

Evaluation of Aeromagnetic Anomalies Over Okigwe Area, Southeastern Nigeria

¹L. N. Onuba, ²G.K. Anudu, ¹O.I. Chiaghanam and ³E.K. Anakwuba

¹Department of Geology, Anambra State University, Uli, Nigeria

²Department of Geology and Mining, Nasarawa State University, Keffi, Nigeria

³Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria

Abstract: Total field aeromagnetic anomalies over Okigwe area have been evaluated in order to map lineaments and estimate the depths to basement (sedimentary thicknesses). Aeromagnetic contour map of Okigwe (Sheet 312) was acquired, digitized and analyzed. Regional-residual separation and Slope methods were applied. The magnetic lineament map shows major geologic lineaments trending in NE-SW direction with minor ones trending in NW-SE direction. The major trend is in conformity with the trend of the Benue Trough. Visual study of the map shows presence of igneous intrusives in the northeastern part of the area. The results obtained using Slope methods indicate two depth sources in the area. On the average the deeper magnetic sources range from 2.0 to 4.99 km, while the shallower magnetic sources range from 0.4 to 1.99 km. Deeper magnetic sources probably depict depths to Precambrian Basement, whereas shallower sources probably depict depths to igneous intrusives and/or magnetized bodies within the sedimentary covers. Hydrocarbon exploration is not recommended since the area has low thickness of sediments on the average. All these deductions were reached after due consideration to both qualitative and quantitative interpretations supported by geological information of the area.

Key words: Aeromagnetic anomalies, depths to basement, lineaments, Okigwe, slope methods

INTRODUCTION

The aeromagnetic survey is the oldest potential field method used for hydrocarbon exploration. The aeromagnetic geophysical method plays a distinguished role when compared with other geophysical methods in its rapid rate of coverage and low cost per unit area explored. The main purpose of the aeromagnetic survey is to detect minerals or rocks that have unusual magnetic properties which reveal themselves by causing anomalies in the intensity of the earth's magnetic field (USGS, 1997). The aeromagnetic survey is applied in mapping these anomalies in the earth's magnetic field and this is correlated with the underground geological structure. Faults usually show up by abrupt changes or close spacing in orientation of the contours as revealed by the magnetic anomalies. For hydrocarbon exploration, residual magnetic anomaly maps are useful since they identify the presence of intrusives, lava flows, or igneous plugs which are areas to be avoided in hydrocarbon exploration (Selley, 1998). The thickness of sediment required for hydrocarbon to form or generate varies from place to place. Generally, the minimum overburden thickness of sediment required for oil to form ranges from 2 to 4 km, while for gas to form the minimum thickness required is between 3 to 7 km. This is common for divergent plate

boundaries and could be more in the deltaic environment and convergent boundary (Dow, 1978). Numerous oil fields have been located by aeromagnetic method like Hobbs in New Mexico (Gatlin, 1960).

There have been some publications on the depths to basements/magnetic source bodies over the Lower Benue Trough in which Okigwe and environs are located. According to Onwuemesi (1997), sedimentary thickness (depth to the basement) in the Anambra Basin which is part of the Lower Benue Trough varies between 0.9 and 5.6 km, whereas Onu *et al.* (2011) stated that depths to magnetic source bodies in the Lower Benue Trough and some adjoining areas vary from 0.518 to 8.65 km with a mean depth of 3.513 km (for deeper magnetic source bodies) and 0.235 to 3.91 km with a mean depth of 1.389 km (for shallow magnetic sources).

This research work involves the evaluation of aeromagnetic anomalies over Okigwe and environs using Slope methods. The Slope methods are simpler than other Published methods because they use all data points available on the anomaly profile and yet does not require calculation of the horizontal and vertical derivatives of the magnetic field. They are much faster and provide more depth estimates than analysis by model curve fitting.

The objectives of this research study are to trace out the lineaments like faults and fractures, to delineate

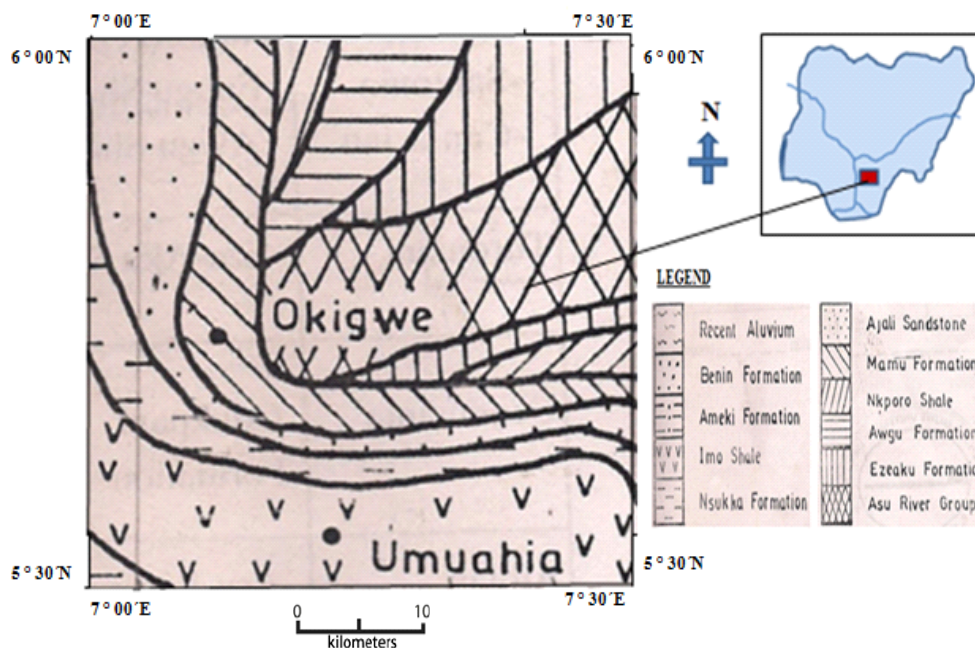


Fig. 1: Geological Map of Okigwe and environs (Onwuemesi, 1995)

lithologic boundaries as revealed by magnetic disturbances caused by different rock types and to determine the depth to basement (thickness of sediments).

Location, accessibility and geology: The study area is bounded by latitudes 5°30'N to 6°00'N and longitudes 7°00'E to 7°30'E. It is located in Abia and Imo States of the southeastern Nigeria. It covers an area of about 3025 km². These areas include Okigwe, Leru, Lokpanta, Lokpesi and can be accessed through the following major roads: Enugu-Port Harcourt Expressway, Umunze-Okigwe road with other secondary and minor roads.

Geological studies in Lower Benue Trough in which Okigwe and environs is situated have been reported widely in literature (Carter *et al.*, 1963; Cratchely and Jones, 1965; Short and Stauble, 1967; Burke *et al.*, 1970; Murat, 1970; Nwachukwu, 1972; Offodile, 1976; Petters, 1978; Ofoegbu, 1985a; Osazuwa *et al.*, 1981). The depositional histories of the Lower Benue Trough are dominated by repetitive transgressive/regressive sedimentary cycles interspersed with two main episodes of structural deformations in Cenomanian and Santonian times. The Geology of Okigwe and environs is composed mainly of Bende Formation of Eocene, Imo Formation of Paleocene, Nsukka Formation, Ajali Formation of Maastichtian, Mamū Formation, Nkporo Formation including Enugu Shale of Campanian, Awgu Formation, Ezeaku Formation and Asu River Group of Albian (Nwajide and Reijers, 1995; Onwuemesi, 1995). The map of Okigwe and environs showing various geologic Formations is presented in Fig. 1.

Physiography and climate: Okigwe area is largely drained by Imo Rivers. The drainage pattern is mainly dendritic and the area is characterized by slightly undulating topography; this shows that the area is generally hilly with most part 70 m above the sea level. The climate of the area under study is tropical with a mean maximum monthly temperature of about 37°C and the mean annual rainfall is approximately 1003.5 mm. The annual temperature is between 23.5-32°C, while the average air pressure of the area is about 1050 millibars.

MATERIALS AND METHODS

The aeromagnetic map over Okigwe area (Sheet 312) was obtained as part of a nationwide aeromagnetic survey sponsored by the Geological Survey of Nigeria. It covers Okigwe and environs located within Abia and Imo States of the southeastern Nigeria. The data were acquired along a series of NW-SE flight lines with a spacing of 2 km and an average flight elevation of about 150 m, while tie lines occur at about 20 km interval. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF). The data were made available in the form of contoured maps on scale of 1:100,000 as shown in Fig. 2. The total area covered was about 3025 km². The aeromagnetic map was acquired and digitized at 1km interval and the regional gradient was removed from the map by fitting a linear surface to the digitized aeromagnetic data using multi-regression least square analysis. The trend surface equation (regional gradient) becomes:

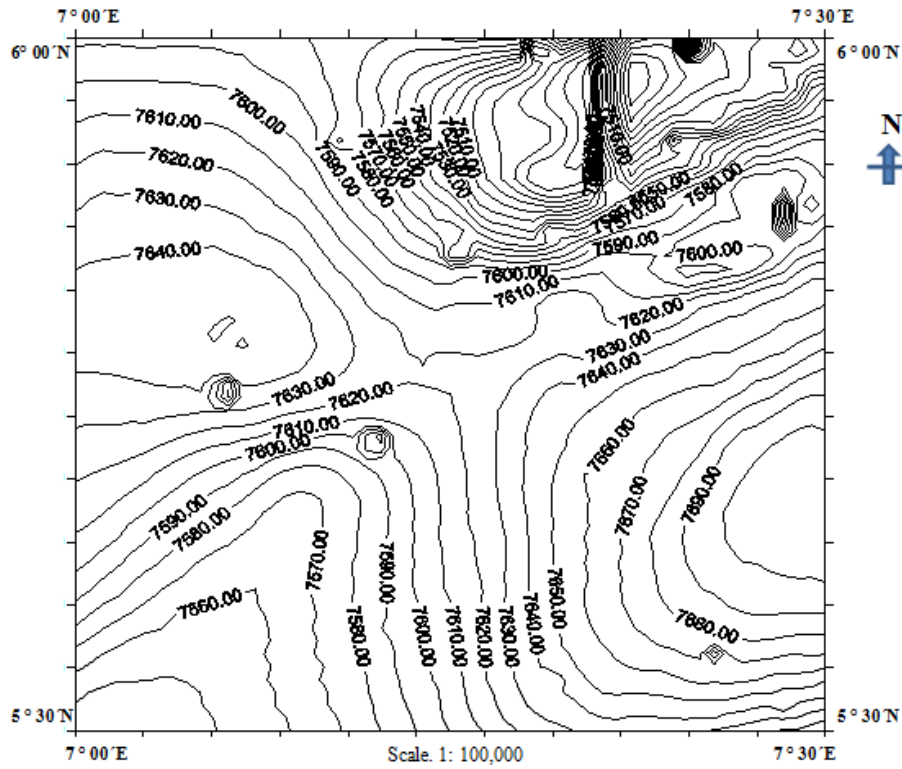


Fig. 2: Total aeromagnetic anomaly map of Okigwe Area (Contour interval ~10nt)

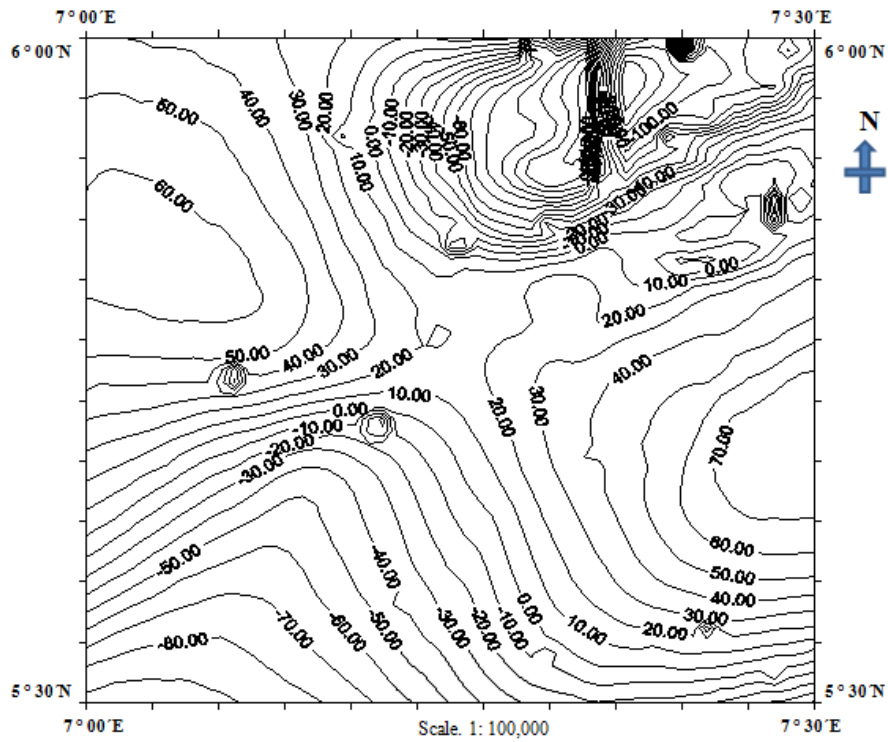


Fig. 3: Residual aeromagnetic anomaly map of Okigwe Area (Contour interval ~10nT)

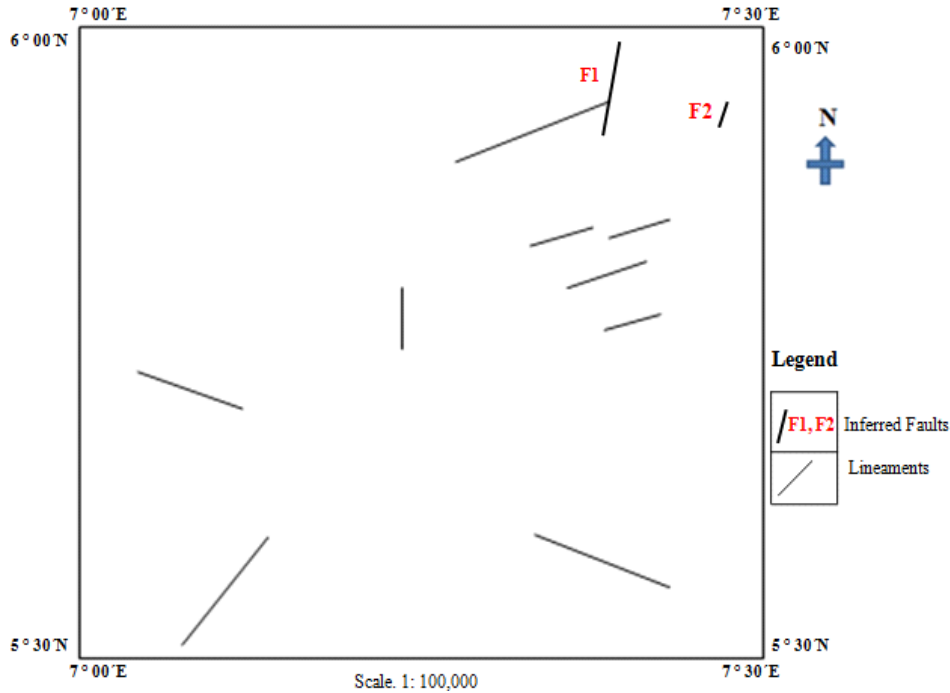


Fig. 4: Magnetic lineament map derived from 'Closure' and 'Nosing' of Fig. 3

$$T(X,Y) = 7654 - 0.8879X - 1.5660Y \quad (1)$$

where, X and Y are units of spacing along the horizontal and vertical axes. The trend equation was then subtracted from the aeromagnetic (observed) data and the resultant residual aeromagnetic anomaly data obtained and plotted in Fig. 3. This research study involves aeromagnetic/geological studies and interpretations as well as numerical computation of the aeromagnetic data employing Microsoft Exc 2007 and Surfer 8 Software.

RESULTS AND DISCUSSION

Qualitative interpretation: The closely spaced, linear sub-parallel orientation of contours from the northeastern part of Okigwe towards the southwestern part suggests the possibility of faults or local fractured zones passing through these areas. Nsikak *et al.* (2000) generally believe there would always be a magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to hematite and/or infilling of fracture planes by dyke-like bodies whose magnetic susceptibilities are different from those of their host rocks. Such geological features may appear as thin elliptical closures or nosings on an aeromagnetic map. Bearing this in mind, prominent elliptical closures and nosings of contours were identified on the aeromagnetic maps in Fig 2. These features represent geologic lineaments and their positions are indicated by lines drawn parallel to the elongation and

through the centre of the anomalies and they are presented in Fig. 4. The main trend of the lineaments is NE-SW with subordinate NW-SE and N-S trends. The main trend is in conformity with the trend of the Benue Trough itself. These trends may have served as a migratory path for hydrocarbon and hydrothermal fluids. Two major faults (F1, F2) were inferred and delineated at the northeastern part of the area with trends in N-S directions and they may have resulted from the pan-African orogeny.

A visual inspection of the aeromagnetic map over Okigwe area shows that the contour lines of northwestern and southeastern parts are widely spaced indicating that the depth to magnetic basement is relatively high when compared to those in the northeastern and southwestern parts. This can be seen in a pictorial view of residual magnetic anomaly of Okigwe area (Fig. 5). The lighter portions show positive magnetic anomaly and larger sediment thickness indicating deeper depths, while the dark portions show mainly negative magnetic anomaly with smaller sediment thickness indicating shallow depths. These shallow depths may have accounted for the presence of high magnetic intensity (susceptibility) in Okigwe area. A positive magnetic anomaly is a reading of magnetic field strength that is higher than the regional average which can indicate hidden ore and geologic structures, while a negative magnetic anomaly is a reading of magnetic field strength that is lower than the regional average.

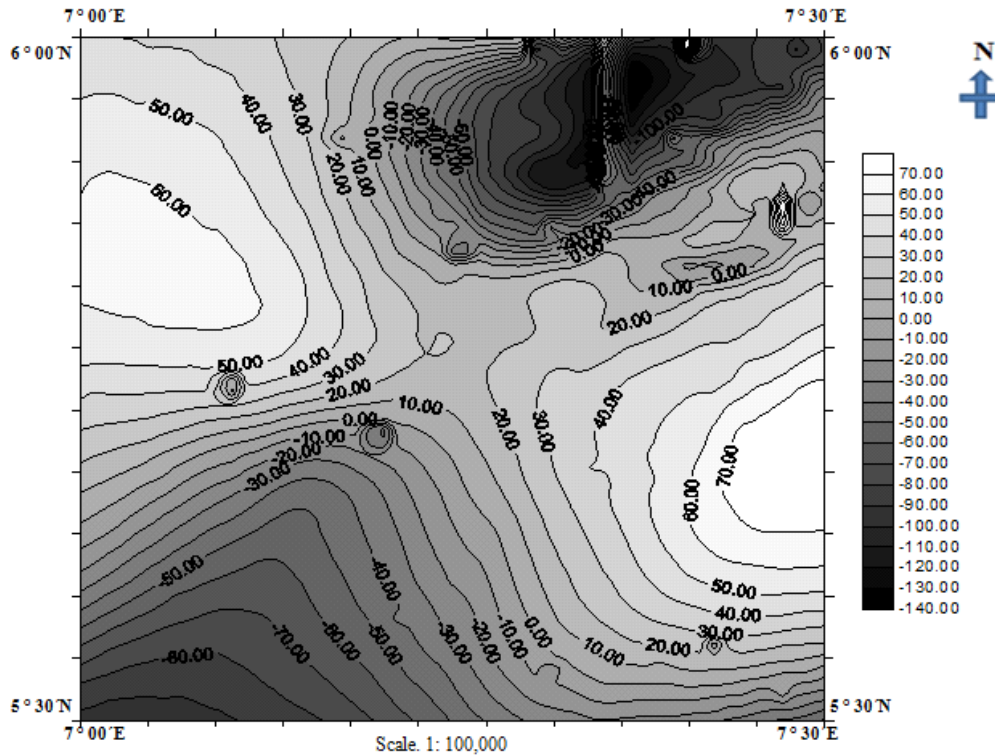


Fig. 5: A pictorial view of residual aeromagnetic anomaly of Okigwe Area (Contour interval ~10nT)

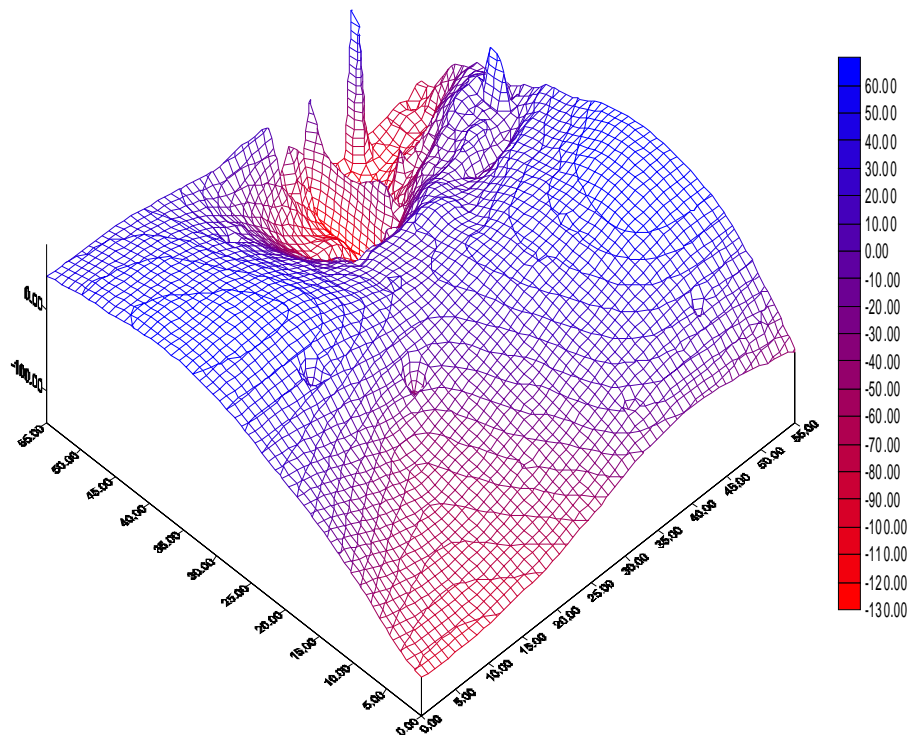


Fig. 6: Surface plot of residual aeromagnetic anomaly of Okigwe Area (Contour interval ~10nT)

It is generally believed that zones of low magnetic intensity correspond to sedimentary rocks; those of intermediate intensity are associated with granitic rocks, while zones of high magnetic intensity are characterized by basic igneous rocks. Okigwe area falls into three of these categories. The southeastern and northwestern part of Okigwe area show low magnetic intensity when compared to southwestern part which shows intermediate intensity and northeastern part that shows high magnetic intensity. This high magnetic intensity may have been associated with several tectonic activities which occurred during pan-African orogeny and this can easily be visualise on the surface plot of residual aeromagnetic anomaly map of Okigwe area (Fig. 6). The high magnetic intensity in Okigwe area may have been the major reason why hydrocarbon prospects in this area may be very unrealistic. Hydrocarbon window temperature may have been exceeded due to high magmatic activities. In addition, complex fracturing in this area could also have led to the draining away of hydrocarbon in study area.

Quantitative interpretation:

Depth estimation: Slope methods namely maximum-slope method and half-slope method are widely used especially for aeromagnetic interpretations. These graphical techniques use the sloping flanks of profiles to estimate depth to magnetic sources or depth to basements (thickness of sediments) in sedimentary basins (Nettleton, 1971; Telford *et al.*, 1998).

In Fig. 7a, S is the horizontal extent of the portion of the curve that is nearly linear at the maximum slope and is used when applying Maximum slope method (Eq. 2), whereas in the Fig. 7b, two additional line segments have been drawn tangent to the profile at half the maximum slope; the distance between the points of tangency is P and is employed when using Half-slope method (Eq. 3).

The depth of the source beneath these portions of the curve is given by:

$$H = K_1 S \tag{2}$$

$$1.67 \leq K_1 \leq 2.0 \text{ (generally, } K_1 \approx 1.82) \tag{2}$$

$$H = K_2 P \text{ (generally, } K_2 \approx 0.63) \tag{3}$$

In areas where the flight lines were not normal to the local geological strikes, the horizontal distances were multiplied by a cosine factor in order to obtain best depth estimates.

According to Telford *et al.* (1998), the use of both methods provides a check on the depth estimates and the care with which the graphical analysis is done. This method generally yields reasonable results for horizontal basement models with steeply dipping contacts; thus, it is suitable in the analysis of airborne data. It is much simpler and faster and provides more depth estimates than analysis by model curve fitting. It can be carried out on magnetic field profiles and maps (Rao and Babu, 1984).

In order to estimate depths to basements (thickness of sediments) across the study area using slope methods, several profiles were taken on the residual aeromagnetic anomaly map of Okigwe area (Fig. 8). Some selected magnetic profiles, namely A1-A, B1-B and C1-C, were used for detailed interpretation (Fig. 9, 10 and 11, respectively) and these may serve as representatives of others as they behave almost in the same way.

Profile A-A1: This profile passes through an area of relatively low magnetic anomalies in the southwestern part of the map. The maximum magnetic intensity value along this profile is 80nT and the minimum is -90nT. The depth values along this profile range from 0.91 km to 2.73 km (Fig. 9). The broad part of the curve indicates deeper magnetic source, while the sharp curves indicate shallow sources.

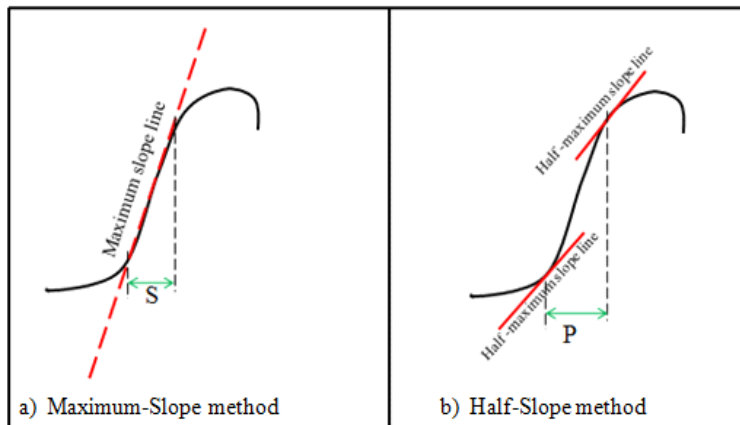


Fig. 7: Depth estimation from a slope of magnetic profile (Nettleton, 1971; Telford *et al.*, 1998)

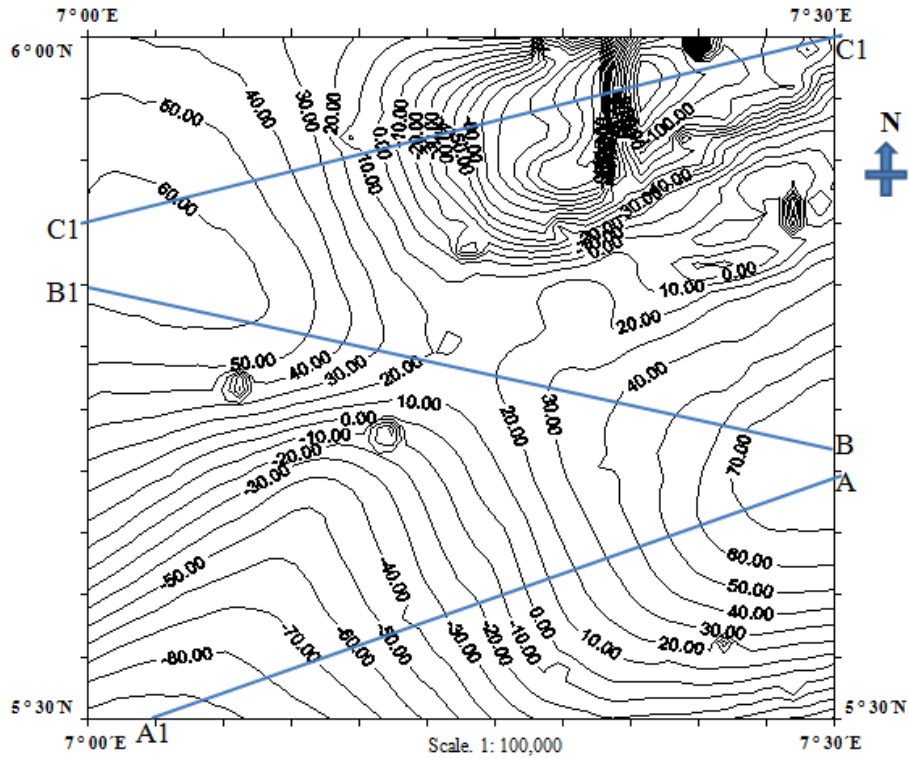


Fig. 8: Selected residual aeromagnetic anomaly profiles of Okigwe area (Contour interval ~10nT)

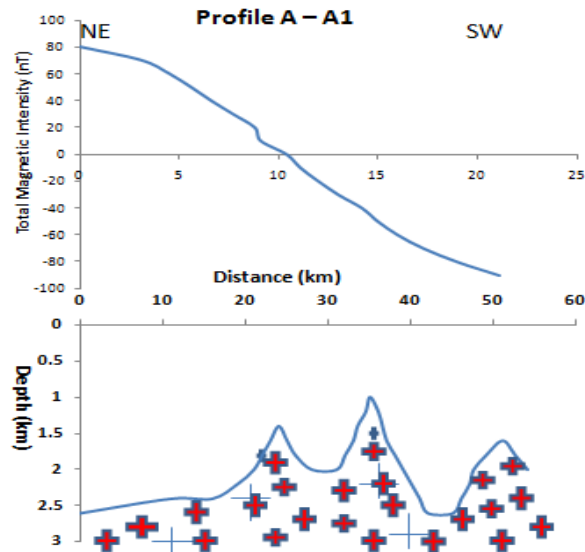


Fig. 9: The anomaly profile A-A1 showing depth to basement

Profile B – B1: The maximum magnetic intensity value along this profile is 80nT and the minimum value is 20nT. The depth values range along this profile is 2.18 to 4.91 km (Fig. 10).

Profile C – C1: This profile passes through middle of the study area cutting across Southeastern part and Northwestern part. The anomaly curve shown in Fig. 11 indicates a broader curve at the Northeastern part and a

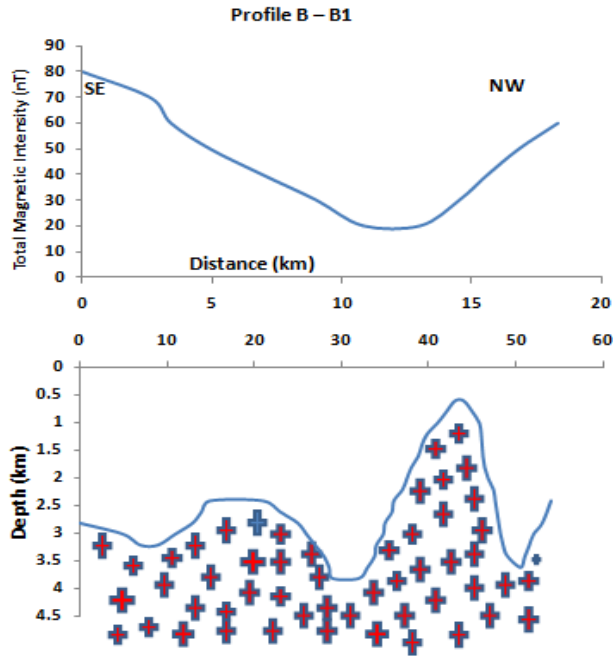


Fig. 10: The anomaly profile B-B1 showing depth to basement

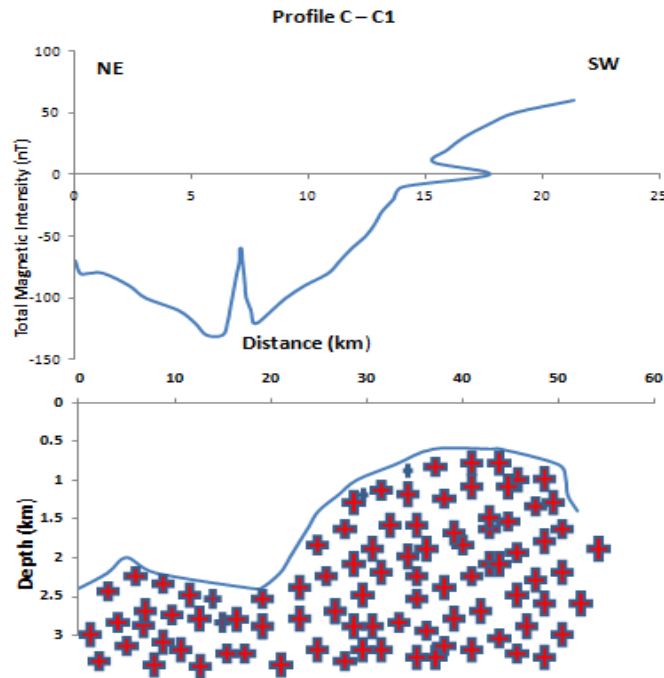


Fig. 11: The anomaly profile C-C1 showing depth to basement

sharp curve at the extreme portion of the east. The maximum magnetic value along this profile is 60nT and the minimum is -70nT. The depth values along this profile

range from 0.55 to 2.37 km (Fig. 11). The broad part of the curve indicates deeper magnetic source, while the sharp curve indicate the shallow source.

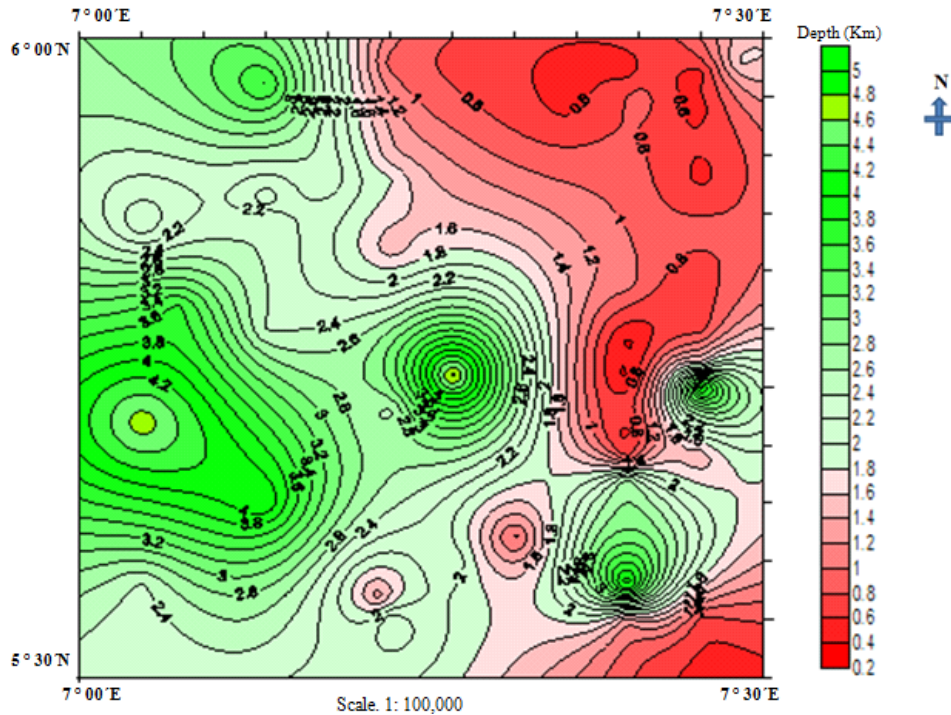


Fig. 12: Depth to basement (sedimentary thickness) map of Okigwe area (Contour interval 0.2 km)

Depth to basement (sedimentary thickness): Using the depth values determined from the Slope methods, two depth models were established. The deeper magnetic sources vary from 2.0 to 4.99 km, whereas the shallower magnetic sources vary from 0.4 to 1.99 km (Fig. 12). Deeper magnetic sources probably depict depths to pre-Cambrian basements, while shallower magnetic sources probably depict depths to basic intrusive and/or magnetized bodies within the sedimentary covers. The depth to basement is shallow in the entire northeastern and part of southeastern ends of the area, while it is deeper in the entire western, central, northwestern and part of the eastern ends of the area (Fig. 12). The depth to basement map was produced based on these determined depths and therefore, gives the configuration of the basements as well as sedimentary thicknesses within the study area. These depth values estimated are in agreement with those determined from aeromagnetic data over Lower Benue Trough by Onwuemesi (1997) and Onu *et al.* (2011) using one-dimensional spectral analysis and 2-D spectral analysis, respectively.

CONCLUSION

The Slope methods are simpler, much faster and provide more depth estimates than analysis by other techniques. They can be applied to both synthetic and real data to obtain reasonable results. The depth to basement (sedimentary thickness) values obtained from Okigwe

area using Slope methods vary from 2.18 to 4.91 km for the deeper sources, while the shallower sources vary from 0.55 to 1.82 km. Hydrocarbon exploration is not recommended since the area has low thickness of sediments on the average. Besides, tectonic activities that occurred in the area may not have enhanced hydrocarbon generation, migration and sealing

ACKNOWLEDGMENT

The authors wish to acknowledge the useful suggestions made by Prof. A.G. Onwuemesi of the Department of Geological Sciences, Nnamdi Azikiwe University Awka Nigeria. Thanks are due to the anonymous reviewers for their useful suggestions and criticisms.

REFERENCES

- Burke, K., T.F.J. Dessaugie and A.J. Whiteman, 1970. Geological History of the Benue Valley and Adjacent areas: In: Dessauvage, T.F.J. and A.J. Whiteman (Eds.), African Geology, University of Ibadan Press Nigeria, pp: 187-205.
- Carter, J.D., W. Barber and E.A. Talt, 1963. The Geology of parts of adamawa, bauchi and bornoprovines in Northeastern Nigeria. Geological Survey of Nigeria Bull., 30: 40-45.

- Cratchely C.R. and G.P. Jones, 1965. An interpretation geology and gravity anomalies of the Benue valley Nigeria. Overseas Geological Survey London, Geophysics. Paper No. 1.
- Dow, W.G., 1978. Petroleum Source Beds on Continental Slopes and Rises (2). American Association of Petroleum Geologists (AAPG) Bulletin, Vol. 62.
- Gatlin, C., 1960. Petroleum Engineering: Drilling and Well Completions. Prentice-Hall, Inc., pp: 35-37.
- Murat, R.C., 1970. Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In: Dessauvage, T.F.J. and A.J. Whiteman (Eds.), African Geology. Ibadan University Press, Ibadan, pp: 251-268.
- Nwachukwu S.O., 1972. The tectonic evolution of the southern portion of the Benue Trough. *Geol. Mag.*, 109(5): 411-419.
- Nwajide, C.S. and T.J.A. Reijers, 1995, Sedimentology and Sequence Stratigraphy of Selected Outcrops in the Upper Cretaceous to Lower Tertiary of the Anambra Basin: SPDC exploration Report XPMW 95007, pp: 21-37.
- Nettleton, L.L., 1971. Elementary Gravity and Magnetism for Geologists and Seismologists: Society of Exploration Geophysicists Monograph Series No. 1, pp: 83-87.
- Nsikak, E.B., A. Nur and I.D. Gabriel, 2000. Analysis of aerial photographic data over Guyuk Area, Northeastern Nigeria. *J. Min. Geol.*, 36(2): 145-152.
- Offodile, M.E., 1976. The geology of middle Benue, Nigeria. *Cretaceous Res.*, 1: 101-124.
- Ofoegbu, C.O., 1985a. A review of the geology of the Benue trough of Nigeria. *J. Afr. Earth Sci.*, 3: 285-291.
- Onu, N.N., A.I. Opara and O.I. Oparaku, 2011. Geological interpretation of the aeromagnetic data over the Lower Benue trough and some adjoining areas. 47th annual International Conference of Nigerian Mining and Geosciences Society (NMGS), Programme and Book of Abstracts, pp: 43.
- Onwuemesi, A.G., 1995. Interpretation of magnetic anomalies from the Anambra Basin of southeastern Nigeria. Unpublished Ph.D. Thesis, Nnamdi Azikiwe University Awka, Nigeria.
- Onwuemesi, A.G., 1997. One-dimensional spectral analysis of aeromagnetic anomalies and curie depth isotherm in the Anambra Basin of Nigeria. *J. Geodyn.*, 23(2): 95-107.
- Osazuwa, I.B., D.E. Ajakaiye and F.J. Verheijen, 1981. Analysis of the structure of part of the Upper Benue Rift Valley on the basis of new Geophysical data. *Earth Evol. Sci.*, 2: 126-135.
- Petters. S.W., 1978. Maastrichtian-Paleocene Foraminifera from NW Nigeria and their paleogeography. *Acta Paleontol. Pol.*, 23: 131-152.
- Rao, D.A. and H.V.R. Babu, 1984. On the half-slope and straight-slope methods of basement depths determination. *Geophysics*, 49: 1365-1369.
- Selley, R.C., 1998. Elements of Petroleum Geology. 2nd Edn., Academic Press. San Diego, USA, pp: 90-97.
- Short, K.C. and A.J. Stauble, 1967. Outline geology of Niger Delta. *Am. Assoc. Petr. Geol. B.*, 51: 761-779.
- Telford, W.M., L.P. Geldart and R.E. Sheriff, 1998. Applied Geophysics. 2nd Edn., Cambridge University Press, USA, pp: 113-114.
- United States Geological Survey (USGS), 1997. Introduction to Potential Fields: Magnetism.