FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

SUBDUING THE EARTH WITH EXPLORATION GEOPHYSICS: MY CONTRIBUTION

By

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INAUGURAL LECTURE SERIES 24

14TH NOVEMBER, 2012

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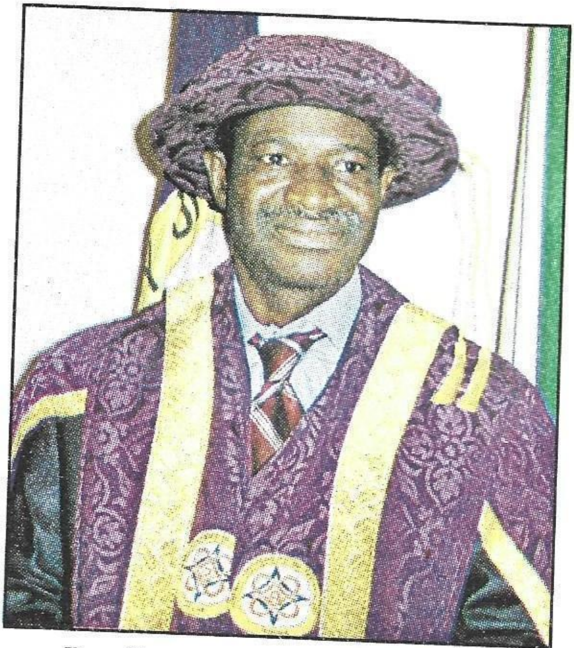

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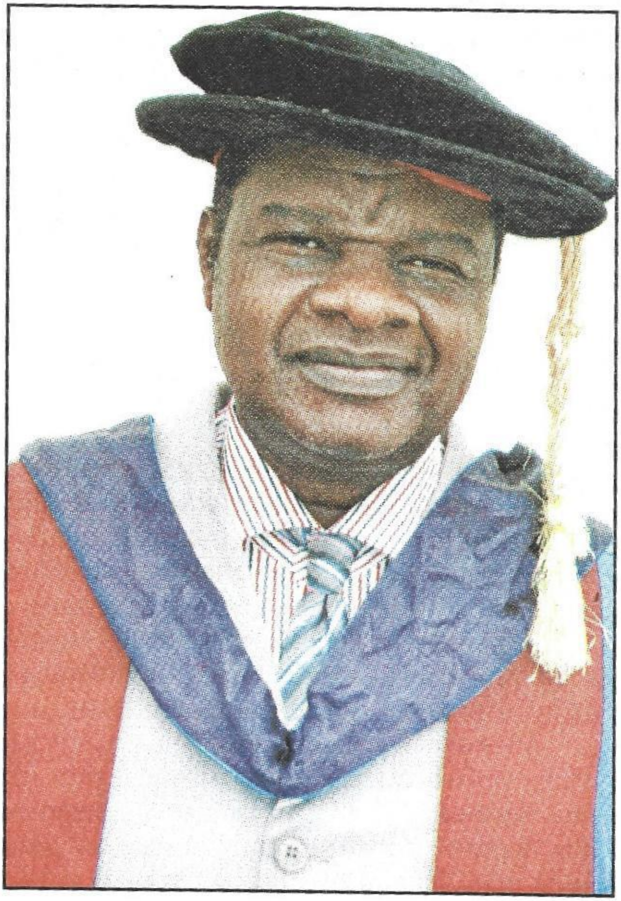

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1. Preamble

The Vice-Chancellor and other Principal Officers of the University, the Special Guest of Honour, the Deans of Schools, Directors, Professors, HODs and Unit Heads, members of the university community and invited guests, great FUT Minna students, distinguished ladies and gentlemen, I give the Almighty God all the glory for making today a reality to me. It is indeed quite a memorable day in my career as a University teacher. When I was the Chairman, University Seminar and Colloquium Committee, within whose purview resides the organization of inaugural lectures, I was challenged times and times again to present my inaugural lecture since I became a Professor. I give God praise that today I am presenting the 24th inaugural lecture of this great University and indeed the first inaugural lecture from the Department of Physics.

2. God

In the beginning God created the earth. Long after this He created man. At creation, God commanded man to '*be fruitful and increase in number, fill the earth and subdue it*', (Gen 1:28). I am particularly concerned with the word subdue. Subdue means to conquer, overcome or bring under control. God therefore expected man to overcome, exploit and control the earth. Since the word subdue was used together with the command to '*fill the earth*' it appears to me that subduing the earth is part of God's ways of providing for the population He intended to fill the earth with. Activities of men on earth must be seen in this light for the world to be a happy place. We are created to subdue the earth, make it a better place for the benefit of all. God did not command us to subdue man; cheat him, deprive him, kill him etc but rather to subdue the earth in order to uplift man. My topic, *Subduing The Earth With Exploration Geophysics: My Contribution* is essentially a record of what I have done in obedience to God's command, '*subdue the earth*'.

3. The Earth

Broadly speaking, the earth consists of two parts, the solid earth and the atmosphere surrounding it. The earth's atmosphere consists of a large mass of gasses held close to the solid earth by force of gravity. However, this lecture will not be interested in the earth's atmosphere, but will be discussing the solid earth (actually only a little part of it).

The earth's equatorial radius is 6378 Km and its polar radius is 6357 Km. The surface area is 5.1×10^8 Km^2 of which only 29% is land. The structure of the earth can be defined in two ways: by mechanical properties such as rheology, or chemical properties. Mechanically, it can be divided into lithosphere, asthenosphere, mantle, outer core, and the inner core. Chemically, the earth can be divided into the crust, upper mantle, lower mantle, outer core, and inner core. The geologic component layers of the earth are at the following depths below the surface:

LAYER	THICKNESS (KM)
CRUST	0 – 35
LITHOSPHERE	0 – 60
UPPER MANTLE	35 – 660
ASTHENOSPHERE	100 – 200
LOWER MANTLE	660 – 2,890
OUTER CORE	2,890 – 5,150
INNER CORE	5,150 – 6,360

The layering of Earth has been inferred indirectly using the time of travel of refracted and reflected seismic waves created by earthquakes.

Figure 1 shows the earth with exposed interior revealing the crust, upper and lower mantle and outer and inner core while Figure 2 is a vertical section through the earth.

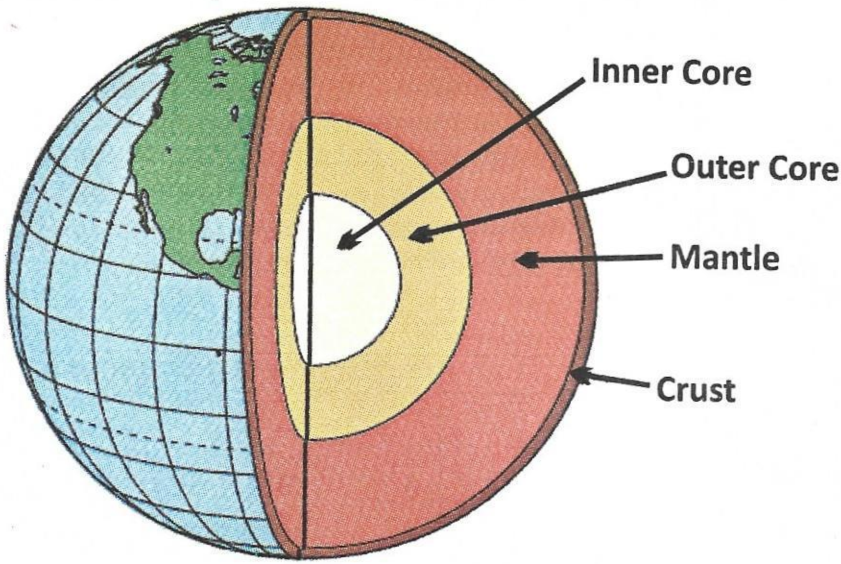


Figure 1. The Structure of the Earth

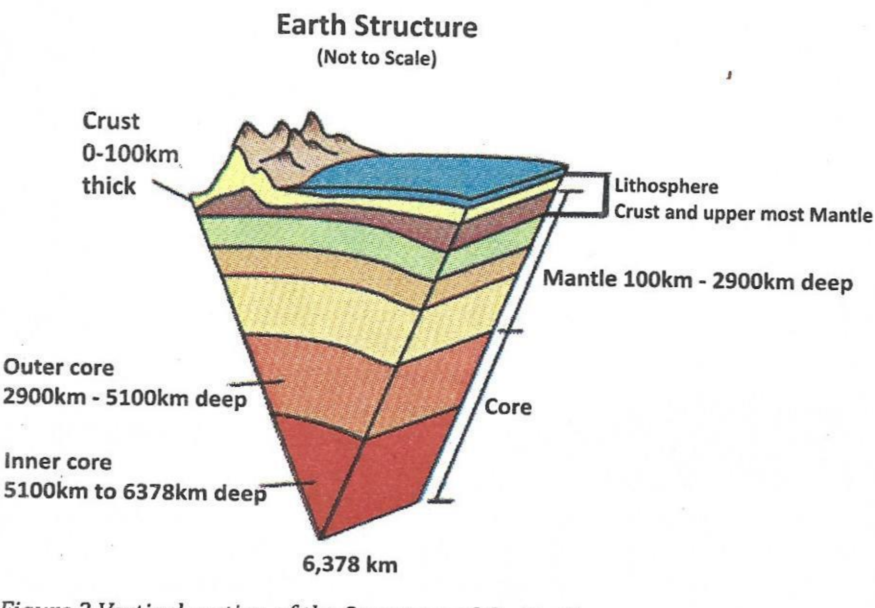


Figure 2 Vertical section of the Structure of the Earth
Source: en.wikipedia.org/wiki/Structure_of_the_Earth

4. Exploration Geophysics

Broadly speaking geophysics is the study of the interior of the solid earth, particularly its structure, composition and behaviour by the application of the principles of Physics. Exploration geophysics is limited to the study of the upper crust, that part of the earth where ore bodies, hydrocarbon, groundwater, etc are found. Exploration geophysics is the applied branch of geophysics which uses surface geophysical methods to measure the physical properties of the earth's subsurface, in order to detect or infer the presence and position of ore minerals, hydrocarbons, geothermal reservoirs, groundwater reservoirs, and other geological structures. Geophysical investigation involves taking measurements on or near the surface of the earth that are influenced by internal distribution of physical properties. Analysis of these measurements can reveal how the physical properties of the earth's interior vary vertically or laterally.

The cardinal point in applied geophysics is to add a third dimension to geological maps. The trained eye of the field geologist is replaced with the scientific instrument whose function is to detect changes in the physical properties of rocks which lie concealed beneath the surface of the earth. Thus, geophysics involves the study of those parts of the earth hidden from direct view by measuring their physical properties with appropriate instrument either from space, on the surface or in the borehole. An alternative method of investigating subsurface geology is the drilling of boreholes, but this can be very expensive and provides very limited results. Exploration geophysics provides a relatively rapid and cost effective means of deriving information on the distribution of the physical properties of a given subsurface geology. Exploration geophysics does not cancel the need for drilling but rather optimizes exploration programmes by maximising the rate of ground coverage and minimizing the need for drilling.

Many of the methods used today in exploration geophysics were developed from methods used in military war fares, particularly during the first and second world wars. These methods were used in locating large stockpile of guns, submarines, etc. Today, a wide range of geophysical exploration methods exists, each of which has a physical property of the earth to which it is sensitive. The methods are listed in Table 1.

(Table 1. Geophysical Exploration Methods, Kearey *et al.*, 2003)

METHOD	MEASURED PARAMETER	OPERATIVE PHYSICAL PROPERTY
Seismic	Travel times of reflected or refracted waves	Density and elastic moduli
Gravity	Spatial variation in the strength of the gravitational field of the earth	Density
Magnetic	Spatial variation in the strength of the geomagnetic field	Magnetic susceptibility and remanence
Electrical resistivity	Earth resistance	Electrical conductivity
Induced polarization	Polarization voltages or frequency dependent ground resistance	Electrical capacitance
Self potential	Electrical potentials	Electrical conductivity
Electromagnetic	Response to electromagnetic radiation	Electrical conductivity and inductance
Radar	Travel times of reflected radar pulses	Dielectric constant
Radioactivity	Radiation pulses	Decay rate

Most of the wealth of the earth is found inside the earth and thus exploration geophysics has been a strong tool in the betterment of human life here on earth. Continuous improvement in geophysical methods has led to more wealth for human use. For example, Table 2 shows world oil production in 1940.

Table 2. Crude Oil Production in 1940 by Geographic Region (Wilson, 1941)

GEOGRAPHIC REGION	BARRELS PRODUCED PER DAY	PERCENTAGE OF TOTAL
USA	3,692,000	63.0
Mexico, Canada, etc	866,000	14.0
Soviet Union	593,000	10.1
Middle East	335,000	5.7
Netherlands East Indies	166,000	2.8
Romania	118,000	2.0
Germany, Poland, etc	43,000	0.7
Rest of the World	49,000	0.8
TOTAL	5,862,000	100.0

By 2010, 115 countries were producing a total of 87,500,000.00 bbl/day. Figure 3 shows the spread of oil producing nations of the world.

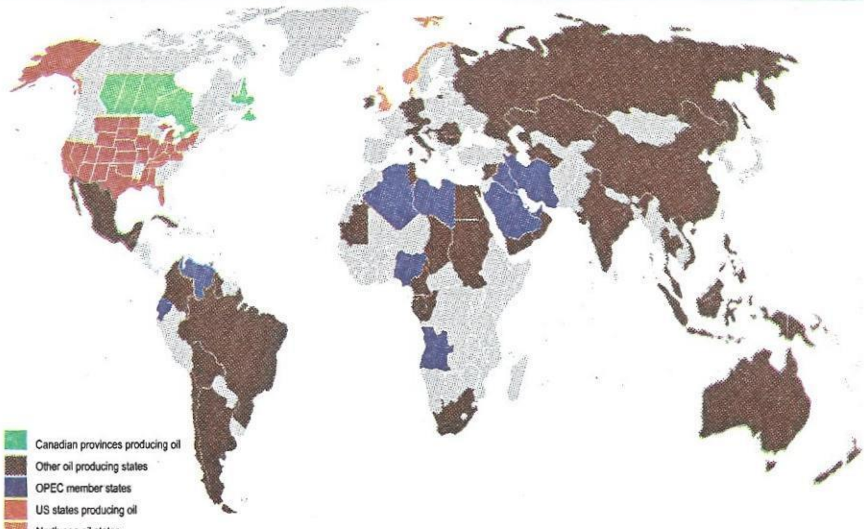


Figure 3. Oil producing nations of the world

Nigeria, which was not an oil producing nation in 1940, is today well grounded in successful oil exploration. It began with the first commercially viable discovery at Oloibiri in the Niger Delta in 1956, with a modest production rate of 5,100 barrels per day. Reserves of crude oil stand at 28.2 billion barrels and Natural gas reserves total 165 trillion standard cubic feet (scf), including 75.4 trillion (scf) of non-associated gas. With a maximum crude oil production capacity of 2.5 million barrels per day, Nigeria ranks as Africa's largest producer of oil and the sixth largest oil producing country in the world. Nigeria appears to have a greater potential for gas than oil. Nigeria's gas production in the year 2000 was approximately 1,681.66 billion scf, 1,3715 billion scf was associated gas and the rest 310.16 billion was non-associated gas (NNPC, 2012).

5. The Structural Setting of Minna Area

My first research as a geophysicist was a gravity survey that I carried out in the Minna area in 1983 to 1984 as a Masters Degree student at Ahmadu Bello University, Zaria. Ajibade (1980) suggested that the Older Granite suite upon which Minna was sitting was a Batholith from his field observations as a geologist. A Batholith is a large discordant plutonic mass, usually granitic or granodioritic in composition, more than 100 Km^2 in area and with visible or clearly inferred floor. I was to confirm or refute this suggestion by investigating the deep structure of the Older Granite suite and suggest its origin and mode of emplacement, (Udensi *et. al.* 1986). The Minna area (Figure 4) lies within latitudes 9^0 25'N and 10^0 5'N, and longitudes 6^0E and 7^0E. Minna the capital of Niger State is located at the southern part of the area. The area is approximately 6000 Km^2 in the area.

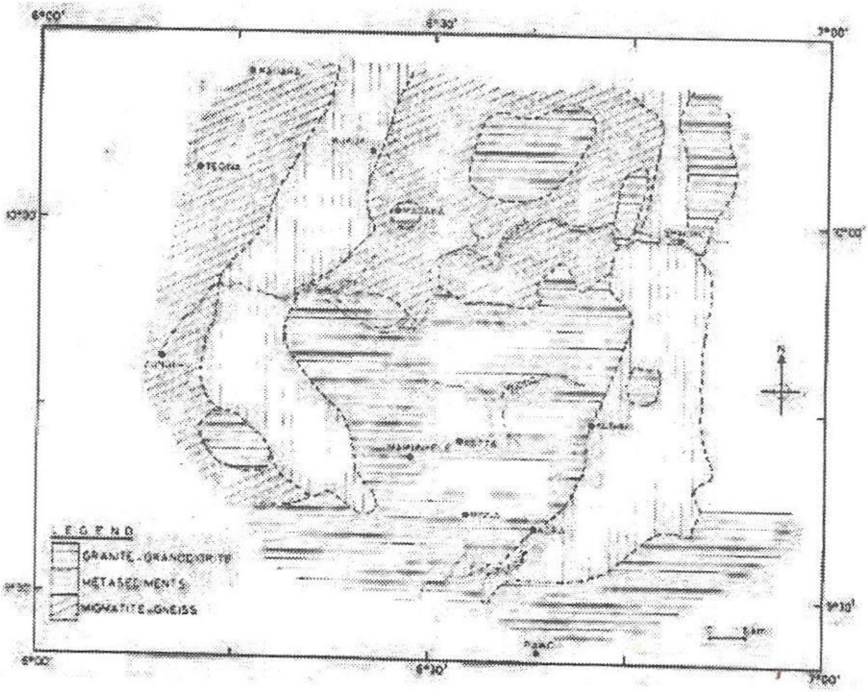


Figure 4. Simplified geology map of the Minna area showing the major rock types and towns. The Birnin Schists Formation is on the left side while the Kushaka Schists Formation is on the left.

Source: Ajibade (1980)

The field work for this study was carried out during two field trips in November – December 1983 and in February 1984. Two gravimeters were used: a LaCoste–Romberg gravimeter and a Worden gravimeter. While the LaCoste–Romberg gravimeter was used in establishing the base stations the Worden gravimeter was used for the detailed survey. A total of 28 base stations and 247 detailed stations covered the survey area. The base stations were established within easily identifiable landmarks such as school compounds, road junctions, milestones etc. Standard corrections were applied to field readings and these were reduced to Bouguer anomalies using a simple computer programme. The regional gravity field was constructed by taking several profiles in the NW–SE direction perpendicular to the long wavelength trend which is apparent in the Bouguer anomaly map. The values of the regional field obtained showed that the regional field in this area has a NE–SW trend and an average gradient of 0.12 mGal/Km to the southeast. Figure 5 shows the residual anomaly map, obtained by subtracting the regional fields from the Bouguer anomaly map, superimposed on the simplified geological map of the area. Two profiles, A-A' and B-B' which were chosen across and along the general strike of the contour trends are also shown in Figure 5. Figure 5 shows that the main concentration of the older granite body is at the central part of the map. The Birnin Gwari Schists in the west and the Kushaka Schists in the east of Figure 5 show significant positive residuals while the granite suite shows negative residuals.

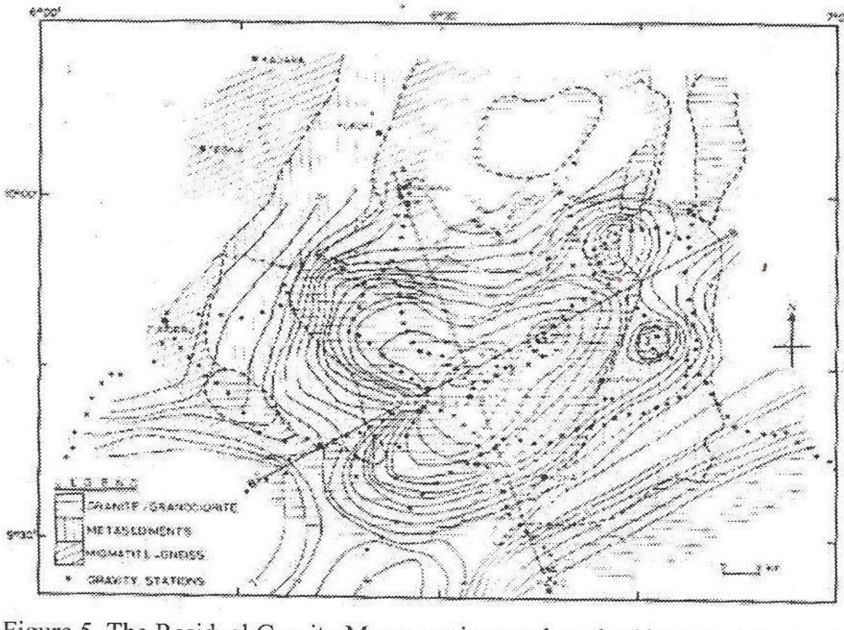


Figure 5. The Residual Gravity Map superimposed on the Simplified Geological Map of the area. The Contour Interval is 2 mGal.

Two residual profiles A-A' and B-B' (figure 5) were quantitatively interpreted for the major granitic intrusion and the surrounding schists and mylonites. Gravity values for a given model were computed at 2 km intervals along each of the two profiles, and approximately 80 systematic trials and adjustments were carried out to obtain the models described below. The vertical sections across profiles A-A' and B-B' are shown in Figures 6a and b.

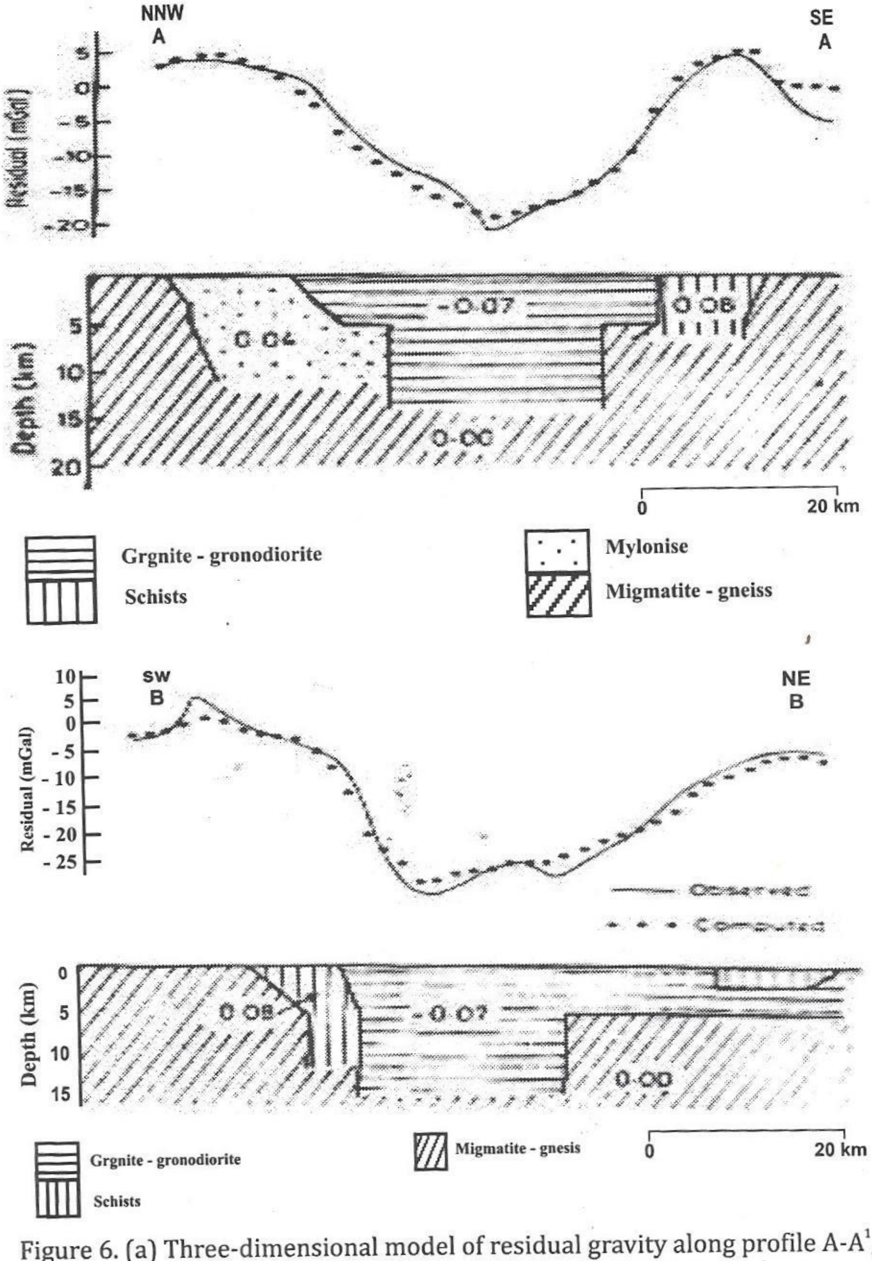


Figure 6. (a) Three-dimensional model of residual gravity along profile A-A[1], (b) Three-dimensional model of residual gravity along profile B-B[1]

Figures 5 and 6 shows that the strike length of the granite body is approximately 72 km and its shortest and longest surface widths are 24 km and 44 km, respectively. The general thickness of the suite over a large area is 5 km. The model suggests that granite suite dips inwards at angle of 65° and 60° in the northeast and southwest, respectively; 50° inwards in the north; and has an onward dip of 27° in the south. The contact with the Kushaka schists on the eastern side continues to a depth of 1.8 km, and on the western side, the contact with the Birnin Gwari schists is steep and continues to a depth of 5 km.

It was therefore our view that the Older Granite suite was formed by magma which initially intruded the middle crust along three conduits represented by the three deep plugs, and later started to spread more laterally through the migmatite-gneiss complex at a depth of 5 km. The close association of the schist formations with the granites, and the inferred sharp contact between them, suggest that the ancient margins of these formations probably were zones of weakness through which the magma initially ascended. This view is supported by geological evidence, notably the abundance of xenoliths and magmatic breccia, and the presence of contact aureoles with the development of contact metamorphic minerals (Ajibade, 1980). The contact relationship between the Older Granite rocks and the schists also indicate that stopping played an important role in the emplacement of the granite body.

6. The Search for Groundwater in the Minna Area

What is of immediate importance in the above study is its implication for groundwater supply in Minna, the capital city of Niger State and its surrounding environment.

Groundwater-bearing formations that are sufficiently permeable to transmit and yield water in usable quantities are called aquifers. By far the most common aquifer materials are unconsolidated sands and gravels (Figure 7) which occur in alluvial valleys, old stream beds covered by fine deposits (buried valleys), coastal plains, dunes, and glacial deposits. Sandstones also are good aquifer materials. Basement rocks; granite, gneiss, and other igneous and metamorphic rocks generally do not make good aquifers. The Basement Complex of Nigeria is a heterogeneous mixture of crystalline rocks, predominantly of a granitic or gneissose character. Groundwater occurs within these crystalline rocks in fractured or in the superficial weathered zones, Figure 8.

Figure 7. Gravel

A fracture is any local separation or discontinuity plane in a geologic formation, such as a joint or a fault that divides the rock into two or more pieces. A fracture will sometimes form a deep fissure or crevice in the rock. Fractures are commonly caused by stress exceeding the rock strength. Fractures can provide permeability for fluid movement, such as water or hydrocarbons. Highly fractured rocks can make good aquifers or hydrocarbon reservoirs, since they may possess both significant permeability and fracture porosity.

Our study of the structural setting of Minna (Udensi *et. al,* 1986) has shown that Minna lies on top of a Batholith. Groundwater can only therefore occur in Minna area in fractured systems or weathered zones.

Figure 8. Fractured Basement formation

To find groundwater in such an area requires a detailed resistivity or seismic refraction survey. The resistivity survey will detect low resistive water bearing zones that can constitute an aquifer. The seismic survey on the other hand will detect the depth of consolidated basement rock which is usually characterised with high velocity. The resistivity of rocks is strongly influenced by the presence of ground water, which acts as an electrolyte. This depends on the fraction of the rock that consists of pore spaces (the porosity) and the fraction of this pore volume that is water filled (the water saturation). The conductivity of the rock is proportional to the conductivity of the ground water; which is quite variable because it depends on the concentration and type of dissolved minerals and salts it contains.

The large contrast in resistivity between water bearing formations and their host rocks is exploited in electrical resistivity surveying. In electrical resistivity surveying the variations in subsurface conductivity alter the pattern of electric current flow in the ground thus changing the electrical potential distribution at the surface. Due to considerable variations in electrical resistivity of bedrock and water bearing overburden (aquifer) the resistivity method can be used to detect this overburden, determine their thickness, relative position and depth under the surface.

Irrespective of the electrode configuration employed, in resistivity survey, there are two ways of investigation used with each of the electrode configuration. They are: Lateral profiling (mapping or trenching) and vertical electrical sounding (VES or drilling) (Telford *et al.*, 1999). The choice of which electrode configuration to use depends on the problem at hand; either investigation of lateral changes in resistivity or investigation of variations of resistivity with depth. Electrical profiling is the fastest and the quickest way of getting the general idea of resistivity spread of the survey area, which may likely give some clue of those points that are to be further probed with VES. Figure 8 shows a typical resistivity field setup and Figure 9 shows the typical profile layout for data collection.

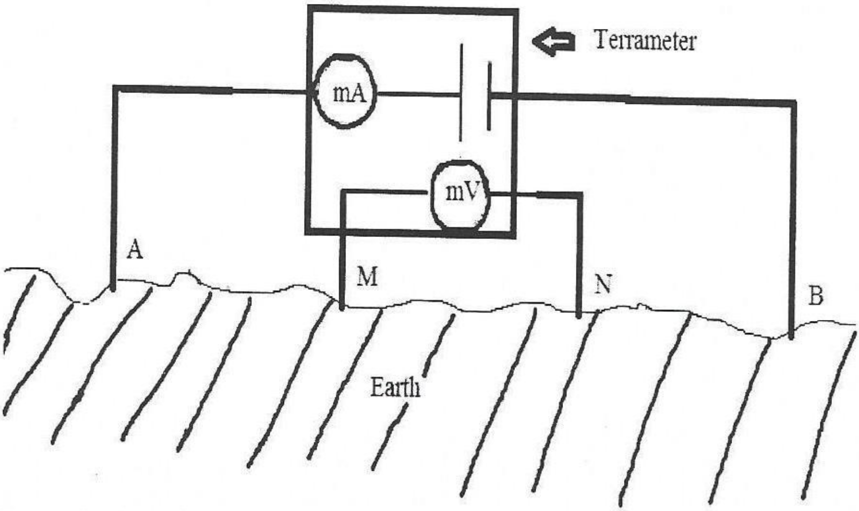


Figure 8. Generalized form of Electrode Configuration for Resistivity Survey

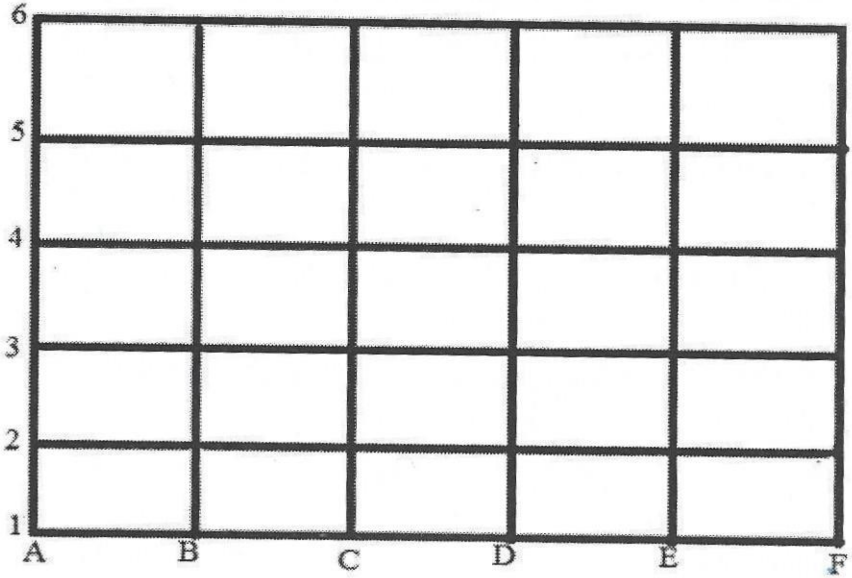


Figure 9. The profile layout for resistivity data collection Lines A, B, to F are profiles while points 1 – 6 are the VES points.

To find water in the structural setting of Minna the profile and VES interval must be low enough so that fractures could be detected. We recommend profile and VES intervals of not more than 50 m. We have done a number of surveys in Minna, Bida and in Nassarawa state in search of groundwater. Some of the surveys include, Udensi *et. al,* (2003), Salissou *et. al,* (2003), Shuiab, *et. al.,* (2004), Udensi *et. al,* (2005), Udensi *et. al,* (2006), Alfa *et. al,* (2007), Mohammed and Udensi (2008), Salako *et. al.,* (2009), Alhassan *et. al.,* (2010), Chikelu (2011), Omale (2011), Daniel (2011), etc.

Figures 10 to 12 shows typical vertical geologic and electrical sections that are usually observed in groundwater resistivity study. The plots resulted from some of our survey for groundwater at the Gidan Kwano Campus of this University and other places.

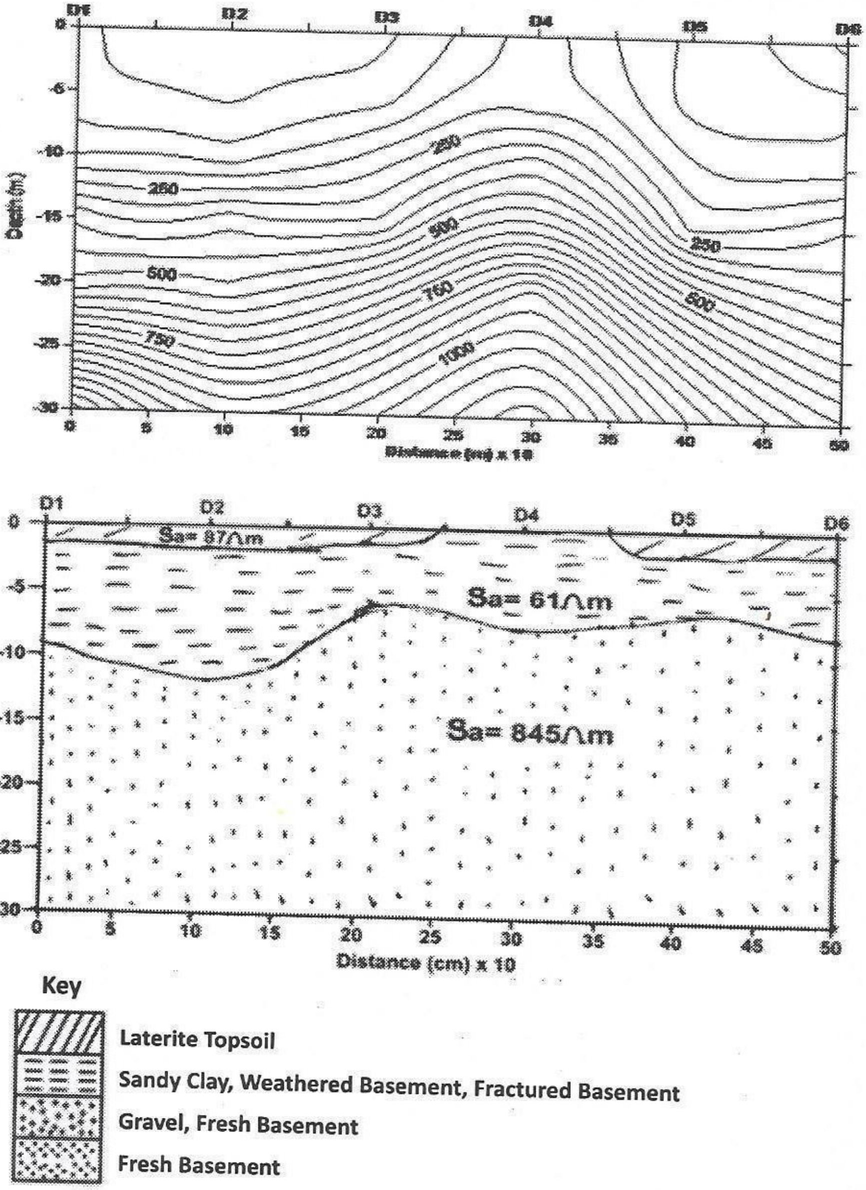
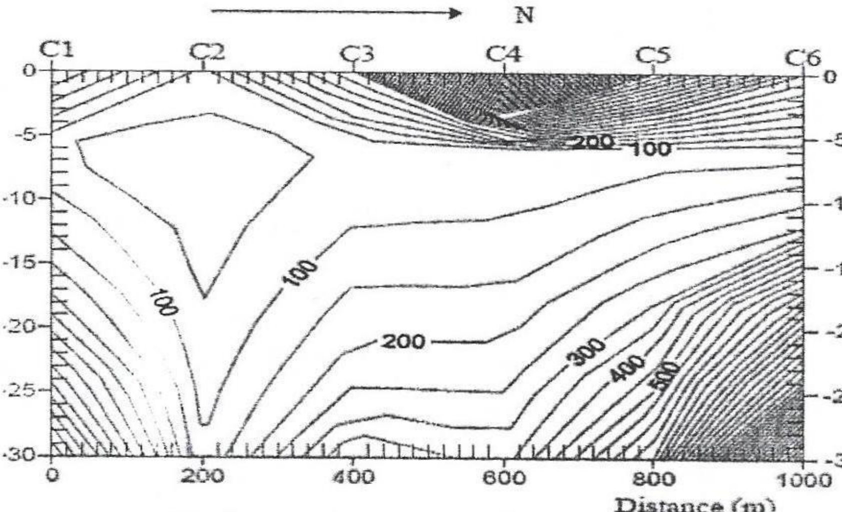
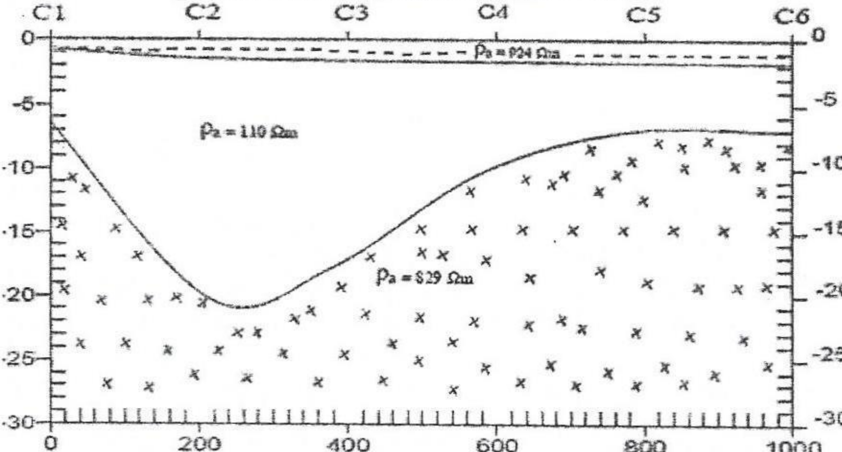


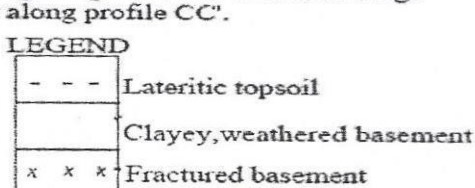
Figure (10a and b) Vertical Section (Resistivity and Geologic) of profile D
Source: Chikelu and Udensi, 2010



Vertical section of subsurface resistivity map through profile CC'. Contour interval = 50 Ωm



Subsurface geologic section with its average resistivity along profile CC'.



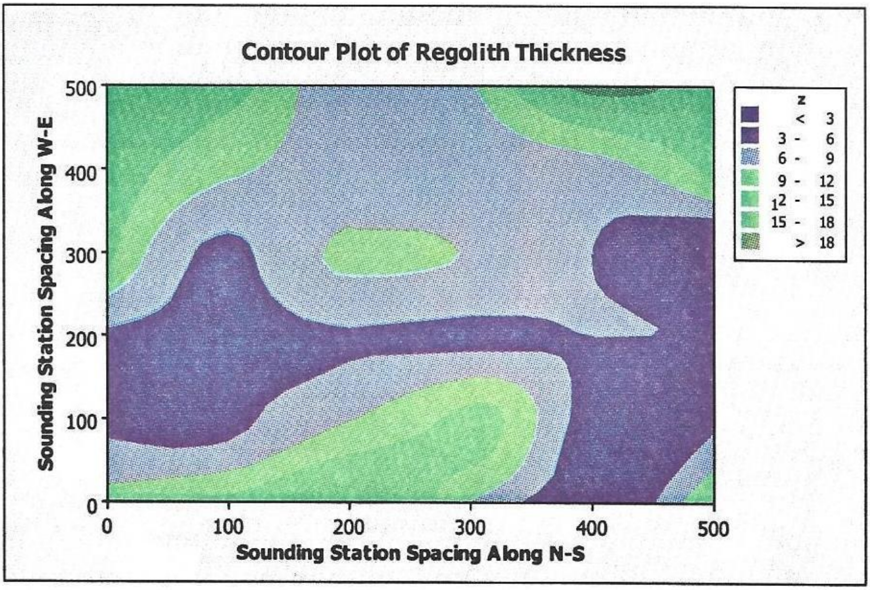


Figure 12a. Contour Plot of Regolith Thickness.

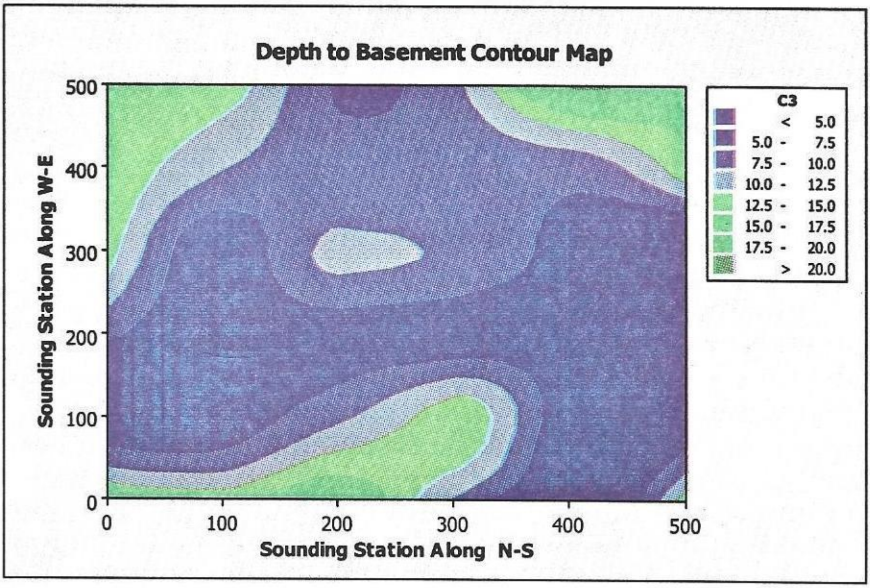


Figure 12b Depths to Basement Contour Map
Source: Omale and Udensi, 2010

7. Inland Basins of Northern Nigeria and Petroleum Resource Potentiality

The distribution of sedimentary basins in Nigeria is shown in Figure 13.

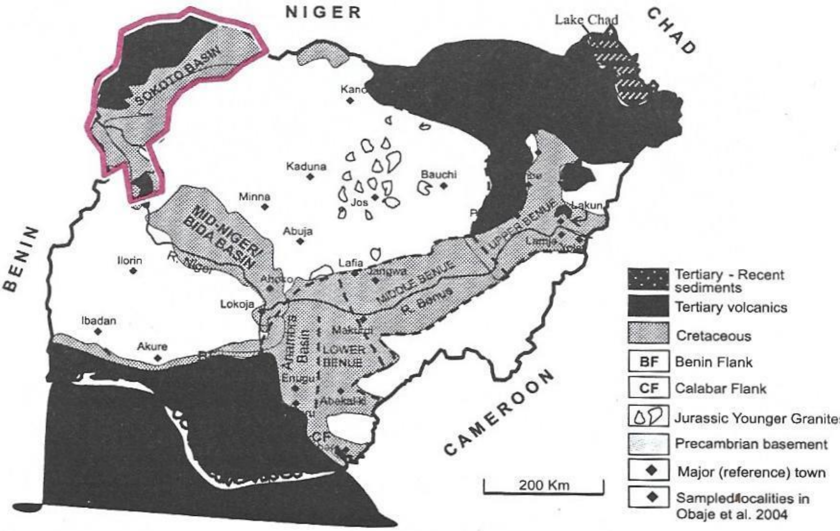


Figure 13. Sketch geological map of Nigeria showing the inland basins of Nigeria
Source: NGSA, Abuja

The conditions that generally favour petroleum formation are the existence of a sedimentary basin filled with thick sequences of sedimentary rocks. Abundant organic matter-type within the fine-grained source rock that is capable of generating the hydrocarbons which must have been rapidly deposited in an anoxic marine environment. This must be overlain by a porous and permeable coarse-grained reservoir rock that contain the required trapping structures/ mechanisms and the necessary migration pathways with a non-porous and non-permeable dense cap-rock overlying the reservoir rock which prevent escape of the hydrocarbons trapped in the reservoir rock, (Figure 14).

CONDITIONS NECESSARY FOR HYDROCARBON GENERATION AND ACCUMULATION

Source rock lithology = Shale or Carbonate (the darker the better)

Organic richness: TOC > 0.5wt%, HI = 50 – 150 mgHC/gTOC (Gas), > 150 mgHC/gTOC (Oil)

Temperature: May manifest in depth of burial and geothermal history:
Tmax = 435 – 450°C (Oil, Oil & Gas), > 450 °C (Gas)
Ro = 0.6 – 1.2% (Oil, Oil & Gas), > 1.2% (Gas)

Reservoir rock lithology = Sandstone or Carbonate (the more porous and permeable the better)

Migration: May be vertical or lateral from source to reservoir

Traps: Structural and/or Stratigraphic

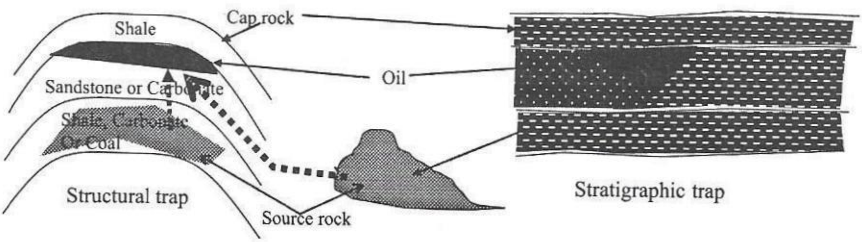


Fig 14 Sketch showing appropriate condition for petroleum generation

The Niger Delta and the Anambra Basin are the two petroleum producing basins with sequences of good source and reservoir rocks as well as hydrocarbon traps. They have sequence of sediments of over 12,000m thick deposited by marine transgressive and regressive cycles. These sediments serve as source and reservoir rocks as well as have the required trapping structures and mechanisms and migration pathways. The upper Benue trough and the Bornu Basin have been proven to have stratigraphic continuity with the main part of the Termit Basin in eastern Niger Republic with potential hydrocarbon source and reservoir rocks as well as trap possibilities, in which some successful wells have been drilled.

The well established exploitation of petroleum resource in the productive Niger Delta since the late 1950s has largely dampened efforts at exploring other parts of the country particularly the inland basins of northern Nigeria, Benue trough, Bida, Sokoto and Bornu or Chad basins. This is in addition to the negative conclusions drawn from earlier attempts made in these basins by oil companies. It is however gladdening to note that interest is shifting to these areas in recent times. We have been part of the NNPC recent efforts in the Bida and Sokoto Basins.

7.1 The Bida Basin

The Bida Basin is an elongated NW-SE trending block situated at the centre of west-central part of Nigeria (Figure 15). It is bounded by latitudes 8° 00' N and 10° 30' N and longitudes 4°30'E and 7° 00'E. The Bida Basin is a gently NW-SE trending intracratonic sedimentary basin extending from Kotangora in Niger State of Nigeria to areas slightly beyond Lokoja in the South. It is delimited in the Northeast and Southwest by the basement complex while it merges with Anambra and Sokoto basins in the northwest and southeast respectively. It is filled with Campanian-Maestrichtian sediments comprising mainly of sandstones and a few marine sediments. The basin is underlain by crystalline rocks of Precambrian to possibly Palaeozoic basement complex the oldest of which are the gneisses and migmatites (Adeleye, 1976).

Geophysical studies in the area include Udensi and Osazuwa (2002), Udensi (2004, 2010), Udensi *et al.*, 2010, Megwara and Udensi (2011).

The entire Basin (Figure 15) is covered by 18 aeromagnetic Map sheets at a scale 1: 100,000.

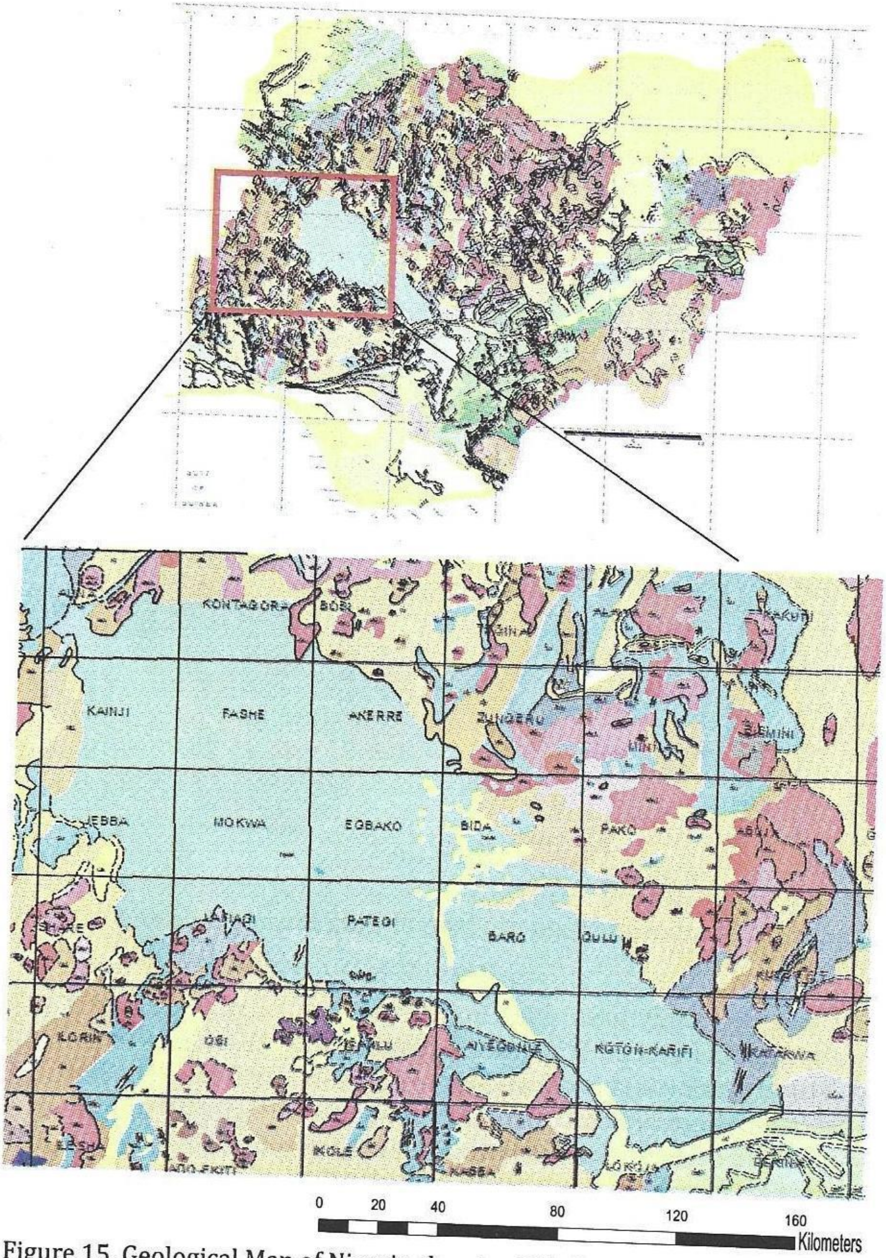


Figure 15. Geological Map of Nigeria showing Bida Basin area in red and the 18 (1:100,000) sheets.

7.1.1 Spectral Depth Determination of Bida Basin Sediments

A composite aeromagnetic map of the Bida Basin was created by combining all the 18 sheets point data files into an Excel worksheet. This combined data is called a super data consisting of 31,359 magnetic intensity points. These date points were used to produce the composite magnetic map of the Bida Basin, Figure 16.

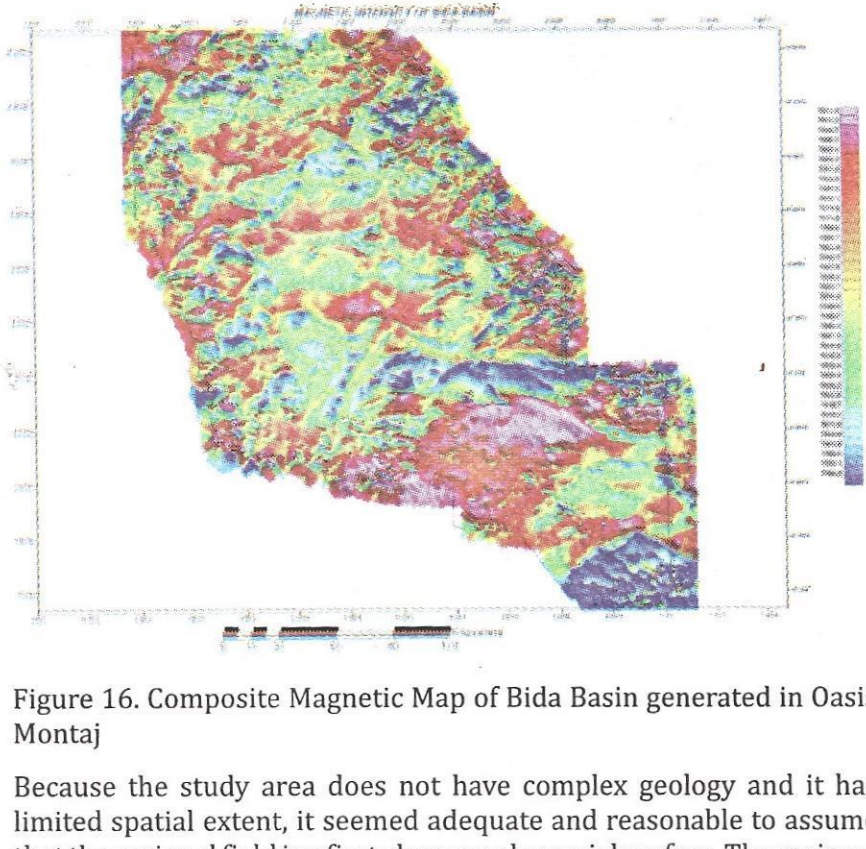


Figure 16. Composite Magnetic Map of Bida Basin generated in Oasis Montaj

Because the study area does not have complex geology and it has limited spatial extent, it seemed adequate and reasonable to assume that the regional field is a first-degree polynomial surface. The regional field was therefore calculated as a two-dimensional first-degree polynomial surface. A simple program was used to derive the residual magnetic values by subtracting the values of the regional field from the total magnetic field values at the grid cross points. The contour map of the residual values is shown in Figure 17.

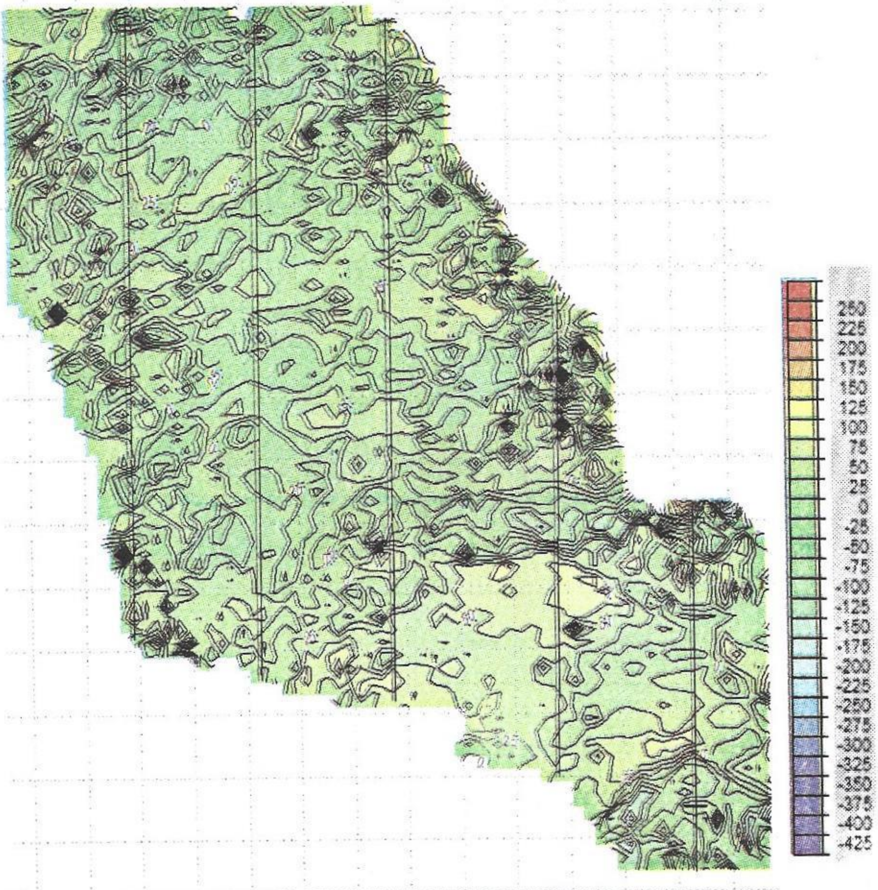


Figure 17 Residual Magnetic Map of Bida Basin

Sixty eight sections were chosen from the 18 aeromagnetic maps covering the basin for the purpose of spectral depth determination. The sections were selected such that a point (SPT) represents each quadrant of 1:100,000 scale map. With each representative point in the middle of the quadrant, a spectral depth represents about 144km^2. The spectral depth result for the deeper sources is shown in Fig 18. The deeper magnetic source depth varies from 0.605km to 3.585km.

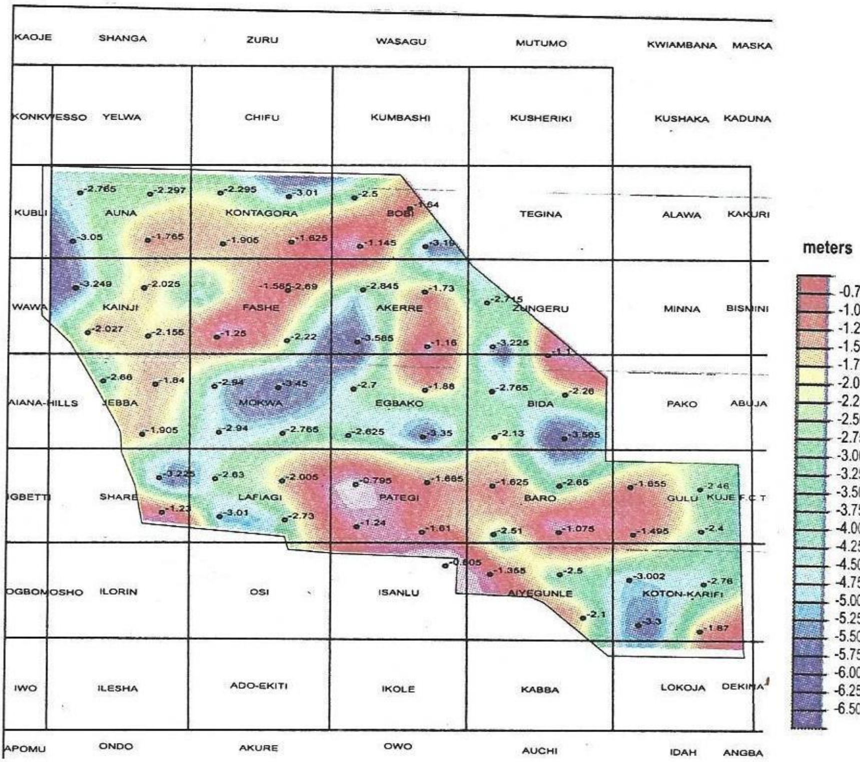


Figure 18. Gridded spectral depth of deep magnetic in Bida Basin.

7.2.2 Modelling of Profiles

Profiles AA', BB' CC' DD' and EE' were drawn over the residual contour map for the purpose of modelling. For the purpose of this lecture only the model for profile B-B' is presented here in Figure 19.

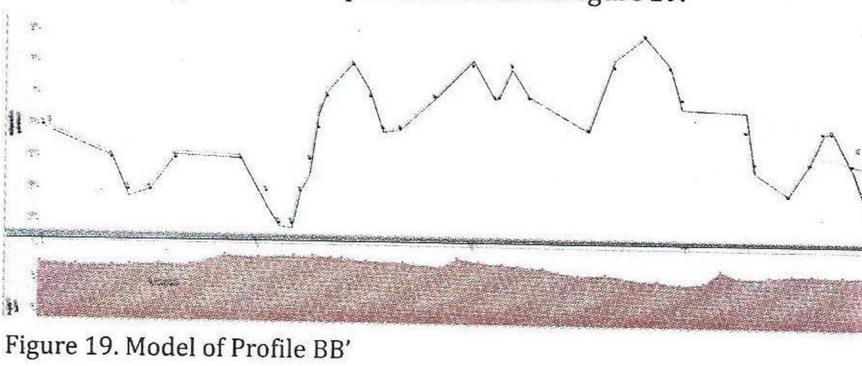


Figure 19. Model of Profile BB'

The basin thicknesses of some selected areas in the basin from the results of the models are shown in Figure 20.

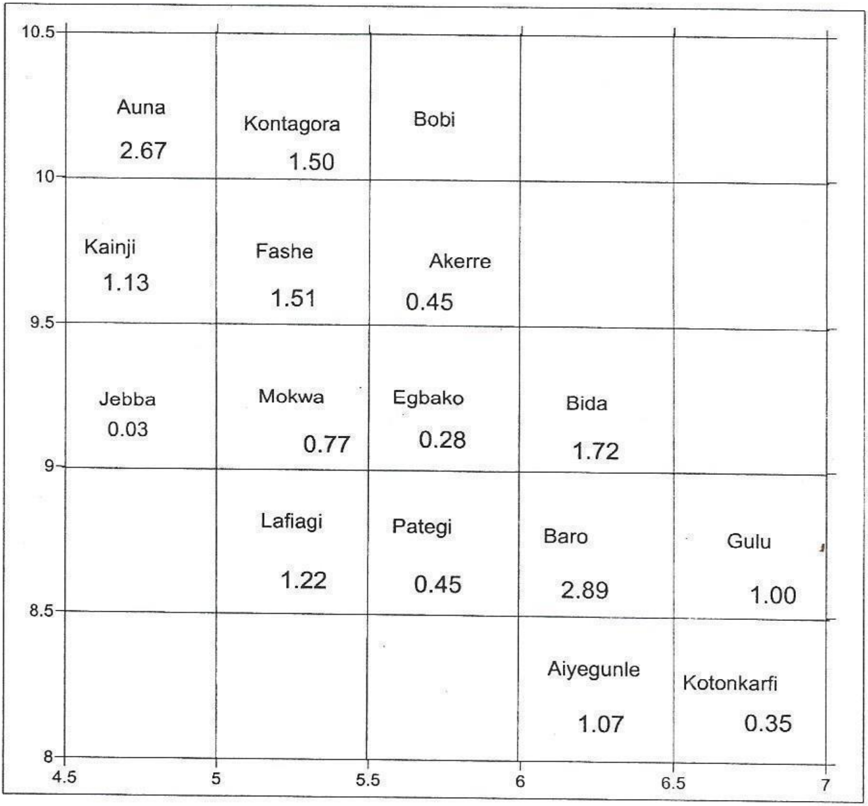


Figure 20. Sedimentary thicknesses in selected areas in the Bida Basin. The sedimentary thicknesses are in Km.

It is noteworthy to mention that an area around Baro indicates a sedimentary thickness of 3.90 Km. This is the steepest sedimentary thickness in the models.

Baro with a sedimentary thickness of between 2.50 and 3. 90 Km looks very promising for petroleum productivity. Udensi and Osazuwa, (2002 and 2003) indicated that Baro lies within a deep fault zone. Idowu and Enu (1992) and Braide (1992) noted that the organic matter found around Lokoja is thermally immature and suggested that a higher geothermal gradient may exist north of Lokoja. The area with sedimentary thickness of up to 3.00 Km around Baro could contain organic matter at depth that is thermally mature.

The Baro area also showed significant radiometric character that is consistent with Th and K, Figure 21. This may indicate the presence of shale which is associated with radioactive mineralization. The sedimentary rocks around Baro comprise of shales and sandstones, Obaje (2009). Considering that shales are impervious then, the shale–sandstone–shale strata could form a trap that may enhance hydrocarbon accumulation. It implies that any hydrocarbon occurrence has a cap rock-shale. Therefore, the Baro area may be characterised with an arched shale–sandstone–shale sedimentary strata overlaying an uplifted basement rock.

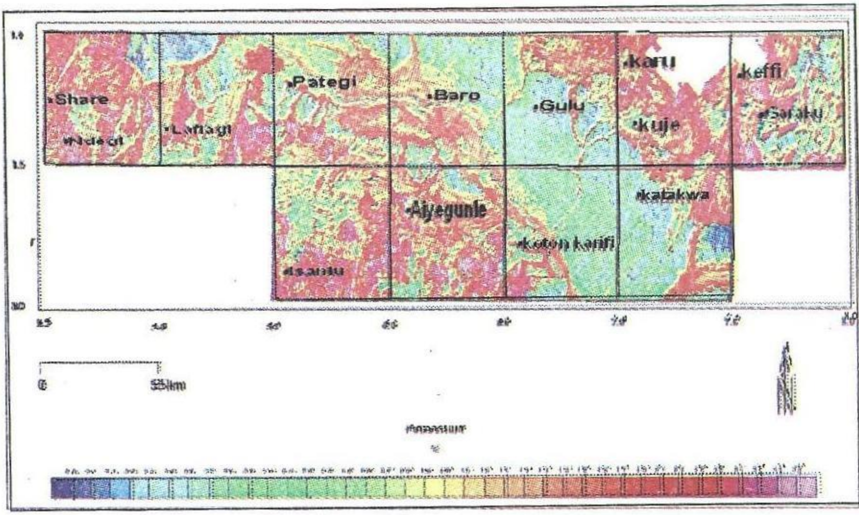


Figure 21. Potassium abundance Map.

Auna is another area with sedimentary thickness of over 2.00 km. The spectral depth analysis also indicates a depth of up to 2.76 km for Auna. It is therefore suggested that drilling of bore hole could be considered within the Baro and Auna areas.

7.2 The Sokoto Basin

The Sokoto Basin (Figure 22) is one of the inland basins in Nigeria.

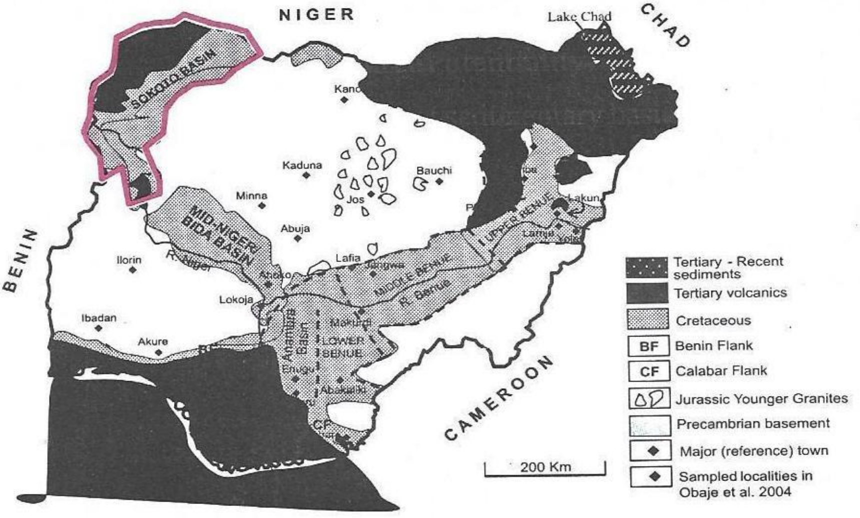


Figure 22. Sketch geological map of Nigeria showing the location of the Sokoto Basin within the inland basins of Nigeria

The Sokoto Basin is the southern part of the interior sag Lullemmeden Basin which covers an area of approximately 800,000Km^2 encompassing parts of Algeria, Mali, Niger and the Benin Republic as well as north-western Nigeria, (Figure 23).

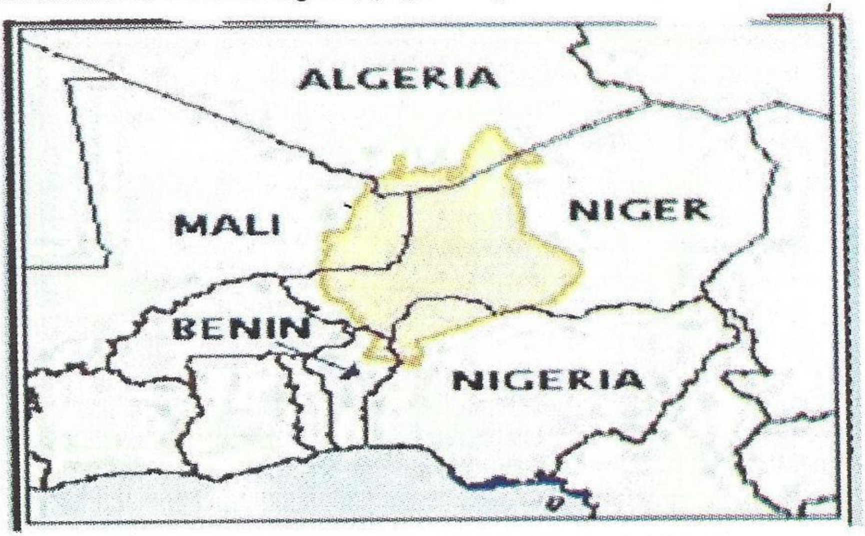


Figure 23. Map showing the coverage of the Lullummeden Basin

7.2.1 Exploration History

Sokoto basin has not attracted much geophysical attention apparently because of the belief that no proven hydrocarbon accumulation or mineral resources potentials have been indicated in the area.

Mobil in 1957 carried a seismic refraction survey of parts of the basin, between Longitude 3.75° and 5.5 °E and latitude 12.25 ° and13.45 ° N. The survey covered only a limited part of the northern part of the Sokoto basin and did not indicate any sedimentary thickness up to 1000m. The survey concluded that the Mesozoic and Tertiary sediments which could have formed the petroleum systems are probably too shallow and also too poorly developed to be of much interest to any further petroleum exploration. Elf Aquitaine did some seismic coverage over portions of the Sokoto Basin in 1979. An interpretation of the acquired data shows that the basin thickness varies between 500m to the southeast and 1000m to the northwest of the basin, Ayoola *et al.,* (1982).

Osazuwa (1985) established a primary gravity network for Nigeria of which five base stations were located within the Sokoto Basin. These were reoccupied as base stations by Umego (1990) who carried out gravity survey over part of the basin. He indicated maximum depths to basement of between 1.0 Km and 1.6 Km. Shehu *et al., (*2004) carried out a spectral depth analysis of the magnetic residual anomalies over the Upper Sokoto Basin, revealing an average maximum depth of 1.386 km to basement in the area. Adetona and Udensi (2007) did spectral depth analysis of the southern Sokoto basin. The result showed an average maximum depth of 1.93 Km. Ishaq and Udensi (2010) carried out a 2-D modelling of part of the southern Sokoto Basin. The survey showed that northern Sokoto basin has sedimentary thickness varying from 0.676 km to 1.80 km.

7.2.2 The Spectral Depth Determination of the Sokoto Basin Sediments

The characteristics of the residual magnetic field over the Sokoto Basin were studied using statistical spectral and quantitative modelling methods. The spectral analysis was achieved by transforming the data from space to frequency domain and thereafter analysing their frequency characteristics. The statistical approach has been found to yield good estimates of the mean depths to the basement underlying sedimentary basins (Spector and Grant 1970, Hahn *et al,* 1976, Udensi and Osazuwa, 2003). Twenty six sections were chosen for spectral analysis. Each section consisted of a ½° aeromagnetic map.

The result of the spectral analysis identified two main magnetic origins under the area. The low frequency segment of the spectral graph represents the deeper sources and the high frequency segment represents the shallower magnetic sources. The first layer d_1 which are of shallower magnetic sources can be attributed mostly to lateritic iron stone capping and the effect of surrounding Basement magnetic rocks. The second layer d_2 which are of deeper sources is attributed to magnetic rocks intruding into the basement surfaces. Another probable origin of the magnetic anomalies contributing to this layer is lateral variation in basement susceptibilities and intrabasement features such as faults and fractures, (Kogbe) 1981. In either case we reasonably deduce that d_2 represents the average depth of the Basement Complex in the section considered. For easy of understanding the spectral results are shown with the base map of the study area in Figure 24.

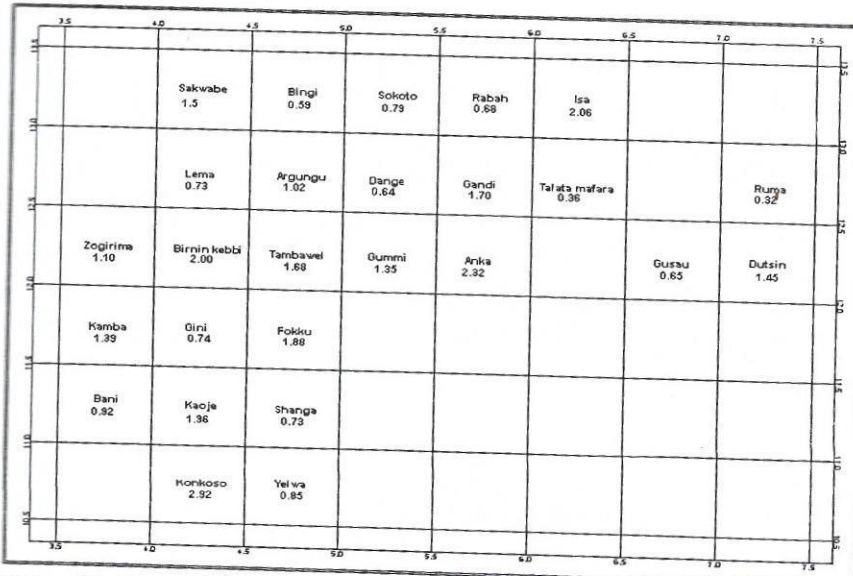


Figure 24. Spectral depth results shown along with the places and positions in the study area.

From Figure 24, four areas Isa, Birnin Kebbi, Anka and Konkoso have depths up to 2.00 Km. The deepest part of the sediments occurs in Konkoso which has a sedimentary thickness of 2.92 Km.

7.2.3 Modelling of Structures Beneath the Sokoto Basin

The residual map of the Sokoto Basin with areas not containing data blanked off is shown in Figure 25. Five profiles A-A', B-B', C-C', D-D' and E-E' were drawn for the purpose of modelling. Cross profiles XX', YY' and ZZ' were also modelled as a check on the five profiles.

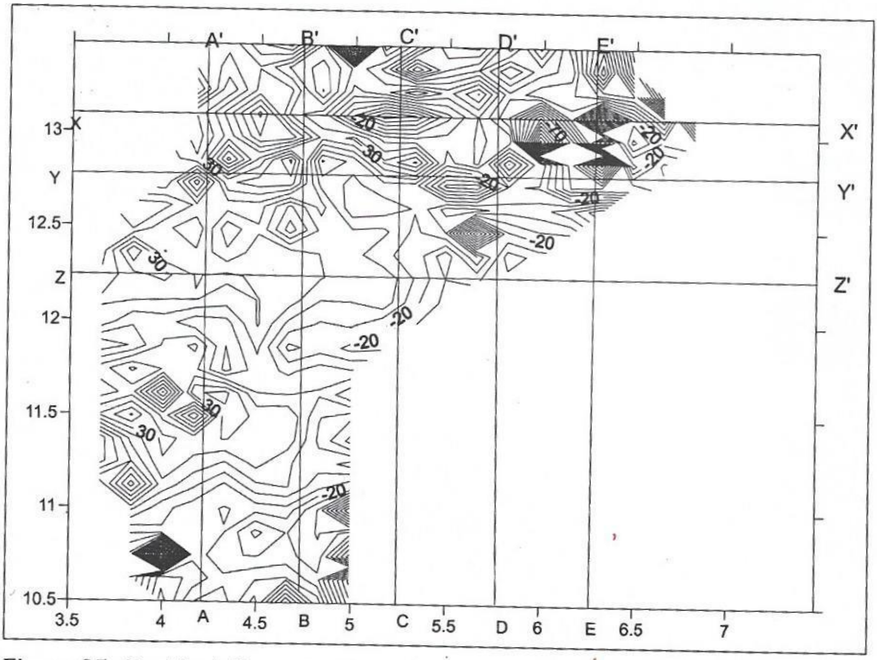


Figure 25 . Residual Magnetic Map of Sokoto Basin showing profiles modelled.

Figures 26 and 27 show the models of profiles A-A' and B-B'. Figure 28 and 29 show the models of the cross profiles. The assumption that was used in the production of the models was that the residual magnetic variations were caused by basement topography and lateral susceptibility variation.

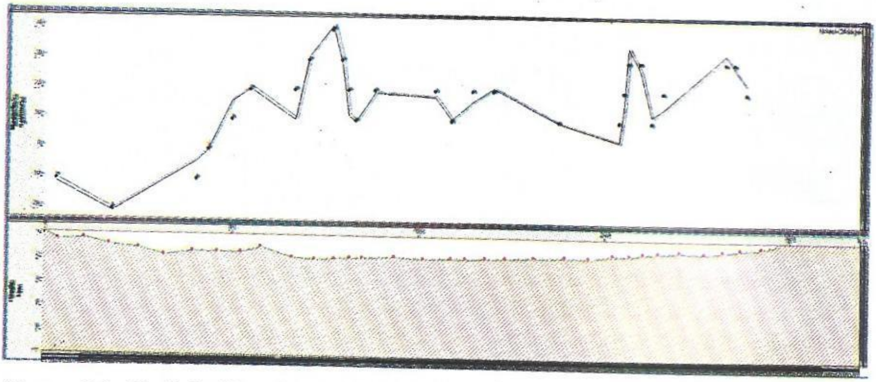


Figure 26 . Model of Profile A-A,'

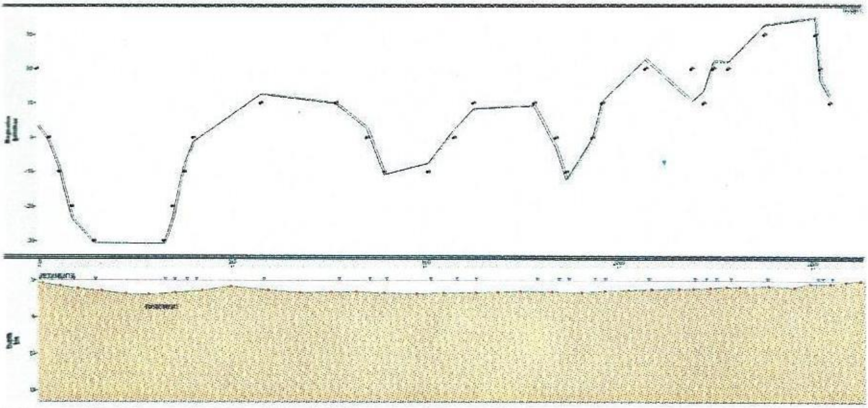


Figure 27. Model of Profile B-B'

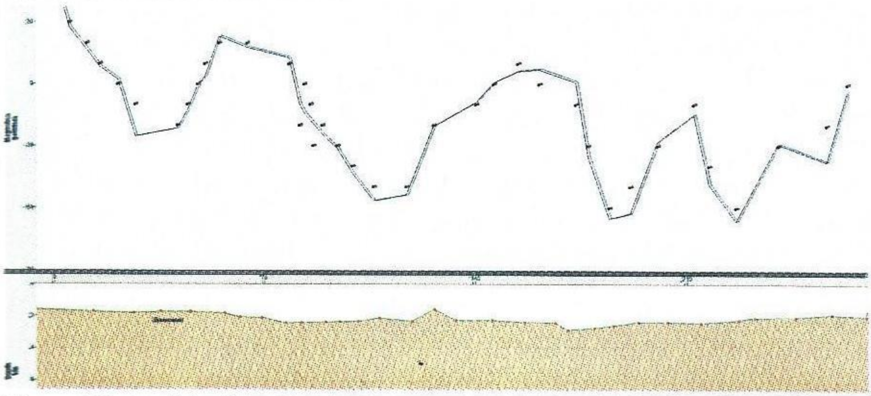


Figure 28 . Model of Profile X-X'

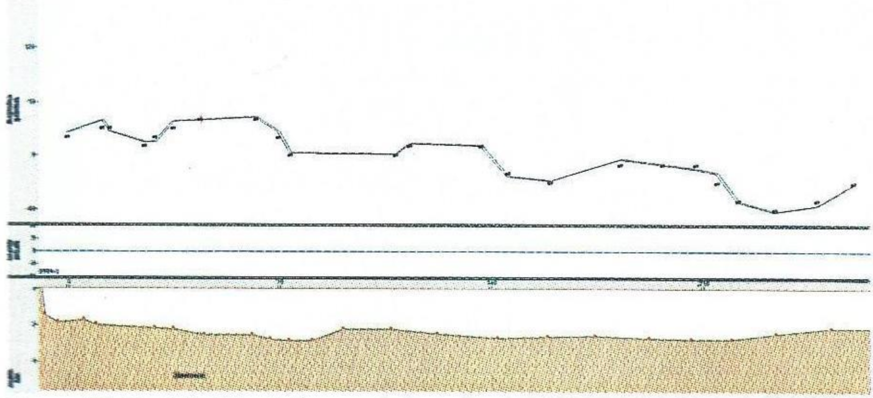


Figure 29. Model of ProYY'

The estimates of the thickness of sediments for corresponding areas where average spectral depths were calculated are shown in Figure 30. Eight areas show basement depths of up to 2.00 Km. These are Sokoto (2.57 Km), Rabba (2.40), Isa (2.45 Km), Dange (2.63 Km), Gandi (2.43), Talata Mafala (2.77 Km), Tambawel (2.0) and Gummi (2.45 Km). The cross profiles indicate the following depths, Sokoto (2.49), Rabba (2.43), Isa (2.52), Dange (2.22 Km), Gandi (2.45), Talata Mafala (2.72 Km), Gummi (2.31 Km) and Anka (2.24km). The depth of the cross profiles agree generally with the results of the main profiles. The differences are marginal.

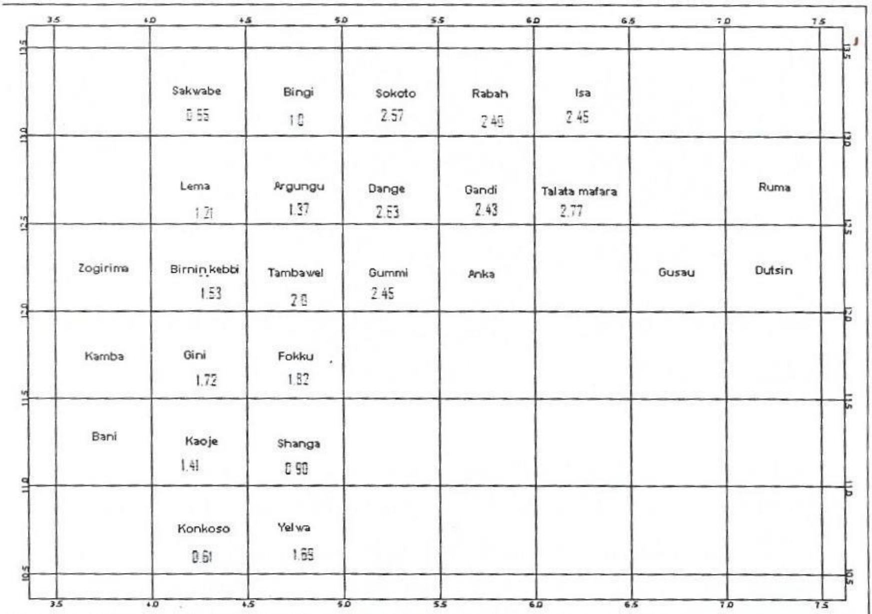


Figure 30. Estimates of basement depths (in Km) derived from modelling

7.2.4 Discussion and Recommendation on Sokoto Basin

The present information on geology of the Sokoto basin is not far reaching on details and preconditions for hydrocarbon generation, accumulation and preservation. However the source rock necessary for hydrocarbon accumulation is available in the basin. The geology has indicated the presence of shale within the basin. The reservoir rock, sandstone, has also been indicated in the basin. However geochemical analysis should be carried out on the potential source rocks of the Sokoto Basin, so as to be able to determine the quality and quantity of the organic matter in the sediments.

The Mobil seismic refraction survey was confined to a limited part of the northern part of the basin. Its maximum depth finding is less than 1000m. The depth contour map of the basin from the Mobil survey shows that the sediments increases towards the northwest. The result of the limited seismic reflection data carried out by Elf agrees with the Mobil result.

The present survey covers the entire basin as much as available magnetic data could go. The results agree with both Mobil and Elf that the southern part of the basin is shallow. However this survey has indicated sedimentary thickness of up to 2.00 km in the northern part of the basin between latitude 12.5^0 and 13.5^0 and Longitude 5^0 and 6.5^0. Ayoola *et al.*, (1982) is of the opinion that the sediments in Sokoto basin may be lying on top of schist. Since schist and sediments do not show much magnetic effect, the thicknesses recorded by magnetics may be depth to the top of the basement below the schist while seismics recorded depth to the top of the schist. If this is true, then it explains the discrepancy between the seismic results and the magnetic results. No drilling to a considerable depth has been done in the basin to corroborate this opinion. Even if this opinion is not correct, the basin still does not seem to have considerable thickness of sediments adequate for thermal maturation of organic matter necessary for petroleum accumulation.

The following conclusions and recommendations could be drawn from this study:

* No area in the Sokoto Basin has sedimentary thickness of over 3 Km that could be normally considered adequate for petroleum accumulation.

* However this survey has indicated sedimentary thickness of up to 2.00 km in the northern part of the basin between Latitude 12.5^0 and 13.5^0 and Longitude 5^0 and 6.5^0. This block is recommended for further studies within the basin.

* Drilling of borehole of up to 3 Km should be considered around

this block (Sokoto, Rabba, Isa, Dange, Gandi and Talata Mafara) to ascertain their real sedimentary thickness, and for stratigraphic and geochemical analysis of borehole source rocks.

8. Geothermal Source Investigation

Reliable energy resource has been an issue for several decades in Nigeria as a result; search for alternative or renewable energy resource for the country has been of paramount importance. We recently began to conduct research for geothermal energy resource within parts of Nigeria. Research on this subject has been conducted in parts of Niger Delta area, parts of Sokoto and Bida basins. Figures 31 and 32 show the results of two of such researches.

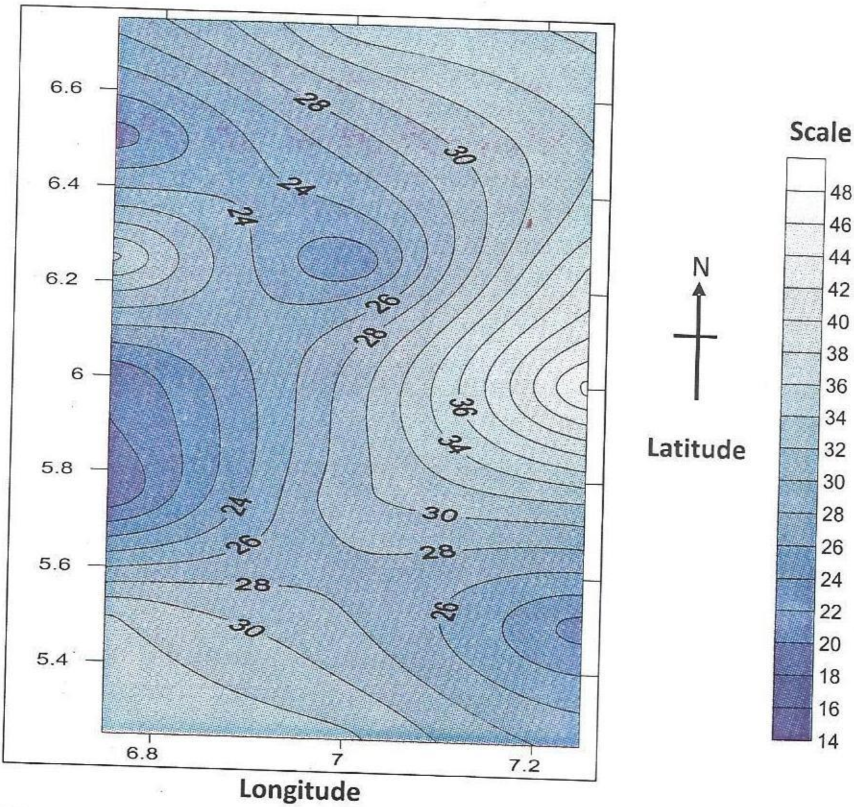


Figure 31a: Contour map of vertical geothermal gradient in (°C/km) (Chukwu, 2012)

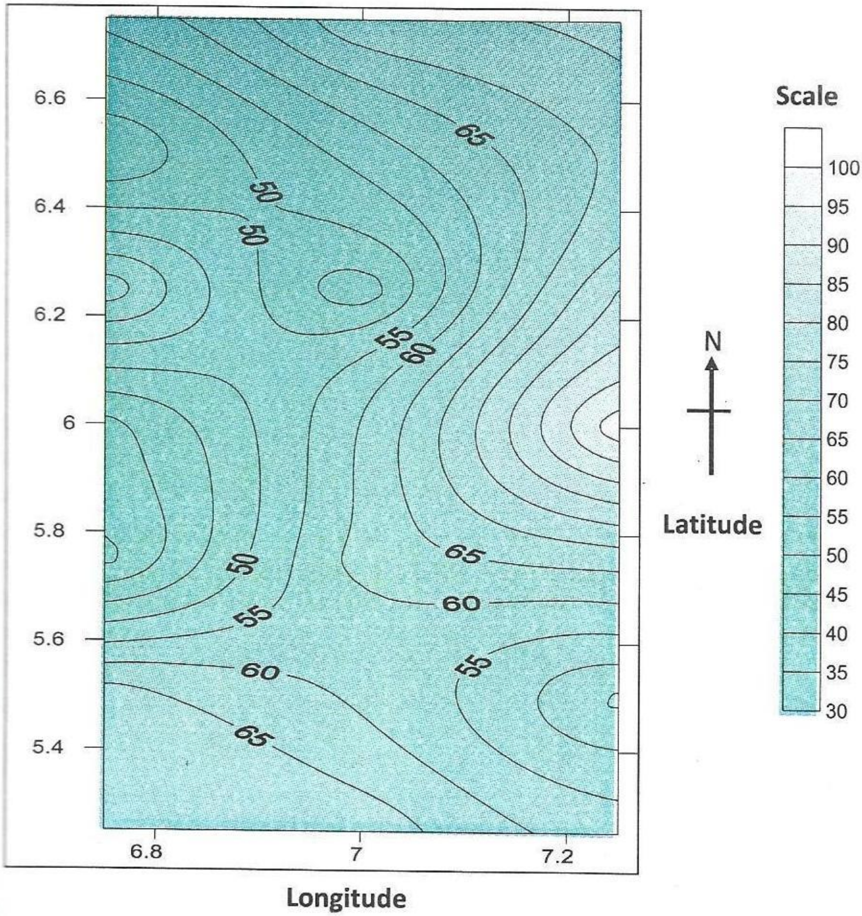


Figure 31b: Heat flow contour map with respect to conductivity of 2.1 $Wm^{-1 o}C$ for the study area (parts of Niger Delta. (Chukwu, 2012)

These results shown in Figure 31 reveal that the southern part of the investigated area has relatively low geothermal potential compared to the northern part of the region under study. It is therefore possible that the present geothermal potential of the region of study is not contributed by the heat either from the mantle or from the radioactive rocks such as shale. It can be attributed to the heat induced due to pressure on basement by and within the sediments in the area. Thus the study area is not potentially viable as a geothermal source.

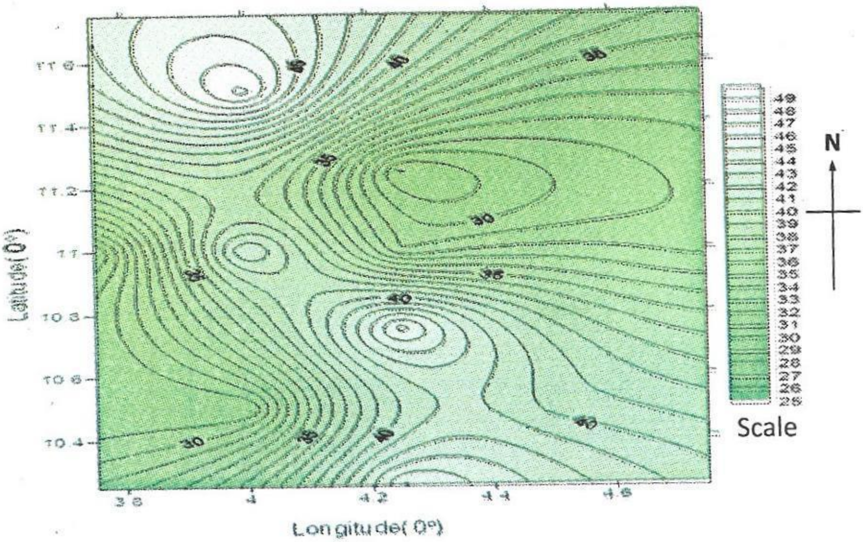


Figure 32a contour map of Geothermal Gradient (°C)/km with respect to Curie temperature (300°) for parts of Sokoto basin. (Maduabuchi, 2012)

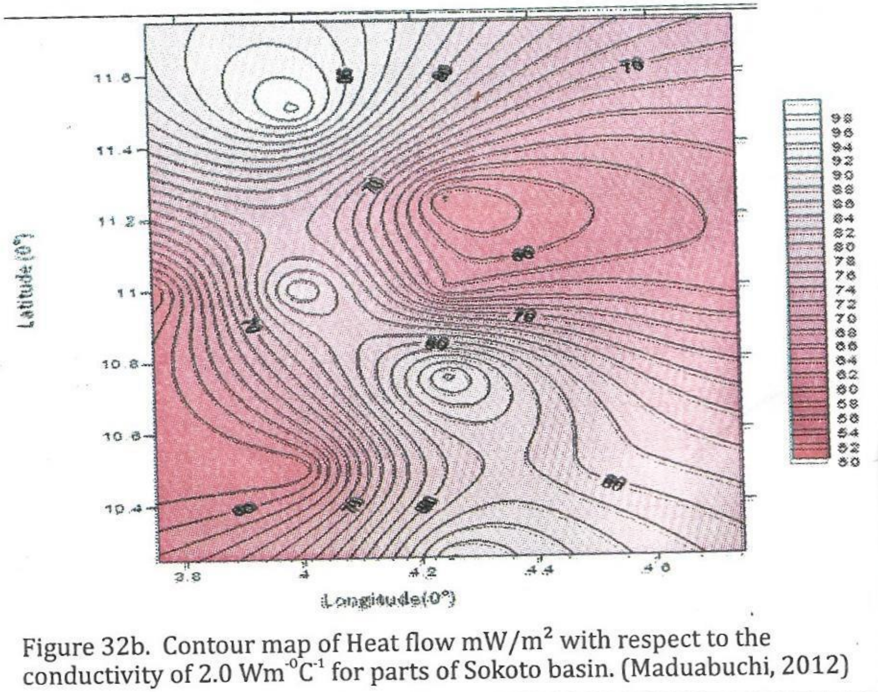
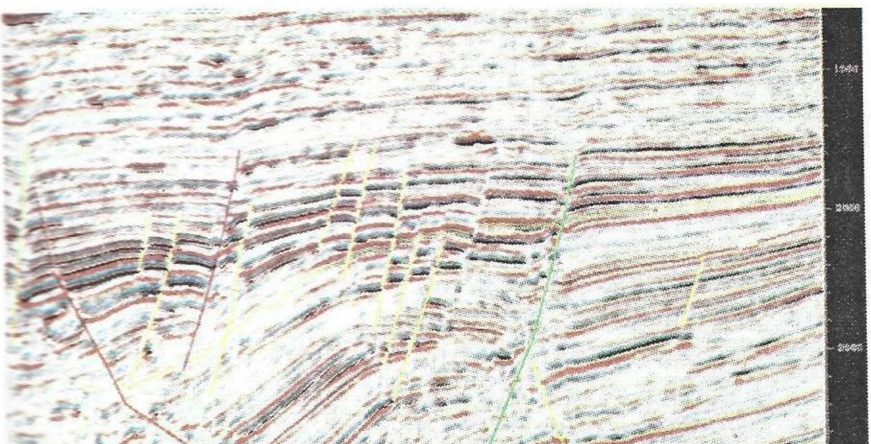


Figure 32b. Contour map of Heat flow mW/m^2 with respect to the conductivity of 2.0 $Wm^{-0}C^{-1}$ for parts of Sokoto basin. (Maduabuchi, 2012)

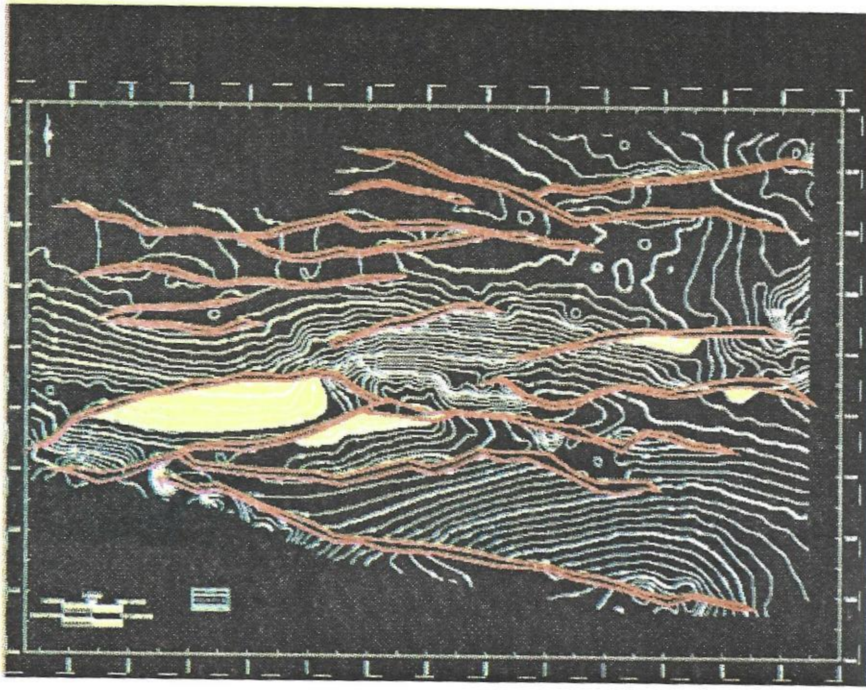
From the results in Figure 32, it can be seen clearly that the southern and Northern part of the investigated area have relatively high geothermal potential and heat flow compared to the eastern part of the region. It is possible that the presence of radioactive isotopes or element in these areas are responsible for a high geothermal potential and heat flow, since radioactive decay produces heat as it occurs. Finally it can be concluded that shallow Curie point and high heat flow values are significant in determining the geothermal potential of an area.

9. Equipping the Universities for Research in Geophysics

Mr. Vice Chancellor Sir, from what I have said so far, you would have noticed that the subject of geophysics is primary to the well-being of this country since more than 95% of the wealth of Nigeria comes from oil. The question therefore is how this country encourage the study of this important subject in Nigerian Universities. There is so much disparity between geophysics in the oil industries and geophysics in our universities. I worked briefly with an oil company seven years ago and I was part of the interpretation of the seismic data from an area. Figures 33 and 34 show typical fault lines and horizon depth maps.



Seismic section (line 5392) showing fault interpretation and uninterpreted fault break.



Horizon B10 Depth map with prospects shaded in traditional yellow

To get to this level of interpretation, nine software were use in a workstation. None of the software is found in a typical Nigerian University that is expected to train geophysicists for the Nigerian oil companies. To worsen the matter, when this country realised that Nigerians should be trained very well in this important area the government initiated the programme of overseas scholarship for a very few number of people. While overseas scholarship is good, it is better to equip the geophysics units in the universities. By so doing, Nigeria would train more people and retain the training facilities.

10. Conclusion

Exploration geophysics is an important tool that God has placed in the hands of men with which they are to subdue the earth, explore and exploit it for the overall good of mankind. It is however an expensive tool. Geophysical equipments cost a lot of money. Deliberate efforts must therefore be made by government to fund this course and indeed education generally. Oil companies in Nigeria should be encouraged to partner with the universities in carrying out their researches.

I saw them tearing a building down,
A gang of men in a busy town,
With a "Yo-heave-ho" and a lusty yell,
They swung a beam and a whole wall fell.

And I said to the foreman,
"Are these men skilled as the men
You'd hire if you had to build?"
So he laughed and said, "Oh, no indeed,
The commonest labour is all I need".

And I thought to myself as I walked away,
Which of these roles should I try to play?
Am I the wrecker who walks the town,
Content with pay for tearing down,
Or am I a builder who works with care
So my town grows better for all to share?
- Anonymous

11. Appreciation

To God be the glory for all that I have become today. Today, I have just presented my inaugural lecture after attaining the highest rank in my chosen profession. To You, dear Lord, I return all the glory.

To my late parents, Pa Ezekiel and Mama Abigail Udensi, I say thank you for the upbringing you gave me. Daddy, several times you caned me to make sure I went to school. Several times you carried me in your bicycle to school. I did not understand it then, but today I do. Mummy, you knew me so well that you urged me to read and get to the end of education. Above all these you taught me the fear of the Lord. Thank you, Daddy and Mummy. Remain in the Lord's bosom until we meet again. I am grateful to my late Uncle, Chief Alloy Ofoma who gave me full scholarship for my first degree. Uncle, rest in peace! I am indeed grateful to my siblings particularly my younger brother, Engr. Jojo Udensi. Jojo, I will always remember that you paid for my Master's degree programme. Thank you my brother and my friend.

I will never forget the mentorship given to me by Profs. S. B. Ojo and I. B. Osazuwa, in my Masters and PhD, theses respectively. You taught me to make myself available to project students. You even visited me in the hostel to encourage me. Sir, thank you very much. I have supervised more than 50 Masters and PhD theses and I have not deviated from what you taught me. I also appreciate Prof. M. U. Umego who also helped in moulding my academic life.

I remain grateful to the past Vice-Chancellors of this great University for their parts in making me what I am today. Prof. J. O. Ndagi employed me in 1984 and in 1986 also employed my wife. Sir, I am grateful. Prof. S. Adeyemi taught me to fight when I was ASUU chairman. Sir, in one occasion I told you I had no personal problem with you, I was only a young man saddled with the responsibility of defending ASUU's position. Thank you also for the great pioneer work you did for this University in Gidan Kwano. Prof. M. A. Daniyan was not just my Vice-Chancellor, he was also my teacher. He taught me at my Masters degree level and also co-supervised my PhD thesis. Sir, I will never forget what you told me when you became the Vice-Chancellor of this University. You called me to your office and said, 'If I want to be selfish, I will ask you to become ASUU chairman again since as my friend you probably will not give me trouble. However, I am more interested in your future and would therefore ask you to immediately proceed on your PhD programme. I will arrange for Prof. Osazuwa to supervise you and I will also ensure that you get adequate research grant from this University. One more thing, I am not asking you to become a Muslim, but I am asking you to drop most of your pastoral work so that you can concentrate on this PhD programme'. When I came back two and half years later with a PhD you quickly appointed me Head of Physics Department. Sir, only few people have affected my life the way you did. God bless you richly. It was in Prof. Tukur's tenure that I became Associate Professor and he appointed me Chairman, University Seminar and Colloquium Committee. This brings me to the present Vice-Chancellor, the chairman of this occasion, Prof. M. S. Audu. Prof. Audu is my friend and I sincerely cherish our friendship. His humility and openness attracted me to him during the early months of his tenure and I have ever found him so. I exploited this friendship to record the successes that I had as the Chairman of the University Seminar and Colloquium Committee. I still remember your phone call to me after the A&PC meeting of 2008. You said Sir, 'my friend, I became unhappy when I could not do anything when your hard copies were incomplete during the promotion exercise, what really happened?' I became a full Professor during your tenure and you appointed me the Director of Advancement and Development Office, a position I am still holding. I sincerely appreciate you for your great achievements in this University. Indeed you have made your mark. Sir, as you round up your tenure as Vice-Chancellor, my prayer is that more doors will be opened for you. Let me also salute my good friends, the two Deputy Vice-Chancellors, Profs. A. O. Osunde and A. Bala for our cherished relationship.

I salute my senior colleagues, especially Prof. A. C. Ajibade who brought me to Minna, Profs. Oladimeji, Momoh, Galadima, for their encouragements. I sincerely appreciate Prof. O. D. Oyedum for being a brother. When I was going for my PhD you gave me all the support even when you knew that it might likely give me an edge over you. Thank you my brother for your encouragement. The staff of Physics Department deserves commendation for the peaceful environment under which we have been working. Every Head of Department that has passed through the department has had the interest of staff at heart. Thank you and let us keep the flag flying. I greet my post graduate students, past and present, for making me to be on my toes searching for new ideas.

This brings me to my one and only wife and girlfriend, Dr. (Mrs.) Juliana Nkechi Uchem Udensi (Associate Professor/Deputy University Librarian). We came together by revelation and we have been faithful to this covenant. Thank you for giving me a peaceful home and for the good upbringing of our children. I will always love you. Should God turn us to young people again seeking partners, I will marry you again. I appreciate my children, Ijeoma, Ifeoma, Emeka and Chinedu. I will not forget you Saviour Udeh. You have been a nice boy. You have all made me happy by your godly character.

I thank my spiritual father, the Bishop of the Anglican Diocese of Minna, Rt. Rev. Daniel A. Yisa for all that he has taught me both in word and in example. I greet my Vicar, Ven. J. C. Akpu. I salute the Full Gospel Business Men's Fellowship International, FGBMFI and the Evangelical Fellowship in the Anglican Communion, EFAC, for moulding my spiritual life.

Finally I thank Prof. (Mrs.) Z. D. Osunde and her team, the Seminar and Colloquium Committee for their encouragement in getting me to deliver this lecture. To everyone that has contributed one way or the other to making me what I am today I am grateful. And you the esteemed audience, I am deeply grateful to you for honouring me today.

Thank you all.

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