# 2-DIMENTIONAL MODELS OF THE STRUCTURAL FEATURES WITHIN THE LOWER BENUE AND UPPER ANAMBRA BASINS NIGERIA, USING (2009) AEROMAGNETIC DATA

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## Abstract

*Analysis base on the CET shows that the basement rocks to the North and Southern edge of the study area intrude into the sedimentary formation. At the lower (middle-portion) of the study area (within Angba and Otukpo sheets) are structures that are Basaltic rocks that intrude into the basement. It is believed that these structures must have predated the depositional period of the sedimentary formation. Several fracture and fault lines are detected on the CET map, most prominent among is that which start from the Eastern end (latitude $7.45^0$ and longitude $8.30^0$) and ends at the Southern end (Latitude $7.00^0$ longitude $7.45^0$).cutting the South Western corner of the study area diagonally. Secondly is that which runs vertically and is parallel to the course of River Niger within this area, supporting the assertion that the River Niger is structurally controlled. The 2-dimentional models of the six profiles revealed sedimentary formations whose susceptibility values are zero (0). Maximum depth of about ten (10) kilometers was obtained within the Southern end of the study area, but a maximum thickness of sedimentation of about four (4) kilometers was observed on profile six within Nkporo formation. The basement susceptibility varies from 0.002 to 0.004 but in some places it is as high as 0.007.*

Keywords: Structural, 2-dimensional, Exploration Targeting, Total Magnetic Intensity

## Introduction

The Benue Trough is a linear rift system whose development was closely associated with the separation of Africa from South America and the opening of the South Atlantic Ocean. It is about 250 km wide in its southern portion, if we include the Anambra Basin, the Abakaliki Anticlinorium and the Afikpo Syncline (Benkhelil, 1989, Ladipo, 1988). Towards the northeast, the width of the trough varies between 80 and 150 km while its overall length is about 800 km. A succession of sediments increasing in thickness, from about 2.5 km in the northeast to over 7 km in the southwest was deposited in the trough in the Cretaceous (Reijers & Nwajide, 1998, 1997). These sediments consisting dominantly of mudrocks and sandstones with occurrences of carbonates and coal were in several places intruded by igneous rocks of felsic intermediate and mafic composition.

Geological studies have shown that the trough was subjected to several depositional cycles which resulted in the deposition of sedimentary rocks of varied compositions and ages (Benkhelil, 19895, Petters & Ekweozor, 1982, Reijers & Nwajide, 1997). Three of these depositional cycles were more pronounced than the rest. A lot of research has been carried out within the Benue and Anambra basins, the Benue Trough is generally known to contain numerous mafic and felsic intrusives, sub- basinal structures together with a bright prospect for hydrocarbon accumulation (Ugbor, 2007; Petters & Ekweozor, 1982). The aim of this present study is therefore, to carry out geophysical investigation in the study area with a view of obtaining information on depth of sediments in the area through their effects on the magnetic field. The availability of a very high resolution aeromagnetic data and more modern processing software will enable the research to reveal as much as possible the geologic and geophysical features of the area which will in turn reveal the structural setting within the area.

## Location of the Study Area

The study area covers the Lower Benue Trough, the Upper part of Anambra Basin and the basement complexes bounding it at the West and Northern edges. The area is bounded by Latitude $7.0^0$N to $8.5^0$N and Longitude $6.5^0$E to $8.5^0$E. The physiological features recognized in the area are the river Benue, river Anambra and river Okulu. Twelve aeromagnetic maps covered the study area and are numbered, 227, 228, 229, 230, 247, 248, 249, 250, 267, 268, 269 and 270. An area of 36,300 square kilometers that touches four states majorly, which are Nassarawa at the upper part, Kogi, Enugu and Benue States at the lower part (Figure 1 & 2).

## Geology of Lower Benue and Upper Anambra Basin

Sedimentation in the Lower Benue Trough commenced with the marine Albian *Asu River Group*, although some pyroclastics of Aptian – Early Albian ages have been sparingly reported (Petters, 1977). The Asu River Group in the Lower Benue Trough comprises the shales, limestones and sandstone lenses of the Abakaliki Formation in the Abakaliki area and the Mfamosing Limestone in the Calabar Flank (Ojoh, 1992). The marine Cenomanian – Turonian *Nkalagu Formation* (black shales, limestones

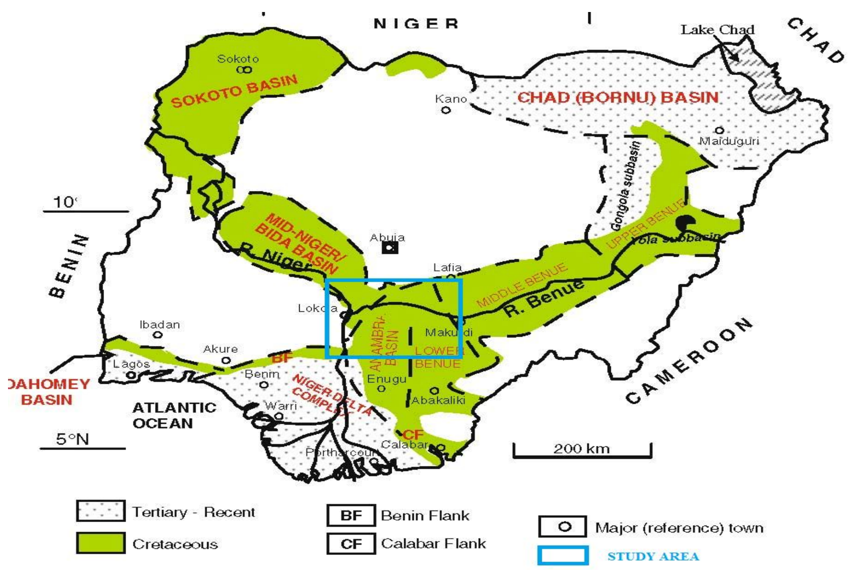
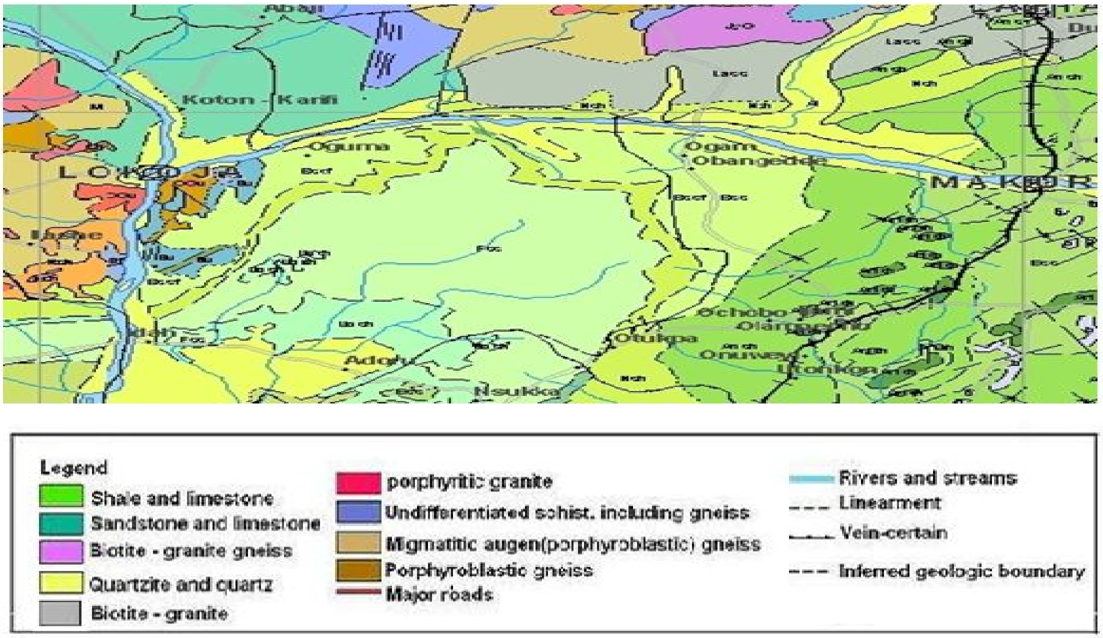



Figure 1: Cretaceous to Recent sediments representing the third phase of marine sedimentation in the Benue Trough (Akande & Erdtmann, 1998)




and siltsones) and the interfingering regressive sandstones of the *Agala* and Agbani Formations rest on the Asu River Group. Mid-Santonian deformation in the Benue Trough displaced the major depositional axis westward which led to the formation of the Anambra Basin. Post-deformational sedimentation that take place within south of the Lower Benue Trough generated the Anambra Basin. Sedimentation in the Anambra Basin thus commenced with the Campanian-Maastrichtian marine and paralic shales of the Enugu and Nkporo Formations overlain by the coal measures of the Mamu Formation. The fluviodeltaic sandstones of the Ajali and Owelli Formations lie on the Mamu Formation and constitute its lateral equivalents in most places. In the Paleocene, the marine shales of the Imo and Nsukka Formations were deposited, overlain by the tidal Nanka Sandstone of Eocene age. Down dip, towards the Niger Delta. Akata Formation of the Niger Delta Basin and Nsukka Formation of the Anambra Basin are Paleocene lithofacies equivalent. The Basin Formation and the Imo Shale mark the onset of another transgression in the Anambra during the aleocene. The shales contain significant amount of organic matter and may be potential source for the hydrocarbons in the northern part of the Niger Delta (Reijers & Nwajide, 1998). In the Anambra Basin, they are only locally expected to reach maturity levels for hydrocarbon expulsion.

The Enugu and the Nkporo Shales represent the brackish marsh and fossiliferous pro-delta facies of the Late Campanian-Early Maastrichtian depositional cycle (Ugbor, 2007). Deposition of the sediments of the Nkporo/Enugu Formations reflects a funnel-shaped shallow marine setting Figure: 2 Geology Map of the Study area, from Nigerian Geological Survey Agency, 2009. that graded into channeled low-energy marshes. The coal-bearing Mamu Formation and the Ajali Sandstone accumulated during this epoch of overall regression of the Nkporo cycle. The Mamu Formation occurs as a narrow strip trending north–south from the Calabar Flank, swinging west around the Ankpa plateau and terminating at Idah near the River Niger The best exposure of the Nkporo Shale is at the village of Leru (Lopauku).

The Ajali Sandstone marks the height of the regression at a time when the coastline was still concave. The converging littoral drift cells governed the sedimentation and are reflected in the tidal sand waves which are characteristic for the 72 km south of Enugu on the Enugu – Portharcourt express road, while that of Enugu Shale is at Enugu, near the Onitsha-Road flyover The Mamu Formation is best exposed at the Miliken Hills in Enugu, with well-preserved secions along the road to Onyeama mine at the left bank of River Ekulu (Offodile, 1980).

## Methods

The procedures employed in this research include:

(i) Production and interpretation of Total Magnetic Intensity (TMI) map of the study area using Oasis Montaj software.

(ii) Application of Centre for Exploration Targeting (CET) Grid Analysis Plug-In For Structural analysis

(iii) Modeling the identified structures within the study area

## Source of Aeromagnetic Data

The by Fugro Airborne Surveys, between 2003 and 2010 carried out the largest airborne geophysical survey ever undertaken in Nigeria. This data acquisition and compilation covers the entire Nigerian land mass, and have produced new data which is helping to position the country as an exciting destination for explorers. The recent data has a Tie-line spacing of 500 m, flight line spacing of 100m and flying altitude of 100 m. For the purpose of this research data covering the study area will be acquire from "The Nigerian Geological Survey Agency who is mandated to archive all geological and geophysical datasets for the entire country.

## Objectives

The Centre for Exploration Targeting (CET) Grid Analysis Plug-In For Structures CET is four stages of analysis, comprising of Standard deviation, Phase Symmetry, Amplitude Thresholding, and Skeleton to Vectors, (Won and Bevis 1987) which is aimed at structural analysis that results in:

(i) locating the contact between the basement and the sedimentary formation of the study area

(ii) locating the extent and position of the outcrops and intrusive bodieswithin the area

(iii) detecting fracture or any fault that may exist within the area

(iv) determining the thickness of the sedimentary rocks and the susceptibility of lithologies within the study area from 2-dmentional modeling of the Total Magnetic Intensity field.

## Theory

Probably the most significant of the computer modeling algorithms are:

(i) Computation of the magnetic field of a two-dimensional (infinite strike) body with an arbitrary polygonal shape (15). This method calculates the effect of the polygon by summing the magnetic effect of a series of horizontal sheets with sloping edges that correspond to the sides of the polygon. Modeling with the routine is commonly referred to as 2D modeling. (Won and Bevis, 1987), have produced a faster version of this routine that can handle situations where the magnetic body can partly above the point of observation and where the observation point can be inside the magnetic body (Cady, 1980).

These routine have been incorporated into various proprietary and commercially available packages of which the most advanced work interactively in windows-type environments. These packages allow the interpreter such option as definition of regionals, computation of residuals multi-source model and inclusion of remanence, demagnetization and anisotrophy. The algorithms used for each modeling exercise depend upon whether the anomalies being interpreted are sufficiently elongated for a two-dimensional or quasi two-dimensional approximation to be used or whether a three-dimensional model is required. The type of three-dimensional algorithm used depends on the form of the magnetic source and the detail required. Such routines have become basic interpretation tools; however, they can be time consuming to apply. They are suited to detailed analyses of single anomalies and cluster of anomalies and cannot be realistically applied to area depth determination problem.

For the data in this research, flight line ran north-south, and the interpretation of the data was done by drawing six profiles perpendicularly across the major structures identify within the study area, these six profiles were modeled using 2D modeling software a module in oasis montaj version 7.3

## Results

### The Total Magnetic Intensity (Tmi) Map of the Study Area

The total magnetic intensity map of the study area bounded by $7.0^0$- $8.5^0$N latitude and $6.50^0$ - $8.0^0$E longitude is produced into maps, (Figure: 4), which is in both color aggregate. The magnetic intensity of the area ranges from -2415.97 minimum to 1264.72 maximum with an average value of 33.87 nT. The total number of data points is 3,667,251. The area is marked by both high and low magnetic signatures, which could be attributed to several factors such as (1) variation in depth (2) difference in magnetic susceptibility (3) difference in lithology (4) degree of strike. The northern edge and the western edge of the study area are inhibited by short wavelength,( high frequency in occurrence) magnetic signatures, which are generally attributed to basement areas. These are mostly prominent on sheets (228) Katakwa, (229) Udegi and (247) Lokoja (Figure 3).

The Northern edge comprising of Koton Karfi, Katakwa , Udegi area and part of the Western edge of Lokoja sheet shows a lot of activities, as they are dotted by mixtures of both high and low magnetic signatures which are features that are characteristics of surface to near surface structures such outcrops. Undifferentiated granite mainly porphyritic granite granitized gneiss with porphyroblastic granite covers Obajana, Ajaokuta, Itobe in Kogi State. Biotite granite covers Gadabuke, Katakwa, Nyegba in Nasarawa State. Ayingba, Dekina, Ejule, Angba in Kogi State are covered by False bedded sandstone (Ajali Formation). Coal, sandstone and shale formation identified around Otukpa, Abejukolo and Ofugo in Kogi State; Abaji in FCT; Udegi and Amaku in Nasarawa State and areas in Benue and Enugu States.False bedded sandstone, coal, sandstone and shale are the lithologic units at the surface within the sedimentary basin. River Alluvium deposition identified along the river channel. These features are strategically targeted as shown in the six profile modeled (Figure 4).

### Application of CET Grid Analysis Plug-In and Results

Application of the standard deviation and the phase symmetry plug-in, application of the amplitude thresholding and the skeleton to vectors plug-in from the CET extension of Oasis Montaj yielded the map in Figures 5 and 6. It will be observed that most of the lineaments are located within the basements bounding the basin to the Northern and Western edges. Some few Structures (Outcrop and Intrusive bodies) are located around the southern edges, and southeastern corner of the map. These structures are outcrop of magnetic basement rocks that intrude into the sedimentary Dormation; it is equally believe that these structures must have predate the depositional period , though no indication of their existence on the Geology and structural map of the area. On the vectorised structural map in (Figure. 6), it can be observed that the southeastern corner of the study is located a NE-SW trending fracture line. From (Figure 5) we observe that the basement rocks at the North and Western edge and the sedimentary basin intrude into the sedimentary formation. Two major fault lines are observed, the first one running parallel to the course of River Niger within the area. The second one is that which cuts the South Western corner of the study area diagonally.

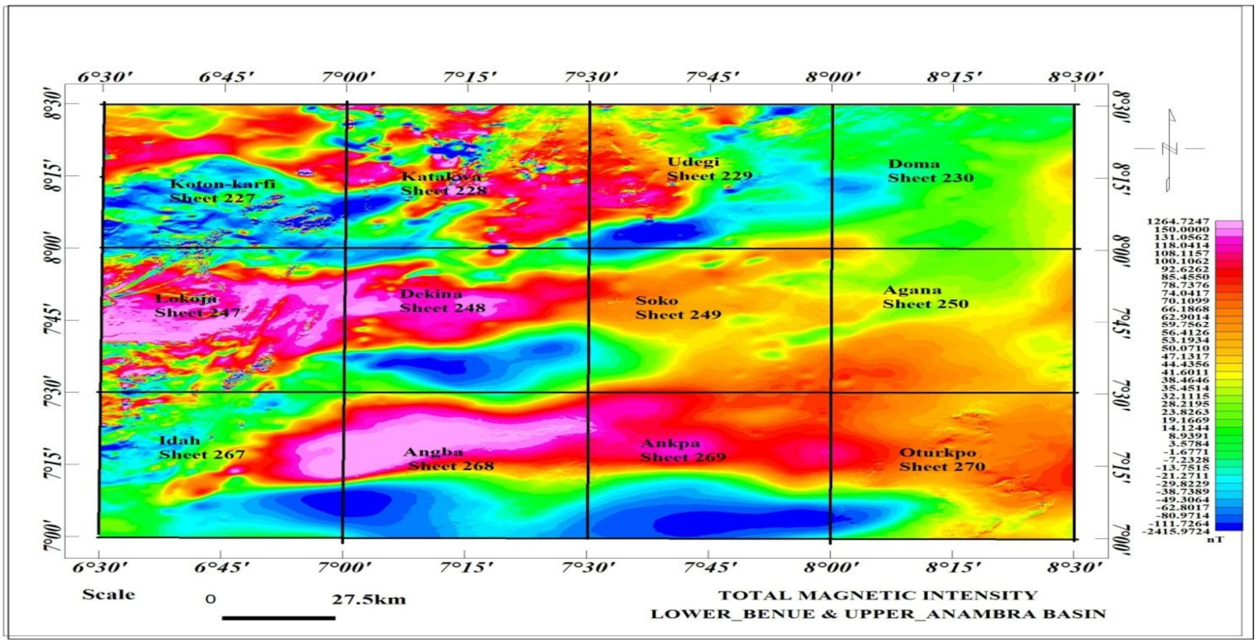



Figure 3: Total Magnetic Intensity Map of the Study Area showing major towns flown over

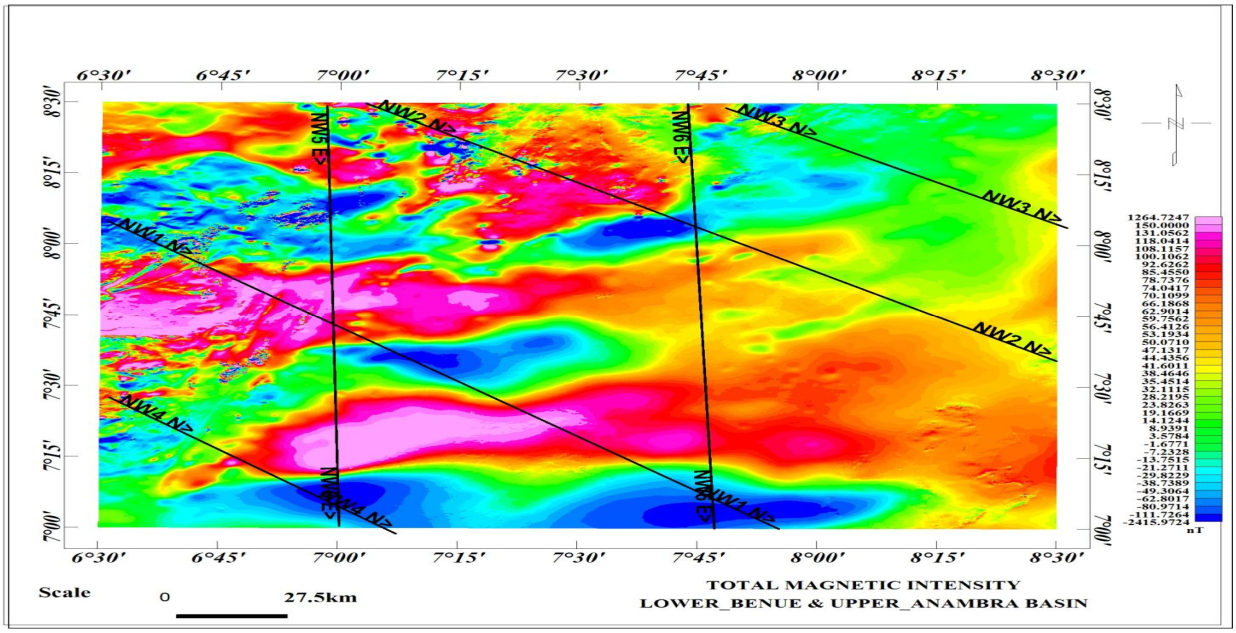



Figure 4: Total Magnetic Intensity Map showing Profiles Modeled

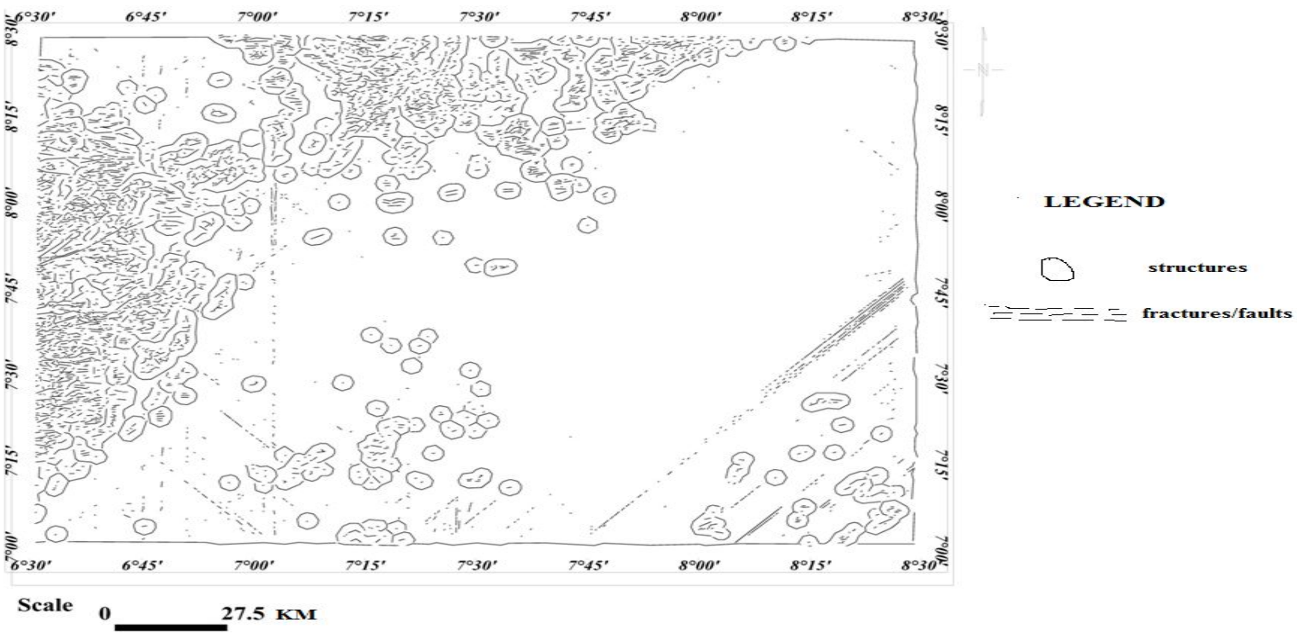



Figure 5: Vectorized Structural Map of the Study Area from CET_Plug-in

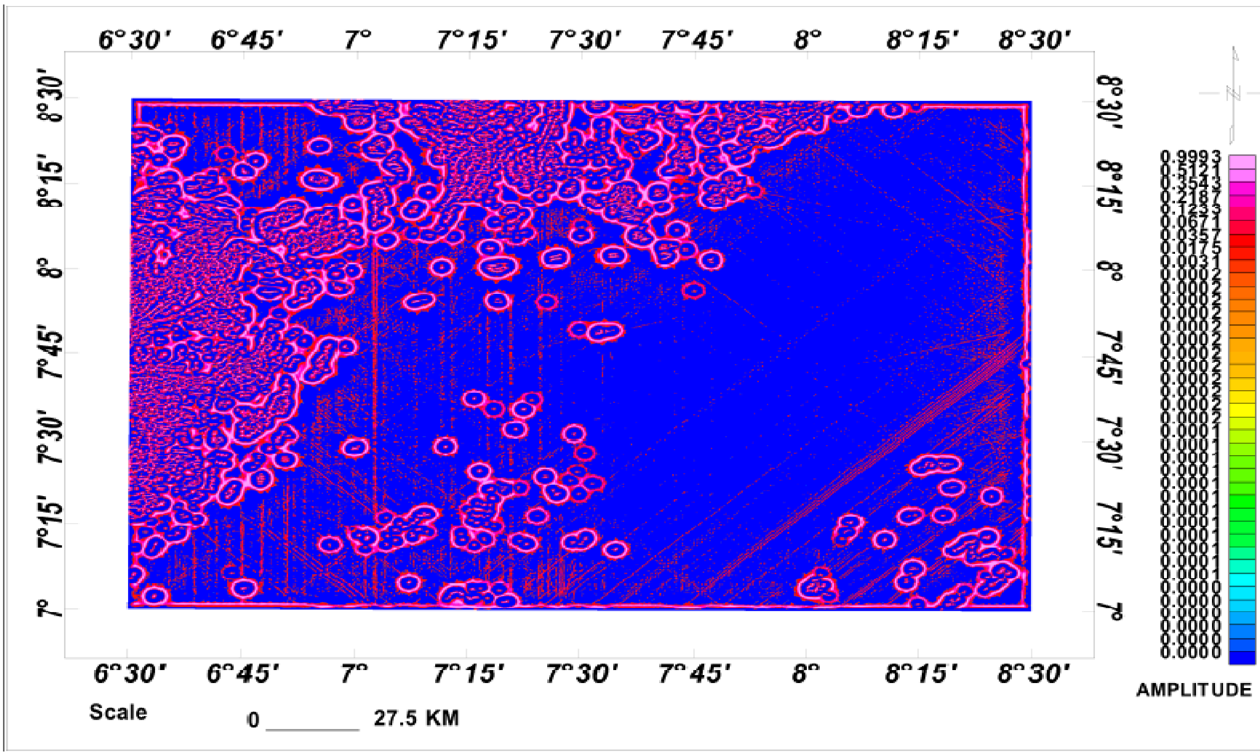



Figure 6: C E T-Vectorized Structural Map of the Study Area

## Modeling and Results

To accomplish a well documented modeling there is a need for a separate database. This database which is obtained from sampled grids consisting of the following:

A. The coordinates in Universal Transverse Mercator (UTM) geographic coordinate system or longitude and latitude value along the require profile
B. The TMI value along the grid profile
C. The SRTM (Shuttle Radar Topographic Mission Grid)
D. Depth – Which is sampled from the SPI value grid
E. The sensor – which is the SRTM+100 meters, 100 meter is the terrain clearance for this survey
F. The distances channel, which represents the length of each profile

Note that the sensor will determine the upper Z value while the dept+SPI value determent the depth along the profile.

For the purpose of this research six (6) profiles were selected to cut orthogonally through the major structures identified on the vertical derivative map of the study area. (Figure 4). They are labeled NW1, NW2, NW3, NW4, NW5 and NW6. Six different models are generated using 2-D modeling module form the oasis montage package. Moving around between the shapes, size of the body, its magnetic susceptibility, remannace magnetization, magnetic inclination and declination , an acceptable model is obtain, which poses good geological interpretation and an acceptable error margin. The result from the model produced are summarized in tables 1 to 6, these tables gives the name of rock(s) of sediment (relative to the region of occurrence), the average thickness of the sediment, its susceptibility, and the constituent of the rocks.

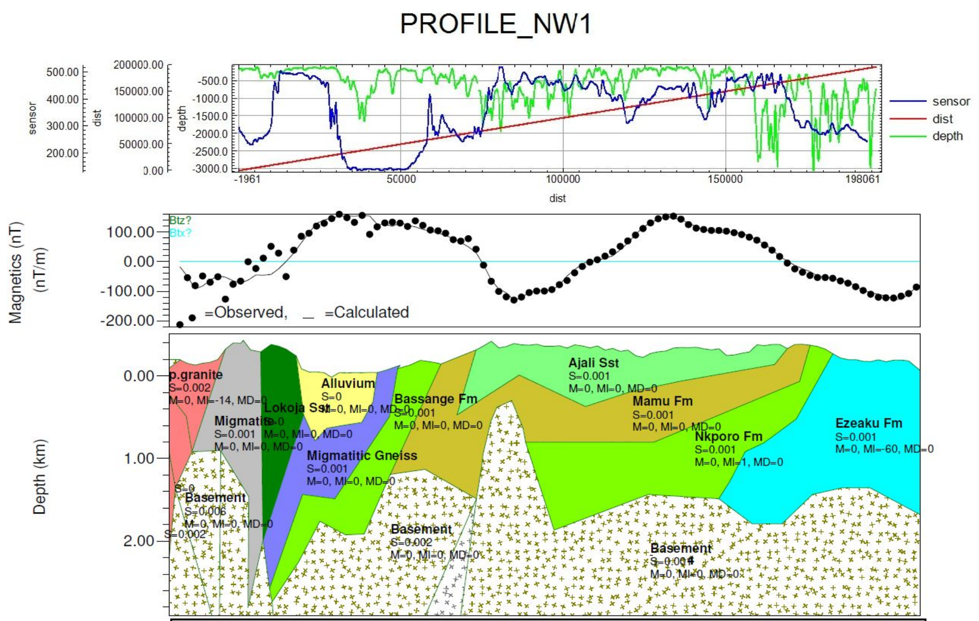



Figure 7: Profile and Model Map for Profile NW1

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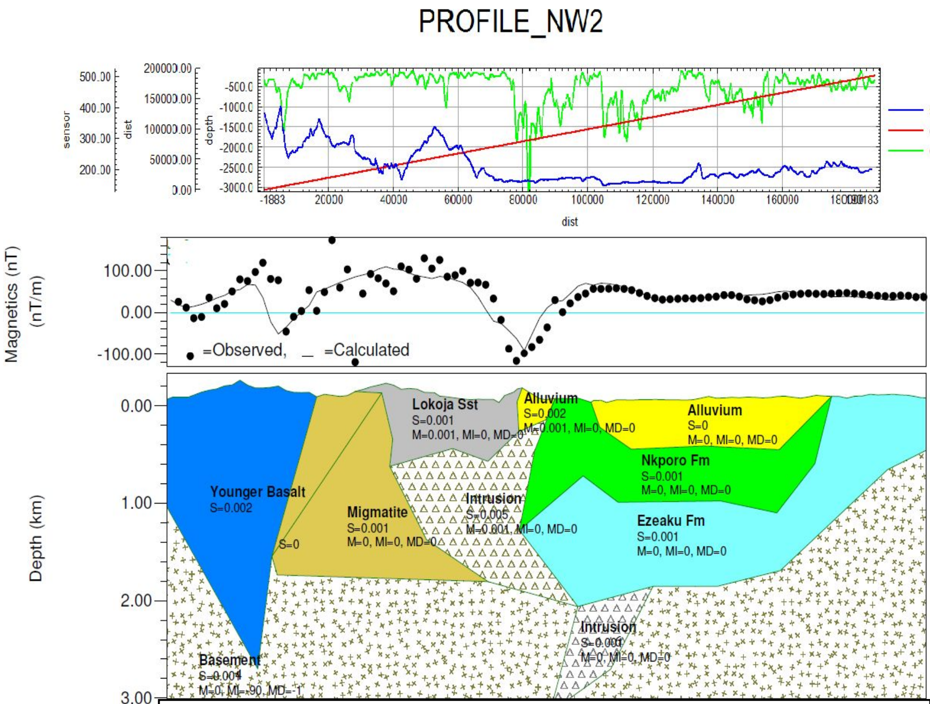


Figure 8: Profile and Model Map for Profile NW2

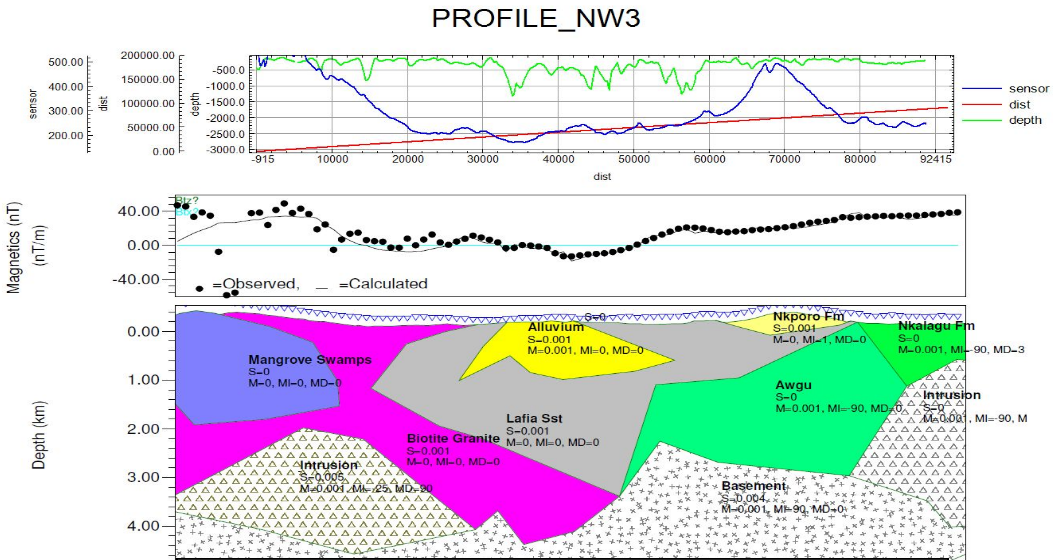


Figure 9: Profile and Model Map for Profile NW3

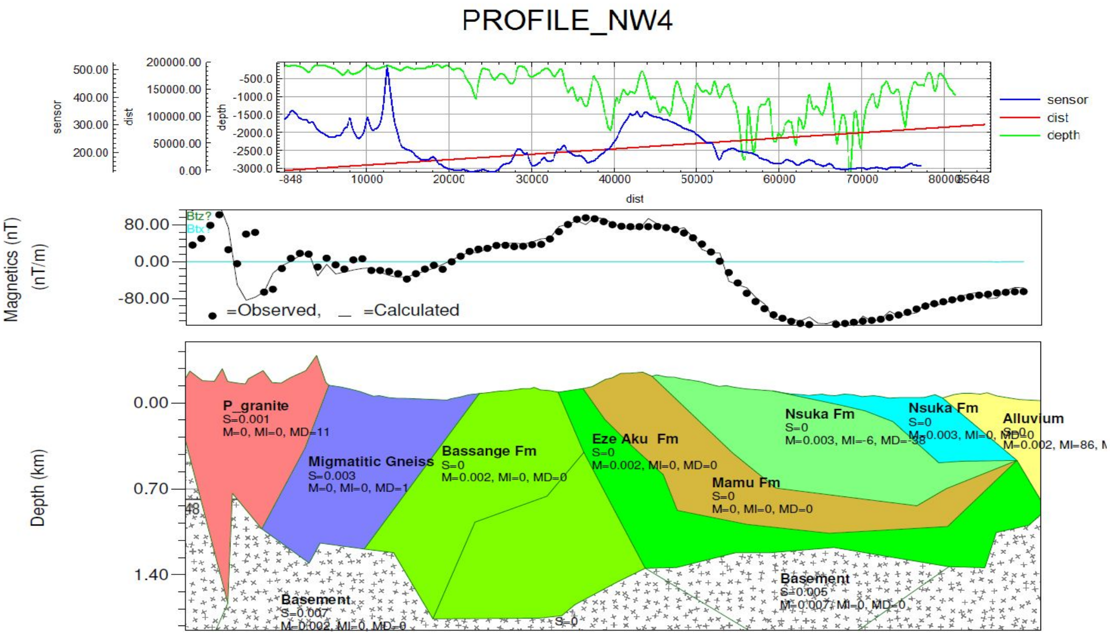


Figure 10: Profile and Model Map for Profile NW4

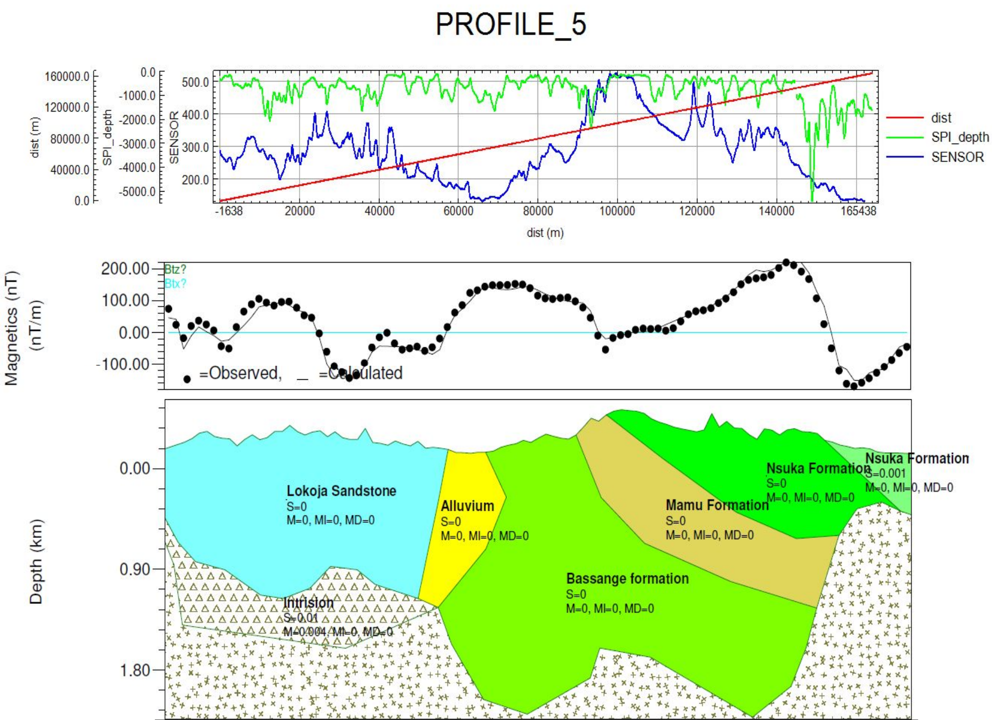


Figure 11: Profile and Model Map for Profile NW5

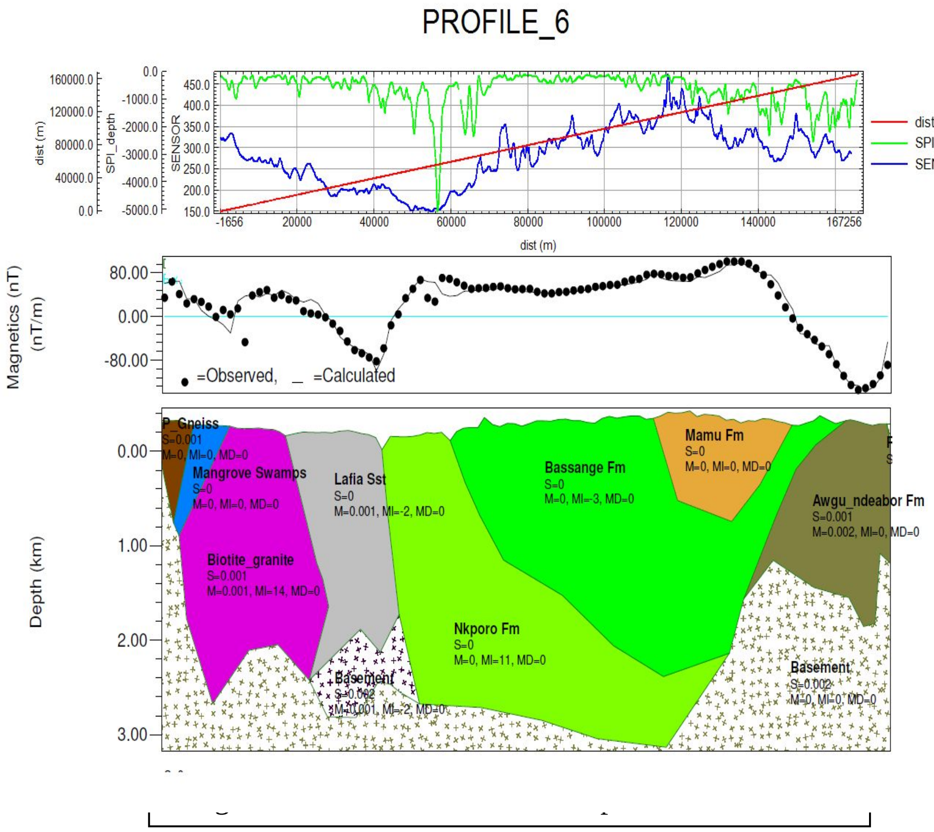


Table 1: Interpretation of Profile_1

| S/N | Formation | Depth/Thickness | Susceptibility | Lithology |
|---|---|---|---|---|
| 1 | p-granite | 1.2 km | 0.2 | Grantic rocks |
| 2 | Migmatile | 2.5 km | 0.001 | Migmatic rocks |
| 3 | Lokoja sand stone | 2 km | 0 | Sand stone and Siltstone |
| 4 | River alluvium | 400 m | 0 | Sand and river alluvium |
| 5 | Migmatite gnesis | 2.5 km | 0.001 | Migmatic rocks |
| 6 | Bassange Formation | 400 m | 0.001 | Sand stone Ironstone |
| 7 | Mamu Formation | 400 m | 0.0001 | Sand stone Sandy-shale and coal |
| 8 | Nkporo Formation | 500 m | 0.001 | Shale Mudstone and sandstone |
| 9 | Eze-Aku Formation | 1.5 km | 0.001 | Sandstone Black shale and Siltstone |
| 10 | Basement | - | 0.002–0.004 | Basement Rocks |

Table: 2: Interpretation of Profile_2

| S/N | Formation | Depth/Thickness | Susceptibility | Lithology |
|---|---|---|---|---|
| 1 | Young Basalt | 2.8 km | 0.002 | Basaltic rocks |
| 2 | Migmatite | 1.5 km | 0.001 | Migmatic rocks |
| 3 | Lokoja sand stone | 400 m | 0.001 | Sand stone and Siltstone |
| 4 | River Alluvium | 300 m | 0 | River alluvium |
| 5 | Nkporo Formation | 400 m | 0.001 | Shale Mudstone and sandstone |
| 6 | River Alluvium | 300 m | 0 | River alluvium |
| 7 | Eze-Aku Formation | 500 m | 0.001 | Sandstone Black shale and Siltstone |
| 8 | Basement | - | 0.002 – 0.004 | Basement Rocks |

Table: 3: Interpretation of Profile_3

| S/N | Formation | Depth/Thickness | Susceptibility | Lithology |
|---|---|---|---|---|
| 1 | Mangrove swamps | 500 m | 0.001 | Sand, Clay, Siltstone and Limestone |
| 2 | Biotite-granite | 2.1 km | 0.001 | Granitic rocks |
| 3 | Lafia sandstone | 600 m | 0.001 | Sand stone iron stone |
| 4 | River Alluvium | 400 m | 0.001 | River alluvium |
| 5 | Nkporo Formation | 100 m | 0.001 | Sand stone shale |
| 6 | Awgu Fm | 2 km | 0 | Shale sand stone coal |
| 7 | Nkalagu Formation | 900 m | 0 | Shale sand stone coal |
| 8 | Basement | - | 0.002 – 0.004 | Basement Rocks |

Table: 4: Interpretation of Profile_4

| S/N | Formation | Depth/Thickness | Susceptibility | Lithology |
|---|---|---|---|---|
| 1 | p-granite | 1.6 km | 0.001 | Granitic rocks |
| 2 | Magmatic gnesis | 1 km | 0.003 | Migmatic rocks |
| 3 | Bassange Formation | 1.6 km | 0 | Coal sand stone shale |
| 4 | Ezeaku Formation | 400 m | 0 | Coal sand stone shale |
| 5 | Mamu Formation | 400 m | 0 | Coal sand stone shale |
| 6 | Nsuka Formation | 400 m | 0 | Coal sand stone shale |
| 7 | Nsuka Formation | 300 m | 0 | Coal sand stone shale |
| 8 | River Alluvium | 300 m | 0 | River alluvium |
| 9 | Basement | - | 0.002 – 0.004 | Basement Rocks |

Table 5: Interpretation of Profile_5

| | | | | |
|---|---|---|---|---|
| 1 | Lokoja sand stone | 1200 meters | 0 | Sand stone and iron stone |
| 2 | River Alluvium | 1100 meters | 0 | River alluvium |
| 3 | Bassange Formation | 2200 meters | 0 | Coal sand stone shale |
| 4 | Mamu Formation | 200 meters | 0 | Coal sand stone shale |
| 5 | Nsuka Formation | 500 meters | 0 | Coal sand stone shale |
| 6 | Basement | - | 0.002 – 0.004 | Basement Rocks |

Table 6: Interpretation of Profile_6

| S/N | Formation | Depth/Thickness | Susceptibility | Lithology |
|---|---|---|---|---|
| 1 | Migmatite Gneiss | 500 m | 0.001 | Sand stone alluvium |
| 2 | Mangrove swamps | 500 m | 0 | Granitic rocks |
| 3 | Biotite granite | 2.4 km | 0.001 | Sand stone iron stone |
| 4 | Lafia sandstone | 2.4 km | 0 | Sand stone shale iron stone |
| 5 | Nkporo Formation | 2.5 km | 0 | Sand stone shale coal |
| 6 | Bassange Formation | 2 km | 0 | Shale sand stone ironstone |
| 7 | Mamu Formation | 600 m | 0 | Shale sand stone coal |
| 8 | Awgu-Ndeabor Fm | 1.2 km | 0.001 | Sand stone shale coal |
| 9 | Basement | - | 0.002 – 0.004 | Basement Rocks |

## Conclusions

The following conclusions were drawn:

(i) The major structural trend observed within the study area, which are NE – SW (at the upper part of the area) and E – W (at the lower part of the area) (Figures: 3 and 4), coupled with the direction of fault line identified in the study area on (Figure: 4.) and that observed from the CET grid analysis in Figure :4 that strike NE – SW, indicates, a rifting and spreading of continental plates, a process that results in spreading tractions in the earth's crust and create some lineaments and faults along which long and narrow depressions bounded by steep slopes occurred (Talwani, and Heirtzler 1960, Beaumont, 1978). Structures mapped on at the Northern and Western part of the study area, which coincide with the basement region are possible mineral veins located within the study area. Maximum depth of about ten (10) kilometers was obtained within the Southern end of the study area, but a maximum thickness of sedimentation of about four (4) kilometers was observed on profile six within Nkporo formation (Adetona & Abu, 2013) this is a favorable depth for geothermal gradient in hydrocarbon generation.

(ii) A major vertically fault line that structurally define the course of river Niger within the study area, and the extension of Chain's fault line that cuts the South East corner of the study area (Figure 5) coupled with the the presence of a basement uplift (Abakaliki uplift) adjacent to the study area cerate's an Isostatic adjustment of the graben-sag along week fault zones as blocks sink down in response to the traction, giving a depression which sediments can accumulate (Beaumont, 1978)

(iii) Considering the existence of intrusive structures of Basaltic rocks within the lower portion of the study area around Udegi and Angba, as revealed by Analytical Signal and CET grid analysis, (Figure 6) supports the theory of intrusion of dense material such as basaltic intrusion into crustal rocks, this emplacement will act as a weight. During isostatic adjustment a depression is created on the surface directly above the dense material where sediments can accumulate (Beaumont, 1978)

(iv) Deduction from the models produced from 2D modeling package, shows that the susceptibility of the sediments is generally zero, except in isolated cases such as in profile one where the profile passes through the highly susceptible basaltic body which slightly influence the susceptibility of the sediments. Susceptibility of basement rocks varies from 0.03 to about 0.07. Despite the classification of the study area into Lower Benue and Upper Anambra basins similar lithologies such as mamu, Nkporo and Bassange formations transcend the two basins thus Anambra basin can be said to be an extension of the larger Banue Basin. Deduction from models produced from 2D models shows that: susceptibility of the sediments is generally zero, except in isolated cases Susceptibility of basement rocks varies from 0.03 to 0.07. Thickness of sedimentation obtained within the area are:
profile 1 = 2.1 km_ Nkporo formatiom
Prifile 2 = 3.2 km_ Lafia formation
Prifile 3 = 2.0 km _Ezeaku formation
Prifile 4 = 2.1 km _Bassange formation
Prifile 5 = 1.2 km _Bassange formation
Prifile 6 = 4.2 km _ Nkporo formation

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