2015

Federal University of Technology, Minna, Nigeria.

NJTR

Nigerian Journal of Technological Research.

Vol. 10, Special Edition, 2015

20th Anniversary

- AGRICULTURAL TECHNOLOGY
- EDUCATIONAL TECHNOLOGY
- ENGINEERING SCIENCES
- ENVIRONMENTAL TECHNOLOGY
- ENTREPRENEURSHIP AND BUSINESS MANAGEMENT TECHNOLOGY
- INFORMATION AND COMMUNICATION TECHNOLOGY
- LIFE SCIENCES
- PHYSICAL SCIENCES.

Production supported by:

tetfund
TERTIARY EDUCATION TRUST FUND
ABUJA, NIGERIA

Table of Contents **Pages**

Two dimentional modeling of subsurface structure over upper Benue trough and Bornu basin in North eastern Nigeria.

Salako, K.A. and E. E. Udensi. Department of Physics, School of Physical Sciences, Federal University of Technology, Minna, Niger State.

Abstract

A two dimensional modelling of the subsurface structures of parts of Benue Trough and Bornu Basin, northeast Nigeria, using aeromagnetic data was carried out in this study. The area under investigation is bounded by latitude 9.5^0 N to 12.0^0 N and longitude 9.5^0 E to 12.0^0 E. It is covered by 25 aeromagnetic maps. The data obtained were subjected to filtering process using polyfit. The residual data obtained were subjected to 2D subsurface modelling. The study area was covered by seven profiles labelling, AA^1, BB^1, CC^1, DD^1, EE^1, FF^1 and GG^1. The depth to magnetic sources results obtained from the Source Parameter Imaging (SPI) was used as depth constraint for modelling the residual magnetic field anomalies. The results of the 2D modelling showed that the sedimentary thicknesses ranged from 0.0 km to a maximum depth of about 5.40 km. The highest sedimentary thicknesses were found around Gombe, Ako Gombe, Bulkachuwa and Damaturu areas, with a value of about 3.80 km to 5.40 km. The highest sedimentary thicknesses obtained, which range between 3.80 km to about 5.40 km is adequate for the hosting of hydrocarbons. The least sedimentary thicknesses obtained from this study could be found around Bauchi axis in the basement complex region, Kaltungo and volcanic area at the eastern part of the survey area. The results of this study also indicated that Borno Basin is separated from the Upper Benue Trough at about latitude 11.0^0 N to 11.2^0 N, which corresponds to "Dulbulwa-Bage High". This separation could have been aided by the paleostructure called St Paul that passes through the area at that latitude. The subsurface lithology obtained from 2D modelling of the residual field showed the presence of two lithological units. The sedimentary rock unit underlined by the basement rock consists of shales, sandstones, limestones, siltstones, clay and non-marine facies. The Basement rock units were composed of pegmatite, granite gneiss and migmatites.

Keywords: Aeromagnetic data, 2D modelling, Sedimentary thickness, Source Parameter Imaging and Subsurface lithology
Email: kasalako2012@gmail.com
Received: 2015/03/20
Accepted: 2015/06/12
DOI: **http://dx.doi.org/10.4314/njtr.v10i1.S11**

Introduction

The entire Benue Trough is believed to have evolved as a result of the continental separation of Africa and South America (King, 1950) and is variously described as a rift system (Cratchley and Jones, 1965), an extensional graben system (Stoneley, 1966 and Wright, 1968), a third failed arm or an aulacogen of a three-armed rift system related to the development of domes associated with the hotspots (Burke and Dewey, 1974 and Olade, 1975). The Bornu Basin (or "Maiduguri Subbasin" of Avbovbo *et. al.* (1986) is the south-western part of the Chad Basin (Figure 1). The Cretaceous sediments in the Bornu Basin are almost entirely concealed by the continental Pliocene to Pleistocene Chad Formation (Carter *et al.*, 1963, Barber, 1965 and Miller *et al.*, 1968) which reaches a thickness of over 1500 m (Olugbemiro, 1997).

The 2D modelling of aeromagnetic fields over the area would differentiate and characterise regions of sedimentary thickening from those of uplifted or shallow basement and also to determine the depths to the magnetic sources. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration. The study area is bounded by latitudes 9.5^0 N to 12.0^0 N and longitudes 9.5^0 E to 12.0^0 E located within the Upper Benue Trough and southern Borno Basin, Northeast Nigeria (Figure 1). It is approximately 275,000 km^2 and was covered by 25 aeromagnetic maps.

Geology of the study area

The study area covers extensively the Upper Benue Trough, some parts of Chad Basin (Southern part of Bornu Basin), the Younger Granites (province of Bauchi area) and the Basement Complex, Figures 1and 4. All the rocks in the area belong either to the Upper Cretaceous or to the Precambrian. All the above mentioned units have already been described in detail by various workers (Buchanan, 1971, Bowden and Turner, 1974, McCurry, 1976, Ajibade, 1976, Eborall, 1976 and Wright, 1976). The sandstones of the Upper Benue Trough and the lower part of the Bornu Basin belong to the Upper Cretaceous and they are underlain by the Precambrian rocks of the Basement Complex.

The Upper Benue Trough comprises the area extending from the Bashar-Mutum Biyu line as far north as the "Dumbulwa-Bage high" of Zaborski *et. al*., (1988), which separates it from the Bornu Basin. Early studies of the Upper Benue Trough and Southern Bornu Basin were carried out by Falconer, (1911), Jones, (1932), Raeburn and Jones, (1934) and Barber, 1965. The basis for all later work was provided by Carter *et. al.* (1963) who undertook a regional study of the area covered by the Geological Survey of Nigeria 1/250,000 Series map sheets 25 (Potiskum), 36 (Gombe) and 47 (Lau). The Upper Benue Trough has since become known in greater detail and has been almost entirely remapped through the work of (Allix, 1983; Benkhelil, 1985; Benkhelil, 1986; Benkhelil, 1988; Popoff, 1988; Guiraud, Ajakaiye and Ugodulunwa, 1989; Guiraud, 1990a; Guiraud, 1991a; Guiraud, 1993 and Zaborski *et al*., 1988).

Descriptions of the Bornu Basin have been given by Guiraud (1993), Matheis (1976), Avbovbo *et. al.* (1986), Okosun (1995a) and Olugbemiro (1997). Those parts of the Chad Basin to the north and east were reviewed by Bellion (1989) with important subsequent accounts having been given by Schneider and Wolff (1992) and Genik (1992 and 1993). The latter provided detailed descriptions of the concealed east Niger, Bongor, Doba, Dosco and Salamat rifts. The Southern part of the Bornu Basin is covered by the Geological Survey of Nigeria 1/250,000 Series map sheets 25 (Potiskum). Raeburn and Jones (1934), Barber, 1965and Avbovbo *et al.* (1986), produced the geological maps of parts of the area to the north.

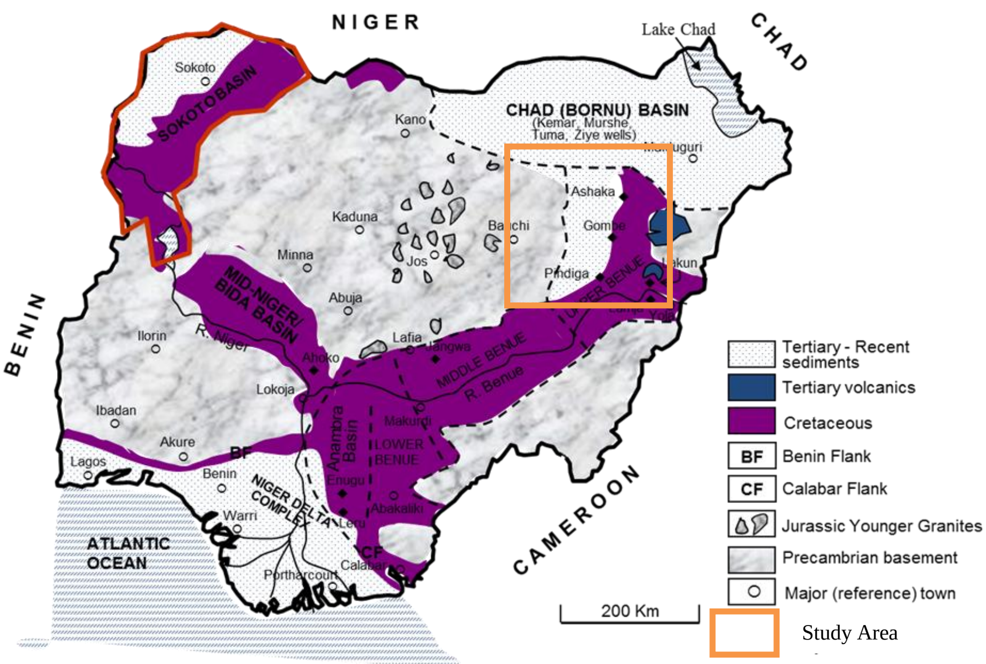


Figure 1: Location of the Study Area (parts of Upper Benue Trough and southern Bornu Basin)

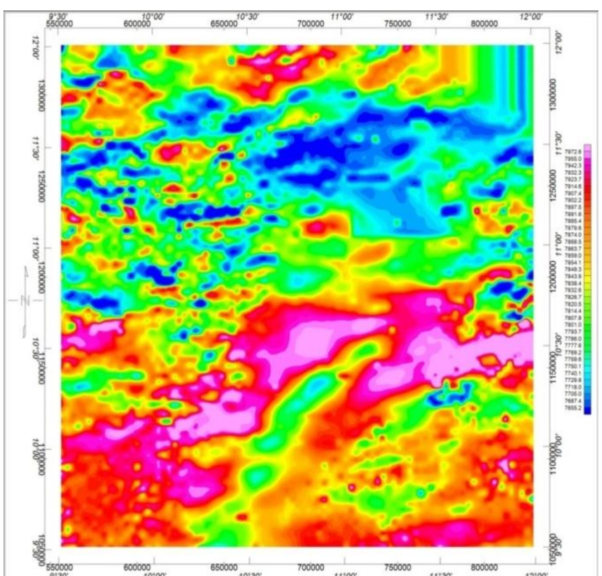
Materials and methods

The aeromagnetic dataset used for this study was obtained from the Nigerian Geological Survey Agency as a part of the nation-wide aeromagnetic survey between 1974 and 1980. The magnetic data were collected at a nominal flight altitude of 154.2 m along approximately N-S flight lines (nearly perpendicular to predicted geological strikes in the area), spaced 2 km apart. The component of the field measured was the total magnetic field. The study area is covered by twenty five aeromagnetic maps of total-field intensity in ½º by ½º sheets. These are numbers 83 - 87, 106 - 110, 128 - 132, 149 - 153 and 170 – 174 on a scale of 1:100,000. The magnetic values were plotted at 10nT (nano Tesla) interval. The actual magnetic values were reduced by 25,000 gammas before plotting the contour maps (Huntings, 1976). This means that the value of 25,000 gammas should be added to the contour values so as to obtain the actual magnetic field at a given point. A correction based on the international Geomagnetic Reference Field, IGRF, and epoch date January 1, 1974 was included in all the maps. The data used were digitised on a 19 x 19 grid systems using ILWIS. The spacing imposes a Nyquist frequency of 1/2.895 km, approximately 3.0 km. Thus, the magnetic feature that can be defined by the digitised data has a narrowest width of 3.0 km. This gridding system was supported by previous studies with crustal magnetic anomalies (Ajakaiye *et. al.* (1985), Udensi (2000) and Udensi and Osazuwa (2002)), which shows that the spacing is suitable for the portrayal and interpretation of magnetic anomalies arising from regional crustal structures. Figures 2 and 3 are the total magnetic intensity map of the study area and residual magnetic map of the study area respectively.

Modelling of Aeromagnetic Anomaly.

This involves making numerical estimates of the depth and dimensions of the sources of anomalies and this often takes the form of modelling of sources which could, in theory replicate the anomalies recorded in the survey. In other words, conceptual models of the subsurface are created and their anomalies calculated in order to see whether the earth-model is consistent with what has been observed, i.e. given a model that is suitable with the physical approximation to the unknown geology, the theoretical anomaly of the model is calculated (forward modelling) and compared with the observed anomaly. The model parameters are then adjusted in order to obtain a better agreement between observed and calculated anomalies.

N



0 55km

Figure 2

N

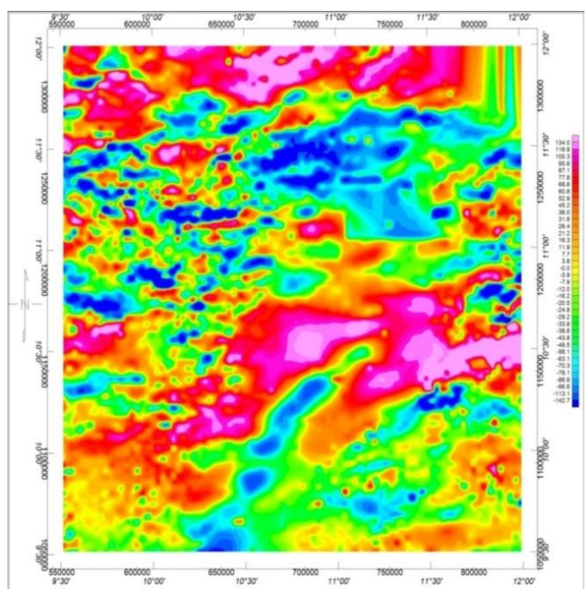


Figure 3

Figure 2: Total magnetic intensity map of parts of Upper Benue Trough and southern Bornu Basin; Figure 3: Residual-magnetic map of parts of Upper Benue Trough and southern Bornu Basin. Unit of total magnetic intensity is nano tesla (nT).

The initial reason for graphical depth determination methods was the fact that exact modelling of anomalies in pre-computer days, is time consuming and it required tedious manual computation of anomaly forms, using different formulae. With the advent of computers and publication of a series of routines that allowed modelling by trial and error, curve-matching processes have become routine. The most significant of the computer modelling algorithms are: Talwani and Heirtzler (1964), Talwani (1965), Hjelt (1972), Shuey and Pasquale (1973), Cady (1980), Coggon (1976), Clark, Saul and Emerson (1986), Valenta *et. al.* (1992), Jessel *et. al.* (1993), Bott (1963) and Lee (1980).

These computer routines have been incorporated into various proprietary and commercially available packages in windows-type environments. These packages allow the interpreter such option as definition of regional, computation of residuals multi-source model and inclusion of remanence, demagnetization and anisotropy. The algorithms used for each modelling exercise depend upon whether the anomalies being interpreted are sufficiently elongated for a two-dimensional or quasi-two-dimensional approximation to be used or whether a three-dimensional model is required. The modelling technique used in this work is a two dimensional (2D) modelling. The program, Gravity/Magnetic Systems (GMSYS), is an extension available in Oasis montaj version 7.5 of 2011.

Two dimensional (2D) modelling of the residual magnetic field anomalies

Figure 4 shows the seven profiles AA^1, BB^1, CC^1, DD^1, EE^1, FF^1 and GG^1 that were modelled in this work. These profiles were drawn across the residual magnetic map (Figure 3) and on the geologic map (Figure 4). These profiles were carefully drawn perpendicularly to the strike of the features identified in analytical signal map for the area. The susceptibility values used for modelling the residual magnetic anomalies are: Sedimentary rock section, 0.0 gaussian units and Basement rock section, which varies between 0.001 – 0.009 gaussian units. The remanence magnetization used was 33235.26 nT while the magnetic inclination was -1.935^0 and the declination was -4.763^0. These values were obtained from literature adapted from Ajakaiye *et. al.* (1985 and 1991), Ofoegbu and Onuoha (1990), Udensi and Osazuwa (2002), Udensi and Osazuwa (2003) and Likkasson *et. al.* (2005). These values fall within range of values for rocks and minerals (Telford *et. al.*, 2001). The depth to magnetic sources results obtained from the Source Parameter Imaging (SPI) was used as constraint depth for modelling the residual magnetic field anomalies. Each depth models were loaded as 'Registered Backdrop' in the GMSYS.

Another data called, Shuttle Radar Topographic Mission (SRTM), was used as the topography data for the models, it is the value above the sea level and it was obtained from Nigeria Geological Survey Agency (NGSA). The terrain clearance value used was 160 m, this value was added to the SRTM, which was used for the magnetic elevation control. This value thus serves as the total topographic value (called sensor) for the models. The models or profiles were created from each selected database line. It is worthwhile to note that, models generated or produced were within an acceptable error margin of 4% to about 12%, which is one of the lowest error margins obtained when compared with other notable literatures.

Results

Results from Profile AA^1 to GG^1

Figures 5, 6, 7, 8, 9, 10 and 11 are the results of models obtained from the profile lines drawn in Figure 4, which represents Profiles AA^1, BB^1, CC^1, DD^1, EE^1, FF^1 and GG^1 respectively. AA^1,

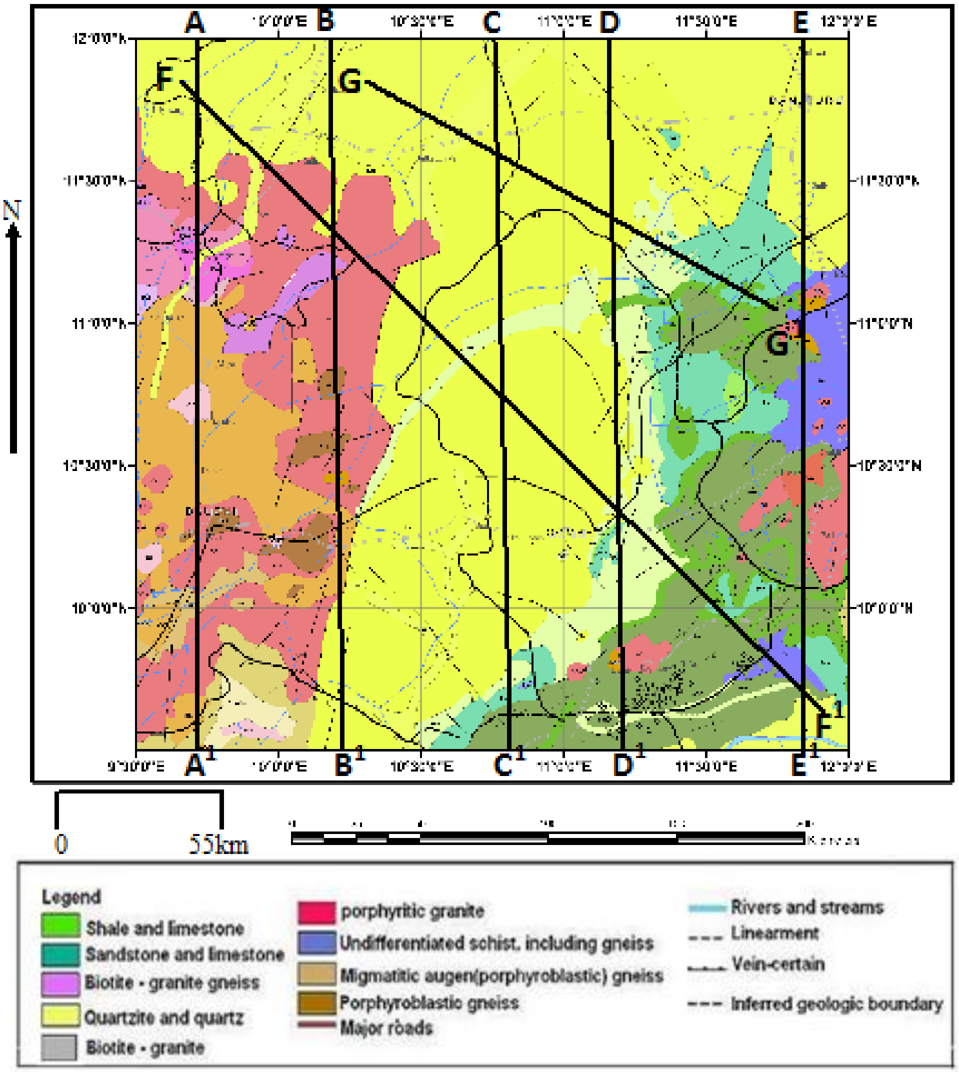


Figure 4: Map of selected profiles for modelling on the geologic map of the area (scale 1:2000000).

BB^1, CC^1, DD^1 and EE^1 are profile lines drawn in a north-south manner across various anomalies like northeast-southwest, northwest-southeast and east-west trend. These profiles AA^1 - EE^1 each covers a total distance of 270 km. Profiles AA^1 and BB^1 passed through the basement complex region (like of Foggo, Maya, Madaki, Magama and Bauchi) in the north as shown in Figure 4. However profiles FF^1 and GG^1 were carefully selected to take care of some notable anomalies in Figure 3. FF^1 has a total length of 355 km and GG^1 has a total length of 180 km.

The model from Figure 5 (profile AA^1), mainly consists of basement rocks outcropped over more than two-third of the profile length. The sedimentary rocks corresponding to Chad Formation could be found at the northern part of the profile and has a length of about 50 km. Its thicknesses range between 0.2 km and 1.6 km. From Figure 4, profile AA^1 passed through a tiny sedimentary body which is evident in Figure 4, the body is a sedimentary formation corresponding to Kerri-Kerri formation and has a depth of about 0.5 km. The out cropped basement rocks as delineated by the geologist are Granite, Biotite-Granite, Younger Basalt and fine-grained-Biotite-Granite. The model has intrusive rocks to both the north and the southern parts. The intrusive rock to the north could be found at a depth of about 0.6 km and has a width of about 18 km and thickness of about 0.4 km. The intrusive rock to the south could be found at about 0.6 km depth. It has a lateral distance (or width) of about 40 km and a thickness of about 2.0 km. The intrusive rocks have similar magnetic properties like that of the basement rocks.

Profile BB^1 (from Figure 4) passes through the sedimentary region in the north, then through the basement complex at the middle of the profile and then through the sedimentary in the south. The profile (Figure 6) consists of sedimentary rocks underlined by the basement rocks. The basement material outcropped at about 90th km from the north which is evident in Figure 4. The thickness of the sedimentary formation in the north ranges from 0.18 km to about 1.30 km. The sedimentary thickness in the south ranges from 0.6 km to about 2.70 km in the south. The sedimentary formation to the north belongs to the Chad Formation and to the south; it belongs to the Kerri-Kerri Formation and Gombe sand stones. The highest sedimentary formation in the south could be found at about few kilometres west of Ako Gombe. The basement is found outcropped as evident in Figure 4 in between the two sediments. It is named as basement material and corresponds to Granite, Biotite-Granite and fine-grained-Biotite-Granite.

Profile CC^1 (Figure 7) mainly consists of sedimentary sections. The sedimentary thickness varies from 0.0 km to about 4.60 km. The highest sedimentary thickness is obtained at the southern part around Gombe axis. This sediment corresponds to Kerri-Kerri Formation, Gombe sand stones and Pindiga Formations in the south. In the north, the sedimentary thickness is about 2.4 km and it corresponds to Chad Formation. The basement is nearly exposed at about 54th km distance from the north (beginning) of the profile, which could be found at about Latitude of 11.0^0 N. This area lies around Dumbulwa-Bage High of Zaborski *et al*., 1998.

Profile DD^1 (from Figure 4) is a north-south line drawn across a predominantly east-west trending anomaly. This profile passes between Damagun and Damaturu in the north; it also passed through Kaltungo area in the south. The profile (Figure 8) passes through sedimentary section underlined by basement rocks. Where the basement is uplifted with about 0.0 km sediments, was intruded by basic igneous rock of susceptibility value of 0.009 c.g.s. This intrusive rock is found at about 0.8 km depth, it has a thickness of about 1.8 km and a width of about 90 km. This feature separates Chad Formation from Benue Trough sediments (Kerri-Kerri, Pindiga, Gombe sand stones and Bima Formations). This intrusive body also lies between latitude 11.0^0 N to about 11.2^0 N, which corresponds also to Dulbulwa-Bage High of Zaborski *et al*., 1998. The shallowness of basement to the south of the profile could also be attributed to Kaltungo Inlier, which was ascribed to thin sedimentary cover by numerous workers. The profile thus has the sedimentary thickness that ranged between 0.0 km to about 3.80 km towards south of the profile. The sedimentary width is almost the length of the profile.

Profile EE^1 (from Figure 4) is a north-south line drawn across a northeast-southwest and east-west trending anomaly. This profile (Figure 9) passes through east of Bun, Maza, Burutai, Meringa, Biu, and Walama. Most of those town listed are located on basaltic rocks as delineated by the geologists. The profile is mainly sedimentary and has thickness that varies from 80 m to about 2.08 km. The highest sedimentary thickness is obtained towards the southern part, while the least thickness is found in the north. This result is typical of the geologic features found in the area.

Profile FF^1 (from Figure 4) is a northwest-southeast line drawn across a predominantly east-west and northeast-southwest trending anomalies. This profile (Figure 10) passes through Azare in the north and through southeast of Walama in the south. It is the longest profile with maximum length of about 355 km. The profile pass through the Chad Formation and some basement rocks in the north with sedimentary thickness of about 1.60 km; also through Kerri-Kerri Formation and Gombe sand stones in the middle where the sedimentary thickness is highest (3.80 km) and finally through Bima.

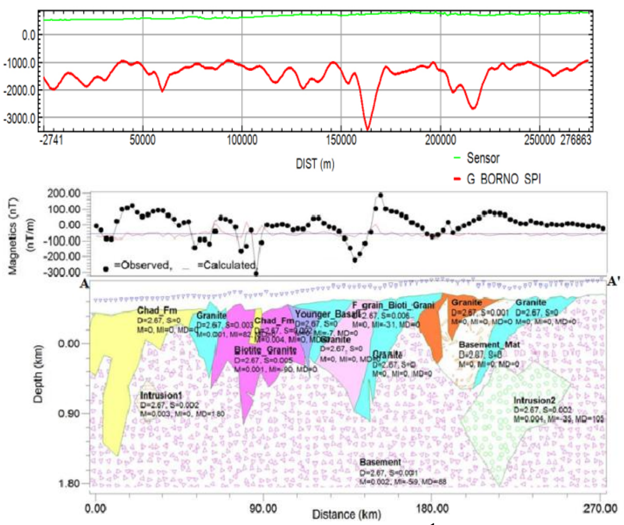


Figure 5: Model results for profile AA^1

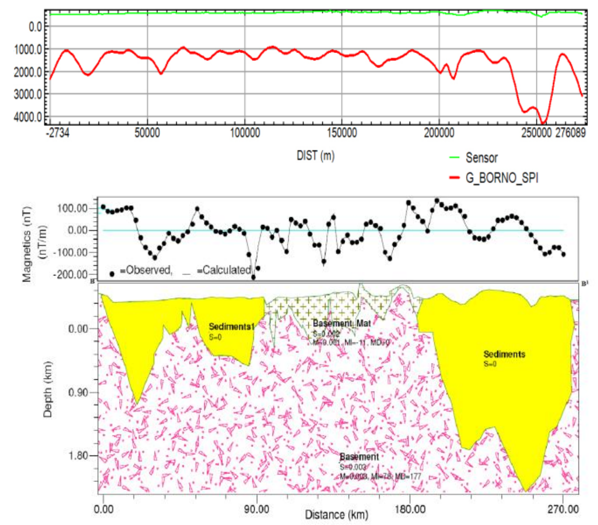


Figure 6: Model results for profile BB^1

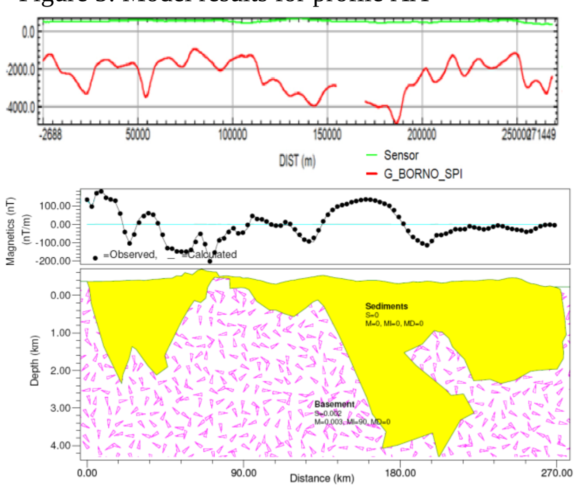


Figure 7: Model results for profile CC^1

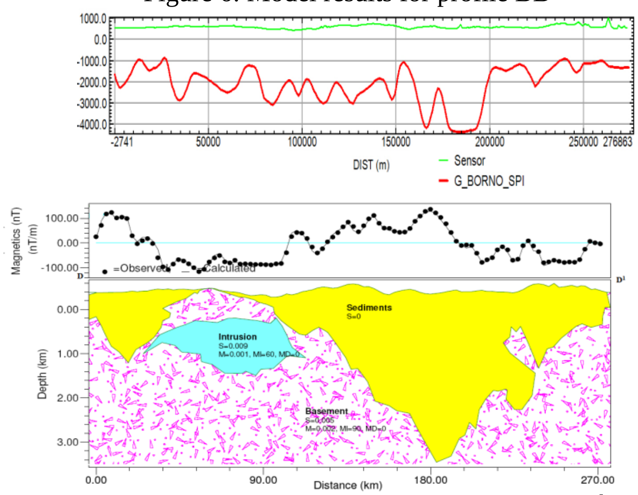
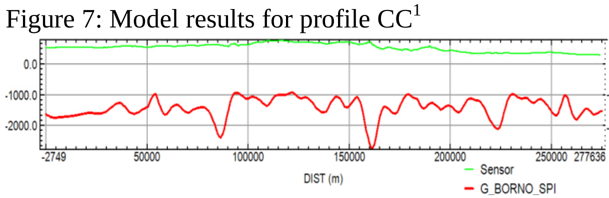
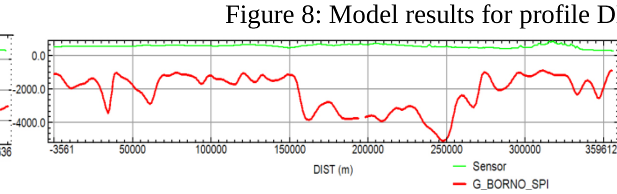


Figure 8: Model results for profile DD^1





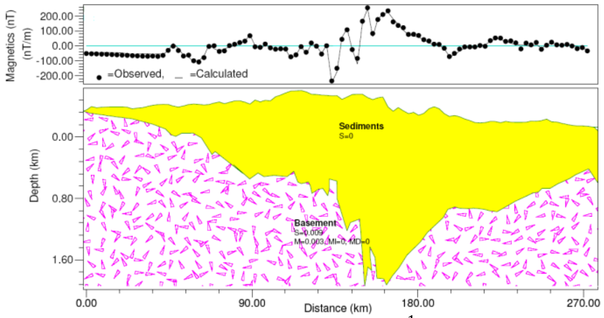


Figure 9: Model results for profile EE^1

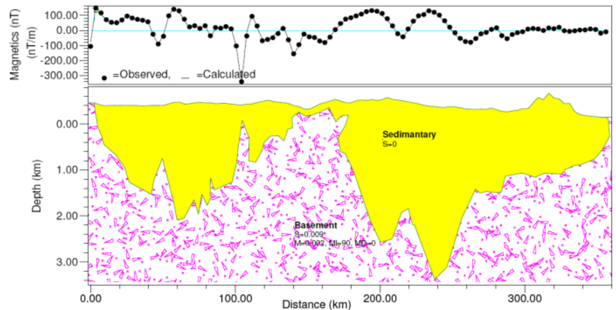


Figure 10: Model results for profile FF^1

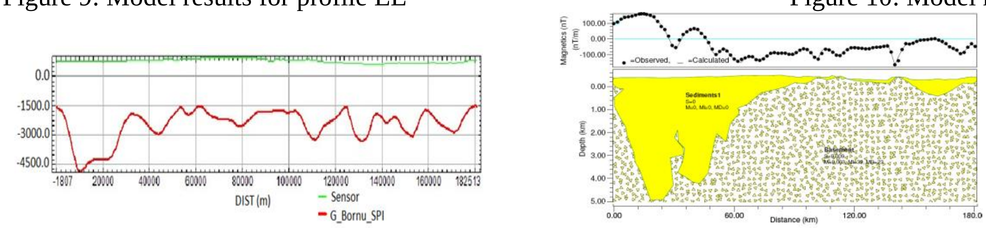


Figure 11: Model results for profile $GG^1$and stones, Pindiga Formation and Alluvium deposits in the south where the sedimentary thickness is thin (about 1.0 km).

The thin area in the south corresponds to Kaltungo inlier area. The basement is shallow at about 140th km from the north of the profile and the sedimentary thickness there is about 0.20 km. This point corresponds to Dumbulwa-Bage

Summary of the Depth Models from 2D Modelling.

Figures 12 and 13 show the depth estimate from the digitization of depth models obtained from Figures 5 to 11. Figure 12 is the contour map of the depth estimates from models AA^1 to GG^1. The maximum depth of 3.8 km is obtained at the southern part of the study area around Gombe and Ako Gombe. Similarly, the maximum depth of about 4.2 km is obtained at the northcentral part towards the nortwest of Damagun, Damaturu and to the northeast of Azare. The minimum depths between 0.00 km to about 0.40 km were obtained at the basement area in the western part and in the east around volcanics area. Figure 13 is the surface map of the depth models. This result corroborates the results obtained from Salako (2014), Salako and Udensi (2013) and other notable results in the area.

The dashed lines in Figures 12 and 13 marked the supposed separation between the Benue Trough and the Bornu Basin. This line passes through the study area at about latitude 11.0^0 N as noted by Zaborski *et al.* (1998). They described the separation area to have occurred around Dumbulwa-Bage High at about latitude of 11.0^0 N. This area is described by Figures 12 and 13 to have shallow basement with maximum sedimentary thickness of about 1.4 km. However, to the either side of the area (north and south), the sedimentary thickness increases to about 3.80 km. Thus this area (Dumbulwa-Bage High) is an uplift that dips sediments towards north (Bornu Basin) and south (Benue Trough) of the study area.

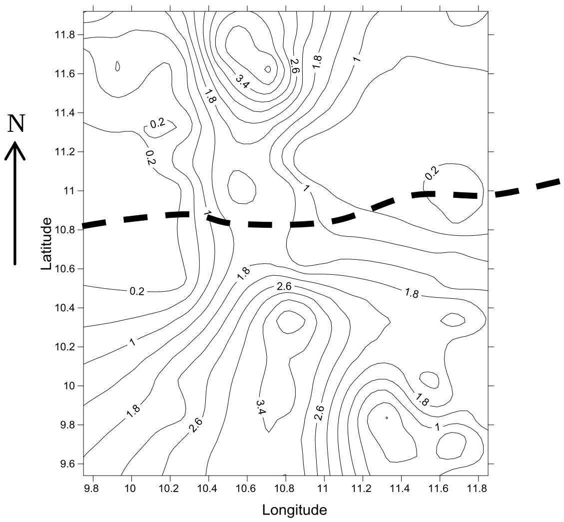


Figure 12: Contour map of sedimentary thickness obtained from 2D models of AA[1] to GG[1]. Contour interval is 0.4 km

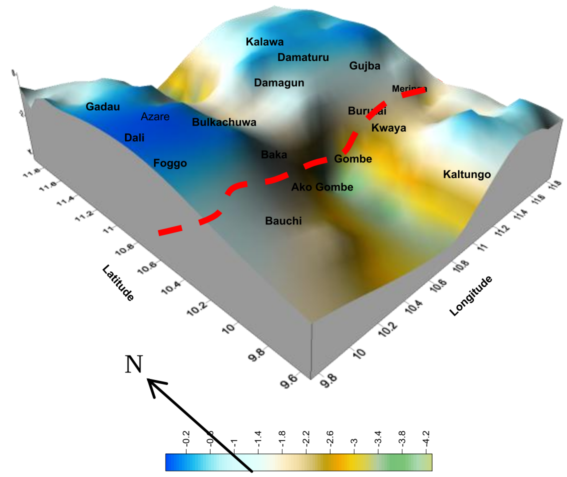


Figure 13: 3D surface map of profile depths obtained from 2D models of AA[1] to GG[1].

Conclusion

Presence of hydrocarbon and its potential is enhanced by the thickness of the sediments of the basin, and also by the kind of geological structures existing within the basement that form traps for oil and gas. The basement rocks were exposed around Foggo and Bauchi axes in the basement complex region. The sedimentary thickness is thin around Kaltungo and volcanic area at the eastern part of the survey area. The highest sedimentary thicknesses obtained, which range between 3.80 km to about 5.40 km may enhance the accumulation of hydrocarbons. These areas of highest sedimentary thickness correspond to Gombe, Ako Gombe, Damaturu and Bulkachuwa. The boundary between the Bornu Basin and the Upper Benue Trough was successfully delineated through: trend analysis of the total magnetic intensity (Salako and Udensi, 2013) and 2D modelling of the subsurface structures. The end results of this method shows that Upper Benue Trough was separated from the Bornu Basin at about latitude 11.0^0 N. This area corresponds to “Dumbulwa-Bage High” of Zaborski *et al*., 1998.

Aknowledgement

The authors appreciate and thanked the management of Federal University of Technology Minna, Nigeria, for the provision of fund for this research through her University Board of Research (UBR).

References

Ajakaiye, D. E., Hall, D. H. and T. W. Millar (1985). Interpretation of Aeromagnetic data across the central crystalline shield areas of Nigeria. *Geophysics J.R. Astron Society*, 83: 503-517.

Ajakaiye, D.E. Hall, D.H., Ashiekaa J.A. and E. E. Udensi (1991). Magnetic Anomalies in the Nigerian Continental mass based on aeromagnetic surveys. *Tectonophysics*, 192, 211-230.

Ajibade, A. C. (1976). Provisional classification and correlation of the schist belts in north-western Nigeria. In C.A., Kogbe (2nd Eds.), *Geology of Nigeria* (pp, 80-90). Elizabeth Publ., Ibadan.

Allix, P. (1983). Environmental Mesozoiques de la Partic Nord-Orientale du Fosse de la Benoue (Nigeria). *Stratigraphic, Sedimentologic, Evolution Geodynamique, Travaux Laboratoire Sciences Terre St.-Jerome Marseille*, (B) 21, iv + 200 pp.

Avbovbo, A.A., Ayoola, E.O.and G. A. Osahon (1986). Depositional and structural styles in Chad Basin of northeastern Nigeria. *Bulletin American Association Petroleum Geologists*, 70, 1787-1798.

Barber, W. (1965). Pressure water in the Chad Formation of Bornu and Dikwa Emirates, northeastern Nigeria. *Bulletin Geological Survey of Nigeria*, 35:1-138.

Bellion, Y.C. (1989). Histoire Geodynamique Post-Paleozoique de l’Afrique de l’ouest d’apres l’etude de quelques Bassins Sedimentaires (Senegal, Taoudenni, Iullemmeden, Tehad). *Publication Occasionnelle Centre International Formation Echanges Geologiques*, 17: 1 - 302.

Benkhelil, J. (1985). *Geological Map of Part of the Upper Benue Valley (Scale 1:100,000) (with explanatory note)*. Elf Nigeria Ltd., Lagos, Nigeria.

Benkhelil, J. (1986). *Structure et Evolution Geodynamique du Bassin Intracontinental de la Benoue (Nigeria)*. Thesis Doctorat, Universite de Nice, France.

Benkhelil, J. (1988). *Structure et Evolution Geodynamique du Bassin Intracontinental de la5Benoue* (Nigeria). *Bulletin Centres Recherches Exploration- Production Elf-Aquitaine*, 12: 29-128.

Bott, M.H.P. (1963). Two methods applicable to computers for evaluating magnetic anomalies due to finite three dimensional bodies. *Geophysical Prospecting*, 11: 292 - 299.

Bowden, P. and D. C. Turner (1974). Peralkaline and associated ring complexes in the Nigeria- Niger province, West Africa. In H. Sorensen, Ed. *The alkaline rocks*, 330-351. John Wiley, London.

Buchanan, M.S., Macleod, W.N., Turner, D.C., Berridge, H.G., and R. Black (1971): The Geology of the Jos Plateau. *Bulletin Geological Survey of Nigeria* no. 32(2) 107p.

Burke, K.C. and J. F. Dewey (1974). Two plates in Africa during the Cretaceous. *Nature*, 249: 313-316.

Cady, J. W. (1980). Calculation of gravity and magnetic anomalies of finite-length right polygonal prisms. *Geophysics*, 45, 1507-1512.

Carter, J. D., Barber, W., Tait, E.A. and G. P. Jones, (1963). The Geology of parts of Adamawa, Bauchi and Bornu Provinces in north-eastern Nigeria. *Bulletin Geological Survey Nigeria*, 30, 1-99.

Clark, D. A., Saul, S. J. and D. W. Emerson (1986). Magnetic and gravity anomalies of a triaxial ellipsoid. *Exploration Geophysics*, 17: 189-200.

Coggon, J.H. (1976). The magnetic and gravity anomalies of polyhedral. *Geoexploration*, 14, 93-105.

Cratchley C.R., & Jones, G.P. (1965). An interpretation of the geology and gravity anomalies of the Benue valley, Nigeria. *Overseas Geological Surveys Geophysical*, paper 1: 1-26.

Eborall, A. C. (1976). Intermediate rocks from Older Granite Complexes of the Bauchi area, northern Nigeria. In C.A., Kogbe (Eds.). *Geology of Nigeria* (pp 65-74). Elizabeth Publ., Ibadan.

Falconer, J. D. (1911). The *geology and Geography of Northern Nigeria*. MacMillan, London, UK.

Genik, G. J. (1992). Regional framework, structural and petroleum aspects of Rift Basins in Niger, Chad and the Central African Republic (C.A.R.). *Tectonophysics*, 213, 169-185.

Genik, G.J. (1993). Petroleum geology of the Cretaceous-Tertiary Rift Basins in Niger, Chad and the Central African Republic. *Bulletin American Association Petroleum Geologists*, 77, 1405-1434.

Guiraud, M., Ajakaiye, D. .E. and F. X. O. Ugodulunwa (1989). Characterisation of late Cretaceous NE-SW sinistral wrench faults in the Upper Benue Trough (Nigeria) using micro-tectonic and aeromagnetic data. *Journal of African Earth Sciences*, 9(1): 9-21.

Guiraud, M. (1990a). *Mecanisme deformation du bassin sur Dechrochements multipless de la Haute-Benoue (Nigeria) . facies et geometrie des corps sedimentaires, microtectonique et deformations synsedimataires*. Memoir d'Habilitation, Universite de Montpellier, France.

Guiraud, M. (1991a). Mecanisme de fermation du bassin cretace sur decrochements multiples de la Haute-Benoue (Nigeria). *Bulletin Centres Recherches Exploration-Production Elf-Aquitaine* 15, 11-67.

Guiraud, M. (1993). Late Jurassic Rifting-Early Cretaceous Rifting and Late Cretaceous Transpressional inversion in the Upper Benue Basin (NE Nigeria). *Bulletin Centres Recherches Exploration-Production Elf-Aquitaine* 17, 371-383.

Hjelt, S. E. (1972). Magnetostatic anomalies of a dipping prism. *Geoexploration*, 10: 239-254.

Huntings Geology and Geophysical Ltd (1976). *Airborne magnetometer survey contour of total intensity Map of Nigeria*. Airborne Geophysical Series.

Jessel, M. W., Valenta, R. K., Jung, G.,Cull, J. P. and A. Geiro (1993). Structural geophysics. *Exploration Geophysics*, 24: 599-602.

Jones, B. (1932). *The geology of southern Bornu*. Annual Report Geological Survey Nigeria 9-14.

King, L.C. (1950). Speculations on the outline and the mode of disruption of Gondwanaland. *Geological Magazine*, 87, 353-359.

Lee, T. J. (1980). Rapid computation of magnetic anomalies with demagnetization included, for arbitrary shaped bodies. *Geophysical Journal of the Royal Astronomical Society*, 60, 67-75.

Likkasson, O. K., Ajayi, C.O. and E. M. Shemang (2005). Some structural features of the Middle Benue Trough, Nigeria, modelled from aeromagnetic anomaly data. *Science Forum, Journal of Pure and Applied Science*, 8, 100-125.

Matheis, G. (1976). Short review of the geology of the Chad Basin in Nigeria. In C.A., Kogbe, *Geology of Nigeria*, (pp 289-294). Elizabethan Publication Company, Lagos, Nigeria.

McCurry, P. (1976). The geology of the Precambrian to Lower Paleozoic rocks of northern Nigeria- a review. In C.A., Kogbe, *Geology of Nigeria*, (pp 15-39). Elizabethan Publication Company, Lagos, Nigeria.

Miller, R. E., Johnston, R. H., Oluwa, J.A.I., and J. U. Uzoma (1968). *Groundwater hydrology of the Chad Basin in Bornu and Dikra emirates, northern Nigeria with special emphasis on the flow life of the artesian system*. Water supply United States Geological Survey 1957-1. 1-148.

Ofoegbu, C. O. and K. M. Onuoha (1990). A review of geophysical investigations in the Benue Trough. . In C.O., Ofoegbu, *The Benue Trough, Structure and Evolution*, (pp 203-216). Vieweg and Sohn, Braunschweig Germany.

Okosun, E.A. (1995a). Review of the Geology of Bornu Basin. *Journal Mining and Geology*. 31: 113-122.

Olade, M.A. (1975). Evolution of Nigeria's Benue Trough (Aulacogen): a tectonic model. *Geological Magazine,* 112, 123-133.

Olugbemiro, O. R. (1997). Hydrocarbon potential, maturation and Paleoenvironments of the Cretaceous (Cenomanian-Santonian) series in the Bornu (Chad) Basin, NE Nigeria. *Tubinger Mikropaleontologische Mitteilungen*, 14, viii+150 pp.

Popoff, M. (1988): Du Gonwana a l'Alantique sud : Connexions du fosse de la Benoue avec les bassins du nord-est Bressilien Jusqu'à l'ouverture du golfe de Guinee au Cretace Inferieur. Journal African Earth Sciences &: 409-431.

Raeburn, C. and B. Jones (1934). The Chad Basin. Geology and Water Supply. Bulletin Geological Survey Nigeria 15. 1 - 61.

Salako, K.A. (2014). Depth to Basement determination using Source Parameter Imaging (SPI) of Aeromagnetic Data: An application to upper Benue Trough and Borno Basin, Northeast, Nigeria. *Academic Research International (AR Int) 5(3):* 74 – 80.

Salako, K.A. and E. E. Udensi (2013). Spectral depth analysis of upper Benue Trough and Borno Basin, northeast Nigeria using aeromagnetic data. *International Journal of Science and Research (IJSR) 2(8)*: 48 – 55.

Schneider, J. L. and J. P. Wolff (1992). Carte géologique et cartes hydrogéologiques à 1/500.000 de la République du Tchad. Mémoire explicatif. Document du BRGM 209, 2 volumes.

Shuey, R. T.and A. S. Pasquale, A.S. (1973). End corrections in magnetic interpretation. *Geophysics*, 38: 507-512.

Stoneley, R. (1966). The Niger Delta region in the light of the theory of Continental drift. *Geological magazine,* 103: 385-397.

Talwani, M. and J. R. Heirtzler,(1964). Computation of magnetic anomalies cuased by two dimensional bodies of arbitrary shapes. In G.A., Parks. (Eds.), *Computers in the Mineral Industries, Part I,* (9, 464 -480).

Talwani M. (1965). Computation with the help of Digital Computer, of Magnetic Anomalies caused by bodies of Arbitrary Shape, Geophysics. 30: 797 – 817.

Telford, N. W., Geldart, L. P., Sheriff, R.S. and D. A. Keys (2001). *Applied geophysics*, Cambridge University Press.

Udensi E. E. (2000). *Interpretation of total magnetic field over the Nupe Basin in west central Nigeria using aeromagnetic data*. Ph.D thesis A.B.U. Zaria Nigeria.

Udensi, E. E. and I. B. Osazuwa. (2002): Two and Half Dimensional Modelling of the Major Structures Underlying the Nupe Basin, Nigeria using Aeromagnetic Data. Nigerian Journal of Physics (NJP), 14(1) : 55 – 61.

Valenta, R.K., Jessell, M.W., Jung, G. and J. Bartlett (1992). Geophysical interpretation and modelling of three dimensional data in the Duchess area, Mount Isa, Australia. *Exploration Geophysics*, 23: 393-400.

Whiteman, A. J. (1982): Nigeria: Its Petroleum Geology, Resources and potential. 1: 176 pp 2-238. Graham and Trotman, London, UK.

Wright, J.B. (1968). South Atlantic Continental Drift and the Benue Trough. *Tectonophysics* 6: 301-310.

Wright, J.B. (1976). Origin of the Benue Trough- A Critical Review, In. C.A., Kogbe, *Geology of Nigeria,* (pp 309-317). Elizabethan Publication Company, Lagos, Nigeria.

Zaborski, P.M., Ugodulunwa, F., Idornigie, A., Nnabo, P. and K. Ibe (1998). Stratigraphy and structure of the Cretaceous Gongola basin, northeast Nigeria. *Bulletin Centres Recherches Exploration-Production Elf-Aquitaine,* 21(for 1997),:153-185.