IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 11, Issue 1 Ser. II (Jan. – Feb. 2023), 19-31
www.iosrjournals.org

Estimation of Basin Model and Magnetic Source Boundaries in Brass Area and Environs from Aeromagnetic Data

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Abstract:
Brass Area and environs, Niger Delta Nigeria were investigated with the aim of delineating the structures and sediment thickness favourable for hydrocarbon formation. The study area is bounded by longitudes 6˚00΄00˝E and 6˚30΄00˝E and latitudes 4˚00΄00˝ and 4˚30΄00˝N with area of about $3{,}025\ km^2$. *Aeromagnetic data covering the area was processed and enhanced using polynomial fitting and source parameter imaging techniques. The results suggest that the sediment thickness within the area ranges from <2.2 km to >9.6 km and the depth to the magnetic structures predominantly ranges from <0.7 km to >2.6 km. The offshore part of thearea generally has basement depths greater than 6.5 km. The results also suggest that the faults and fractures within the area predominantly have NE-SW trend. High lineament density delineated suggests high deformation of the basement and sediments arising from much impact of tectonic activities in the area. This suggests that the area predominantly has structural traps with potentials for hydrocarbon accumulation and structural conduit for hydrocarbon migration. The sediment thickness and structural endowment of the area prompted the classification of Brass, Spiffs Town, Elepa and environs as zones with very high potentials for hydrocarbon generation, accumulation and migration.*
Keyword*: Lineament Density, Magnetic Basement, Sediment Thickness,Structural Traps, Subsurface Deformation,*

Date of Submission: 28-02-2023 Date of Acceptance: 11-03-2023

I. INTRODUCTION

Sedimentary basins are formed over hundreds of millions of years by the combined action of deposition of eroded material and precipitation of chemicals and organic debris within water environment. Organic matter and different materials deposited at different times, over thousands of years, produced regular 'layering' of strata in the basin and volcanic action, or the movement of the earth's crust, caused faults to appear in the basin (Enwenode 2014). A sedimentary basin is an area of the earth's crust that is underlain by a thick sequence of sedimentary rocks. Hydrocarbons commonly occur in sedimentary basins and are absent from intervening areas of igneous and metamorphic rocks (RichardandStephen 2015).

Most Sedimentary basins in the world are known for petroleum generation and accumulation. Sedimentary basins, in which the great majority of oil reservoirs are found, are formed by the deposition of sediments carried down by rivers and settled under bodies of water (Ryen *et al.* 2017). Sands are deposited near shore, silts further out, and clays in the deep lake or ocean water. Nabil (2018) defined petroleum source rock as the fine-grained sediment with sufficient amount of organic matter, which can generate and release enough hydrocarbons to form a commercial accumulation of oil or gas. Source rocks are commonly shales and lime mudstones, which contain significant amount of organic matter. A petroleum source rock is defined as any rock that has the capability to generate and expel enough hydrocarbons to form an accumulation of oil or gas (Nabil 2018).

The maturation of hydrocarbon source rocks depends on a range of factors, including the primary rock type and its original content of organic matter (kerogens); the history of sedimentation and burial (depth); the local geothermal gradient (temperature); and duration of sedimentation (time) (Filippo *et al.* 1999). Studies have shown that the hydrocarbon source evaluation is primarily based on the organic matter quantity (organic richness), quality (kerogen type), and the thermal maturation generation capability and of the organic matter disseminated in the rock (Nabil 2018).

The thermal maturation primarily is a function of depth and Nabil (2018) has shown that the source rock reaches the required levels of thermal maturity to onset of the oil window at a depth of about 2315 m. The burial (depth, subsidence) and thermal histories are necessary in order to predict the timing of hydrocarbon generation and expulsion.

The study area is Brass and environs,Bayelsa State, Nigeria. The area is located in the eastern Niger Delta Region, Nigeria. There has been growing interest in identifying new petroleum prospects within Bayelsa State, Nigeria as expressed when the State hosted the National Council on Hydrocarbon Summit in 2020 (Ibe 2021). This growing interest in new hydrocarbon prospects within this part of the Niger Delta Basinis a major driving force of this research.One of the fundamental features that affects the formation of hydrocarbon in a basin is the thickness of the sediment (Wright *et al*. 1985, Anyanwu and Mamah 2013, Ibe and Uche 2021a). The research focused on the delineation of the basin's depth models and magnetic boundaries; hence, highlighting the sediment thickness and structures favourable for hydrocarbon formation, accumulation and migration in the area. This research therefore identified new suitable prospect areas for localized studies.

II. THE STUDY AREA

The study area is within Bayelsa State, Nigeria (Fig. 1), located in the eastern Niger Delta Region. The place is bounded by longitudes 6˚00´00″E and 6˚30´00″E and latitudes 4˚00´00″ N and 4˚30´00″N; it covers an area of about 3,025 km^2. It shares boundary with Sangakubu in the north, Kambora in the northwest, Sengana in the southwest, Botokiri in the east and Atlantic Ocean in the south. It falls within the humid tropical region with two distinct seasons, the rainy season, from March to October, and dry season, from November to March. The annual rainfall in the Niger Delta is high and varies from 500 mm per annum at the coasts, to about 300 mm at the northern part of the place (Etu-Efeotor andOdigi 1983). Evapo-ranspiration is 1000 mm, leaving an effective rainfall of 2000 mm (Nwankwoala and Ngah 2014). The study area has a riverine and estuarine setting, with bodies of water within the place preventing the development of significant road infrastructure.

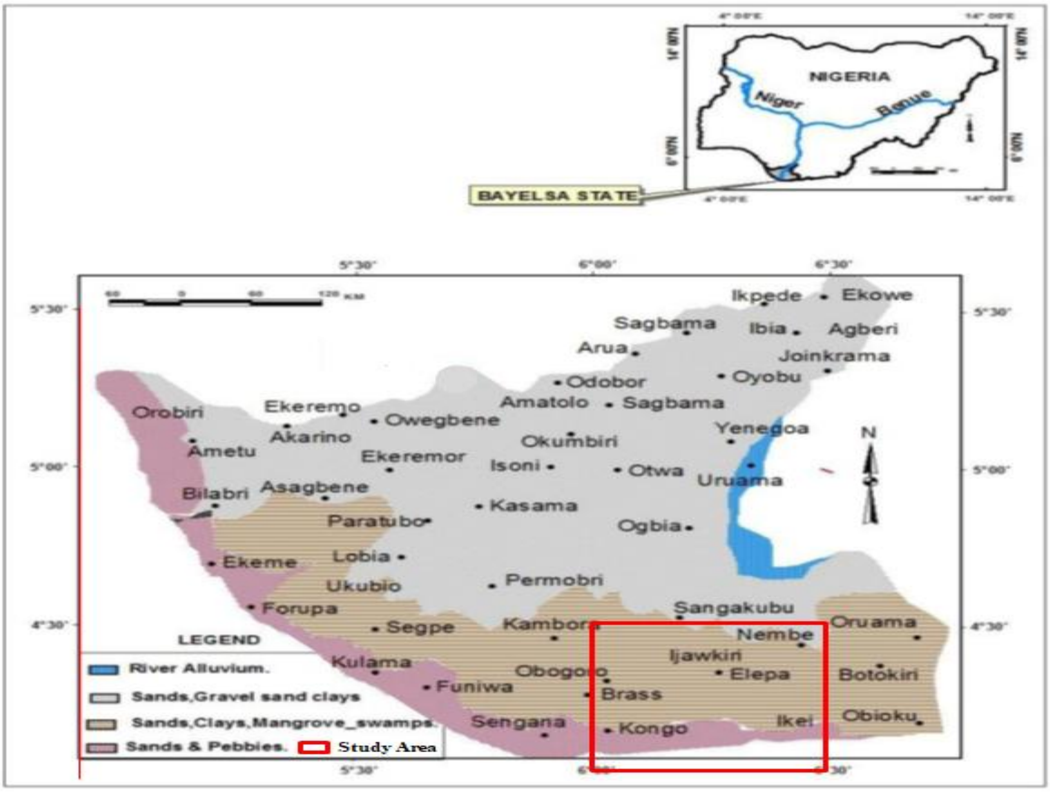

Figure 1: Geology Map of Bayelsa Showing the Boundary of the Study Area

Many researches on the geology of the Niger Delta Basin have been carried out by Reyment (1965), Short andStauble (1967), Murat (1972), Nwajide (2013) and the exploration activities of oil and gas companies. The Quaternary geologic units of the Niger Delta Area are shown in Table 1. The depositional pattern which accompanied the accumulation of sediments during the formation of the delta, gave rise to structural traps (growth faults and roll-over anticlines) in the Agbada Formation (Nwankwoala andNgah 2014). Virtually all the hydrocarbon accumulations in the Niger Delta occur in the sands and sandstones of the Agbada Formation where they are trapped by the rollover anticlines related to the growth fault development (Ekweozor and Daukoru 1994).

Table 1. Quaternary Deposits of the Niger Delta (Adopted from Ibe andAnaekwe 2018).

Geologic Unit	Lithology	Age
Alluvium	Gravel, Sand, clay, silt	
Freshwater Backswamp, meander belt	Sand, clay, some silt, gravel	
Saltwater Mangrove Swamp and backswamp	Medium-fine sands, clay and some silt	Quaternary
Active/abandoned beach ridges	Sand, clay, and some silt	
Sombreiro-warri deltaic plain	Sand, clay, and some silt	
Benin Formation (Coastal Plain Sand)	Coastal to medium sand; subordinate silt and clay lenses	Miocene-Recent
Agbada Formation	Mixture of sand, clay and silt	Eocene-Recent
Akata Formation	Clay	Paleocene

Digital Elevation Map of the Study Area

The digital elevation model of the study area (Fig. 2) reflects the topographic distribution of the area. The study area is characterized by relatively low elevation; its elevation ranges from -48.2 m to 22.6 m. The negative elevation of <0 m indicates areas below sea level (offshore environment). The highest elevation with range 7.3 m to 22.6 m (onshore environment) is observed at Akassa, Funumu, Egeregere, Brass, Diema, Otokolopiri, Agbalamabugokiri, Abolikiri, Botokiri, Ewelesuo and Aganatoku. The lowest elevation range within the onshore environment (>0m to <7.3 m) is observed at Clarendon Island, Elepa, Fantuo, Tomkiri, Odioma, Mbokokiri, Monikiri and Opourubou. About 50% of the study area is covered by places below sea level and located within the entire southern part of the study area.

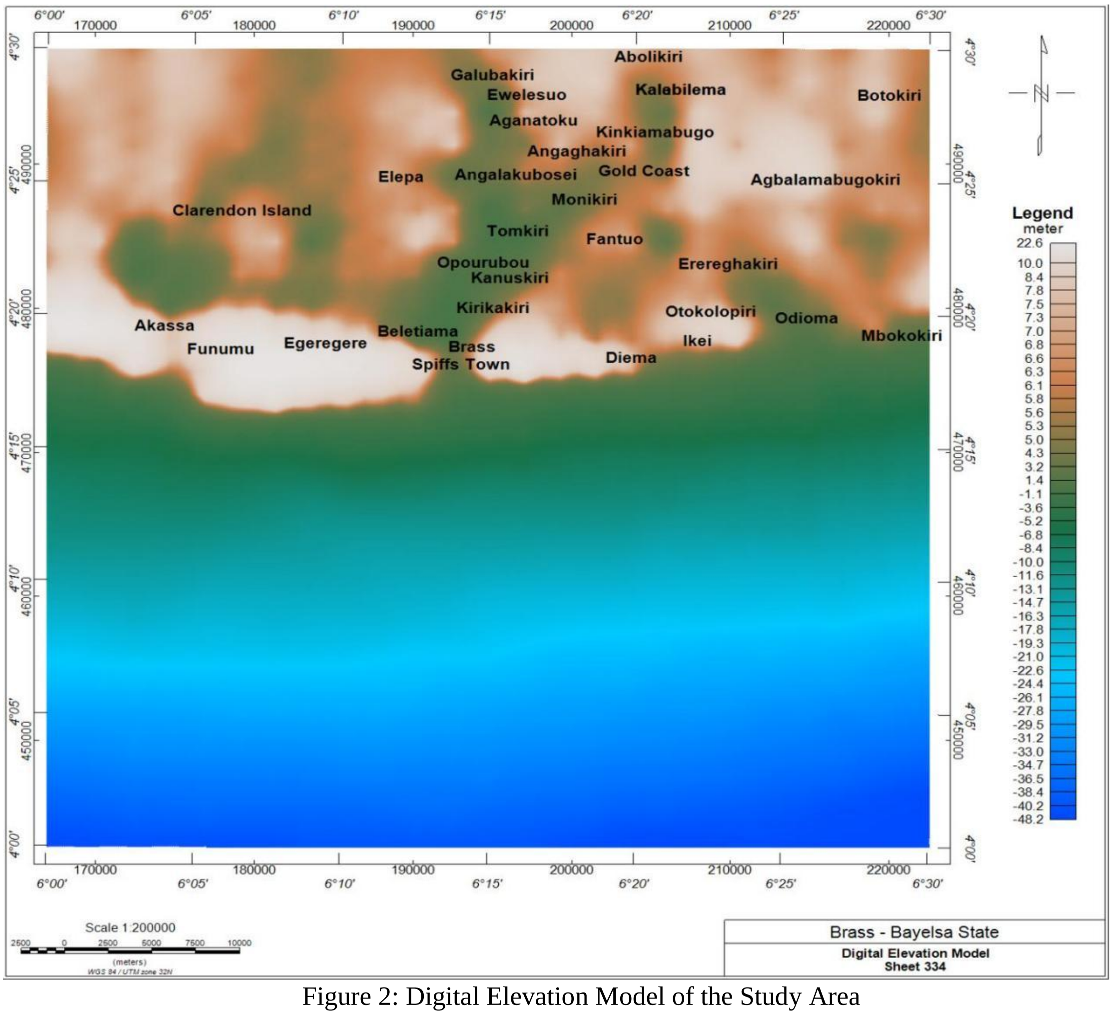

Figure 2: Digital Elevation Model of the Study Area

III. MATERIALS, METHOD, DATA PROCESSING AND ENHANCEMENT

The aeromagnetic data used for this study were acquired along NW – SE flight lines at 500 m line spacing, 20 km tie lines spacing and 80 m terrain clearance. The datawere acquired by Fugro Airborne Survey and the Nigerian Geological Survey Agency.The study area is covered by airborne magnetic Index Sheet 334-Brass.The acquired total magnetic field intensity data were processed, and the data grid was developed by employing a minimum curvature algorithm at 100 m grid cell size.Data enhancement techniques involving First Vertical Derivative and Source Parameter Imaging were applied to the magnetic data.

Vertical derivatives were used to delineate the anomalous sources' boundaries. They can be used to delineate the contacts of lithologies of contrasting physical properties such as densities and susceptibilities. These contacts are reflected by inflation point in the potential field which, while difficult to locate on the anomaly map, are accurately traced by the zero contours of the vertical derivative map. First vertical derivative is physically equivalent to measuring the magnetic field simultaneously at two points vertically above each other, subtracting the data and dividing the result by the vertical spatial separation of the measurement points (Nabighian *et al.* 2005). In accordance with Hendra andDarharta (2017), the First Vertical Derivative (FVD) was used to delineate the anomalous sources' boundaries while limiting the high frequency amplification.

The basic equation for first vertical derivative is:

$$\frac{\partial \mathrm{T}}{\partial \mathrm{z}} = -\left(\frac{\partial \mathrm{T}}{\partial \mathrm{x}} + \frac{\partial \mathrm{T}}{\partial \mathrm{y}}\right) \quad (1)$$

Where T = magnetic anomaly field.

More detailed account of first vertical derivative technique in estimating anomalous sources' boundaries has been discussed by Ibe andUche (2018a).

Source Parameter Imaging (SPI) is a profile or grid-based method for estimating magnetic source depths, and for some source geometries, the dip and susceptibility contrast. The method utilizes the relationship between source depth and the local wave number (k) of the observed field, which can be calculated for any point within a grid of data via horizontal and vertical gradients (Thurston*et al*. 1999). The SPI method estimates the depth from the local wave number of the analytical signal. More detailed account of source parameter imaging technique in estimating magnetic source depths has been discussed by Uche andIbe (2018), Ibe and Uche (2018b).

IV. RESULTS AND DISCUSSION

Figure 3 is the total magnetic field intensity map of the study area. The map shows different magnetic anomalies corresponding to different lithologies and geological structures in the study area. The amplitude of a magnetic anomaly depends on magnetization which subsequently corresponds to the magnetic susceptibility of the rocks at specific geographical locations. This total field intensity map contains both regional and residual magnetic fields. The study area is characterized by thick sedimentary rocks with area generally non-magnetic; therefore, the main sources of magnetic anomalies in the area are dependent on the basement settings, geologic structures and their magnetic properties.

The total magnetic field intensity of the area has a range of <32506.2 nT to >32672.5 nT. The offshore environment is generally characterized by low magnetic field intensity with range <32506.2 nT to 32618.3 nT (indicated by yellow to green colours in Fig. 3). Intermediate magnetic intensity within the study area has a range of >32618.3 nT to 32649.2 nT; it is observed within Clarendon Island, Akassa, Egeregere, Brass, Kirikakiri, Kanuskiri, Diema, Ikei, Otokolopiri, Odioma, Erereghakiri and Mbokokiri. High magnetic field intensity, with range greater than 32649.2 nT, is observed around Tomkiri, Fantuo, Monikiri, Agbalamabugokiri, Gold Coast, Angalakubosei, Elepa, Aganatoku, Kalabilema, Abolikiri and Botokiri. The high magnetic field intensity most likely hasoriginated from highly ferruginized Older sediments (sandstone) within the study area; while the low magnetic field intensity region is most likely occupied by Younger sediments that are generally none magnetized.

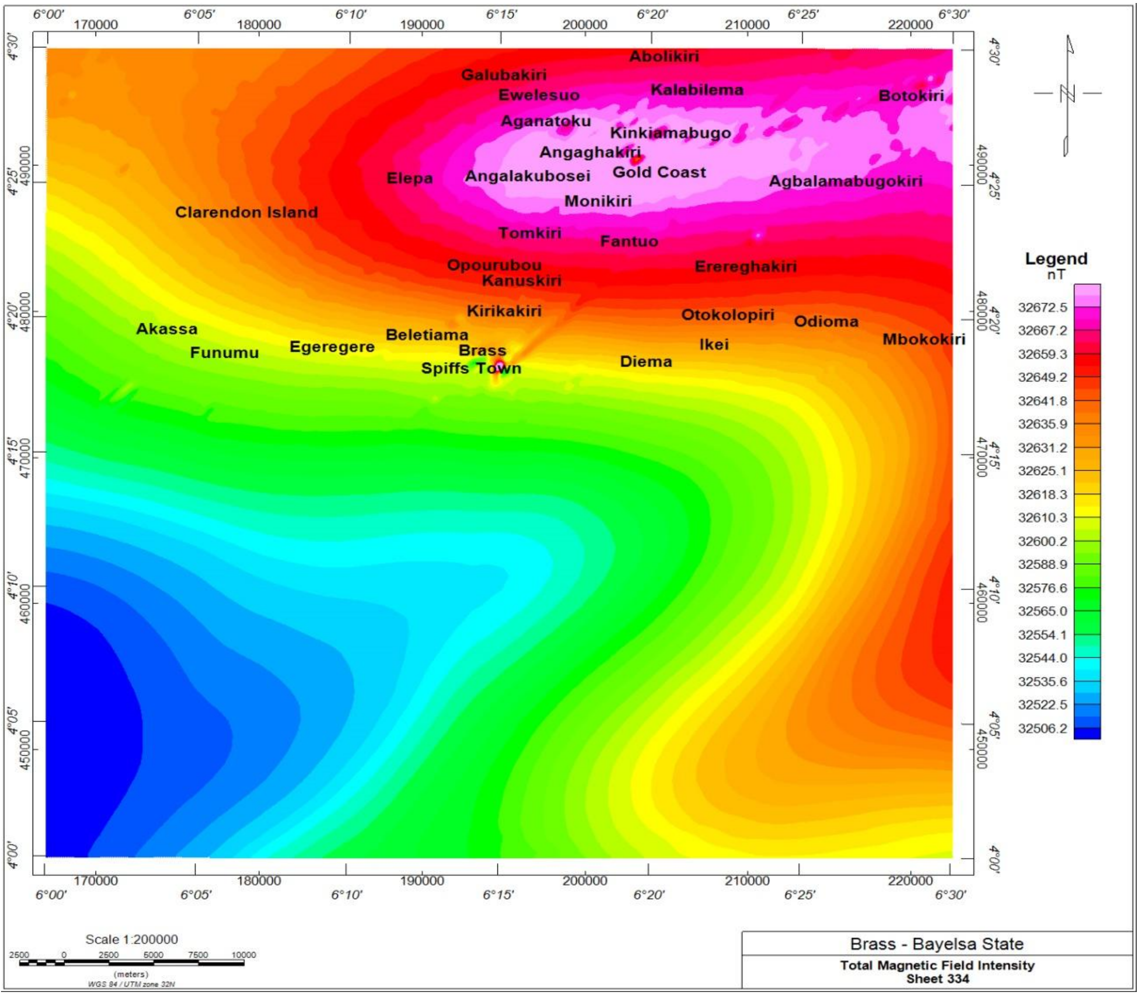

Figure 3: Total Magnetic Intensity (TMI) Map of the Study Area.

Very strong regional fields which mask the weak near surface residual fields were removed using polynomial fitting of the first order to the total magnetic field intensity data. Figure 4 shows the residual magnetic field intensity map of the study area. The residual magnetic field intensityof the area has a range of <-19.6 nT to >13.5 nT. The study area is characterized by both long wavelength magnetic anomalies (low frequency) and short wavelength magnetic anomalies (high frequency). The long wavelength magnetic anomaliestrend majorly in the NE-SW direction. The offshore environment is characterized by NE-SW trending long wavelength anomalies with both high and low magnetic amplitudes. This is generally indicative of deep magnetic basement or thick sedimentary cover.

High frequency bodies are predominant within Brass, Spiffs Town, Kirikakiri, Opourubou, Fantuo, Tomkiri, Monikiri, Angalakubosei, Elepa, Aganatoku, Galubakiri, Gold Coast, Kinkiamabugo and Akassa Areas. All the high frequency anomalies within theseareas are characterized by high magnetic amplitudes. They are most likely due to structural displacements(faults/fractures) within the basement rocks and structures within the sedimentary basin. A major regional dyke-like structure(F1)wasdelineated within Spiffs Town, Brass and extends to Fantuo (Fig. 4); it has a length of about 15.2 Km and looks to have originated from Spiffs Town – Brass Area. High frequency bodies with low magnetic amplitude anomalies are observed within Botokiri, Agbalamabugokiri and Clarendon Island. Generally, the high frequency bodies trend in the NE-SW direction. This result is in agreement with the works of Burke *et al.* (1972), Obaje (2009), Nwajide (2013) which stated that the major trend of structures within the Niger Delta Basin is NE-SW.

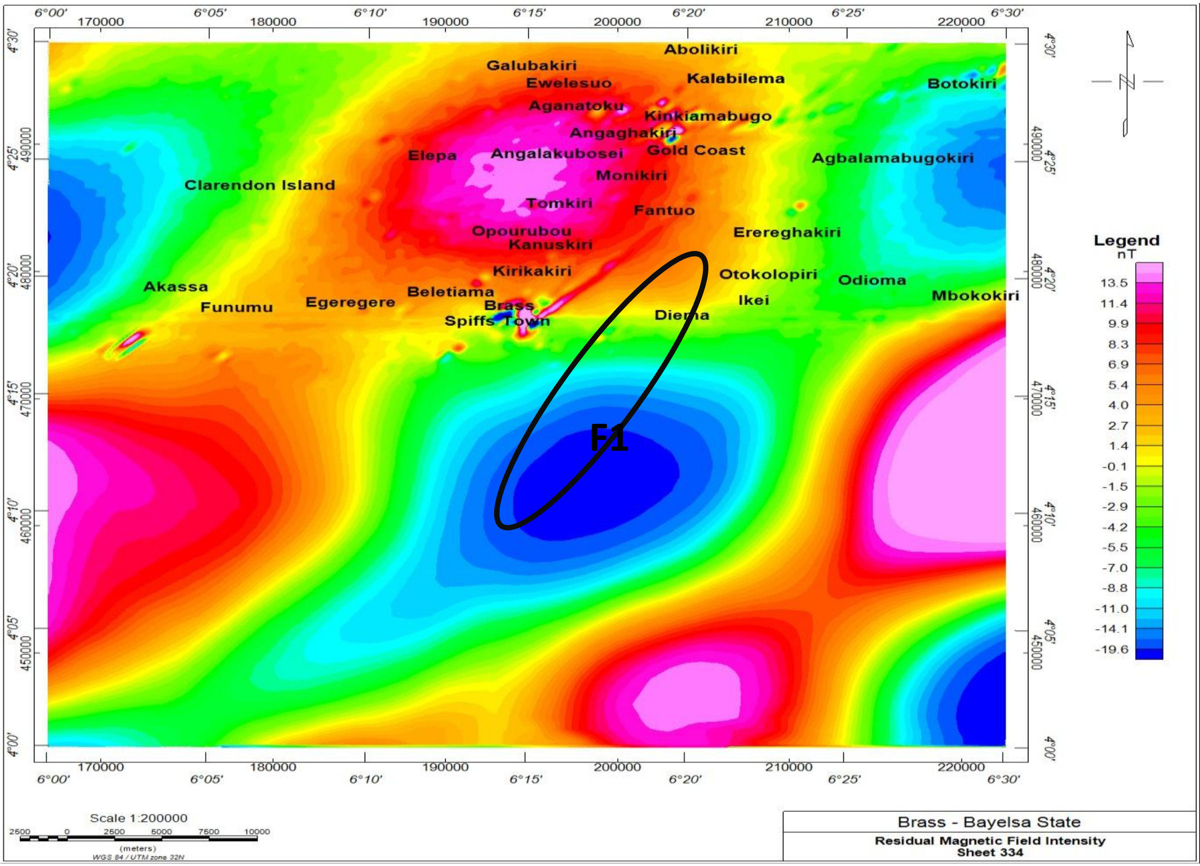

Figure 4: Residual Magnetic Intensity Map of the Study Area

First Vertical Derivative of the Magnetic Field Data of the Study Area

The first vertical derivative delineates high frequency features more clearly especially in areas where they are shadowed by large amplitude, low frequency anomalies (Gupta andRamani 1982, Opara *et al.* 2014). The first vertical derivative map of the study area (Fig. 5) enhanced better the structures within the area. The high frequency anomalies were also better characterized and differentiated with its application. There are two major types of high frequency bodies within the study area. The first are high frequency bodies that resulted in the displacement of magnetic anomalies and these are observed within Elepa, Angalakubosei, Opourubou, Kanuskiri, Egeregere, Funumu, Clarendon Island, Galubakiri Otokolopiri, Ikei, Diema and Agbalamabugokiri Areas. These most likely resulted to structural displacement (faults) of sediments in the areas. The second type of high frequency bodies observed are bipolar structures; they are observed within Spiffs Town, Brass, Akassa, Odioma, Mbokokiri, Botokiri, Kinkiamabugo, Angaghakiri, Gold Coast, Aganatoku, Beletiama and Kirikakiri Areas. They are most likelydue to magnetized rocks (Plutonic) occurring at the subsurface within the areas.

The regional fault (F1) is also better enhanced in the first vertical derivative map; it is most likely faulted around Gold Coast. The high frequency bodies at Botokiri, Kinkiamabugo, Angaghakiri, Gold Coast, Aganatoku, Odioma and Mbokokiri, which were not visible in the residual magnetic intensity map, are better enhanced in the first vertical derivative map (Fig. 5).

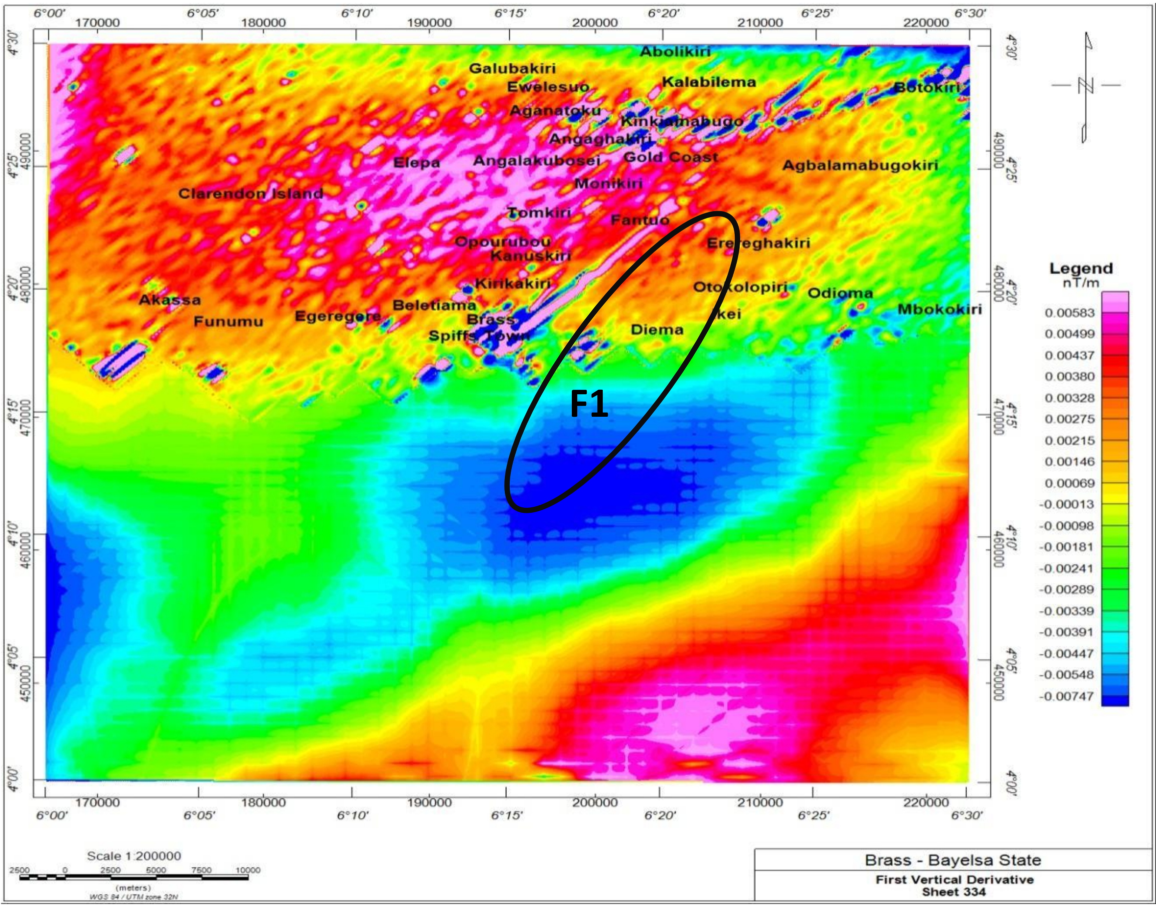

Figure 5: First Vertical Derivative Map of the Study Area

Magnetic Lineament within the Study Area

Lineament extraction was done using Centre for Exploration Targeting (CET) Grid Analysis which is a set of algorithms that enhances, locates and vectorizes discontinuity structures within the potential field data (Siddorn andHalls 2002). Lineaments are linear features which express the underlying geological structures in an area.These lineaments result from faults, joints, folds, contacts and other geological structures found in igneous, sedimentary and metamorphic rocks (Megwaraand Udensi 2014, Ibe andUche 2018b). The lineaments (faults/fractures) in the study area (Fig. 6) are marked in black ticks while dykes and sills are marked in arched curves. The magnetic lineaments, reveal a dominate NE-SW trending structures with minor NW-SE and NS trending structures. The F1 structure is the most extensive structure within the study area.

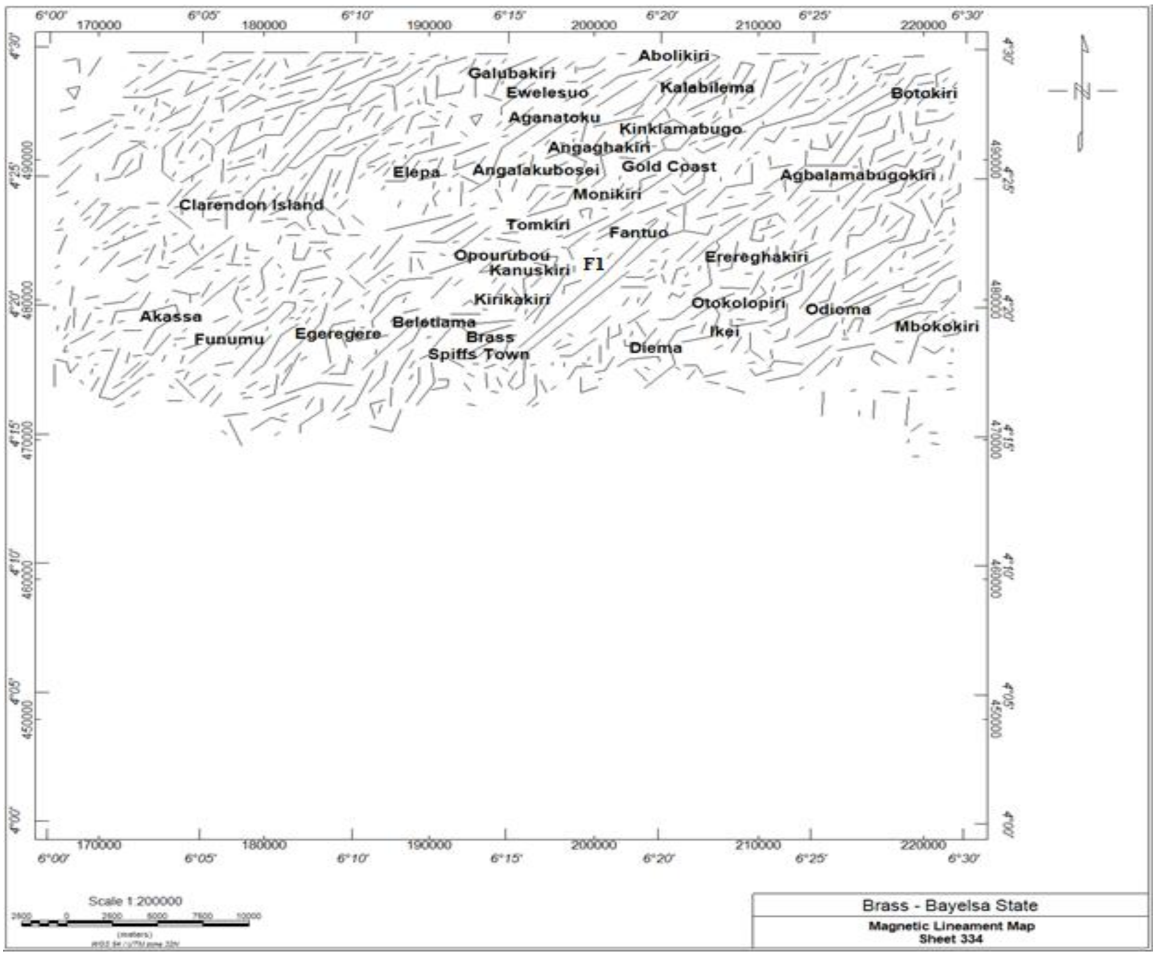

Figure 6: Lineament Map of the Study Area

Lineament Density within the Study Area

The impact of tectonic activities on the basement and sediments was evaluated by computing the lineament density. This generally reveals the intensity at which the subsurface rock was deformed by evaluating the number of structures occurring at a particular location. Geographical locations with high lineament density generally indicate high deformation while locations with less lineament density indicate low deformation (Chukwu *et al.* 2013, Ibe and Uche 2018a). This is also significant in identifying areas with high potential of having structural traps that could trap hydrocarbon. Figure 7 is the lineament density map of the study area.

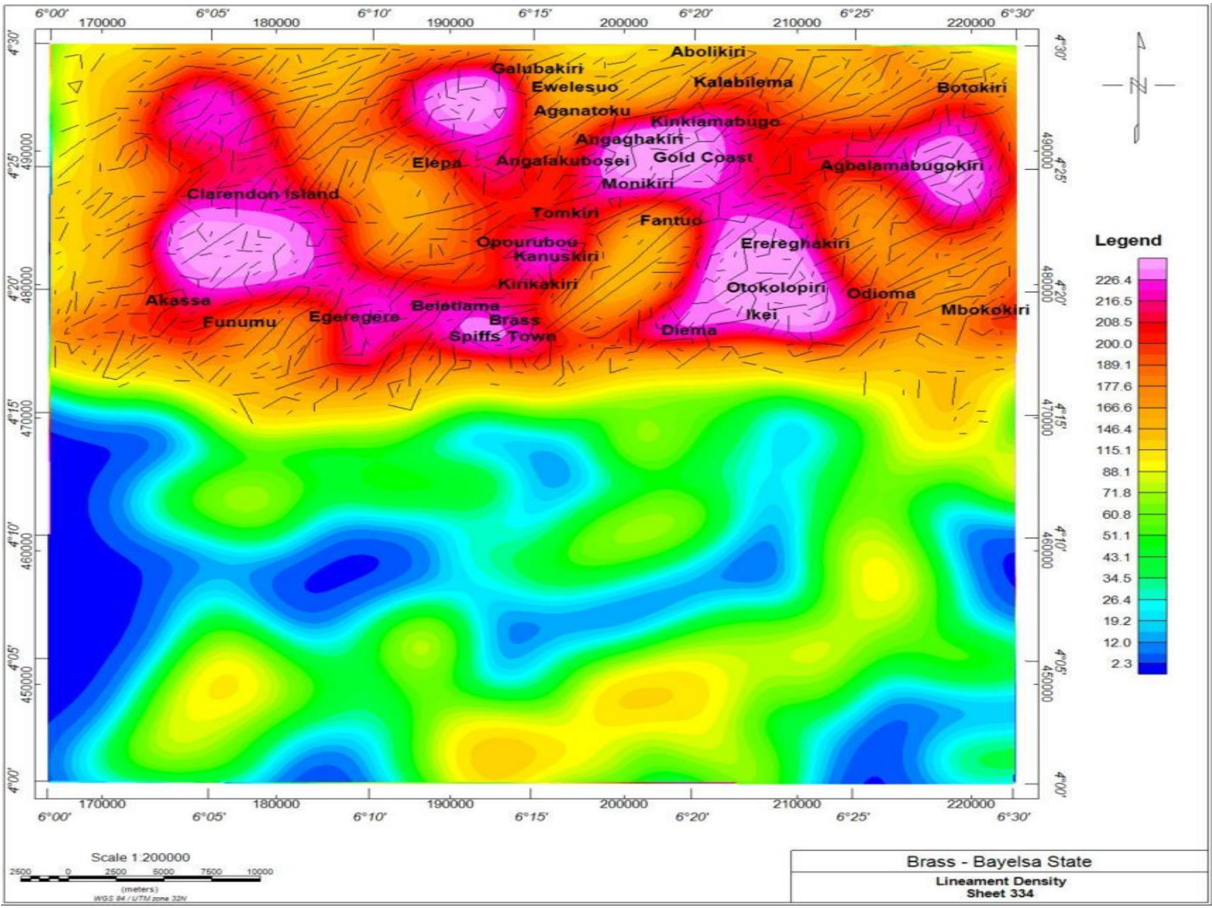

Figure 7:Lineament Density Map of the Study Area.

High structural deformation is observed around Brass, Spiffs Town, Ikei, Otokolopiri, Erereghakiri, Agbalamabugokiri, Gold Coast, Angaghakiri, Galubakiri, Clarendon Island and Akassa Areas. Moderate deformation is observed around Egeregere, Beletiama, Funumu, Mbokokiri, Tomkiri, Opourubou and Kanuskiri Areas. The offshore environment is generally characterized by low deformation intensity, except for the southeastern part of the study area.

Source Parameter Imaging of the Study Area

Source parameter imaging technique was used to estimate the depth to magnetic basement within the study area. Figure 8 is the source parameter imaging map of the study area. The depth to magneticbasement is synonymous with the thickness of the sediment and plays very important role in the hydrocarbon generation potential of a place (Ibe andUche 2021b, Ibe 2021).Wright *et al.* (1985) stated that the minimum thickness of the sediment required to achieve the threshold temperature of 115˚C for the commencement of oil formation from organic remains is 2300 m, when all other conditions for hydrocarbon accumulation are favourable.

The sediment thickness within the study area ranges from <2.2 Km to >9.6 Km. Brass, Spiffd Town, Beletiama and Kirikakiri Areas have average sediment thickness of 2.3 Km; Mbokokiri, Odioma, Ikei and Otokolokiri Areas have average sediment thickness of 5.9 Km and Diema has sediment thickness of about 6.2 km. The thickest sediment within the onshore environment wasdelineated within Clarendon Island, Funumu, Egeregere, Tomkiri, Elepa, Fantuo and Otokolopiri Areas with an average of 8.0 km. The thinnest sediment within the study area wasdelineated within Abolikiri, Galubakiri, Kalabilema, Kinkiamabugo and Agbalamabugokiri Areas with an average of <2.2 km. The offshore environment in the area predominantly has basement depth >6.5 km. The interpreted depths indicate that the study area predominantly has sediment thickness with potential for commencement of the formation of hydrocarbon and natural gas.

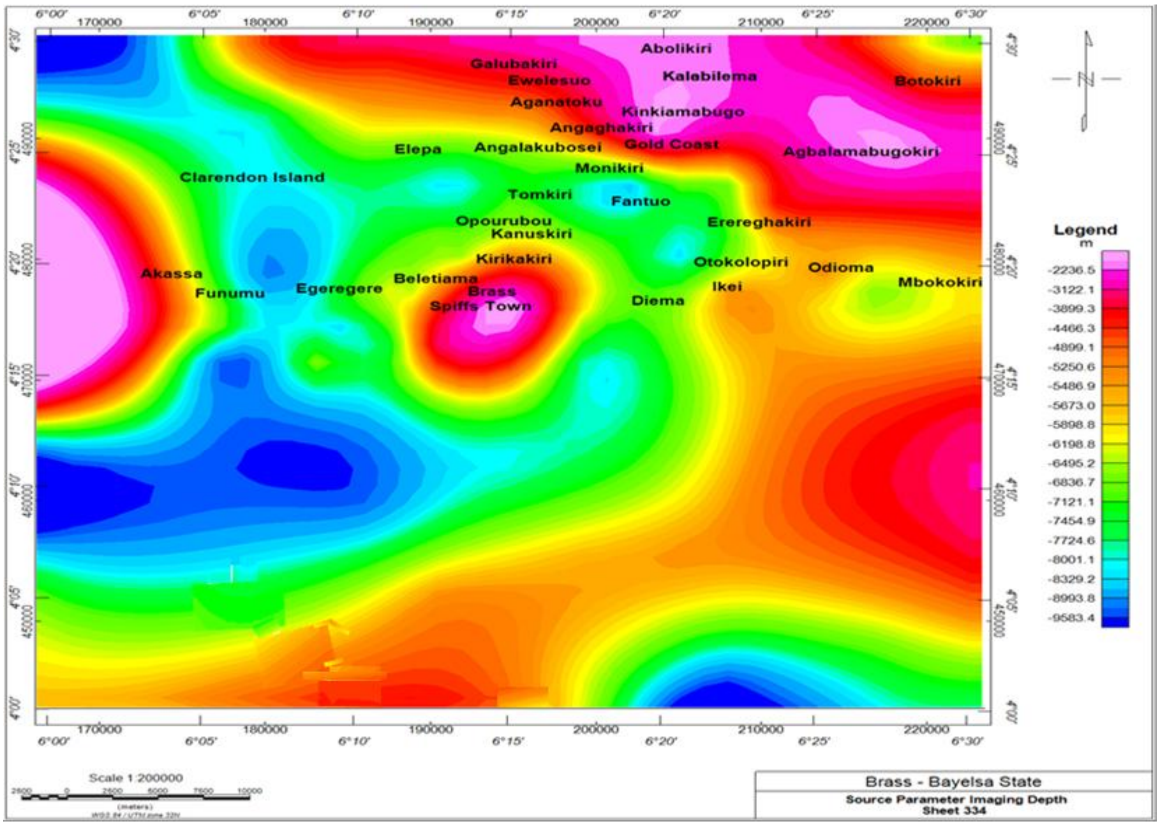

Figure 8: Source Parameter Imaging Map of the Study Area

Extended Euler Depth Solution of the Study Area

The Extended Euler algorithm used in this study is based on the work of Mushayandebvu *et al.* (2001). This approach calculatessolutions using both the conventional Euler equation (Reid *et al.* 1990) and the rotational constraint equation from extended Euler. Solving both equations jointly (Extended Euler) gives distance, depth, dip, and susceptibility, assuming there is no remnant magnetization (Ravat 1996, Golshadi *et al*. 2016). Extended Euler of aeromagnetic data used different models based on structural indices 0-3 (Structural Index 0 for contacts, Structural Index 1 for dykes and sills, Structural Index 2 for horizontal cylinders and pipes and Structural Index 3 for spheres). Considering the geology of the study area, in this studyStructural Index 1 was used. Figure 9 is the Extended Euler depth map of the study area.

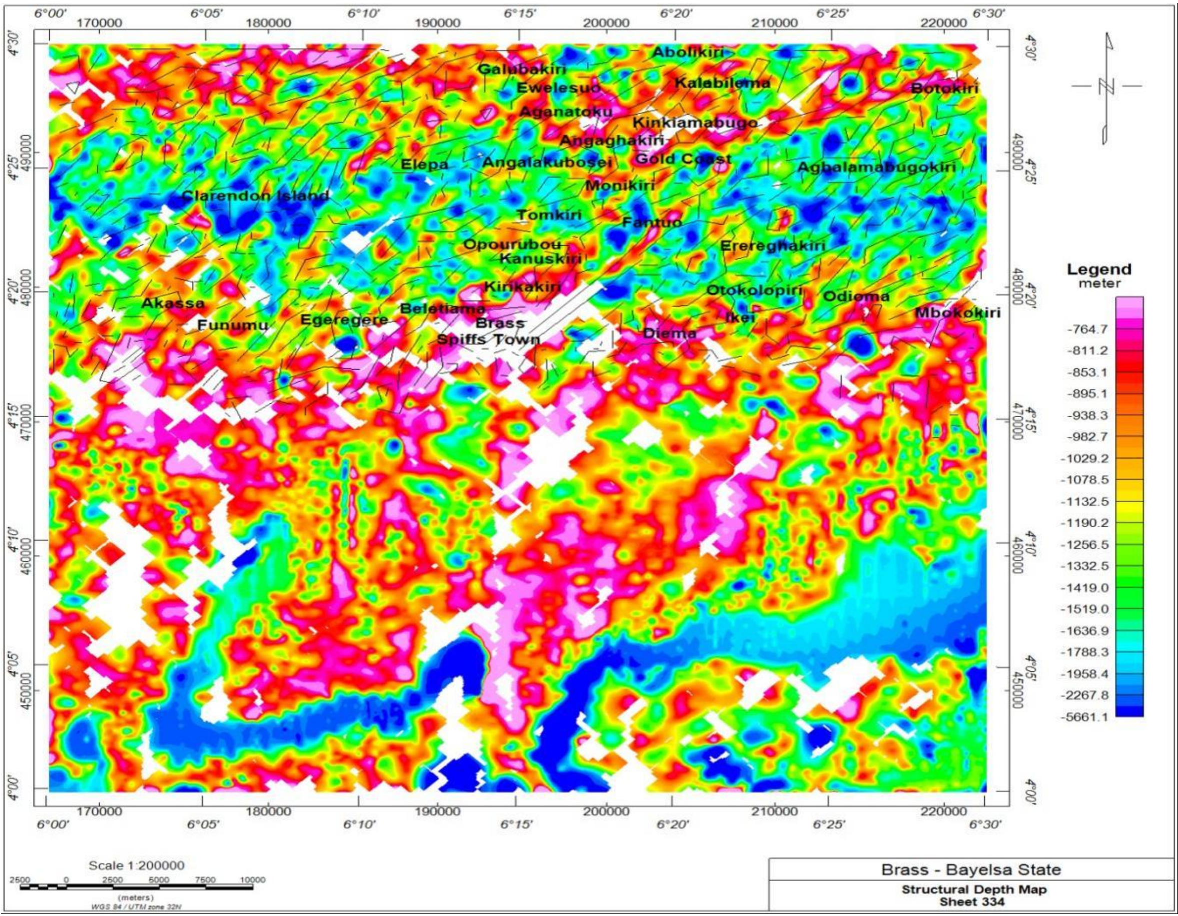

Figure9: Extended Euler Map of the Study Area

The Extended Euler depth of the study area revealed that the depth to the structures in the area predominantly ranges from <0.7 km to >2.6 km.The depth to the F1 structure ranges from about 0.7 km to 1.1 km. The onshore structures withinElepa, Angalakubosei, Opourubou, Kanuskiri, Egeregere, Funumu, Clarendon Island, Galubakiri Otokolopiri, Ikei, Diema and Agbalamabugokiri Areas have the highest depth with a range of 1.2 km to >2.6 km. The bipolar structures located within Spiffs Town, Brass, Akassa, Odioma, Mbokokiri, Botokiri, Kinkiamabugo, Angaghakiri, Gold Coast, Aganatoku, Beletiama and Kirikakiri Areas have depths less than 1.0 km. The deepest structures within the study area were delineated within the offshore environment.

V. CONCLUSION

The sediment thickness within Brass and environs, Niger Delta Nigeria was delineated and it ranges from <2.2 Km to >9.6 Km. The thickest sediment within the onshore environment of the area was delineated within Clarendon Island Area and its vicinity with an average of 8.0 km. The thinnest sediment within the area was delineated within Abolikiri Area and its vicinity with a value of <2.2 km. The offshore part of the study area generally has a basement depth greater than 6.5 km. The depth to the magnetic structures in the area predominantly ranges from <0.7 km to >2.6 km. The fault and fracture systems associated with high magnetic frequency and amplitude anomalies were delineated within the basement and sedimentary rock at Brass, Spiffs Town, Kirikakiri, Opourubou, Fantuo, Tomkiri, Monikiri, Angalakubosei, Elepa, Aganatoku, Galubakiri, Gold Coast, Kinkiamabugo and Akassa Areas. A major regional dyke-like structure was also delineated within Spiffs Town, Brass and extends to Fantuo; it has a length of about 15.2 Km and most likely originated from Spiffs Town – Brass Areas. These structures predominantly have NE-SW trend. This study revealed high lineament density within the study area which suggests high deformation of the basement and sediments arising from much impact of tectonic activities in the area. This suggests that the study area predominantly has structural traps with potentials for hydrocarbon accumulation and structural conduit for hydrocarbon migration.The sediment thickness and structural endowment of the study area prompted the classification of Brass, Spiffs Town, Kirikakiri, Opourubou, Fantuo, Tomkiri, Monikiri, Angalakubosei, Elepa, Aganatoku, Galubakiri, Gold Coast, Kinkiamabugo and Akassa Areas as zones with very high potential for hydrocarbon generation and migration. Hence, these places were recommended for detailed geophysical studies for hydrocarbon generation, accumulation and migration.

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Ibe Stephen O, et. al. "Estimation of Basin Model and Magnetic Source Boundaries in Brass Area and Environs from Aeromagnetic Data." *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 11(1), 2023, pp. 19-31.