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Geometrical Characterisation of the Mamfe Basin, Cameroon, from the Earth, Gravitational Model (EGM 2008)

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Abstract

Gravimetric studies using the ETOPO1-corrected high resolution satellite-based EGM2008 gravity data was used to define the surface extent, depth to basement and shape of the Mamfe basin. The Bouguer anomaly map was produced in Surfer 11.0. The Fast Fourier Transformed data was analyzed by spectral analysis to remove the effect of the regional bodies in the study area. The residual anomaly map obtained was compared with the known geology of the study area, and this showed that the gravity highs correspond to the metamorphic and igneous rocks while the gravity lows match with Cretaceous sediments. Three profiles were drawn on the residual anomaly map along which 2D models of the Mamfe basin were drawn. The modeling was completed in Grav2dc v2.06 software which uses the Talwini's algorithm and the resulting models gave the depth to basement and the shape of the basement along the profiles. After processing and interpretation, it was deduced that the Mamfe basin has an average length and width of 77.6 km and 29.2 km respectively, an average depth to basement of 5 km and an overall U-shape basement. These dimensions (especially the depth) theoretically create the depth and temperature conditions for petroleum generation.

Keywords: EGM 2008 gravity data, residual anomaly map, 2D models, petroleum generation

1. Introduction

In the quest for oil and gas, the subsurface of most of Cameroon's basins have been thoroughly studied through the processing and interpretation of the gravity data (Fairhead *et al.*, 1991; Kamguia *et al.,* 2005; Ndougsa-Mbarga *et al.,* 2007; Eyike *et al.,* 2010; Oyoa *et al.*, 2012; Mouzong *et al.*, 2014). The study area which is the Mamfe basin is one of these basins and is a branch of the Benue Trough that extends into the South West Region of Cameroon.

Though many authors have worked to understand the geology, biostratigraphy and lithostratigraphy of the Mamfe basin (Dumort, 1968; Eben *et al*., 1984; Hell *et al*., 2000; Petters, 1978, Eyong, 2001, 2003; Eseme *et al.,* 2002; Bassey *et al*., 2013; Eyong *et al.*, 2013; Njoh *et al*., 2014.), and others published on its subsurface layering (Kamga *et al*., 2008; Nguimbous-Kouoh *et al*., 2012), the length, width and depth of the basin are still not well defined. This work is aimed at making some contribution to understanding the nature of the geometric framework of the Mamfe basin through the processing and interpretation of gravity data. The results will propose an idea of its length, width, average sediment pile thickness and the shape of its basement.

Gravity data is useful in the study of the subsurface (Kearey, Brookes and Hill, 2002). Abate Essi *et al*., 2017 used satellite derived geavity data to study the subsurface of Central Northern Cameroon with structural and mining implications, hence it was used in this research to determine the geometrical characteristics of the Mamfe basin. The ground gravity dataset from the ORSTOM database (Poudjom-Djomani *et al*., 1995) have been used in the basin (Fairhead et al. 1991; Ndougsa- Mbarga, 2004; Ndougsa- Mbarga *et al.* 2007), but its poor spatial resolution in the study area (since it follows only roads, Poudjoum *et al.*, 1995) makes it not suitable for geometrical characterization. We therefore use the high resolution satellite-based Earth Gravitational Model 2008 (EGM2008) which has been corrected using the ETOPO1 to propose reliable values of the length, width and depth of the Mamfe basin and to give the shape of its basement.

1.1 Geologic and Tectonic Setting

The Mamfe basin is located between latitudes 5°30 and 6°00 N, and longitudes 8°50 and 9°40 E (**Figure 1**), with average altitude ranging between 90 and 300m above sea level. It is one of the numerous basins that form the West and Central African Rift Systems (Gennik *et al.* 1993) and it is precisely part of the Benue Trough found between the West African and the Congo Cratons (**Figure 1)**. This Cretaceous-filled sediments Basin opens to the west into the Ikom-Mamfe Embayment and is bordered to the north by the granito-gneissic Obudu Massifs. To the south the Oban Massif separates it from the Rio Del Rey Basin; and the Bamenda Highlands n the Cameroon Volcanic Line (C.V.L) border it in the NE.

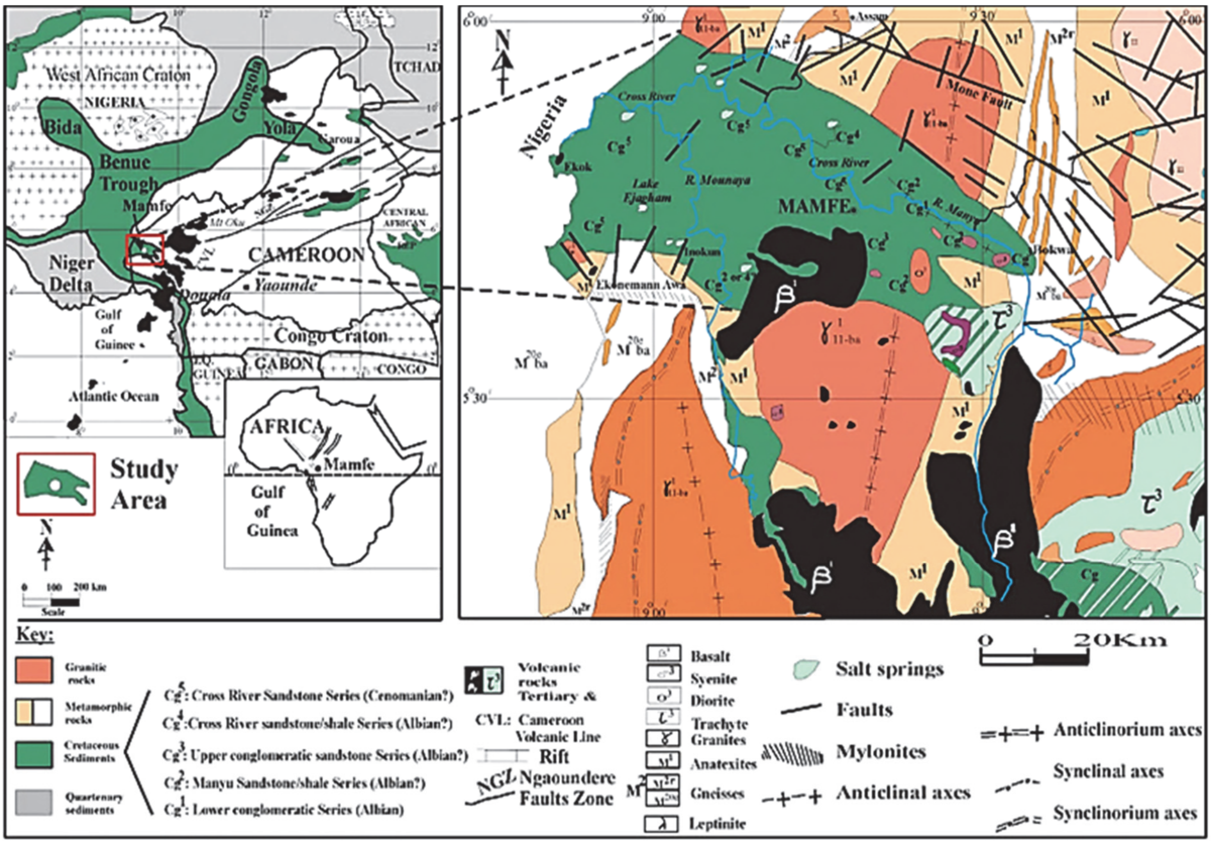

Figure 1. Location of the Mamfe basin in relation to the Benue Trough, Cameroon Volcanic Line (CVL) and the West and Central African Rift System (WCARS) (adapted from Benkhelil, 1989, the geologic map of Cameroon, 1979 edition and Eyong et al., 2013

The Cretaceous sedimentary rocks were later intruded by syenites and extruded by trachytes and basalts, all of which are Tertiary in age (**Figure 1**) and are related to the C.V.L. Basalts are seen as enormous flows in the central southern part of the Basin. Alternating Cretaceous sandstone-shale Formations of the Mamfe basin are slightly folded and locally affected by very low-grade metamorphism (Moreau et al., 1987).

2. Data and Method

The set of gravity data were obtained from the World Gravity Map or Model (WGM). The World Gravity Map (WGM) denotes a set of high-resolution gravity anomaly maps and digital grids computed at global scale from available reference Earth's gravity and elevation models. Based on rigorous computations that are consistent with geodetic and geophysical definitions of gravity anomalies, WGM provides homogeneous information on the Earth's static gravity field at regional and global scales (also available in in digital form) for various geophysical applications in education and research (Bonvalot et al., 2012). Recently, new formulations have been proposed to compute gravity anomalies based on both a realistic Earth model and rigorous geodetic definitions. More details on these modern views of anomaly computation can be found in Featherstone and Dentith (1997), Li and Götze (2001), Hackney and Featherstone (2003), Hinze et al. (2005), NGA (2008) and Kuhn et al. (2009).

The EGM2008 model includes surface gravity measurements (from land, marine or airborne surveys), satellite altimetry and satellite gravimetry (GRACE mission) measurements. Updated information on the Arctic gravity field provided by the Technical University of Denmark (Andersen, 2010) and included in the DTU10 global gravity field model (1'x1' resolution ~ 1850m x1850m) are also included in the EGM 2008. Thus this makes it certain that though at a regional or global scale (scale of the data is 1:50,000,000) this gravity dataset thoroughly covers the entire world (Bovalot et al., 2012)) and has gone through the best corrections so far attainable. The Bouguer correction was done with a density of 2670kg/cm^3.Therefore using EGM2008 is advantageous since: (1) It uses an ellipsoidal harmonic coefficient up to degree and order 2190 to follow a more rigorous approach as compared to previous methods (Weiyong and Rummel, 2013). (2) It has the highest available spatial resolution and ability to provide precise and uniform gravity data. (3) It has been well developed and is freely available, and can resolve features corresponding to a spatial resolution of 5 arc minutes or ~ 9 km for most regions, or about 6 times higher resolution than the previous models. (4) It provides good information on areas previously inaccessible or having terrestrial data gaps, and extends across natural and artificial boundaries. (5) It incorporates data from different sources, including satellite altimetry over oceans, satellite gravity, and the terrestrial gravity (Pavlis et al., 2012). It has been used in the mapping of cratons and coal fields in India (Pala et al., 2016, Jitendra and Pala, 2015), and also in delineating vertical discontinuities hence updating the geological map of the Mamfe basin in Cameroon by Djieto Lordon et al., (2017).

The presence of oil and gas in a basin might be due to two factors: in-situ generation and migration of fluids into its sub-basin (Ndougsa-Mbarga et al, 2007). Subsurface pressure is a function of the sediment thickness (i.e., the sediment weight) and is one of the environmental conditions needed for oil and gas formation in a basin. The average density contrast between the sediment pile and the basin's basement are recorded in the Bouguer anomaly, which is made up of the regional anomaly and the residual anomaly. The residual anomaly is therefore a useful tool in both the qualitative and quantitative studies of the structure of the substratum, and hence eases the evaluation of oil and gas potentials of a sedimentary basin and in the identification of potential prospects of oil and gas concentration (Schoeffler, 1975; Savit and Dobrin, 1998).

The Bouguer anomaly map was obtained by contouring the dataset in Surfer 11. Spectral analysis was applied to the gravity data to determine the effect to both shallow (residual) and deep (regional) sources of anomalies. To separate the regional from the Bouguer anomaly, the MAGMAP module in Oasis Montaj software was used. The derivation of regional and residual components of the gravity field for quantitative analysis through spectral analysis is usually done by wavelength filtering or band-pass filtering of the power spectrum of the data, and is accomplished through the association of a specific range of wavelengths with different source depths. Wavelength filtering is based on the generally valid assumption that there is some correlation between source bodies from specific depths and a finite range of wavelengths (Spector and Grant, 1970). Indirectly invoked by the Fourier analysis is the fact that the number of cells in the x and y directions of the grid must conform to some power of 2, though this ideal condition is rarely met. This mismatch is commonly overcome through statistical extension of the time series by applying the Fast Fourier Transformation (FFT) (Hearst and Morris, 2001).

Conventionally, the representative cut-off frequencies are selected on the basis of the form of the radially averaged power spectrum of the Bouguer gravity field (Spector and Grant, 1970). The linear segment having the steepest slope in the radially averaged power spectrum usually identifies the regional signal (Spector and Grant, 1970).

Most models are logical and give a lot of information about the subsurface, but because of the non-unicity of solutions, the model that best fits the real subsurface can only be confirmed by seismic surveys followed by drilling. 2D forward modelling was carried out using Grav2dc software in order to present a conceptual structural model of the Mamfe basin. Grav2dc is a software developed by J. R. C. Cooper (1998) that uses the Talwani's algorithim to model gravity data. The 2D models were done in Grav2dc v2.06 software by drawing bodies that generate calculated anomaly curves that fits the observed anomaly curves. The raw models of the subsurface of the basin along the profiles were imported into ArcGIS 10.2 to give them a geological appearance based on the geology of the area and the density chart from Sharma, 1997.

3. Results and Interpretation

The Bouguer anomaly map (**Figure 2)** shows anomaly values from 55 to 155mGal. There are small gravity lows in the NE that trend generally NE-SW. In the SW portion of the map small gravity highs trend generally NNE-SSW. Apart from these, there exists a major positive anomaly that trends almost N-S and gradually fades to a gravity low from West to East. This gradual shift of intensity from the West to the East of the map can be interpreted as the progressive thinning of the basement from East to West which is mainly composed of granites and gneisses. The basement is also isostatically compensated in the West by the asthenosphere which is composed of dense mafic minerals (Ndougsa-Mbarga *et al.*, 2007). The Bouguer map shows that the area is also superimposed by smaller anomalies between (95 and 125 mGal), indicating the presence of thick sediments in the study area. Variations of high and low Bouguer anomalies observed around Owom, Mbinda and Bakumba which have Bouguer anomaly from 100-140 mGal could be associated to a succession of horsts and grabens which are a result of the tectonic activities linked to the formation of the Basin and to the rifting and intrusion of mafic material in the crust. The NE portion of the map around Leme and Etuko, has a fairly continuous blue anomaly which corresponds to some peaks on the Adamawa plateau that are crater-like in shape.

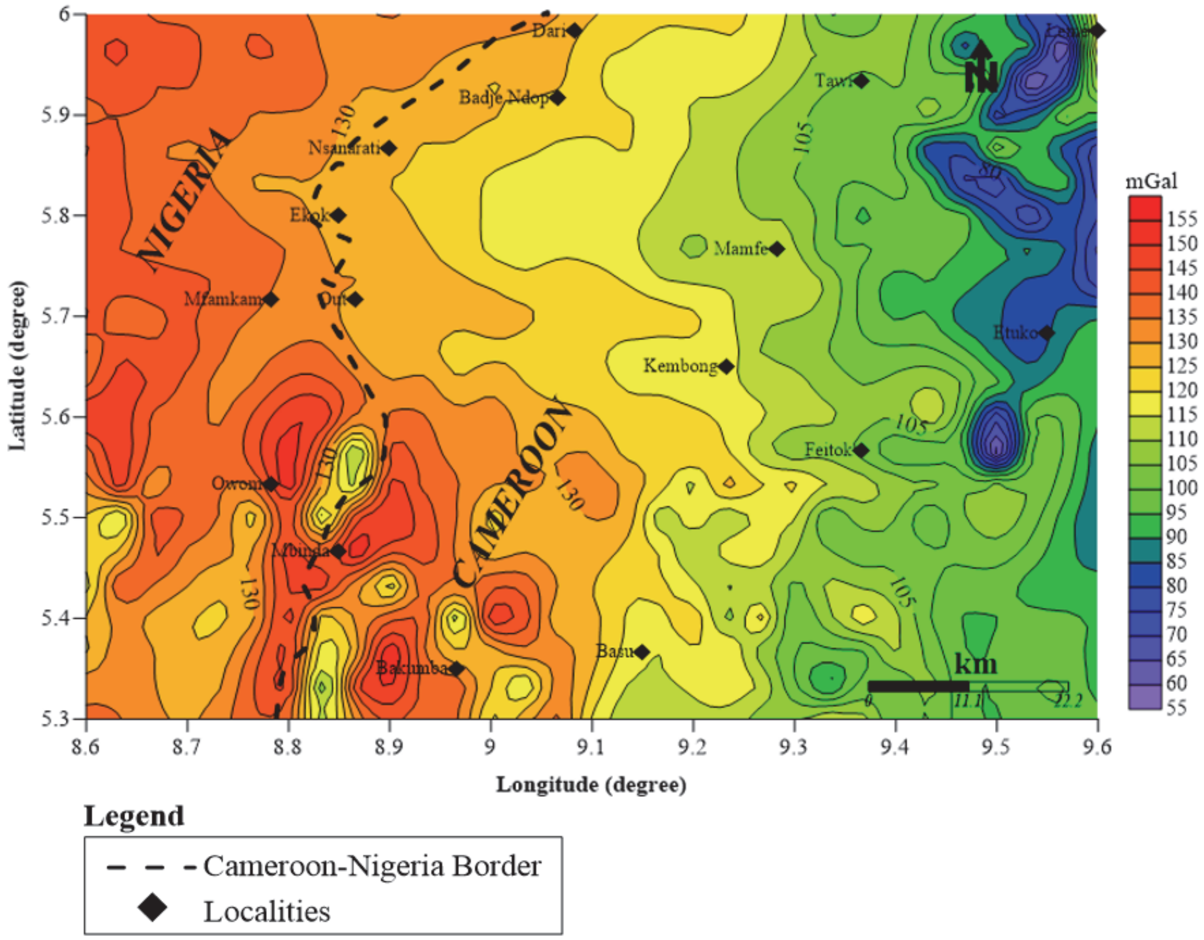

Figure 2. Bouguer anomaly map of the Mamfe basin

The power spectrum of the gravity data (**Figure 3**) was produced by applying a FFT in Oasis Montaj. The power spectrum was interactively filtered through the band-pass filter; there by removing the band of signals a wave number between 5.62 and 269.8 m^{-1}. This band corresponds to the steepest part of the power spectrum and hence to the deep-seated bodies in the area. Therefore, the signals at the left on the filter are only those from the relatively shallower bodies and the contour map that they produce (lower preview in **Figure 3**) is not very different from the residual anomaly map obtained in Fourpot. The implication is that the chosen regional conforms to the relationship between the basement and the Asthenosphere in the area (Kamguia *et al.*, 2005). On the filtered data that was contoured (**Figure 5**) in Surfer 11.0, three profiles were then drawn and the data along the profiles used to model the basin in Grav2dc v2.06.

The regional gravity anomaly map obtained (**Figure 4**) reproduces most of the already described large-scale features observed in the Bouguer anomaly map. It shows a general E-W gravity gradient. The isogal lines have an approximately N-S orientation, and define two N-S elliptical anomalies in the East and in the West. They also show undulations which elbow into the space between the elliptical anomalies. The two elliptical anomalies in the western part of this regional anomaly corresponds to the two bulges of the crust in responds to the isostatic compensation of the asthenosphere (Ndougsa-Mbarga *et al.*, 2007). Because the western part of the study area has a thin crust that is compensated underneath by the dense asthenosphere, the eastern side normally assumes the negative anomalies in response to relative lowering and less dense thicker crust.

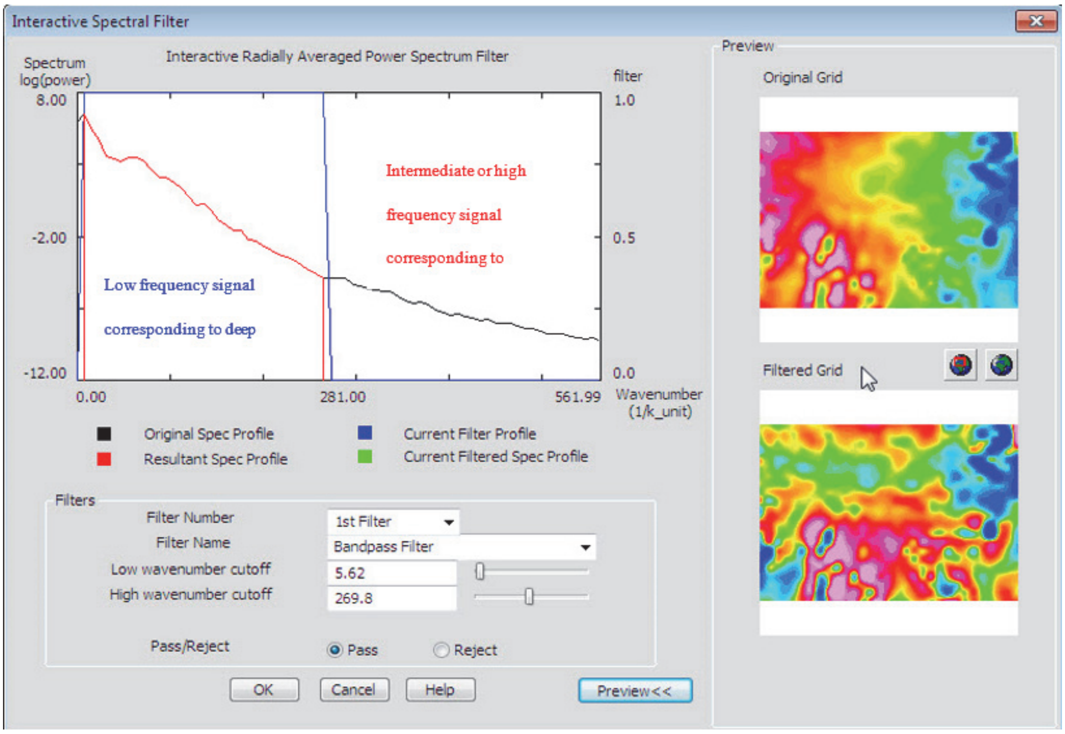

Figure 3. Result of band-pass filtering in Oasis Montaj

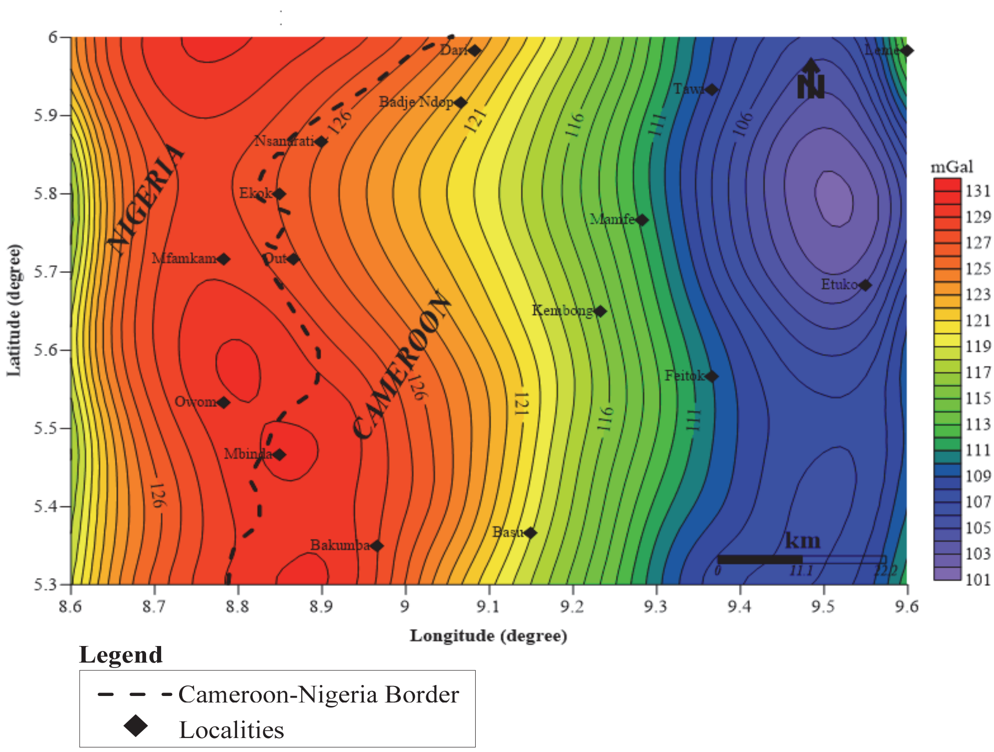

Figure 4. Regional anomaly map of the Mamfe basin

The residual anomaly was obtained by subtracting the regional anomaly from the Bouguer anomaly. **Figure 5** shows the residual anomaly produced by contouring its data in Surfer 11.0. The residual anomalies in the contour range from -15 mGal and 5 mGal correlate well with the geology in **Figure 1**. The gravity highs correspond to areas where the basement or volcanic rocks have been mapped (Ndougsa-Mbarga *et al.*, 2007). In this residual anomaly map (**Figure 5**), the 0 mGal isoline bounds the zones in the study area that are covered by sedimentary material i.e. corresponds to the basin-metamorphic rock contact. This can be confirmed by the presence of sedimentary rocks around the localities of Mamfe, Feitok, Bakumba, Tawi and Basu. The relative gravity high the gravity low at Bakumba and those at Mbinda and Owom are associated with igneous and metamorphic rock on the geologic map. The high gravity anomaly on the western side of the map corresponds to the Abakiliki Fold Belt in Nigeria that separates the Mamfe basin from the Anambra basin. The blue (very low negative) anomalies in the east of Mamfe town corresponds to the craters of extinct volcanoes of the Adamawa plateau on the C.V.L. All these anomalies indicate that the Mamfe basin has a complex structure, and is probably made up of sub basins separated by structural highs as seen left of Kembong and around Bakumba and Mbinda.

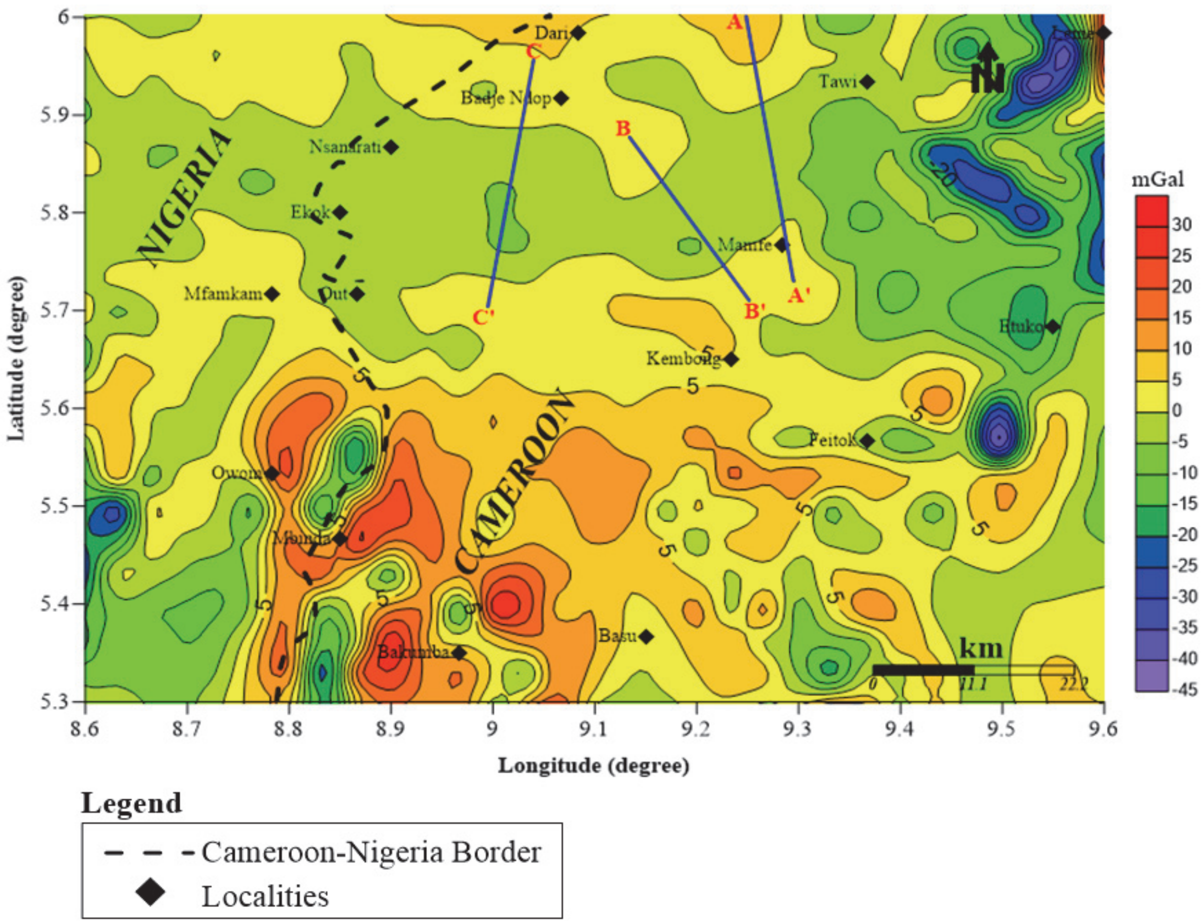

Figure 5. Residual anomaly map with cutoff wave-numbers between 5.62 and 269.8 m^{-1}; showing the profiles along which the Basin was modeled

The geological models obtained after forward modelling are presented in **Figures 6-8.** The distances are measured in kilometers; the densities are in g/cm^3 and the anomalies in mGal.

Profile A-A'

Profile A-A' has a NNW-SSE orientation, is 28 km long and passes through Mamfe town. The model along the profile shows that the part of the Basin beneath it has a V-shape and a maximum depth of about 5km. The Bouguer anomaly values range from about -1.41 to 7.07 mGal and the lowest value corresponds to the deepest portion of the Basin located at about 15.3km along the profile. The sides of the basin are quite regular and gentle. Density contrasts and correlations with geology led to the conclusion that the sediments in part of the Basin are possibly lying on granites in the NNW side of the profile and on Basalts which are intrusions on the SSE side.

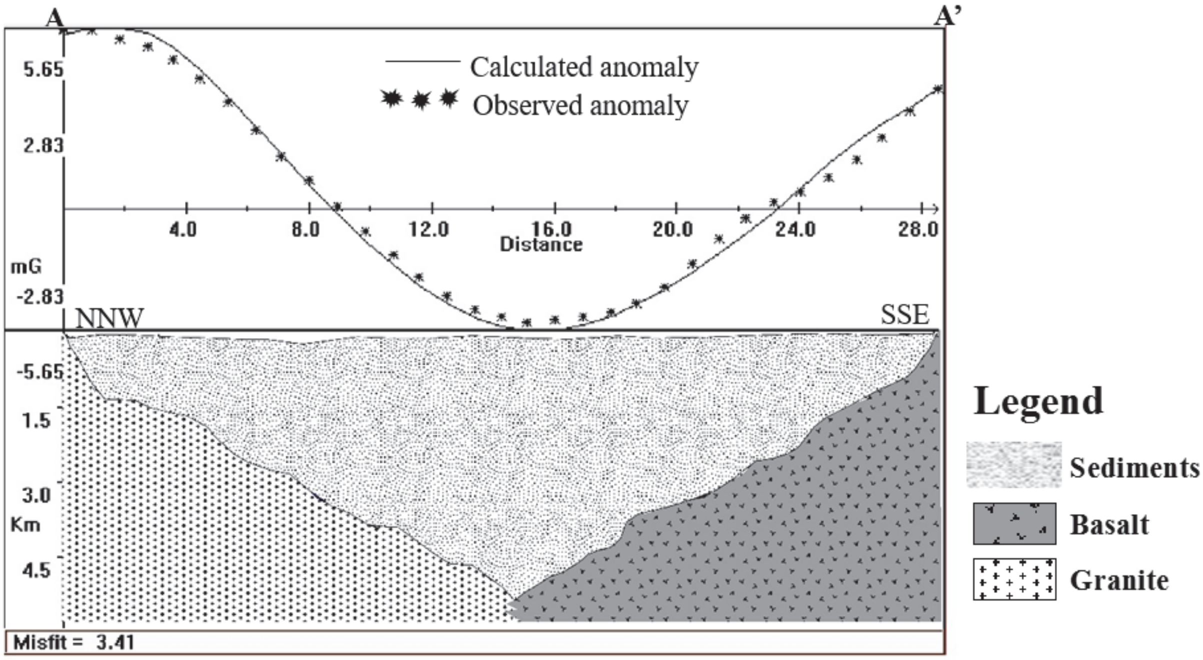

Figure 6. Model along profile **A-A'**

Profile B-B'

Profile B-B' has a NW-SE orientation and is 20 km long. The model along the profile shows that the Basin has a roughly V-shape and two maximum depths: one of about 3km at 5km along the profile and another of about 6km at 14km along the profile. The Bouguer anomaly values range from about -4.41 to 2.82 mGal and the lowest value corresponds to the deepest portion of the Basin. The sides of the Basin along this profile are very irregular. The left side is relatively gentle and arches at about 9km from the NW end along the profile, while the right side is very steep and is embayed at its top. The depth of the Basin rapidly changes from maximum to less than 1km and then spreads out. The rock densities (**Table 1**) and correlations with geology suggest that the sediments in the Basin are possibly lying on gneisses in the NW side of the profile and on Basalt on the SE side, which is the same intrusion as the one in Model A-A'.

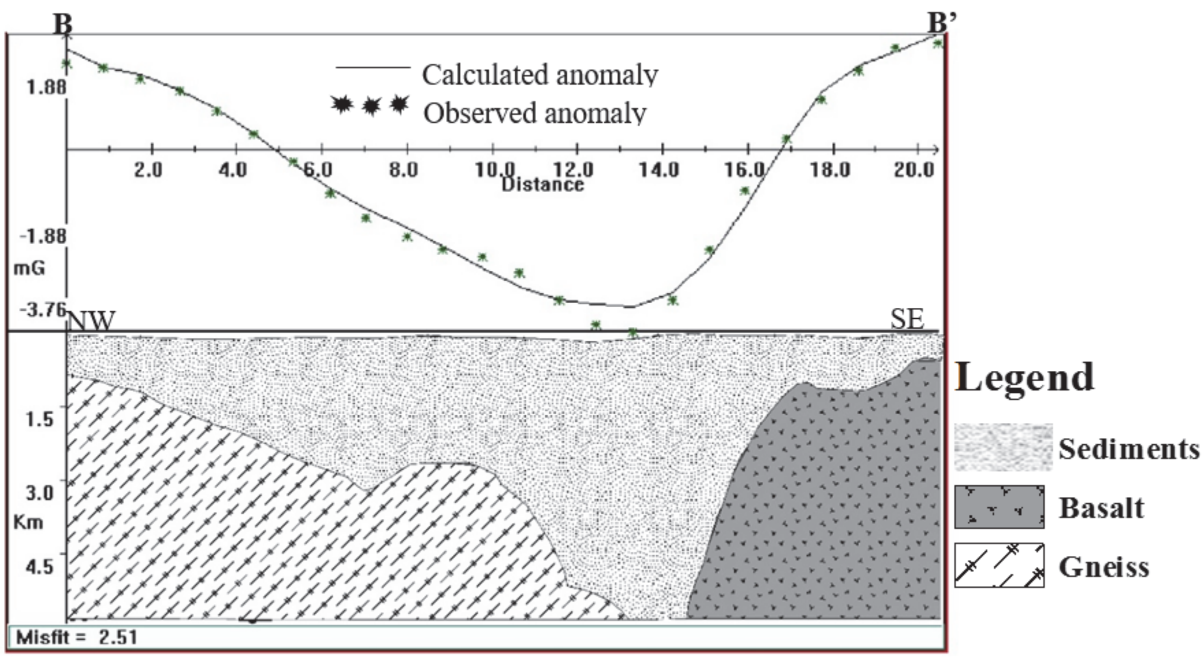

Figure 7. Model along profile **B-B'**

Table 1. Model rock densities. The density range is from density chart of Sharma (1997)

Model along profile	**Rock types present**	**Density range from density chart (g/cm^3)**	**Density from model (g/cm^3)**
A-A'	Granite	2.52 -2.81	2.78
	Basalt	2.7 -3.3	2.73
	Sediments (Sandstone)	2.35 -2.65	2.61
B-B'	Gneisses	2.6 -2.9	2.72
	Basalt	2.7 -3.3	2.739
	Sediments (sandstone)	2.35 -2.65	2.608
C-C'	Gneisses	2.6 -2.9	2.738
	Sediments (sandstone)	2.35 -2.65	2.605

Profile C-C'

Figure 8 shows the model along profile C-C', whose NNE end isn't very far from Bdje Ndop (**Figure 5)**. This profile has a NNE-SSW orientation and is 26 km long. Its model shows that this part of the Basin has a more or less W-shape and two maximum depths: one of about 4.7km at 13km along the profile and the other of about 5.3km at 20km along the profile. A horst located at about 16km along the profile separates the two depths, giving the impression of two sub-basins along this profile. The Bouguer anomaly values range from about -4.80 to 4.05mGal and the lowest value corresponds to the deepest portion of the Basin. The sides of the Basin along the NNE side of the profile is gentle while that on the SSW side is very steep. This steep side can be considered a fault since the sides of the horst are also steep, making the sub-basin to be seen as grabens. The depth of the Basin rapidly changes from maximum to less that 1km and then spreads out.

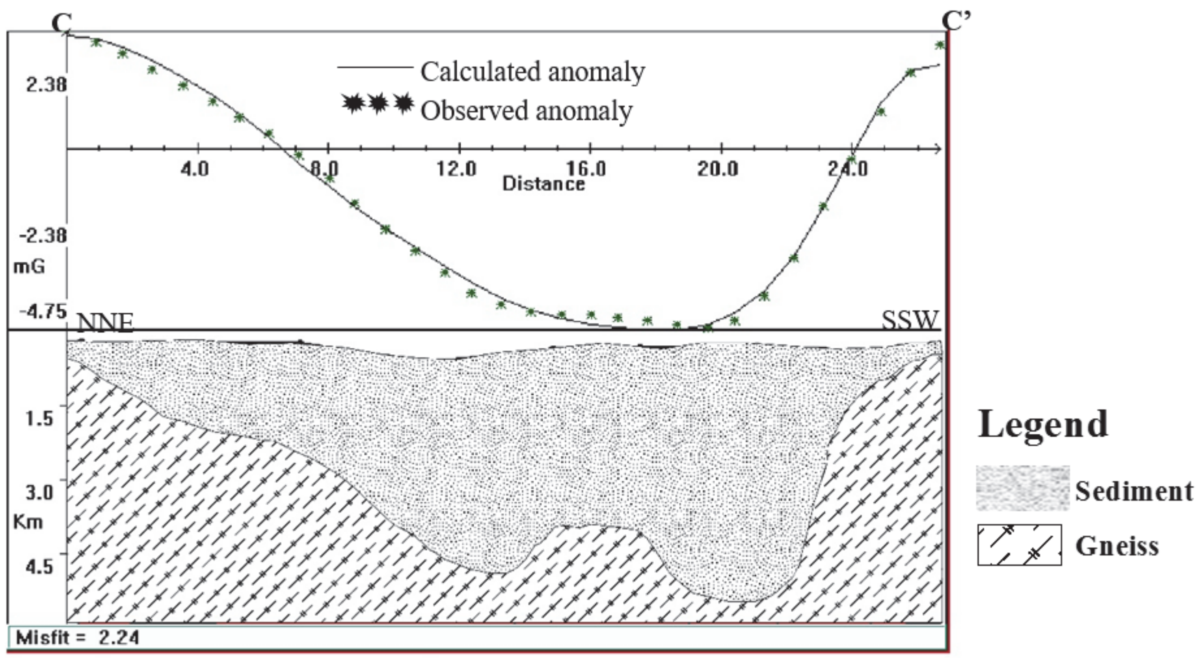

Figure 8. Model along profile **C-C'**

4. Discussion

The Bouguer anomaly map obtained from satellite-based EGM2008 gravity data (**Figure 2)** shows isogal lines with a general N-S orientation. The small anomalies around Leme and Etuku in the NE and those around Mbinda. Owum and Bakumba in the SE are absent in the Bouguer anomaly map obtained from ground data in Ndougsa-Mbarga *et al*. (2007). Their presence in the Bouguer map of this study is certainly due to the uniform coverage of the data.

The regional anomaly map obtained from this study (**Figure 4)** generally shows isogal lines trending almost N-S, though we can identify some general undulations throughout**.** We also observe closed-up high anomalies in the West and closed-up very low anomalies in the East. This slight difference is again due to the higher resolution and uniform coverage of the Basin by the EGM2008 data.

There is a W-E fading from gravity high to gravity low in the regional anomaly map from this study. This same trend has been seen in the regional anomaly map obtained from ground data in Ndougsa-Mbarga *et al.* (2007). The fading corresponds to a W-E deepening of the Crust-Asthenosphere contact which implies a basement that deepens from west to the east as deduced from the audiomagnetotellurics studies of Nguimbous-Kouoh *et al*. (2012) which concluded that the basin deepens from west to east.

From the 0 mGal isogal line that encompasses the towns of Mamfe, Feitok and Tawi in the residual anomaly map from this work (**Figure 5),** the anomalies progressively become positive to the northern, western and southern directions. These positive anomalies around the Basin in the north and south corresponds to the metamorphic rocks of the Bamenda highlands and those of the Oban highlands respectively. This is in accordance to the interpretations of the residual anomaly map obtained from ground data in Ndougsa-Mbarga *et al*. (2007). The progressive change of the anomalies from positive to negative toward the Basin means the basement deepens basinward. Ndougsa-Mbarga *et al*. (2007) from ground data gravimetric studies and Nguimbous-Kouoh *et al*. (2012) from audiomagnetotellurics studies, made a similar affirmations of the Mamfe basin.

In the SE portion of the residual anomaly map in **Figure 5,** all the anomalies were expected to be positive since the geologic map shows the occurrence of gneisses. Instead, positive anomalies spotted by negative anomalies are present. This can also be linked to the fact that the EGM2008 gravity data due to better coverage contains signals from bodies that were not sampled during the production of the geologic map. These negative anomalies can be associated to depressions which in context with the tectonic activities that formed the Mamfe basin can be considered grabens. Obi *et al*. (2013) also described horst and grabens from aeromagnetic studies of the Nigerian side of the Mamfe basin.

From the residual (**Figure 5)** the surface extensions of the Basin in terms of average length from the Cameroon-Nigeria border and average width are respectively 77.6 km and 29.2 km. these dimensions are similar to those obtained by Le Fur (1965), Dumort (1968), and Eben (1984) who stipulated that the Mamfe basin was about 80 km long by 20-40km wide. Using the dimensions of the Basin, it is clear that the residual from this study rightly defines the Basin.

The bodies in the models have densities that fall in the range of densities of rocks in the geologic map that are under the profiles. In the model along profile A-A' we have granite on the NNW (A) end and basalt on the SSE (A') end. These granites are thought to have mingled with Precambrian basement gneisses during the Pan-African orogeny that opened zones of weaknesses in the gneisses and let some felsic magma in. The opening of the Benue Trough in the Cretaceous reactivated some E-W faults (Eyong *et al.,* 2013) and hence opened the Basin into which sediments started accumulating.

The SSW end of the model along profile A-A' shows basalt, which is an intrusion that could be associated to the volcanic activities of the Cameroon Volcanic Line (CVL) which passes SE of the basin. Since the basalts came with the CVL they are younger than the basement granites. The basalt is also seen in the geologic and residual maps around the town of Mamfe, hence approving this model.

In the model along profile C-C' passing around Badge Ndop, the sediments are sitting on the Precambrian basement gneisses that opened from the reactivation of the zones of weakness left in the crust from the Pan-African orogeny. Because the gneissic basement opened, surface processes like erosion by rivers and transgression of the South Atlantic Ocean filled this space with sediments.

All the models show on their left sides to have a gentle sloping basement and hence will help us conclude that the northern side of the Basin has a basement-sediment contact that deepens basinward. This is in line with a conclusion made from studies of ground data by Ndougsa-Mbarga *et al.* (2007). The Mamfe basin has its greatest average sediment thickness (5 km) along the E-W axis and approximately at the center of the Basin.

4. Conclusion

The Mamfe basin in the Manyu Division of Cameroon according to geology, organic geochemistry and indigenous reports, could be a good petroleum prospect and as such is of high economic and scientific interest. But the quality of the ground gravity data available to guide a detailed gravimetric exploration of the basin is poor in terms of spatial coverage and as such by using the high resolution satellite-based EGM2008 gravity data this problem has been resolved to a great extent. Spectral analysis of this gravity data produced a map on which profiles were drawn and used to make geological models of the basin. The information obtained from the map from spectral analysis and the models are:

- The Mamfe basin has an average length of 77.6km by an average width of 29.2km.
- It has a maximum sediment pile thickness of 6.5km as shown in **Figure 7** and an average depth of 5km along its central E-W axis.
- The basin has a general V-shape with the northern basement-sediment contact being gentler than the southern one.
- Sub-basins exist within the main basin, and even around it. Two of them are seen around Mbinda (and Bakumba) and Kembong.

The EGM2008 can be used reliably for geophysical and geodetic exploration due to its precise and uniform coverage over the Earth. It can also replace the ground data in both research and development since it reveals all the structures already shown by the ground data and even more.

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