17]. Thompson, D.T. (1982) A new technique for making computer-assisted depth estimates from magnetic data. *Geophysics*. **47**, 31-37.
[18]. Reid, A.B., Allsop, J.M., Granser, H., Millet, A.J. & Somerton, I.W. (1990) Magnetic interpretation in three dimensions using Euler deconvolution. *Geophysics*.**55**. 180-191.
[19]. Louis, P. (1970) Contribution de la géophysique à la connaissance géologique du bassin du lac Tchad. Mém. Orstom, Paris, 311 p.
[20]. Cratchley, C.R., Louis, P. and Ajakaiye, D.E. (1984) Geophysical and geological evidence for the Benue Chad basin Cretaceous rift valley system and its tectonic implications. *Journal of Africa Earth Sciences*, 2, 141-150. https://doi.org/10.1016/S0731-7247(84)80008-7
[21]. Koumetio, F., Njomo, D., Tatchum, C.N., Tokam, K.A.P., Tabod, C.T. and Manguelle-Dicoum, E. (2014) Interpretation of gravity anomalies by multi-scale evaluation of maxima of gradients and 3D modelling in Bipindi region (South-West Cameroon). *International Journal of Geosciences*. **5**, 1415-1425. https://doi.org/10.4236/ijg.2014.512115

Kamto Paul Gautier,et al. "Contribution of satellite gravity data (EGM2008) for structural characterization of the Goulfey-Tourba sedimentary basin (Northern Cameroon)." *The International Journal of Engineering and Science (IJES)*, 9(4) (2020): 01-07.