APPLICATION OF AEROMAGNETIC AND LANDSAT-ETM DATA IN THE STRUCTURAL ANALYSIS OF PART OF THE MIDDLE BENUE TROUGH

By

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DECLARATION

I, ODUMOSU GABRIEL EKUNDAYO, hereby declare that this work titled “Application of Aeromagnetic and Landsat-ETM Data in the Structural Analysis of part of the Middle Benue Trough” is an original work submitted to the school of postgraduate studies, Federal University of Technology, Owerri. I declare that apart from references made to other people’s work which have been duly acknowledged, this work is the product of my own research and has never been presented, either in whole or in part, for other awards elsewhere.

........................................

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CERTIFICATION

This research work was carried out by ODUMOSU, GABRIEL EKUNDAYO of the School of Postgraduate Studies, Department of Geology, Federal University of Technology, Owerri and is hereby certified.

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DEDICATION

This work is dedicated to the Almighty God for His providence and love towards me throughout the journey and to the Loving memory of my dad, Mr Christopher Olabode Odumosu whose passion for education had been successfully inculcated in me.
I would like to specially acknowledge my project supervisor, Dr. A.I. Opara, for his support, encouragements and painstaking commitment to the realization of this work.

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ABSTRACT

Recent quests for increased hydrocarbon potentials have necessitated further geological enquiries into the Middle Benue Trough. Structural and tectonic interpretations over the Middle Benue Trough were carried out using aeromagnetic and Landsat data to delineate the structural features of the study area and to assess their significance to hydrocarbon and mineral potentials of the area. Several analytical techniques were employed in the aeromagnetic and Landsat data. Analytical techniques used for the aeromagnetic data include the regional/ residual separation, second vertical derivative, spectral analysis and the Euler deconvolution. Similarly, image restoration and enhancement techniques were carried out on the Landsat ETM data using ILWIS 3.1 Academic. Several lineaments with dominant trends of NE-SW and NW-SE directions were revealed in the study area. Results of the 2-D spectral analysis of the aeromagnetic data revealed a two depth source model. The depth to the deeper magnetic source bodies range in depth from 2.1km to 5.5km with an average depth of 4.1km. This layer may be attributed to magnetic rocks of the basement, lateral variations in basement susceptibilities and intra- basement features like faults and fractures. The shallower magnetic sources ranging in depth from 0.1km to 1.2km with an average depth of 0.7km could be attributed to near surface magnetic sources, which are magnetic rocks which intruded into the sedimentary formations. Depth evaluation from Euler deconvolution methods also indicated the presence of contacts all over the study area. The Euler deconvolution analysis revealed that contacts were observed at depths ranging from 500m to 3000m while dykes and sills were also observed at depths ranging from 500m to 3000m. Results show that the average sediment thickness of 4.1km and structural indications such as faults obtained in the study area are significant for the generation, accumulation and entrapment of hydrocarbons.

**Keywords:** hydrocarbon potentials, aeromagnetic, landsat-etm data
CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND INFORMATION

The release of the aeromagnetic maps of Nigeria has turned the application of aeromagnetic surveys primarily, from interpretation of solely basement structures to detailed examination of structure and lithologic variations in the sedimentary section. In many sedimentary basins, magnetic anomalies arise from secondary mineralization along fault planes, which are often revealed on aeromagnetic maps as surface linear features. Most mineral deposits are related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concepts (O’Leary et al., 1976; Ananaba and Ajakaiye, 1987). Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits. They include the traces of major regional lineaments, the intersection of major lineaments or both major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineament, between echelon lineaments, and lineaments associated with circular features. Linear features are clearly discernible on aeromagnetic maps and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts, and other geologic features that may lead to the location of individual mineral deposits. They often indicate the general geometry of subsurface structures of an area thereby providing a regional structural pattern. Similarly, magnetic basement is an assemblage of rocks that underly sedimentary basins and may also outcrop in places. If the magnetic units in the basement occur at the basement surface, then depth determinations for these will map the basin floor morphology and its structure (Onyedim and Awoyemi, 2006).

Several studies have been carried out on the structure, stratigraphy, petroleum geology and economic geology of the Benue Trough (Murat, 1972; Whiteman, 1982; Benkhelil, 1988, 1989; Ofoegbu, 1988; Ajayi and Ajakaiye, 1981; Cratchley
and Jones, 1965; Fairhead and Okereke, 1987; Burke et al., 1971, 1972, among others). The Benue Trough is a linear NE-SW trending trough with a length of approximately 800km and opens into the Gulf of Guinea where the Cenozoic Niger Delta has built out upon oceanic crust. The Benue Trough is conventionally subdivided into Lower Benue Trough, Middle Benue Trough and Upper Benue Trough (Murat, 1972, Whiteman, 1982). Anomalous magnetization of parts of the solid earth’s surface might be associated with local mineralization or be due to subsurface structures. Determination of magnetic basement depth beneath sedimentary cover has been known as one of the key functions of aeromagnetic surveys and its interpretation. Remotely sensed data such as Landsat TM can be used in locating new, in addition to previously known features, probably faults, which may be of economic importance in the area. Literature reveals that geologic features, particularly lineaments, are readily interpreted despite dense vegetation cover.

This study aims at emphasizing the synergistic application of aeromagnetic and Landsat TM data for locating and interpreting lineaments and geologic structures in the area. There has been a major speculation about the possible existence of hydrocarbons in the Middle Benue Trough and this study seeks to clarify this speculation and other issues bothering on the geology of the area. The interpretation of the aeromagnetic and Landsat data of the study area will significantly improve the structural and tectonic delineation of the basin and better characterize the basin morphology, interpret the historical geology and kinematics of deformation implied by the tectonic events preserved in the area.

During the past two decades, the interpretation of Landsat imagery using manual or digital processing (Chorowicz and Rangin, 1982; Ferrandini et al., 1993), finds application in designing new maps and or revising and improving the pioneer maps on poorly outcropping areas, Wenmenga (2005). Regional structural analysis by this process is effective and more with radar interpretation (Carrère
and Chorowicz, 1982; Odeyemi, 1983).

This research work presents an aeromagnetic and Landsat based structural interpretation of part of the Middle Benue Trough.

1.1 STATEMENT OF RESEARCH PROBLEM

Recent falls in the price of oil in the global market has necessitated enquiries into means of accessing and producing hydrocarbon in more economic settings. This has necessitated search into the inland basins including the Middle Benue Trough. Government’s interest in diversifying the economy has also propounded further interest in solid mineral exploration schemes. This study would seek interpret the structural and tectonic geology of the area, infer the kinetics of deformation and further seek to answer some of the questions relating to the feasibility of hydrocarbon and mineral prospects in the study area.

1.2 JUSTIFICATION OF PRESENT STUDY

Scholarly publications abound on structural and depth interpretations in the Middle Benue Trough (Benkhelil 1982; 1989, Opara et al 2001, Cratchley and Jones, 1965; Nwachukwu, 1972; Olade, 1975); not much has however been done on the interpretation of the kinematics of deformation in this area. Recent interests in the hydrocarbon potentials of the Middle Benue Trough have therefore necessitated various detailed inquisitions into the structural and stratigraphic orientation of the trough which is believed will shed more light on resource-exploitation potentials of the area. The interpretation of aeromagnetic and Landsat data of the study area will significantly improve the structural and tectonic delineation of the basin and better characterize the basin morphology and dynamics for hydrocarbon and solid mineral prospects. This study will also improve on the literature content of the geology of the Middle Benue Trough.

1.3 AIM AND OBJECTIVES OF THE STUDY
This research work is aimed at delineating the structural features associated with parts of the Middle Benue Trough. The objectives of the study include among other things:

- To delineate the basement morphology and topography.

- To delineate significant structural features that may be associated with the area.

- To determine trends of deformation.

- To determine depths to magnetic basement rocks.

- To show the applicability of the remote sensing data in structural geological study (lineament) of the Middle Benue trough.

- To present geological interpretation of the Middle Benue Trough based on remote sensing and aeromagnetic data integration.

- To generate information on the lithology, tectonics, geomorphology and drainage characteristics of the study area

- To infer the hydrocarbon potentials of the study area

- To produce a lineament map of the study area and hence attempt an interpretation of mineralization potential of the study area, and

- To make a contribution to the existing literature on studies made on the
1.4 SCOPE OF WORK
This research work is an integrated study on a regional scale using aeromagnetic and Landsat data. The scope is therefore limited to the analysis and geologic interpretation of the aeromagnetic and Landsat data of parts of the Middle Benue Trough, the area shown in Figure 1.

1.5 LOCATION AND PHYSIOGRAPHY OF STUDY AREA
The study area is shown in Fig. 1 below. It is located in the Middle Benue Trough Nigeria within latitude 7° 00’N to 8° 00’N and Longitude 7° 30’ E and 9° 30’E. In the aeromagnetic maps, it is represented by the sheets number 249 Loko, Sheet 250 Agana, Sheet 251 Makurdi, Sheet 252 Akwana, Sheet 269 Ankpa, Sheet 270 Oturkpo, Sheet 271 Gboko and Sheet 272 Katsina-Ala.
Most of the physiographic units in the Benue Trough are undulating plains and differences between them reflect the underlying geology. These can be grouped into:

i) Mainly over sandstones (the Loko, Namu, Doma, Keana, Alaide and Wukari Plains)

ii) Mainly over shales (the Jangwa, Okpolo and Tarakuplains) and

iii) Mainly over Basement Complex (the Katsina Ala plains)
The Benue River itself forms the main axis of the area and falls from 90m in the east to 45m at its confluence with the Niger. On either sides of the Benue, extensive plains slope irregularly towards the river from a height of about 150m. To the north of the Benue these plains rise gradually to the foot of the dissected zone marking the northern boundary of the Benue valley, reaching a height of 600m in the north-east. South of the Benue River to the south and east of Katsina Ala town the plains rise gently to the foot of an escarpment which rises from 300m to about 1500m on the Obudu plateau. South of Makurdi lays an area of plains rising to almost 210m. To the west of Otukpo the major relief feature is the Ankpa Plateau consisting of plains over 300m.

1.6 Geology of the Study Area.

The Benue trough is a Cretaceous folded rift basin which lies across Nigeria. It has extension from the Niger Delta through the Gongola Rift to the Chad basin in the north. It is NE-SW trending sedimentary basin, subdivided into the lower, middle and upper Benue troughs. It extends for about 1000 km in length (NE-SW
direction) with width ranging from 180 km to 250 km (Whiteman, 1982).

The Benue Trough is part of the long stretch arm of the Central African rift system originating from the early Cretaceous rifting of the Central West African basement uplift (Obaje, 2004). The tectonic evolution of the Benue Trough originated from the separation of the African continent from the South American continent in the Aptian (Grant, 1971). The study area is characterized by the presence of thick sedimentary cover of varied composition whose age ranges from Albian to Maastrichtian, with the earliest being the marine Asu-River group of Albian age (Obaje, 2004). Stratigraphically, the Cretaceous sedimentary succession in the study area is shown on Fig 5. The Asu-River Group of marine origin is the oldest deposited sediment in the Middle Benue Trough followed by Ezeaku Formation, Keana/Awe Formation, Awgu Formation and Lafia sandstone as the youngest sediment (Obaje, 2004).
Fig. 3: Map of Nigeria showing the Major Geological Basins (Obaje, 2004)
The depositional history of the trough is characterized by phases of marine regression and transgression (Murat, 1972; Reyment, 1965; Short and Stauble, 1967). These sedimentary sequences were interrupted by large scale tectonism which occurred in two phases: the Cenomanian and the Santonian deformations (Nwachukwu, 1972; Olade, 1975). The Santonian deformation was characterized by compressive folding, generally along a NE-SW direction, parallel to the Trough margin. The folding episode that took place during the Santonian strongly affected the development of the Abakaliki Anticlinorium. The predominantly compressional nature of the folds that developed during this period is revealed by their asymmetry and the reversed faults associated with them. Benkhelil (1988), in a detailed report of geology of Abakaliki suggests that the compression responsible for the large scale folding and cleavage was directed N155° E. The
magmatism that occurred resulted in the injection of numerous intrusive bodies into the shale of the Eze Aku and Asu River Group. The Cenomanian deformation affected only Albian sediments. The lithostratigraphy of the Benue trough comprises formation ranging from Cretaceous to tertiary in age. The lithostratigraphic units are shown in Fig. 5

Fig. 5: Stratigraphic Succession of the Benue Trough (Obaje, 2004)

The sediments that occur in the study area belong to the following geological formation: Asu River Group (Albian), Eze Aku Shale (Turonian), AwguShale (Coniancian) and Nkporo Shale (Campanian) (fig.5).
CHAPTER TWO: LITERATURE REVIEW

2.0 REVIEW OF LITERATURE ON PREVIOUS STUDIES

Aeromagnetic method can be employed in mapping of fracture and fault system of the basement rock which possibly controls the mineralization of any area. Basement structures and depth can be delineated and mapped using magnetic data. Definition of the various basins and sub-basins geometries would enable the mapping of the regional hydrocarbon and mineral fetch areas. Trends in magnetic features often have related trend in the overlying sediments. Systematic offset of magnetic anomalies may indicate strike-slip faults; which have displaced basement rocks; possibly affected the sediment section. A magnetic basement interpretation can, to a certain extent, lead to a better understanding of the structures of the overlying sedimentary rocks.

The Benue trough is an intracontinental rift basin within which deformed Cretaceous sediments Pb-Zn ore deposits are localized (Ofoegbu 1985). The Benue Trough being generally regarded as a rift structure is noted to have many features in common with other intra-continental rifts. The Benue rift can be compared with some well-known rift systems such as the East African, the Rhine Graben, the Baikal rift, the Viking Graben, Red sea and the Rio Granade. Viking Graben was reported to be a product of active rifting event (Pangrum and Mounteney, 1978). Heritier et al (1979) asserted that Viking Graben developed from an aborted opening of the North European continental shield. This compares well with the history of the Benue trough, which Wright (1968) considered as a sediment-filled intracratonic rift in which deformation was affected by the release of torsional stress associated with the separation of Africa from the South America. Heritier et al (1979) reported that structures like faults (both normal tilted and polygonal), folds (anticlinal and synclinal), salt generated structures, dykes, sills, etc, associated with rift systems are prevalent in the Viking graben.
These kinds of structures have been reported in the Benue trough (Benkhelil, 1982) and the Red sea by James et al (1975). These listric normal faults were as a result of lithospheric thinning that led to formation of the sea, James et al (1975).

Cratchley and Jones (1965) studied the Benue Trough using geophysical data. They proposed a rift origin for the Benue trough and suggested that the main boundary rift proposed were concealed by the Cretaceous intrusives.

It has been established that the major Atlantic transform faults extend landward, along major deep-seated basement shear deformations. Five of such oceanic Fracture Zones, trending NE-SW direction have been mapped in the offshore delta to the northeast of the Gulf of Guinea. They include the Romanche Fracture Zone located along the northern part of the Gulf of Guinea, the Chain Fracture zone extending near the Niger Delta and the Charcot Fracture zone. Others are Fernando Po Fracture zone (Emery et al, 1975) bounding the Guinea ridge to the north and marking the southern limit of the Niger deltaic complex and the Ascension Fracture zone which constitute the southern boundary of the Guinea Ridge.

Ananaba (1991) observed that lineaments extrapolated from parts of central Nigeria and the overlapping parts of Chad Basin and the Niger-Benue rift, towards the West Africa coast; were in agreement with the four major fracture zones in the continental margins of WestAfrica.

In a magnetic work on the offshore of Niger Delta, Ponsard and Saugy (1988) observed that mapped deep-crustal features (Chain and Charcot Fracture zones) extend onshore, where they are correlated with the oceanic fracture zones. Also, Okereke and Ananaba (2006) observed that the Chain and Charcot Fracture zones extend from the oceanic crust to the continental crust and trend in a NE-SW direction.
Onyewuchi et al. (2012) had inferred from airborne magnetic and Landsat study of Nkalagu area that the Okposi Brine Lake was structurally controlled and lineaments in the N-S, NE-SW,NW-SE, and E-W directions were dominant in the area. 2D spectral analysis also revealed a two layer depth model with the shallower magnetic depth (d1) having an average depth of 1.041Km while the deeper magnetic source bodies (d2) were seen to have an average depth of 3.574Km. They concluded from the study that the average sedimentary thickness of 3.574Km estimated in the area was favorable for hydrocarbon generation.

In a similar study, Opara et al., (2014) attempted the structural interpretation of the Afikpo sub-basin based on evidences from airborne magnetic and Landsat-ETM data and results of the study revealed that the dominant structural trend direction of the study area was in the NE-SW direction. Other dominant trends in the area were in the N-S and E-W directions. The lineament density map also revealed the presence of high density fracture zones around Afikpo and Ezi-Alayi, 8Km SW of Afikpo. 2D spectral analysis revealed a two-layer depth model with the shallower magnetic depth (d1) having an average depth of 1.195Km while the deeper magnetic source bodies (d2) were seen to have an average depth of 2.660Km. The study concluded that the average sedimentary thickness of 2.660Km estimated in the area was not favorable for hydrocarbon generation but would be favorable for quarrying and Pb/Zn exploration based on the presence of Dolerite sill which has galena as an associated ore.

Murat (1972) identified four Cretaceous depositional cycles in the Lower Benue, each of which was associated with transgression and regression of the sea. The first sedimentary cycle lasted from the middle Albian to upper Albian and is thought to have been initiated by the opening of the South Atlantic Ocean. It is associated with the deposition of the Asu River Group. The second sedimentary phase occurred between the upper Cenomanian and middle Turonian and it was
associated with the deposition of Ezeaku Shale. The third sedimentary cycle ranged from the upper Turonian to the lower Santonian. It is associated with the deposition of Awgu Shale and Agbani Sandstone. Turonian transgression, which marked the start of this cycle, is believed to have commenced from the Gulf of Guinea through the Anambra basin to the Benue Trough. Most of the deposits of this cycle have been eroded as a result of the upper Cretaceous tectonic activity.

The fourth sedimentary cycle was marked by deposition of the Nkporo Shales, Owelli Sandstones, Afikpo Sandstones and Enugu Shales during the Campanian-Maastrichtian transgressive phase. This cycle also marked the deposition of the coal measures including: the Mamu Formation, Ajali Sandstones and Nsukka Formation.

Ajakaiye, 1981; and Ofoegbu, 1984, 1985 and 1988, by their analysis of both ground and airborne magnetic data over the Benue trough have shown extensive block faulting in the trough. These faults in places attain considerable lengths and mark out several basinal structures in the trough. Ofoegbu and Onuoha (1991) suggested that the elevated position of the basement in large part of the lower Benue trough and the geological history involving contact metamorphism, folding, and igneous activities indicate that there may be no significant petroleum plays.

Gravity studies within the Benue Trough have been given considerable attention when compared with the other geophysical tools. Consequently, the entire area of the trough has been covered by gravity studies (Ajakaiye, 1981). From the studies by these workers, they concluded that gravity field over the Benue Trough is characterized by a prominent axial positive anomaly of 200 to 400g.u which stretches over the lower Benue trough.

This axial zone of positive anomalies is flanked on both sides by elongated negative anomalies of values in the range of -200g.u. to -500g.u. Generally, the
negative and positive anomalies observed, range in value from 600g.u. to about 400g.u. (Ajakaiye, 1981) while the Free Air anomaly values are close to zero except for the local attainment of values of about 300g.u. (Ajakaiye, 1981; Adighije, 1981a).

Superimposed on these free air anomalies is a pronounced regional positive anomaly, which has been independently interpreted in terms of an uplifted mantle and the thinning of the crust underneath the Benue Trough (Cratchley and Jones, 1965; Artsybashev and Kogbe, 1974; Adighije, 1981b; Ajayi and Ajakaiye, 1981; Fairhead and Okereke, 1987).

In their findings, they concluded that the results of the interpretation of gravity anomalies suggest the existence of intra basement intrusives of high densities in the trough at depths between about 0.5 and 2km. The existence of intrusives suggests the existence of deeply penetrating fractures within the area. This according to them conforms to basic intrusives which have been inferred from results of geophysical studies in different parts of the world over major rift systems such as the Rhine Graben and Baikal rift (Logatchev, 1993). They went further to suggest that the width of the rift was acquired early in the evolution of the rift. The buried basic intrusions at depths of 0.5 - 2 km suggests the existence of deep fissures in the crust beneath the area of their study, which might have originated during rifting and parts of which became the foci of intrusive into the crust.

Ikponkonte and Ajayi, (2007) posited based on a recent gravity data collected over the area, that the Lower Niger and Lower Benue basins are interpreted to comprise five major structural zones. The locations, trends, extent and relationships between most previously known structures in the area are confirmed and detailed by the data. However, the structure mapped in the Ankpa area that lies between Abejukolo, Ayangba, Ankpa and Otukpo is a broad gravity minimum
that suggests a sedimentary basin hereby referred to as “Ankpa Basin”. On the other hand, the gravity high to the northeast of this anomaly which is centred around Umaisha in the Lower Niger, and which is referred to as the “Umaisha high” is interpreted as an intrabasement basic intrusion existing at shallow depth (2 km). Similarly, the gravity high around Abaji which they referred to as the “Abaji high” was interpreted as having a depth extent of about 2.0-4.2 km. Another broad linear positive gravity anomaly trending NE and located to the northeast of the Ankpa basin was interpreted as a basic intrusive ridge lying under the northern margin of the Lower Benue. Another previously unrecognized broad positive anomaly was located around Idah area. The anomaly was interpreted as a ridge structure made up of known highly metamorphosed or folded basement. To the southeast of the basin, the broad positive gravity anomaly hereby referred to as “Oju high” and which is located around Igumale, Agila and Oju areas was interpreted as part of the northern edge of the previously known Abakaliki anticlinorium. Estimates of the thickness of the sedimentary rocks in the Benue Trough obtained from the interpretation of the magnetic anomalies agree fairly with those obtained through the analysis of the gravity field. Ofoegbu (1988) working in the Yolaarm estimated the depths between 0.5km and 4.6km. Ofoegbu (1984) working in the Lower Benue Trough found the thickness of the sediments to vary between 0.5km and 7km. Ajakaiye (1981) and Ofoegbu (1984), analyzed the small amplitude, medium wavelength anomalies of general regular shapes and gentle gradients on which are superimposed several locally occurring high frequency anomalies.

The magnetic field over the Benue Trough is made up of the contributions from short, medium and long wavelength anomalies. The basement complex bordering the trough and outcropping in some places within it is characterized by short wavelength anomalies, which arise from either susceptibility changes within the basement, near surface intrusive in the basement or their combined effects.
Ofoegbu (1985) subjected the aeromagnetic anomalies to a power spectrum analysis in an effort to estimate the anomalous components due to shallow source. It was deduced from the resultant long wavelength anomalies that the anomalies are essentially due to variable curie isotherm underneath the trough. The study found the depth to vary between 1.8km – 2.7km, which is of immense interest and can be related to the thermal history of the area.

In 1986, Ofoegbu also transformed several aeromagnetic profiles over the Benue Trough to the corresponding pseudo gravimetric profiles using the equivalent layer method. A joint analysis of the magnetic, gravity and pseudo gravimetric anomaly profiles confirms that: the short wavelength anomalies on the aeromagnetic profile are caused by the variation in the magnetization due to existence of the very thin intrusions occurring at shallow depths. Similarly, the medium and long wavelength anomalies on the aeromagnetic and pseudo gravimetric profiles are due to the magnetization from deep seated intrusive bodies of asthenospheric origin.

Ofoegbu and Onuoha (1991) used 2D spectral analysis of aeromagnetic data to determine the mean depth to the buried magnetic basement rocks in Abakiliki Anticlinorium of the lower Benue Trough in Nigeria. They estimated average thickness of the sedimentary cover overlying the basement. From their result, two depth source models with the depth to deeper sources vary between 1200m and 2500m. The isolated linear magnetic features which are prominent on the aeromagnetic map as studied in detail revealed that the anomalies over such features (which in many cases have spatial dimensions that are greater than 10km) were modeled in terms of dyke-like bodies. They concluded that, on the basis of sediment thickness in Abakiliki, the occurrence of numerous intrusive bodies and the deformational history of the sedimentary rock in Abakiliki Anticlinorium, that
this part of Benue trough may not hold much promise in terms of hydrocarbon accumulation. This depth estimate is in agreement with Kogbe (1989), who speculated total thickness of 3.3 km for Cretaceous sediments and Fairhead et al (1991) basement depth of 3km.

Nwogbo (1997) mapped shallow magnetic sources in the Upper Benue Basin of Nigeria in order to determine their structures, distribution and location at depths by employing the techniques based on the Fourier analysis of the aeromagnetic fields. Spectral depth determination to magnetic source in the region yielded two magnetic depth ranges. The mean depth value to the basement range from 2km to 2.62km which corresponds to the fine basement topography surface indicates clearly the magnitude of the undulation of the basement topography of the region. Mean depth to the shallower magnetic sources in the region varies between 0.07km and 0.63km and may be attributed to shallow intrusive materials or some near surface basement rocks. Some deeper intrusives occur within the basement at depths of up to 2.45km. The numerous shallow intrusions in the basin however occur substantially outside the basement surface in the region show a gentle general southward increase with mean depth value ranging from 2km in the northern area to 2.62km in the south.

Njoku (1985) was able to delineate the nature and subsurface morphology that are responsible for the striking magnetic anomaly pattern that occurs in Ndi-Akparanta area, northeast of Abakaliki. Sharma (1987) also concluded that of all geophysical methods, magnetic mapping is the oldest, simplest, most reliable and widely used technique for locating both hidden ores and structures associated with mineral deposits. The use of satellite imagery for regional mapping of geologic units and structures has long been demonstrated as a vital tool for regional geologic mapping. This is as result of its ease of operation, speed, accuracy, low cost and coverage. Advancements lately, in satellite and digital technologies have led to remarkable improvement in this technique.
Rotherly, (1987) identified rock types in the Oman ophiolite using Landsat Thematic Mapper (TM) imagery. Similarly, Bala et al (2000) used Landsat 5 imagery to identify lineaments that are favourable for the occurrence of groundwater, especially in the crystalline terrains of Dutsin-Ma, NW Nigeria. Wenmenga, (2005) used Landsat and aeromagnetic data to identify the structural features of the paleoproterozoic basement of Boussouma area in Burkina Faso.

The use of Landsat TM in geologic studies received a boost in Nigeria with the creation of the National Space Research and Development Agency (NARSDA) a decade ago. Ologun (2004) generated and developed filtered images and clusters in order to obtain structural and geologic map of the Jos plateau. Igbokwe and Ayomaya (2004) also carried out gully erosion mapping and monitoring in parts of southeastern Nigeria using satellite imagery.

2.1 LANDSAT THEMATIC DATA (LANDSAT-TM5)

The basis of remote sensing traces back into ground and aerial photography. But modern remote sensing really took off as two major technologies evolved simultaneously: 1) the development of electro-optical sensors that operate from air and space platforms and 2) the digitizing of data that were then in the right formats for processing and analysis by versatile computer based programs. Because of the solid-state multispectral scanners and other raster input devices, we now have available digital raster images of spectral reflectance data. The major advantage of having these data in digital form is that they allow us to apply computer analysis techniques to the image data. These processes are known as digital image processing. Digital image processing gives the image analyst the ability to carry out the following functions:

   i) Correct the data for geometric and radiometric imperfections.

   ii) Improve the visual quality of the image data.
iii) Carry out appropriate user customer manipulations to enhance or suppress certain details necessary for information extraction.

iv) Conduct computer assisted thematic mapping from digital imageries.

These functions are conveniently referred to as image rectification, enhancement, transformation and classification respectively.

2.1.1 PREPROCESSING

Preprocessing activities involve those operations that are normally required before the main data analysis and extraction of information, and are generally grouped as radiometric or geometric corrections. Radiometric corrections include correcting the data for sensor irregularities and unwanted sensor or atmospheric noise, and converting the data. So, they represent accurately, the reflected or emitted radiation measured by the sensor. Geometric corrections include correcting for geometric distortions due to sensor-earth geometry variations, and conversion of the data to real world coordinates (latitude and longitude) on Earth’s surface. This produces an image that corresponds geometrically to a chosen coordinate system or map projection.

2.1.2 IMAGE ENHANCEMENT

Image enhancement is concerned with the modification of images to make them more suited for the capabilities of the human eye. In order to improve the visual quality of the imagery, image enhancement techniques were carried out. This was done based on the intended use of interpreted results. Two main approaches were involved: the imagery was enhanced on the basis of individual and neighbouring pixels (spatial) and on the multiband basis for which values of individual pixels are transformed (spectral). There is a variety of image enhancement methods but only three are fundamental to geological applications. These methods include: contrast stretching, spatial filtering and colour composite generation.
2.1.2.1 CONTRAST STRETCHING

The programs that convert the raw Digital Number (DN) values from individual bands into photographs or computer displays often produce visually poor products, especially if there is a narrow range of DN’s which is usually the case. The DN range for digital data is usually 8 bit (0-255), but most imagery would have DN values occupying just a limited fraction of the normal 8 bit range. This is improved, often greatly, by applying contrast-stretching methods, which includes simple linear stretch, linear stretch with saturation and histogram equalization stretches. The simplest is the simple linear stretch which involves spreading the range of data equally over the range 0-255 range, so that the minimum DN is set to 0 and the maximum set to 255. For linear stretch with saturation, a user-defined percentage of the total range is assigned a single value; this is applied to both ends of a histogram. Most times, it will be observed that the distribution of DN values is uneven; in this case, a histogram-equalized stretch may be better. This stretch assigns more display values (range) to the frequently occurring portions of the histogram. In this way, the detail in these areas will be better enhanced relative to those areas of the original histogram where values occur less frequently.

A histogram equalization stretch was conducted using the appropriate module in ILWIS 3.1 academic. This was done for all the seven TM bands used. The result was compared to that of a linear stretch with saturation and it was found that for this study a histogram equalization stretch is most suitable.

2.1.2.2 SPATIAL FILTERING

Spatial filtering comprises another set of digital processing functions, which are used to enhance the appearance of an image. Spatial filters are designed to highlight or suppress specific features in an image, based on their spatial frequency. Spatial frequency is related to the concept of image texture; it refers to
the frequency of the variations in tone that appear in an image. “Rough” textured areas of an image, where the changes in tone are abrupt over a small area, have high spatial frequencies; while “smooth” areas with little variation in tone over several pixels, have low spatial frequencies. A common filtering procedure involves moving a ‘window’ of few pixels in dimension for example, 3×3, 5×5, etc., over each pixel in the image, applying a mathematical calculation using the values under that window, and replacing the central pixel with the new value. The window is moved along in both the row and column dimensions one pixel at a time and the calculation is repeated until the entire image has been filtered and a “new” image has generated. By varying the calculation performed and the weightings of the individual pixels in the filter window, filters can be designed to enhance or suppress different types of features.

A low-pass filter is designed to emphasize larger, homogenous areas of similar tone and reduce the smaller, detail in an image. Thus, low-pass filter generally serve to smooth the appearance of an image. High-pass filters do the opposite and serve to sharpen the appearance of fine detail in an image. One implementation of a high-pass filter first applies a low-pass filter to an image and then subtracts the result from the original, leaving behind only the high spatial frequency information. Directional, or edge detection filters are designed to highlight linear features, such as roads or field boundaries. These filters can also be designed to enhance features, which are oriented in specific directions. Hence, they are useful in the enhancement of linear geological structures.

Two major filters were applied to the band 5 imagery using ILWIS 3.0 filter module: Laplace filter and edge enhancement filter. This was done to increase the spatial frequency of the imagery so as to enhance high frequency features, which would include fractures. The edge enhancement filter image was observed to be more appropriate for this work.
COLOUR COMPOSITE GENERATION

Colour composites are mostly applied in visual analysis. They make fullest use of the capabilities of the human eye. Depending upon the graphics system in use, composite generation ranges from simply selecting the bands to use, to more involved procedures of band combination and associated contrast stretch. The IDRISI COMPOSITE module is used to construct three band colour composites. This resulted into 24–bit images with original values and stretched saturation points presented in RGB.

IMAGE TRANSFORMATION

Typically, image transformation involves the manipulation of multiple bands, whether from a single multispectral image or from two or more images of the same area acquired at different times (multispectral image data). Either way, image transformations generate “new” images from two or more sources, which highlight particular features or properties of interest, better than the original input images. Basic image transformation procedures useful for geological applications include: Principal Component Analysis (PCA) and Vegetationindex (VI)

VEGETATIONINDEX.

There are varieties of vegetation indices that have been developed to help in the monitoring of vegetation. Most are based on the very different interactions between vegetation and electromagnetic energy and in the red and near-infrared wavelengths.

A generalized special response pattern for green broad leaf vegetation show that reflectance in the red region (about 0.6 - 0.7μm) is low because of absorption by leaf pigments (principally chlorophyll). The infrared region (about 0.8 – 0.9 μm), however, characteristically shows high reflectance because of scattering by the cell structure of the leaves. A very simple vegetation index can thus be achieved
comparing the measure of infrared reflectance to that of the red reflectance. Although a number of variants of this basic logic have been developed, the one, which has received the most attention, is the normalized difference vegetation index (NDVI). It is calculated using the formula:

$$\text{NDVI} = \frac{\text{NIR} - \text{R}}{\text{NIR} + \text{R}}$$

Where NIR = Near Infrared and R = Red.

2.1.3.2 IMAGE CLASSIFICATION

Digital image classification uses the spectral information represented the digital numbers in one or more spectral bands, and attempts to classify each individual pixel based on this spectral information. This type of classification is termed spectral pattern recognition. In either case, the objective is to assign all pixels in the image to particular classes or themes for example, water, vegetation and bare rocks. The resulting classified image is comprises a mosaic of pixels, each of which belong to a particular theme, and essentially thematic “map” of the original image. Common classification procedures can be broken down into two broad subdivisions based on the method used: supervised classification and unsupervised classification.

In a supervised classification, the analyst identifies in the imagery homogenous representative samples of the different surface cover types (information classes) of interest. These samples are referred to as training sites or areas. The selection of appropriate training areas is based on the analyst’s familiarity with the geographical area and their knowledge of the actual surface cover types present in the image. Thus, the analyst is “supervising” the categorization of a set of specific classes. The numerical information in all spectral bands for the pixels comprising these areas is used to “train” the computer to recognize spectrally similar areas for each class. The computer uses a special program or algorithm (of which there are
several variations), to determine the numerical “signatures” for each training class. Once the computer has determined the signatures for each class, each pixel in the image is compared to these signatures and labeled as it most closely “resembles” digitally. Thus, in a supervised classification we are first identifying the information classes, which are then used to determine the spectral classes, which represent them.

Unsupervised classification in essence reverses the supervised classification process. Spectral classes are grouped first, based solely on the numerical information in the data, and are then matched by the analyst to information classes (if possible). Programs, called clustering algorithms, are used to determine the natural (statistical) groupings or structures in the data. Usually, the analyst specifies how many groups or clusters are to be looked for in the data. In addition to specifying the desired number of classes, the analyst may also specify parameters related to the separation distance among the clusters and the variation within each cluster. The final result of this iterative clustering process may result in some clusters that the analyst will want to subsequently combine, or clusters that should be broken down further, each of these requiring a further application of the clustering algorithm. Thus, unsupervised classification is not completely devoid of human intervention. However, it does not start with a pre-determined set of classes as in a supervised classification.

2.1.3.3 SHADED RELIEF MAP

Shaded relief displays are particularly valuable when used in conjunction with other geophysical and geological data and displays. In general, the interpreter is looking for two types of features on the sun shade plots: 1) Linear anomalies highlighted by a perpendicular or near-perpendicular sun position; and 2) shear zones, generally in basement, that are highlighted best by a near-parallel sun angle. It is easier to interpret linear anomalies trending near-perpendicular to the
sun angle and shear zones trending near-parallel to the sun angle because a linear anomaly will have its highest reflectance values at angles normal to the sun, and because shear zones are best recognized by terminations and offset in anomalies they intersect. Although they will not be quite as obvious, features at an oblique angle to the false sun angle can also be interpreted. A natural azimuthal bias is minimized by using two or more sun angles.

The shaded relief display of aeromagnetic intensity can be used as an interpretation tool to help locate lineaments within a defined area. It can also be used to connect structures at the top of magnetic basement, shear zones in basement, and tectonic province boundaries in basement.

2.2.0 AEROMAGNETIC DATA

2.2.1 REGIONAL AND RESIDUAL SEPARATION

Regional anomaly is referred as the component of magnetic anomaly that has longer wavelength. This deep large feature shows up as regional trends and continues smoothly over a wider aerial extent. The residual anomaly has shorter wavelength and shows up as smaller, local trend which are secondary in size but primary in importance. These residual anomalies may provide structure for mineral or ore emplacement. For effective interpretation to take place, the regional and residual anomalies must be separated. Generally, only the residual anomaly or local variations are of interest and hence, interpretation is based on it. Although, there is no way to accomplish perfect separation of local and regional anomalies, geophysicists have developed methods for isolating the principal features of different anomalies. Twomajor separation schemes involve;

(i) Graphical Smoothing.

(ii) Analytical Smoothing.
(A) **Graphical Smoothing:**
This method involves a geophysicist making a judgmental decision from the appearance of a profile or a contour map and how the regional part would look like were it not distorted by local irregularities.

(B) **Analytical Smoothing:**
These methods are used in such conditions to isolate anomalies without great reliance on the interpreter's sense of judgment as in graphical method. Four Analytical approaches are in common use:

(i) Direct computation of residual using empirical gridding method.

(ii) Determination of second derivatives.

(iii) Polynomial fitting.

(iv) Upward and downward continuation.
For the purpose of this work, the analytical smoothing methods adopted are determination of second derivatives and polynomial fitting.

(i) **EMPIRICAL GRIDDING METHOD**

This is a simple method of removing the regional by the second derivative of analysis. The regional is considered to be the average value of the total magnetic field intensity in the vicinity of the station and is obtained by averaging the observed values on the circumference of a circle centered at the station.

(ii) **DETERMINATION BY SECOND DERIVATIVE**

This is applied in situations where for some reasons; the regional - residual separation is difficult to apply. Example of such situation is where two or more sources with their centers of mass are closer together than their depths; the anomalies overlap so that it becomes difficult to discern the source that is causing a more serious anomaly. It enhances near surface effects at the expense of the deeper sources.

The vertical derivative map relies on the fact that nearby sources even though they may be small have greater influences on regional gradients than on total field magnetic intensity itself. Hence, it can be reasoned that local features will manifest more prominently on the map as one of the derivatives of thus indicating places where residual anomalies may be located.

Generally, the second derivative of a magnetic field can be shown to be a measure of curvature of the field, and large curvatures are associated with shallow or residual anomalies. It helps to resolve and accentuate shallow sources.
POLYNOMIALFITTING

This is one of the most flexible of the analytical methods of separating anomalies. It is a method in which matching of the regional by the polynomial surface of low order exposes the residual features as random errors. The treatment is based on statistical theory. The magnetic field of the survey area is expressed by a low-order polynomial given by:

$$F(x, y) = Ax + By + 2Cxy + Dx^2 + Ey^2 \quad \text{………………………………. (1)}$$

Here, the method of least squares is applied to the observed magnetic intensity to obtain a describable surface, which gives the closest fit to the magnetic field. This surface so obtained is referred to as regional surface. If the regional surface is expressed as the function

$$Z = Ax + By + 2Cxy + Dx^2 + Ey^2$$

Then the residual anomaly function $M$, for the observed magnetic intensity $M$ is given as:

$$R = M - Z = M - (Ax + By + 2Cxy + Dx^2 + Ey^2) \quad \text{………………… (2)}$$

The coefficients in equation (2) are obtained using least square method.

It should be noted that the regional trend is represented by a straight line, or more generally by a smooth polynomial curve. The fitting of polynomials to observed geophysical data is used to compute the mathematical surface giving the closest fit to the data that can be obtained within a specified degree of details. This surface is considered to approximate the effect of deep seated or regional structures if it of low degree. The function that generates this surface is called the trend for that specified degree and the consequent analysis of this constitutes the trend surface analysis. The fitting surface which represents the regional is a surface which will have both positive and negative deflections from the observed data points with the residuals balanced between positive and negative areas (Nettleton, 1976). For this
study, 1st, 2nd, 3rd, and 4th order polynomial were fitted to the contoured data. This process was done using the Radhakrishna Murthy and Krishnamacharyulu’s (1990) algorithm written in Fortran 77 to adjust the polynomial surfaces to the total field magnetic intensity map.

2.2.2 ANALYTICAL CONTINUATION:

(UPWARD AND DOWNWARD CONTINUATION)

Upward continuation transforms the potential field measured on one surface to the field that would be measured on another surface farther from all sources. As we shall see, this transformation attenuates anomalies with respect to wavelength; the shorter the wavelength, the greater the attenuation. In this sense, the process of upward continuation degrades the measured data, and we might wonder why such a process would have any application at all. Several useful examples come to mind. First, it is sometimes necessary to compare or merge aerial surveys measured at disparate altitudes, and upward continuation provides a way to transform individual surveys onto a consistent surface. Second, upward continuation tends to accentuate anomalies caused by deep sources at the expense of anomalies caused by shallow sources. A magnetic survey over the younger granite region for example, may be dominated by short-wavelength anomalies due to near-surface igneous rocks; upward continuation can be used to attenuate the shallow-source anomalies in order to emphasize deeper, more profound sources, such as underlying plutonic rocks.

Downward continuation on the other hand, tries to measure data into region closer to the source, because it is assumed that all sources are located below the observation surface and that all points of the continuation are above the observation surface. It would tend to accentuate the details of the source distribution, especially the shallowest components. It attenuates anomalies with respect to wavelength; the longer the wavelength, the greater the attenuation.
2.2.3 REDUCTION TO POLE (RTP)

A reduction-to-pole transformation is a standard practice applied to aeromagnetic data to minimize polarity (Blakely, 1995). Also, RTP involves the conversion of the anomalies into their equivalent form at the north magnetic pole. From the analysis of magnetic anomaly, it was observed that the shape of an anomaly is most simple when the earth’s magnetic field is vertical. In practice, this only happens for surveys at the magnetic North or South Pole. However, there are mathematical techniques that can aid in converting data observed at any location to the form that would have been observed at the magnetic poles. RTP (Reduction to Pole) filtering removes the effect of the earth’s magnetic field by way of a gross shift of the observed magnetic readings. It removes the non-vertical magnetic component (the earth’s magnetic field) and leaves only the vertical component (causative body) in its correct spatial position. The reduction to the pole operator transforms data to appear as it would if collected at the magnetic pole. This greatly simplifies interpretation.

2.3.0 ESTIMATION OF DEPTH TO MAGNETIC BASEMENT

Contoured aeromagnetic maps present several anomalies whose sources are traceable to the basement. It now becomes imperative that depth estimation from those anomalies provide useful clue to approximate sedimentary thickness. Apart from contours, depth to magnetic basement could be calculated using any of stretched histogram, pseudo-colour compositions and first vertical derivative data. Recently, new techniques for depth calculation have been developed. They include: Improved Naudy Automatic Model, Matched filter depth separation and slicing, Spectral analysis, Traditional and extended Euler Deconvolution, Complex amplitude and instantaneous Phase, Philips Method, Analytic signal, magnetic coherence map, Vertical derivative, pass, continuation and directional
filters, and Powerful visualization and hard copy composition language and tools. All the methods rely on the transform of potential field anomalies into special functions that form gradient peaks and ridges over the sources. These maxima peak values are located directly above the magnetic contacts, depending on an assumed geometric model. All the methods can use the same function to locate the contacts and estimate the source depths.

Peters’ half-slope method is normally used because the method gives the distance to the magnetic body within about 25% (Nettleton, 1976). The point at which lines with half the maximum slope are tangent to the curve (Magnetic Profile) are determined. The horizontal distance between these two points is determined and this value is divided by any factor from 1.2 to 2.0 to give the depth to the magnetic body. The middle number 1.6 is normally preferred (Sheriff, 1978).

2.3.1 2-D SPECTRAL ANALYSIS

The application of 2-D spectral analysis in aeromagnetic studies has received wide attention (Bhattacharyya, 1966; Spector and Grant, 1970; Ofoegbu and Onuoha, 1991; Ofoegbu and Hein, 1991; Cowan and Cowan, 1993; Kangkolo et al., 1997). Odegard and Berg (1965) showed for simple bodies, and Bhattacharyya and Leu (1975) showed for complex shaped bodies, that the depth to the center of anomalous mass of the body is found easily from the power spectrum.

The method allows an estimate of the depth of an ensemble of magnetized blocks of varying depth, width, thickness and magnetization. Most of the approaches used involve Fourier transformation of the digitized aeromagnetic data to compute the energy (or amplitude) spectrum. This is plotted on a logarithmic scale against frequency. The slopes of the segments yield estimates of average depths to magnetic or gravity sources of anomalies.
Given a residual magnetic anomaly map of dimensions \( l \times l \), digitized at equal intervals,

\[
T(x, y) = \sum_{n=1}^{N} \sum_{m=1}^{M} P_m^n \cos\{(2\pi/l)(nx + my)\} + Q_m^n \sin\{(2\pi/l)(nx + my)\} \quad \ldots \ldots \quad (3)
\]

the residual total intensity anomaly values can be expressed in terms of a double Fourier series expression given as:

Where \( l = \) dimensions of the block, \( P_m^n \) and \( Q_m^n \) are Fourier amplitude, and \( N \) and \( M \) are the numbers of grid points along the \( x \) and \( y \) directions respectively. Similarly, using the complex form, the two dimensional Fourier transform pair may be written as:

\[
G(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g(x, y) e^{-j(u_x|x|+v_y|y|)} \, dx \, dy
G(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g(x, y) e^{-j(u_x|x|+v_y|y|)} \, dx \, dy
\]

\[
\ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldotted
Turkey, 1965). Next, the frequency intervals are subdivided into sub-intervals which lie within one unit of frequency range. The average spectrum of all the partial waves falling within this frequency range is calculated and the resulting values together constitute the radial spectrum of the anomalous field. A plot of the logarithm of the energy values versus frequency consists of linear segments each of which groups point due to anomalies caused by bodies occurring within a particular depth. If \( z \) is mean depth a layer, the depth factor for this ensemble of anomalies is \( \exp(-2zk) \), where \( k \) is the magnetic moment per unit depth (Spector and Grant, 1970). Thus the logarithmic plot of the radial spectrum would give a straight line whose slope is \(-2z\). The mean depth of burial of the ensemble is thus given as

\[
Z = -\frac{m}{2} \quad \text{.................................................. (8)}
\]

Where, \( m \) is the slope of the best fitting straight line. Equation (15) can be directly if the frequency unit is in radians per kilometer, but if it is cycles per kilometer, the corresponding relation can be expressed as

\[
Z = -\frac{m}{4\pi} \quad \text{.................................................. (9)}.
\]

The use of Discrete Fourier Transform introduces the problems of aliasing and the truncation effect (Gibb’s phenomenon). Aliasing was reduced by the digitizing interval of 2km used in this study. Truncation effect was reduced by applying a cosine taper to the observed data before Fourier Transformation (Bath, 1974).

In this study, Discrete Fourier Transform analysis and the problems of aliasing and truncation effects have been taken care of by using software written in MATLAB™ developed by Odegard and Berg (1965). The advantage of using the method is that, for noisy data the spectral method may be the only way to determine an estimate of the depth to magnetic basement. This is because other direct inversion methods have difficulty in dealing with noise.
2.3.2 GRAPHICAL METHODS

PETERS’ SLOPE METHOD

The depth to magnetic body is estimated as,

Depth to body = 0.625 × horizontal distance (P) between points of tangency of lines that have \( \frac{1}{2} \) slope that occurs at point of inflection. Vertical slab with infinite depth was assumed.

Fig. 7: Depth Estimation from Magnetic Profile Using Peter’s half-slope Method (Telford et al., 1998)

HANNEL’S RULE

The depth to magnetic is estimated from this rule by the expression:

Depth to body = \( \frac{1}{2} \) horizontal distance (B) between flanks of curves at an amplitude of 1/3 maximum deflection. A single pole source (long vertical extent:
chimney pipe) was assumed.

**TIBURG’S RULE**

The use of Tiburg’s rule in depth estimation involves the expression:

Depth to body = \(\frac{2}{3}\) horizontal distance (BT) between flanks of curves at an amplitude of \(\frac{1}{2}\) maximum deflection. A single pole source (long vertical extent: chimney-pipe) was assumed.

**2.3.3. Depth Estimation by 3-D Euler Deconvolution**

The objective of the 3-D Euler deconvolution process is to produce a map showing the locations and the corresponding depth estimations of geologic sources of magnetic or gravimetric anomalies in a two-dimensional grid (Reid, 1990).

The Standard 3-D Euler method is based on Euler's homogeneity equation, which relates the potential Field (magnetic or gravity) and its gradient components to the location of the sources, by the degree of homogeneity N, which can be interpreted as a structural index (Thompson, 1982). The method makes use of a structural index in addition to producing depth estimates. In combination, the structural index and the depth estimates have the potential to identify and calculate depth estimates for a variety of geologic structures such as faults, magnetic contacts, dykes, sills, etc. The algorithm uses a least squares method to solve Euler's equation simultaneously for each grid position within a sub-grid (window). A square window of predefined dimensions (number of grid cells) is moved over the grid along each row. At each grid point a system of equations is solved, from which the four unknowns (x, y as location in the grid, z as depth estimation and the background value) and their uncertainties (standard deviation) are obtained for a given structural index. A solution is only recorded if the depth uncertainty of the calculated depth estimate is less than a specified threshold and the location of the
solution is within a limiting distance from the center of the data window (Whitehead and Musselman, 2008).

Thompson (1982) showed that for any homogenous, three-dimensional function \( f(x; y; z) \) of degree \( n \):

\[
f(tx; ty; tz) = t^nf(x; y; z)
\] ................................. (15)

It can be shown that, the following equation, which is known as Euler's homogeneity relation can be satisfied:

\[
x \frac{\delta f}{\delta x} + y \frac{\delta f}{\delta y} + z \frac{\delta f}{\delta z} = nf x \frac{\delta f}{\delta x} + y \frac{\delta f}{\delta y} + z \frac{\delta f}{\delta z} = nf
\] ................................. (16)

In geophysics, the function \( f(x,y,z) \) can have the general functional form:

\[
f(x, y, z) = \frac{G}{r^N}f(x, y, z) = \frac{G}{r^N}
\] ................................. (17)

Where \( r^2 = (x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2 \), \( N \) a real number \((1,2,3...,) \) and \( G \) a constant (independent of \( x,y,z \)). Many simple point magnetic sources can be described by this equation, with \((x_0; y_0; z_0)\) the position of the source whose field \( F \) is measured. The parameter \( N \) is dependent on the source geometry, a measure of the fall-off rate of the field and may be interpreted as the structural index (SI).

Considering potential field data, Euler's equation can be written as:

\[
(x - x_0) \frac{\delta T}{\delta x} + (y - y_0) \frac{\delta T}{\delta y} + (z - z_0) \frac{\delta T}{\delta z} = N(B - T)
\]

\[
(x - x_0) \frac{\delta T}{\delta x} + (y - y_0) \frac{\delta T}{\delta y} + (z - z_0) \frac{\delta T}{\delta z} = N(B - T)
\] ................................. (18)

With \( B \) the regional value of the total magnetic field and \((x_0; y_0; z_0)\) the position of the magnetic source, which produces the total field \( T \) measured at \((x; y; z)\).
Thompson (1982) showed that simple magnetic and gravimetric models are consistent with Euler's homogeneity equation. Thus Euler Deconvolution provides an excellent tool for providing good depth estimations and locations of various sources in a given area, assuming that appropriate parameter selections are made. Applied to aeromagnetic surveys, the 3D Euler process is a fast method for obtaining depth and boundary solutions of magnetic sources for large areas.

Though it is a general advantage of the Euler Deconvolution method, that it is applicable to all geologic models and that it is insensitive to magnetic remanence and geomagnetic inclination and declination, an initial assumption of the source type has to be made. Dependent upon the potential source type, a structural index is chosen. This structural index is also a measure of the distinctive fall-off rate of the geologic feature. For example, the best results for a contact are obtained by structural indices of 0 to 0.5, while for thin two-dimensional dyke structures a structural index of 1 yields the best estimates. Table 1 summarizes the structural indices (SI) for given geologic models. The number of infinite dimensions describes the extension of the geologic model in space.

**Table 1: Structural Indices for Simple Magnetic Models Used For Depth Estimations by 3D Euler Deconvolution.**

<table>
<thead>
<tr>
<th>Geologic Model</th>
<th>Number of Infinite Dimensions</th>
<th>Magnetic Structural Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Pipe</td>
<td>1 (z)</td>
<td>2</td>
</tr>
<tr>
<td>Horizontal cylinder</td>
<td>1 (x-y)</td>
<td>2</td>
</tr>
<tr>
<td>dyke</td>
<td>2 (z and x-y)</td>
<td>1</td>
</tr>
</tbody>
</table>
The significance of the location and depth estimates obtained by 3-D Euler Deconvolution is given by the specificity of the chosen parameters like the grid cell size, window size, structural index, chosen depth uncertainty tolerance, etc. The selection of the grid cell size should be based on the grid spacing and the wavelength of the anomalies to be analyzed, as the software Geosoft Oasis Montaj allows a square window size of up to 20 grid cell units. If the wavelengths of the anomalies are significantly longer or shorter than the window size, the 3D Euler method does not yield appropriate results. On the other hand, the limiting distance from the centre of the algorithm window, in which solutions are still recorded, should be chosen with respect to the wavelength of potential anomalies. In general, 3D Euler Deconvolution yields results for each window position; therefore it is necessary to eliminate solutions with high uncertainties.

A reliable tool for the limitation of results is the specification of a threshold value for depth and horizontal uncertainties. Geosoft Oasis montaj reports the depth and location uncertainties as percentage of the depth below the recording sensor position. As matter of principle, low SI values are associated with source bodies which give rise to low gradients, thus depth estimation solutions with low SI values have high uncertainties. The data quality determines the general level of uncertainty, so an examination of the recorded solutions will define the selection criteria.

The consideration of appropriate solutions should be guided by two aspects. On the one hand, the position (and depth) anomalies should be kept low to improve the accuracy of the computations, on the other hand a sufficient number of solutions must be retained in order to delineate geologic features sought and

<table>
<thead>
<tr>
<th>sill</th>
<th>2 (x and y)</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>contact</td>
<td>3 (x,y,z)</td>
<td>0</td>
</tr>
</tbody>
</table>
provide meaningful solutions.

The results of the Euler method are displayed in ordinary maps as point solutions combining the location (position of solution) and the depth (colour range). Given the choice of an appropriate structural index, 3D Euler Deconvolution will lead to a clustering of solutions, which can be interpreted. A vertical pipe structure will for example be shown as a cluster of solutions around a specific point, whereas an elongated dyke structure will be recognized as a linear trend of solutions.

Another approach to limit the solutions obtained by the Euler method is the Located Euler 3D method, which, unlike the Standard Euler method, tests and limits grid locations before calculating depth estimations by Euler deconvolution. The Located Euler method calculates the analytic signal (3.10) and finds peaks in the analytic signal grid. The normal depth estimation by Euler Deconvolution is then only applied to these peak locations. As this method however produces far fewer solutions than the Standard Euler method, it is only applicable for very prominent anomalies and does not yield solution clusters.

\[ ASig = \sqrt{(dx.dx) + (dy.dy) + (dz.dz)} \]

\[ ASig = \sqrt{(dx.dx) + (dy.dy) + (dz.dz)} \]

............................................................................................................. (19)
CHAPTER THREE: RESEARCH METHODOLOGY

3.0 DATASOURCES

The aeromagnetic maps used for the study were obtained from the Geological Survey of Nigeria. The data were acquired and compiled by FAIREY SURVEYS LTD during an airborne geophysical survey between May to December, 1975. The nominal flying altitude above the terrain was 500 feet (approximately 152m) with flight line and tie-line spacing of 2km and 20km respectively. However, the flight and tie line direction is 150°/330° 60°/240° respectively. The regional correction of the magnetic data was based on IGRF (Epoch date 1 January, 1974). In order to obtain the actual total field magnetic data, 32000 gammas should be added to the contour values. Out of this, 25000 gammas represent the regional field while 7000 gammas are arbitrarily removed from the contour values.

The seven-band Landsat 5 TM image acquired on the 17th of December 2000, belong to a scene with Path number 188 and Row number 56. EROS EDC prepared and supplied the dataset in the new National Landsat Archive Production System (NLAPS), the National Data Format (NDF) to National Centre for Remote Sensing Jos. The image organization is in band sequential (BSQ) and the same data, in raster format, is presented in seven bands. Each scene was also radiometrically corrected. Four image scenes were mosaic, corrected for tonal
variations before being subseted to correspond to the coordinates of the study area.

3.1 DATA PROCESSING.

3.1.1 AEROMAGNETIC DATA

The first phase of digital processing of the contoured aeromagnetic total intensity field map on 1:100,000 scale was digitization. The map was digitized manually with a 2cm by 2cm (equivalent to 2km by 2km) grid spacing. The method of interpolation adopted, is the Kriging method. This method determines the most probable value at each grid-node from the surrounding real data values. This was done by noting the coordinates (X and Y) and magnetic value (Z), forming a XYZ file. This is continuously done at every grid-node interval across the flight-lines. This produces XYZ as text files. These are run a 2XYZ program of the United States Geological Service (USGS) Potential Field method (Version 2.2 software) and Surfer Software to convert the binary numbers to post files called PST files. The Detour program, a Fortran 77 program is launched to view the data on screen to check errors. The Detour program produces the minimum and maximum values of X, Y, Z and shows the contour intervals. Geocon program a screen viewing shows the contouring interval. Then finally the contour program plots the Command (cmd) file to produce a total magnetic intensity map (Fig.29). The reduction of magnetic data is important, in order to remove all causes of magnetic variation from the observations other than those arising from the magnetic effects
of the subsurface.

The contoured aeromagnetic data used for this study was obtained as part of the nation-wide aeromagnetic survey which was sponsored by the Geological Survey of Nigeria (GSN) and completed in 1976. Flight line direction was NNW-SSE at station spacing of 2km with flight line spacing of 2.0km at an altitude of about 150m terrain and a nominal tie line spacing of 20km. Tie lines were flown in an ENE-WSW direction. Regional correction of the magnetic data was based on the IGRF (epoch date of 1st January, 1974). For this study, eight (8) aeromagnetic sheets were used which covered the area within latitudes $7^000'$ - $8^000'$N and longitudes $7^030'$ - $9^030'$E. These maps are published on a scale of 1:100,000. The regional gradients were removed by fitting a plane surface to the data by multi-regression least squares analysis.

The aeromagnetic map was digitized by using a low pass filter across the flight lines with a spacing interval of 2km. The nature of filtering applied to the aeromagnetic data in this study was chosen to eliminate certain wavelengths and to pass longer wavelengths. Analytical methods used include 2D spectral inversion, trend surface analyses and second vertical derivative. Reduction-To-Pole filter was also used in analyzing the residual anomaly.

In this study, attempt has been made to estimate depth to anomalous sources within the area using: 2-D spectral analysis and some simple graphical depth rules such as Peters’ slope method (half-slope and maximum slope method), Peters’ error curve etc., Hannel’s rule, Tiburg’ rule and half-width rule. Although Peters’ slope method is widely used in our latitude, it is recommended to use in addition, Tiburg and Hannel rules. Onyekwere (1986), in his test of the validity of some aeromagnetic depth rules and their applicability in Nigeria (low magnetic latitude), opined that Peters’ slope method gives more reliable results.

In this work, Peters’ slope method has been used. It gives better result in the
middle and low magnetic latitudes. Alongside this rule, uses have been made of the Tiburg and Hannel rules to facilitate a comparison of results of depth estimate to with the result from Peters’ method.

3.1.2 LANDSATDATA

Landsat Thematic Mapper (Landsat-TM) imagery acquired on 29/03/2011 from NASRDA, Nigeria was used to map linear structures in the study area. The geo-reference projection was carried out using the universal Transverse Marcator (UTM). Image processing, enhancement and analysis were carried out using ILWIS 3.1 Academic software. Image enhancement operations carried out on the imagery include contrast stretching, spatial filtering and edge detection. ArcView 9.3 software was used to extract the lineaments and carry out statistical analysis of the interpreted lineaments in the area.
CHAPTER FOUR: RESULTSPRESENTATION,INTERPRETATIONAND DISCUSSION

4.1 LANDSATRESULTSAND INTERPRETATION

4.1.1 Results from TerrainAnalyses

A Digital TerrainModel (DTM) or Digital Elevation Model (DEM) was created in IDRISI 32 by performing a colour shaded operation on Shuttle Radar Topographic Mission (SRTM) data.

The DEM and the contour map of the area are shown in Fig.8 and 9. The highest elevations are represented by light green colour patches and as green contours on the DEM and contour map respectively. This feature is seen on the bottom left corner of the map. This feature is interpreted as sandstone ridge, running North-South direction. The ridge is suspected to be part of Oturkpo Ridge. The slope of the ridge is identified where light green, yellow and red colours are closely packed together; representing a sudden change in topography from 232 to 109 meters. The slope is characterized by numerous streams, gullies and a river. On the contour map, this area is marked by the intertwining of yellow, green and red contours.
Fig. 8: Digital Elevation Model (DEM)

The northern and southern portion of the DEM is dominated by dark blue to black coloured features, and red coloured patches sandwiched in between. This portion corresponds to elevation of 46 to 135 meters. This feature is interpreted as drainage channels. The EW trending feature represents the Benue River, while the NW-SE trending feature represents the River Katsina-Ala. On the contour map (Fig.9), these areas correspond to purple and blue contours.

It will be correct to interpret the topographic high areas as characterized by sandstone and the low areas as characterized by shale and mudrock. This is justified by the dendritic drainage pattern expressed in the low lying area, which points to an underlying clayey lithology. Geologically the area with dendritic pattern correlates to the Ezeaku group.
4.1.2 LINEAMENT INTERPRETATION

Lineaments are surface expression of subsurface deformation that reveals the hidden architecture of the basement rock. However O’Leary et al. (1976) defines lineament as a mappable, simple or composite linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ from the pattern of adjacent features and presumably reflects some subsurface phenomenon. In this study, the definition by O’Leary is applied and only linear features equal to or greater than 1km in length were considered. The longer lineaments have the greatest potential of being more fully developed and of penetrating greater depths.

The lineaments reveal two groups of linear features. The maxima having NE-SW direction and the others trending NW-SE directions. Umeji (1988, recognized Pan
African as characterized by NNW-SSE to NNE-SSW trending structures and varied intrusives and the lower Cretaceous, characterized by NE-SW oriented shear zones and fractures controlled by volcanism. Murat (1972) described three tectonic trends. The first, of Albian age gave rise to Abakaliki-Benue trough with NE-SW trending faults.

The lineaments image of the study area reveals that lineament traces were hardly seen along the drainage channels which suggest that they are of tectonic origin and not hydrographic. The NDVI reveals vegetation around the lineament clusters in a dendritic pattern. Lineaments having longer lateral extension show trend in the NE-SW, which indicates the direction of the last regional tectonic structures. Dense concentrations of lineaments are observed around Gboko, Gburuku and Ugba. This suggests that these areas are sites of intense tectonic activities and were strongly deformed.

Fig. 10: Lineament Map of the study area
Fig. 11: Lineament Density Map of the study area

Fig. 12: Azimuth Frequency (Rose) diagram of the study area generated from the Landsat Data [Number of data plotted = 99; Sector Interval Angle = 5°; Scale spacing = 3% (3 data) Maximum =14.6% (14 data); Mean Resultant direction = 032; Circular Mean Dev. = 44°]
Fig. 13: Lineaments on Filtered band 5

4.1.3 COLOUR COMPOSITES

The composites were generated mainly for enhancing spectral signatures of the image for the study area thereby enhancing the observation of the different stratigraphic units, thus helping in the interpretation of their features and limits.

NORMALIZED DIFFERENCE VEGETATIVE INDEX (NDVI) COMPOSITE

The NDVI relies on the chlorophyll content of a plant. This was generated to delineate zones of vegetation and bare rocks. Healthy plants have a higher value of NDVI because of their high reflectance of infrared light and relatively low reflectance of red light. A closer look on the imagery (fig.14) reveals that the dark brown areas (–0.37 to – 0.63) correspond to bare rock zones, light brown
areas (-0.31 to -0.37) correspond to soil + little vegetation, yellow areas (0.02 to -0.24) correspond to sparsely vegetated areas and green (0.02 to 0.42) correspond to thick vegetation.

**Fig. 14: NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) COMPOSITE**

From the NDVI (Fig.14) of the study area, it was discovered that areas around the western parts of the image have more of exposed rock zones. These areas include Otukpa, Otukpo, Adope, and Bopo. The eastern part which includes places like Gboko, Gburuku and Ugba are sparsely vegetated. Obangedde and the areas between Otukpa and Otukpo are seen to have dense vegetative cover. These areas fall within the dendritic pattern channels. Interpretation is based on the colour and pattern of features.
RGB 432

This composite clearly displays patterns in red and different shades of green. A dull green patch located in the extreme top NW of the map, also observable on the DEM, was as a sandstone ridge. Similarly other dull green patterns correspond to sandstone lenses or shows. There is a light green pattern seen around Otukpa and north of Otukpa towards Adoke. This same pattern is also seen around Oturkpo. The difference in the shades of green lies in the mineral content of the sandstone (Fig.15). The presence of sandstone lenses around Oturkpo and Otukpa suggests that Nkporo group has shale as well as sandstone beds within it.

![Figure 15: Colour Composite RGB432](image-url)
RGB 321

In this composite, bare soil is rendered in green, rivers in blue and vegetated areas in mauve (fig.16). Green spots are seen in some of the areas on the image which implies areas of sandstone lenses. Other patterns interpreted are same with the previous images.

Fig. 16: Colour Composite RGB 321
Fig. 17: Colour Composite RGB 531
4.1.4 DRAINAGE OF THE STUDY AREA

The drainage pattern of the study area is exhibited as a blue pattern, which corresponds to Benue River channel. The drainage system reveals the presence of streams that are seen as small red patterns, which are seen as dendritic pattern. The dendritic pattern suggests that the underlying sediment is a homogenous unit. Also dendritic pattern reveals that the lithology has least resistance to erosive action of the river and streams. Such litho-unit includes clay, mudstone, shale and limestone. These litho-units are covered within the areas underlain by Ezeaku Shale. This implies that the stream channels are covered with vegetation.
Fig. 19: Drainage Map of the area

Fig. 20: Edge Enhanced Band 5
4.1.5.0 Results from Image Classification

4.1.5.1 Unsupervised Classification of the Study area

The image generated from the unsupervised classification to a large extent gives a fair knowledge of the various geologic units in the study area. In unsupervised classification, the classification is tied around tonal differences of the pattern seen. In the study area, eight tonal features were observed. This classification becomes necessary when ground trotting was not done to ascertain the geology of the area.

Fig. 21: Unsupervised Classification Image

4.1.5.2 SHADED RELIEF MAP

The major features interpreted on the shaded relief displays coincide with and extend features located with other processing and interpretation tools. The eastern parts of the relief map (Fig. 22) show numerous spikes and undulations. On the
geologic map this corresponds to undifferentiated basement rocks predominant around Gboko, Gburuku and Ugba areas and extending to the South-eastern edge of the study area. The high elevations seen on the DEM around Obangede and Otukpa can also be seen on this shaded relief map while areas around the course of the Benue River are seen to be calm and unperturbed.

Fig. 22: Shaded relief map of part of the Middle Benue Trough, Nigeria

4.2.0 INTERPRETATION FROM AEROMAGNETIC DATA

The total magnetic field over the study area was obtained by digitizing eight (8) aeromagnetic maps (sheets 249, 250, 251, 252, 269, 270, 271, 272) supplied by the Geological Survey of Nigeria. Digitization was at 2 km. The resultant magnetic field over the area is shown as a contour map and other enhanced maps.

4.2.1 Spectral Depth Analysis of the Aeromagnetic Data of the Study Area
Spectral analysis of the aeromagnetic data was done using software that runs on MATLAB 7.0, developed by Odegard and Berg. For the spectral determination of depths to layers of magnetization, the study area was divided into thirty-two (32) blocks containing 14×14 data points. In doing this, adequate care was taken so that essential parts of each anomaly were not cut by the blocks. Care was also taken to ensure that each block contained more than one maximum, as suggested by Hahn et al (1976). In order to achieve this, the blocks were made to overlap each other. Graphs of the logarithms of the spectral energies against frequencies obtained for various blocks are shown in figure 23. Each of these plots present two clear linear segments (the first few points which represent contributions from much deeper sources have been ignored because of the reduced dimensions of the areas covered by these sections). The gradients of the linear segments were evaluated and equation (9) was used to calculate the depths to causative bodies. These depths are shown as $D_1$ and $D_2$ in table 2.
Fig. 23: Energy Spectra for Blocks taken over parts of the Study Area.
Table 2: Location and Magnitude of First and Second Layer Spectral Depths.

<table>
<thead>
<tr>
<th>SPECTRAL BLOCK</th>
<th>LONGITUDE</th>
<th>LATITUDE</th>
<th>DEPTH KM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_1$</td>
<td>$Y_1$</td>
<td>$D_1$</td>
</tr>
<tr>
<td>$X_2$</td>
<td>$Y_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agana A</td>
<td>0.00</td>
<td>25</td>
<td>3.0</td>
</tr>
<tr>
<td>Agana B</td>
<td>0.25</td>
<td>50</td>
<td>3.6</td>
</tr>
<tr>
<td>Agana C</td>
<td>0.00</td>
<td>25</td>
<td>3.1</td>
</tr>
<tr>
<td>Akwana A</td>
<td>3.00</td>
<td>25</td>
<td>3.9</td>
</tr>
<tr>
<td>Akwana B</td>
<td>3.25</td>
<td>50</td>
<td>4.1</td>
</tr>
<tr>
<td>Akwana C</td>
<td>3.00</td>
<td>25</td>
<td>4.2</td>
</tr>
<tr>
<td>Akwana D</td>
<td>3.25</td>
<td>50</td>
<td>4.2</td>
</tr>
<tr>
<td>Akwana E</td>
<td>3.50</td>
<td>75</td>
<td>5.0</td>
</tr>
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The first layer depth ($D_1$) is the depth to the shallower source represented by the second segment of the spectrum (Fig. 23). This layer ($D_1$) varies from 0.1km to 1.2km, with an average of 0.72km.

The second layer depth ($D_2$) varies from 2.1km to 5.5km, with an average of 4.1km. This layer may be attributed to magnetic rocks intruded onto the basement surface. Another probable origin of the magnetic anomalies contributing to this layer is the lateral variations in basement susceptibilities, and intrabasement features like faults and fractures (Kangkolo et al., 1997). It can be deduced that
the $D_2$ values obtained from the spectral plots represent the average depths to the basement complex in the blocks considered.

Depth to basement map estimated from spectral inversion of the area was generated (figs.32 and 33). The maps reveal the sedimentary thickness, as thinning towards the NE direction. This direction coincides with areas were the basement outcrops such as in the north-eastern parts of Akwana. The sedimentary thickness of this area ranges from 4.6km to 5.2km. The colour codes show the depth in km.

### 4.2.2 POLYNOMIALFITTING

From the total magnetic field obtained, the residual magnetic field of the area was calculated by removing the regional field over the area. The regional gradient was removed by fitting a plane surface to the data by multi regression least squares analysis. The expression obtained for the regional field $T(R)$ was:

$$T(R) = 76122.158 + 0.371x 0.248y$$

Where $x$ and $y$ are units of spacing. The regional field values are subtracted from the observed data to obtain the residual anomaly values. The technique is carried out on the aeromagnetic data of the study area to produce the first to fourth degree residual and regional trend surfaces (figs.24 and 25).

From Fig.24, it was discovered that the residual magnetic intensity of the study area ranges between -20 to 30 gammas. The figure above portrays the study area as of negative residual anomalies flanked by positive residual anomalies. The negative residuals area reflects zone of low magnetization while the positive residual anomalies reflects area of high magnetization. These negative anomalies surrounded by the elongated positive anomaly reflect high magnetization zone engulfed by the lower magnetization zone. The first, second, third and fourth residuals (Fig. 25) shows small clusters which indicate igneous intrusions, granitic
rocks, mineral bodies etc and that areas around Gboko and towards the far eastern parts of the study area have positive residual anomalies. This implies that shallow to near surface magnetized bodies exist in the area.

The regional fields establish the major tectonic elements of deeper and regional extent which affect and control the structural framework of the study area (Fig.24). First to fourth degree regional anomalies of the aeromagnetic data reveal a dominant regional trend NW-SE trends. This result is in agreement with previous studies which suggested that Nigeria has a complex network of fractures and lineaments with dominant trends of NW-SE, NE-SW, N-S, and E-W directions (Ananaba, 1991; Burke et al. 1971; 1972).

Fig. 24: First to Fourth Degree (polynomial) surfaces of the Regional fields of the Aeromagnetic data.
Fig. 25: First to Fourth Degree (polynomial) surfaces of the Residual fields of the Aeromagnetic data.

4.2.3 REDUCTION TO POLE

The effects of reduction to pole are manifested as shift of the main anomaly from the centre of the magnetic source and are due to vector nature of the measured magnetic field. It removes the effect of earth’s magnetic field. The shape of any anomaly depends on the inclination and declination of the main magnetic field of the earth. The reduction to pole filter reconstructs the magnetic field of a data set as if it were at the pole.

The reduction to pole of the total magnetic field intensity map of the study area reveal that there is a negligible shift or no change in the anomalies on reduction to the pole (Fig.26). This is apparent because the study area is a low latitude zone. The reduction to pole filter reconstructs the magnetic field of a data set as if it were at the pole.
**Fig. 26: Reduction to Pole of the Total Magnetic Field Intensity**
(contoured at 10nT).

### 4.2.4 THE SECOND VERTICAL DERIVATIVE

The closures seen on the zero contours of the second vertical derivatives (Fig.27) similar to the residual anomalies reflect area with similar lithology and shallow to near surface magnetized source bodies. Similar to the total magnetic intensity, it reveals lineaments with NE-SW trend. Analysis of the second vertical derivative map also shows prominence of felsic rocks in the eastern and extreme south-western parts of the study area.
Fig. 27: Second Vertical Derivatives of Zero contour map of the Study area.

4.2.5 Total Magnetic Field Intensity Map

The total magnetic field intensity map obtained after digitization of the contour map is presented as total field intensity map, image map, basement surface map and relief map (Figs. 28, 29 to 31).

From figures 28 to 31, magnetic anomalies of both short and long wavelengths are seen within the study area. These are represented by magnetic highs and lows. Areas with high magnetic intensity anomalies are seen on the western flank and around Gboko, Gburuku, Ugba and towards the extreme north-eastern parts of the study area. At Gboko, the intensity ranges from $7840\gamma$ to $7900\gamma$. These high intensity anomalies are interpreted as lineaments which may be an indication of part of the Gboko fault line due to the tectonic events on the basin. The presence of intrusions may also be suspected. Intrusions are described on the aeromagnetic
maps by elliptical or circular contours (Akanbi and Udensi, 2006). Towards the extreme south-western parts, magnetic intensities were as low as 7800γ which were then surrounded by increasing intensities up to 7860γ. This may depict a drop in the basement occasioned by faulting and subsequent subsidence. Fig. 28 indicates some of these faults that may be of regional scale. It is worth noting that most of these faults have a NE-SW orientation while others are aligned in the E-W direction as was indicated in the rose diagram analysis of the lineaments. This NE-SW predominant trend of magnetic lineaments is therefore in conformity with the Pan African orogenic trend and so would have played a major role in the control of the geo-dynamic evolution of the region. This dominant trend observed from the study area is suggested as the continental extension of the known pre-Cretaceous oceanic fracture zones viz: Chain and Charcot fracture zones (Ananaba, 1991) which runs along the trough axis beneath the sedimentary cover.

Fig. 28: Total Field of the Aeromagnetic Data presented as an Image Map contoured at 10nT (Gray Scale).

Fig.28 also shows two (2) sinistral faulting patterns with the speculated fault lines
indicated in red, one of which may be associated with the Gboko fault line. This further depicts that the blocks A1-A'1, A2-A'2 and A0-A'0 have all been shifted to the left relative to one another. An angular rotation of the blocks is also observed.

Elongated linear anomalies which could represent deformation of regional extent are seen around Gboko and towards the southwestern portion of the study area (Fig. 28).

The north central portion of the study area is depicted on the figures, as moderately low magnetic intensity. Sedimentary rocks and poorly consolidated sediments have much lower magnetizations (Hudson et al., 1999). This portion could be interpreted as sedimentary area with non magnetic materials. On the geology map of the study area, this covers the Awgu Shale group and the Ezeaku Shale group known for Limestone and mudstone.

The image map and the 3-D relief maps (Figs 30 and 31) show areas of high and low magnetic relief similar to those identified on the total field maps.
On the basis of the high elevation, Obangede, Otukpa, Gburuku, Gboko and Ugba could be described as tectonically active zones where tectonic events that led to the formation of the basin have been most evident and preserved.
Fig. 31: Total field of the aeromagnetic data presented as a wire frame map showing the basement topography.

Basement intrusions as seen around Gboko, Gburuku and Ugba areas indicates that sedimentary cover in this areas will be thinner than that along the stretch of the Benue river where there had been significant subsidence and a consequent overlaying of sediments over geologic time.
Fig. 32: Sedimentary Thickness Map Estimated from Spectral Inversion

Fig. 33: Depth to Basement (Sedimentary thickness) Map estimated from spectral inversion.

From the sedimentary thickness map (fig.32), an area of thick overburden ranging from 4.4Km to 6Km is seen sandwiched between shallower regions. The River Benue course follows the line of this thick overburden which are areas of least resistance, which is also indicative of the underlying geology (Alluvium). This
further emphasizes the graben and horst structure of the Benue Trough.

It can be seen on this image that sedimentary cover is thicker along the river Benue course showing there had been a significant rifting and depression followed by acute sedimentation. The sedimentary thickness thins towards the eastern, southern and western edges of the River course indicating areas of uplift during the rifting that initiated the valley. These areas include Obangede, Otukpa, Oturkpo, Ihugh, Gboko, Gburuku and Ugba.
Most of the areas studied have an average thickness ranging from 3.6Km to 5.7Km (Table 3.) except Gboko which is predominantly an active tectonic region with basaltic intrusions permeating the overburden. Further analysis however shows that some areas within Gboko still have depths to basement up to 4.7Km. This predisposes the graben and horst structure initiated by the Gboko fault line. Extended depression of the basement and subsequent infilling in these parts of Gboko account for the anomalous overburden thickness in those areas. Further studies may be initiated in these areas to evaluate the lateral expanse of this encampment as structures in this region including the Gboko fault are favorable conditions for hydrocarbon accumulation.
Fig. 34: Typical Magnetic Profiles taken across the Study Area
### Table 3: Average Depths to the Magnetic Basement Computed from Depth Estimation Methods

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<th>Town</th>
<th>Coordinates of Profiles</th>
<th>Depth Estimation (km)</th>
<th>Average Depth Width (km)</th>
<th>Amplitude Magnification</th>
<th>1% Radiation Magnetic Field Intensity</th>
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4.3 3-D EULER DECONVOLUTION

Figures 35 – 38 shows both the standard and located Euler deconvolution depth maps. For a better comparison of the obtained solution, only solutions in the depth range between 0m to 3000 m were kept, which entailed an elimination of a few spurious solutions. The Euler solutions used for the plots were gotten under the assumption of wide range of geologic models determined by contacts, dike and sill, pipes and spheres structures. Thus structural indices of 0 to 3 were used. While solutions were gotten for the standard Euler deconvolution, using the different structural indices, there is however a similarity in all the solutions. Thus the Euler Deconvolution suggests a depth of the source horizon of 0 m to a little above 3000m. Comparing these depth estimates with the information gotten from the spectral analysis, there is a positive correlation between the results from both depth estimation methods.
Fig. 35a: Standard Euler Deconvolution Depth Solution Plot Draped on the Colour Shaded Grid of the Total Magnetic Intensity of the Study area (Structural Index=0)
Fig. 35b: Standard Euler Deconvolution Depth Solution Plot Draped on the contour map of the total map intensity field of the study area (Structural Index=0)
Fig. 36a: Standard Euler Deconvolution Depth Solution Plot Draped on the Colour Shaded Grid of the Total Magnetic Intensity of the Study area. (Structural Index=1)
Fig. 36b: Standard Euler Deconvolution Depth Solution Plot Draped on the contour map of the total map intensity field of the study area (Structural Index=1)
Fig. 37a: Standard Euler Deconvolution Depth Solution Plot Draped on the Colour Shaded Grid of the Total Magnetic Intensity of the Study area. (Structural Index=2)
Fig. 37b: Standard Euler Deconvolution Depth Solution Plot Draped on the contour map of the total map intensity field of the study area (Structural Index=2)
Fig. 38a: Standard Euler Deconvolution Depth Solution Plot Draped on the Colour Shaded Grid of the Total Magnetic Intensity of the Study area. (Structural Index=3)
Fig. 38b: Standard Euler Deconvolution Depth Solution Plot Draped on the contour map of the total map intensity field of the study area (Structural Index=3)

3-D Euler deconvolution of the aeromagnetic data of the study area using different scenarios based on structural indices (structural index 0 for contacts, structural index 1 for sills and dikes, structural index 2 for horizontal cylinders and pipes, and structural index 3 for spheres), revealed standard Euler solutions. These solutions for the different structural indices revealed the same solution indicating the presence of these geologic models in the study area. The structural interpretation of the study area is therefore very complex with variable geologic features, typically dikes, sills, contacts, spheres in the form of ring dikes, etc.

The Euler deconvolution analysis revealed that contacts were observed at depths ranging from 500m to 3000m. Dykes and Sills were also observed at depths ranging from 500m to 3000m around the eastern parts of the study area and
towards the north western parts.

Indications for pipes and horizontal cylinders were even scantier and observed at depths of about 1500m to 3000m. Indications for spherical models were very sparse and range in depth between 1500m to 3000m.

4.4 DISCUSSION

The magnetic anomalies over the Middle Benue Trough are thought to arise from the existence of a stretched continental crust underneath the trough. This stretched crust may have been differentially block faulted, with variable thickness of sediments deposited on it and highly invaded with igneous intrusive bodies emplaced by magma rising up along the fault planes. Evidence of this is revealed along the course of the River Benue which has the thickest sedimentary fill in the study area while the adjacent flanks have lesser sediment thickness. Thus, in detail, the study area from this study is interpreted to be a structural junction evolved by faulting, block subsidence, folding and uplift.

Several research works have been carried out to decipher the behavior of rocks under influential stress factors (Anderson, 1951; Parsons and Thompson, 1993; Thompson and McCarthy, 1990). Rotation of rigid blocks or plates is commonly associated with tectonic processes and an interesting feature of all finite rotations of rigid blocks is that they are kinetically unstable, and the geometry of the blocks must change with time (Mckenzie & Jackson, 1988). Parsons and Thompson (1993) also asserted that intrusive magmatism can have severe effects on the local stress field of the rocks intruded. They suggested that igneous mid-crustal inflation occurring at rates faster than regional extension causes increased horizontal stresses in the crust that alter and rotate the principal stresses. Mantle-derived basaltic melts can erupt from high volcanoes, which imply that the magma intrudes the crust at pressures exceeding the lithostatic stress. Consequently, high-pressured melts can impose stresses rivaling the principal
stresses in the Earth and may change them (Rubin, 1990).

Fig. 28 shows elementary structural fault blocks $A_0 - A_1^0$, $A_1 - A_1^1$ and $A_2 - A_2^1$ and two traversing regional scale single faults shown in red. It is believed that faults often appear as set of more or less parallel fractures which move contemporaneously on long enough time scale, slip in the same sense and have similar offsets (Garfunkel, 1988). Such fault sets define domains, which are the simplest structural assemblages in faulted areas. The domains may be separated or delimited by major faults that are considerably longer and have greater slips than the faults within the domain. Within each domain, the fault blocks translate and rotate simultaneously, their motion being strongly governed by kinematic constraints (Garfunkel, 1988).

Rotation of rigid blocks or plates is commonly associated with tectonic processes. Relative to the domain boundary or to adjacent unfaulted areas, block rotation is always in the opposite sense to the fault slip within the domain. This block shifting (sinistral fault) may have been caused by igneous intrusions in the southeastern part of the study area around Gboko and environs. This upwarping of magmatic materials must have caused a rotational displacement of the original arms $A_2 - A_2^1$ from the initial NE-SW orientation to an E-W orientation in arms $A_0 - A_0^1$. Although the second arm of the block $A_1 - A_1^1$ did not reflect within the area covered by this study, it is believed that this second arm ($A_1^1$) of the block will be a few kilometers to the south of $A_1$. These faulted blocks show a NE-SW trend which may be attributed to the Chain and Charcot faults that transcends the Benue Basin. These blocks were however later tilted and rotated towards an E-W direction by regional-scale Gboko fault. Of particular interest is the equal distance between the various arms of the faulted blocks even after reorientation. The faults seen in Fig. 28 are those which can be said to be of a regional scale. This is the
A geological continuity of the Eze-Aku Group is also seen across the fault line although sinistrally displaced to the left. Geometric analysis shows that motion of sets of strike-slip faults should cause block rotation; otherwise the distorted fault domain would not fit with its surrounding. The sense of the block rotation depends on the sense of fault slip and the spacing and orientation of the faults, all of which can be obtained from structural data. The predictions of the geometric models can then be independently tested by paleomagnetic measurements. The results demonstrate large block rotations, in different senses, in domains of strike-slip faults.

The results of the present study are in good agreement with the interpretation of gravity anomalies over the trough (Catchley & Jones 1965; Adighije 1981; Ajayi & Ajakaiye 1981). The interpretation in terms of intrusive bodies can be justified from the available geological information within the trough. Ofoegbu (1983) indicated that outcrops of sediments from SW Gboko to Awe contain numerous minor intrusions whose composition range from intermediate to basic. Furthermore, a positive gravity anomaly over Gboko has been interpreted in terms of an intrusive body of probably intermediate composition having a width of 30Km and a depth of 5Km. Thus, in summary, the study area as interpreted from this work is believed to be a structural junction evolved by faulting, block subsidence, uplift, folding and emplacement of intrusive bodies.

CHAPTER FIVE: SUMMARY, CONCLUSION AND
RECOMMENDATION

5.1 SUMMARY

Insights from this work have shown that the study area is an intermediate zone cutting from sedimentary into basement complex environments. The western parts were predominantly calm with lower basement uplifts and intrusions whereas the eastern areas around Gboko and adjoining towns are more tectonically impacted during geologic time.

Results from the aeromagnetic and Landsat data have also shown predominantly NE-SW trending lineaments which is synonymous with the chain and charcot relief of the African orogeny, with fewer older ones trending NW-SE, E-W and N-S directions. The average sedimentary thickness of 3.9Km and structural signatures such as faults observed within the study area therefore indicates that these areas may be conducive for hydrocarbon generation and entrapment. The eastern parts of the study which includes areas such as Gboko, Gburuku and Ugba where high tectonic indications were eminent and high basement reliefs were observed could also be prominent sites for mineral exploration due to the presence a high density of crosscutting fractures and lineaments within the area. Analyses of the lineaments also show some indication that there may have been possible block faulting and subsequent rotation of these blocks along axis of least resistance.

5.2 CONCLUSION

Results of this study have been able to delineate the basement morphology and topography of the area as indicated by the digital elevation models and the topographic contour map of the area. Significant structural features associated with the area have also been delineated and represented by the lineament map and the lineament density map. This shows that major lineament were concentrated
around the eastern parts of the area.

Wright et al., 1985 had reported that when all other conditions are favorable, the minimum thickness of sediments required to achieve threshold temperature for commencement of oil formation from marine organic remains would be 2.3km. Average depths of 4.1km observed within the study area gives evidence of possible hydrocarbon potentials in the area especially around the Makurdi axis. The results of the aeromagnetic data also demonstrate large block rotations, in different senses, in domains of strike-slip faults.

It is therefore pertinent to conclude that the eastern parts of the study area from the Gboko axis will be favorable for mineral exploration whereas areas to the west may hold significant potentials for hydrocarbon exploration.

5.3 RECOMMENDATION

Based on the results from this study, the following recommendations are necessary in order to further expand on the realizations here-made. That:

1.) Further works be carried using seismic reflection methods in other to delineate direct hydrocarbon indicators if present.

2.) Gravity and radiometric methods be also employed to respectively decipher the structural trends and mineral composition of the area.

3.) Further geochemical analysis of the area be carried out in order to further evaluate the presence and maturity of kerogen if any so as to further justify the hydrocarbon potentials of the area.

4.) Based on Euler deconvolution results, several sills and dykes were interpreted within the areas which are believed to be intrusives. Efforts should therefore be made to ascertain the quality, quantity and recoverability of the resources for their economic potentials as quarry sites.
5.) The predictions of the geometric models of block rotations can be further tested by interpretation of paleomagnetic measurements taken from outcrops in the study area.

REFERENCES


Bala, A.E., Batelaan, O., and De Smedt, F., 2000. Using LANDSAT 5 Imagery In


Physics, Vol.19, No. 2, pp. 285-301


Ibadan, Nigeria.


Wenmenga, U., 2005. Landsat and Aeromagnetic interpretation of the structural


APPENDICES

MAGNETIC PROFILES OVER SELECTED LOCATIONS IN THE STUDY AREA
Gboko A-A'
La77°02'N;Long.8°40'E-8°42'E

Gboko B-B'
La77°20'N;Long.8°31'E-8°33'E

Gboko C-C'
La77°22'N-77°23'N;Long.8°31'E-8°33'E

Gboko D-D'
La77°19'N;Long.8°41'E-8°43'E
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**106**
Spectral plots of Agana aeromagnetic sheet sheet

Spectral plots of Akwana aeromagnetic sheet sheet
Spectral plots of Ankpa aeromagnetic sheet sheet

Spectral plots of Gboko aeromagnetic sheet sheet
Spectral plots of Loko aeromagnetic sheet sheet

Spectral plots of Makurdi aeromagnetic sheet sheet