Journal of Basic Physical Research ISSN: 2141-8403 Prints, 2141-8411 Online
Vol.11, No.1 pp. 63- 76, March., 2023. Available online at www.jbasicphyres-unizik.org

STRUCTURAL CHARACTERIZATION OF MIDDLE BENUE TROUGH, NIGERIA USING AEROMAGNETIC, RADIOMETRIC AND DIGITAL ELEVATION DATA

Efobi,U.S.1, Obiadi, I.I., Nwokeabia, C.N.1,Onwuemesi, A.G.1, Okpara, A.O2, and Onyebum, T.E.1
1) Department of Geophysics, Nnamdi Azikiwe University, Awka, Nigeria
2) Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria

Abstract
Detailed structural analysis was conducted over parts of the Middle Benue Trough using aeromagnetic data acquired from the Nigerian Geological Survey Agency (NGSA). The data was analysed using Geosoft Oasis Montaj and Esri ArcGis Pro. The aeromagnetic data was compiled into a grid and colour map. Different filters were then applied to the total magnetic intensity (TMI) grid and the results were compiled equally into grids and colour maps. Elevation and aero radiometric data over the area, also compiled into grids and colour maps were used to constrain the structural analysis and interpretation of the result. The result of the structural analysis and interpretation revealed structures typical of rift basins. There are numerous intra basin, large scale and medium scale normal faults, with two easily recognizable zones of accommodation. Identified from the map interpretation was also a deep trough flanked by intra-basin basement highs. There was also evidence of magmatic intrusionswhich appear as small wavelength magnetic anomalies on the TMI map. Estimation of depth to magnetic sources using the source parameter imaging (SPI) technique shows a range of 0.33 to 4.67 for the sources. Pseudo-two-dimensional depth modelling confirms the influence of tectonic evolution of the study area on present-day surface and subsurface geomorphology.
Keywords*: Middle Benue Trough, Aeromagnetic data, Structural Interpretation*

Introduction

The study area is part of the Middle Benue Trough, a northeast-southwest folded rift basin that runs diagonally across Nigeria. It is within latitudes 7^0 30^I N to 8^0 30^I N and longitude $8^0 30^I$ E to 9^0 30^I E (figure 1.1). Interests in the Benue Trough, driven in part by the economic success in the southwardly lying Niger Delta Basin, have focused mostlyon the application of various direct and indirect techniques of investigation to problems dealing with hydrocarbon exploration and prospecting for economic mineral deposits.The direct techniques include geological field mapping and collection and analysis of various outcropsand borehole samples. The indirect techniques include various remote sensing techniques which may be arbitrarily categorized in to geophysical and non-geophysical methods.

Geophysical methods have become very essential in the study of the earth (Hamza and Garba, 2010). Ventured as one of or perhaps the oldest method of applied geophysics, the use of the magnetic method has evolved significantly over the years, initially employed as a tool for navigation, it developed into an excellent tool for minerals and solid ore or metal prospecting. It is increasingly used as an aid for both surface and subsurface geological mapping. Its relative cheap cost of acquisition and faster and wider areal coverage, give it an advantage over other methods of applied geophysics, particularly non-potential field methods.

Geologic structures such as folds, faults, lineaments, fractures among others play different roles in any sedimentary basin (Sorkhabi and Tsuji, 2005). These roles can range from the control of the sedimentary architecture and stratigraphy of a basin, to the distribution of hydrogeological facies.They also are of economic importance too.Faults have been identified to play a role in the emplacement of mineral ores. The magnetic method whencombined with other methods of investigation such as aeroradiometric methods can be used to build reliable structural models and maps.

For this research, aeromagnetic analysis was be conducted over parts of the Middle Benue Trough with the aim of structural interpretation, the result of which was constrained using other datasets; aeroradiometric and digital elevation model (DEM). The depth to the magneticsources was also estimated using the SPI technique. A simple 2D comparison of elevation profile, TMI profile and profile of depth to magnetic sources was also done.

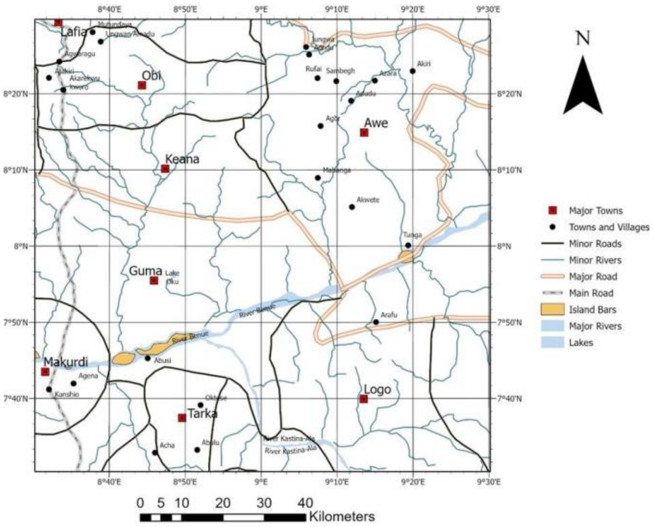


Figure1: Geographic Map of the study area.

Table 1: General amounts of uranium, thorium, and potassium in common rocks (Adapted from Turekian and Wedepobl (1961) in Pitkin, 1968)

CommonRocks	Uranium million)	Thorium (Partsper	Potassium(percent)
Ultramafic	0.001	0.004	0.004
Basaltic	1.0	4.0	0.8
Granodiorite	3.0	8.5	2.5
Syenite	3.0	13.0	4.8
Granite	3.0	17.0	4.2
Shale	3.7	12.0	2.7
Sandstone	0.5	1.7	1.1
Carbonate	2.2	1.7	0.3

Geology of Study Area

The study area is within the Middle Benue Trough. The Middle Benue Trough is the central portion of the Benue Trough (figure 2) which is a rift feature in Nigeria along Central Africa. The history and tectonics have been studied and is well by established by Fitton, 1980, Benkhelil, 1986, 1987, 1989, Fairhead and Okereke, 1987, 1988, 1990, Genik, 1992, Guiraud and Maurin, 1992 and Fairhead, 2015. For much of its geohistory, the Benue Trough feature was under extensional tectonic regime. But a mid-Santonian compressional event led to areversal in tectonics and the formation of massive fold and fold like features, some of which are the Abakaliki Anticlinorium and Afoikpo syncline, both in the lower trough.

Succeeding this is an episode of localized magmatism which is well known and has been recorded in some parts of the trough. This post-Santonian magmatism is believed to have led to the initiation of the Anambra Basin in the west.

Also, the sedimentary units and stratigraphy of the Middle Benue Trough is well known andwell established, and has been studied extensively by Cratchley and Jones, 1965, Reyment, 1965, Ayoola, 1976, Offodile, 1976, Offodile and Reyment,1976, Kogbe,1981a and Ofoegbu,198. The major sedimentary units found within this portion of the trough (figures and4) starting from the oldest unit is the Asu River Group, overlain by the Keana Sandstone and Awe Formation and capped by the Lafia Formation which is the youngest sedimentary unit in the Middle Benue Trough. In addition to these, two other sedimentary units have been identified and studied by Ofoegbu, 1985; theAwgu and Eze-aku Formations.

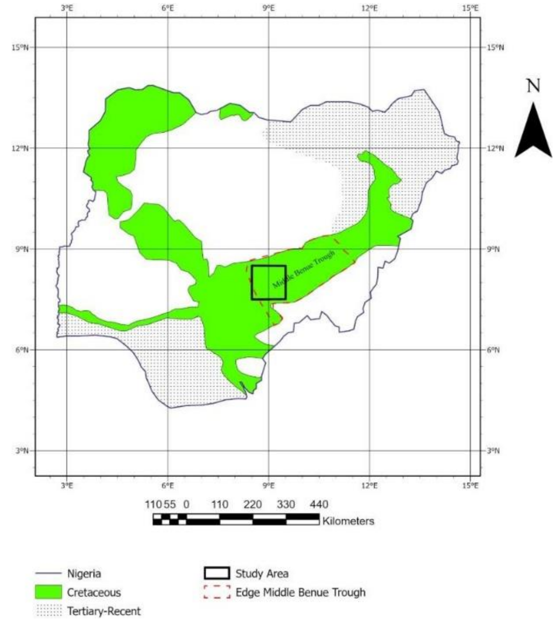


Figure2: Geological sketch map of Nigeria showing the major geological component; Sedimentary Basins (modified and adapted after Obaje, 2009)

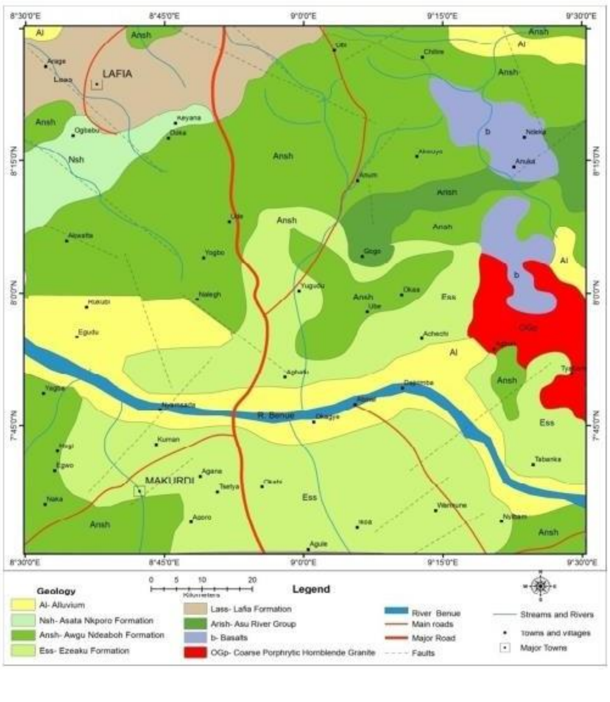


Figure3: Geologicmap of thestudy area (Onyishi and Ugwu, 2019)

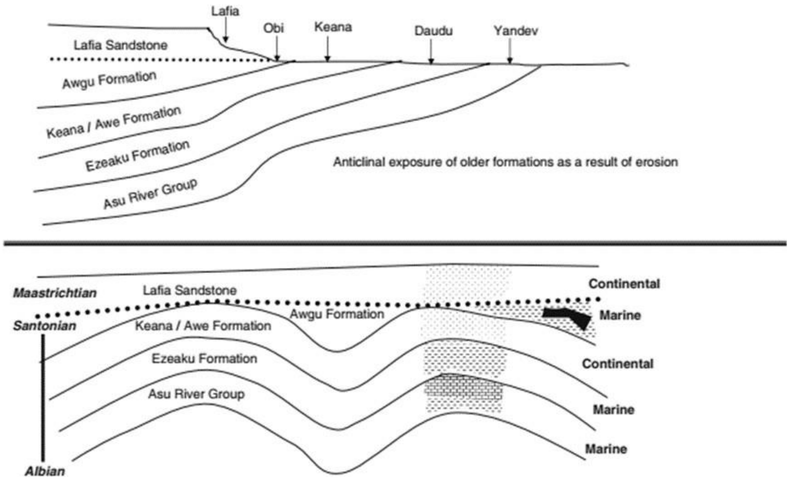


Figure 4: Stratigraphic successions in the Middle Benue Trough (Obaje, 2009)

Methodology

Four sheets of aeromagnetic maps or grids in excel format with names 231, 232, 251 and 252 acquired within Lafia, Akiri, Makurdi and Akwana regions in Nigeria were acquired from theNGSA, assembled, and interpreted within the Geosoft Oasis Montaj Software 8.4. These data as noted by Nwogwugwu *et al*. (2017) were obtained as part of a nationwide airborne survey carried out by Fugro and sponsored by the Federal government through its parastatal NGSA in 2009. The survey specifications or parameters are a flight height of 100 m along a line spacing of 500m oriented NW-SE and a tie line spacing of 2000m. The geomagnetic gradient was removed using the International geomagnetic Reference Field (IGRF). The total area covered is about 12,252sqkm.

The grids were first combined together to get a single grid covering the study area. This grid was then contoured using Oasis Montaj software to make a TMI map of the study area. Filters were applied on the TMI grid of the study area to enhance the primary magnetic anomalies which are related to the geologic structures and rock units found within the study area. The TMI grid was first reduced to the equator (RTE) (figure 5a) then the following filters were applied on the RTE grid, total gradient filter and the horizontal gradient filter. From the total gradient and horizontal gradient filtered grids, the Goussev-filtered grid was derived which is simply a scalar difference of both filtered grids (Goussev et al., 2003). Thisf iltered grid is an excellent for edge detection. The Goussev-filtered grid was then contoured and a map produced (figure 5g) which was then used for the final structural interpretation and the result obtained compared to other maps, aeroradiometric (figure 5a to 5d and 5e) an delevation (figure5f) maps to help to constrain the interpretation.

The SPI technique was also used to determine the depth to magnetic sources. The SPI technique is based on the extension of the complex analytical signal (AS) to estimate magnetic depths and it is also known as local wave number (Odidi et al., 2020). The method was originally developed by Thurston and Smith, 1997 for two models, a 2D sloping contactora 2D dipping thin sheets.The local wave number can befound using the relationship:

$$K(x,y) = \frac{\frac{\partial^2 T}{\partial x \partial z}\frac{\partial T}{\partial x} + \frac{\partial^2 T}{\partial y \partial z}\frac{\partial T}{\partial y} + \frac{\partial^2 T}{\partial^2 z}\frac{\partial T}{\partial x}}{(\frac{\partial T}{\partial x})^2 + (\frac{\partial T}{\partial y})^2 + (\frac{\partial T}{\partial z})^2} \qquad (1)$$

The maxima of k for dipping contacts are located directly over the edges and are independentof magnetic inclination, declination, dip, strike and remnant magnetization. The depth is estimated at the sourced ge of the reciprocal of the local wave number.

$$Depth_{x=0} = {}^{1}/_{K_{max}} \qquad (2)$$

Kmaxis the peak value of the local wave number K over the source (Al-Badani and Al-Wathaf, 2018). SPI technique is a quick, easy and powerful method for estimating the depth to magnetic sources and has been shown to have some accuracy +/- 20% in tests on real data sets with well controls (Salako, 2014, Al-Badani and Al-Wathaf, 2018). It also has the advantage of reducing the interference for anomalous zones since it uses second-order derivatives. The input for depth estimation using the SPI technique was the TMI, horizontal and vertical derivative grids.

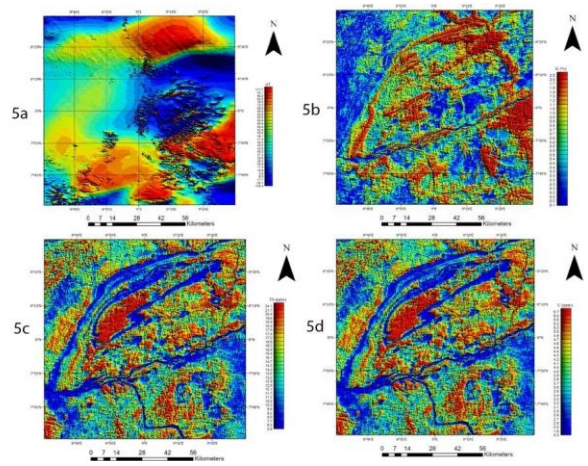


Figure 5a-d: a: Reduced to pole TMI map, b: Aeroradiometric map showing the surface distribution of element Potassium, c: Aeroradiometric map showing the surface distribution of the element Thorium, d: Aeroradiometric map showing the surface distribution of elementUranium

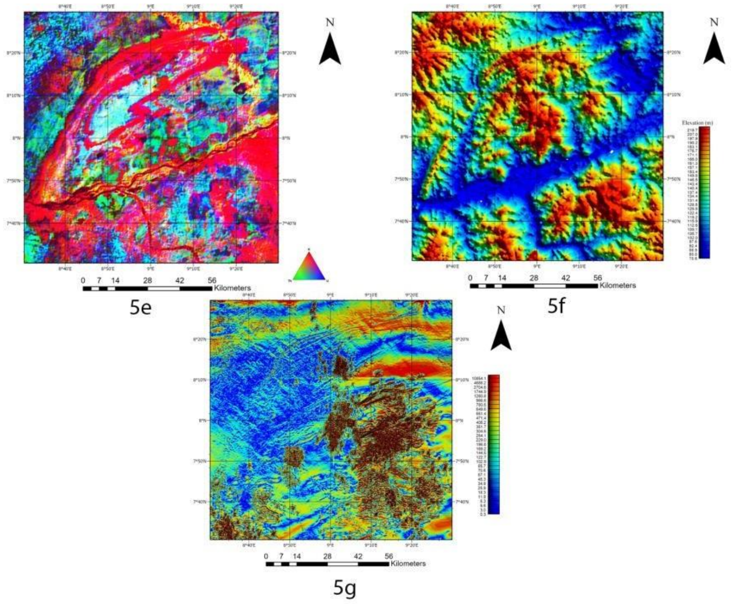


Figure 5e-g: 5e: Aeroradiometric map showing the ternary plot for the surface distribution ofelements Potassium, Thorium and Uranium colour shaded with the total count of the three radioactive elements, 5f: Elevation map of the study area, 5g: Goussev-filtered TMI map

Results and discussion

Aeroradiometric Structural View and Qualitative Interpretation of Elevation Map

The area under investigation is part of the Middle Benue Trough, one of the sedimentary basins in Nigeria. It covers parts of the middle belt and north central to north-eastern regions of Nigeria, covering parts of the following four states: Nasarawa, Benue, Plateau and Taraba.The area spans an extent of about 12,252 sq km. A key notable geographic feature of the area which is easily seen (Figure1) is the River Benue which branches into two main distributaries, part of which is the River Kastina-ala in the south. The area is predominantlymoderately high to low land with elevations between 60 m to 250 m above sea level (Figure5f). Another key feature which is seen easily on the radiometric and topographic maps Figure 6a to 6d and Figure7) is a linear ridge which starts at the point where theBenue Riverappears to enter the map in the southern part and trends in a southwest-northeast direction.This feature is of key or primary significance because as the study will show, it appears tocoincide with a fault line which trends in the same direction and which played a significantrole in both the geology and geomorphology of the area. This feature also shows up on theradiometricmaps.

Maps were made from data obtained from airborne measurements of terrestrial radioactivity (aeroradiactivity or aeroradiometric). The interpretation of the maps was made by correlatingwith areal geology map got from the work of Jatau and Abu, 2013, Onyishi and Ugwu, 2019, and Oguadinma and Aku, 2019. Furthermore, as a guideline, references were made to rock-unit classification for varying amounts of uranium, thorium and potassium (Table1). Topography, lithology and soil type and their distribution are the main factors which affect aeroradioactivity. Variation in both bedrock lithology and radioisotope results typically in varying patterns of radioactivity that will contribute to getting more useful results from the interpretation of aeroradiometric maps. Ideally, boundaries on the aeroradiometric map would coincide directly with geologic contacts and this has been utilized to delineateconcealed geologic contacts better. But usually, this correlation is often impossible, but anassociation may be established between areal radioactivity unit and with an areal geologicunit. Variation may signify facies changes or any other change of geologic or non-geologicsignificance. In the area under investigation, on the various aeroradiometric maps, the shapeof the Benue River profile is seen, and areas underlain by alluvium may be correlated fairlyeasily and with a reasonable level of confidence. But this is not the case for the other geologicunits. Non-agreement of geologic boundaries for the various geologic units found in the area between different authors and work found in literature may account for this. A fair assessment for lithology types may be made from the aeroradiometric maps. From the aeroradiometric map of ternary plot for potassium, thorium and uranium, places where rivers flow through appear to show a high concentration for potassium. Also, places high in potassium appear to vary between values of 1.0 and 1.3. Therefore, using this criterion andreferringtotable1,on the ternary plot, places high in potassium may be confidently correlated to sandstone lithology. Based on this, the lithologies found in the area under investigation were determined to be sandstone, shale, granite and possible metasediments.

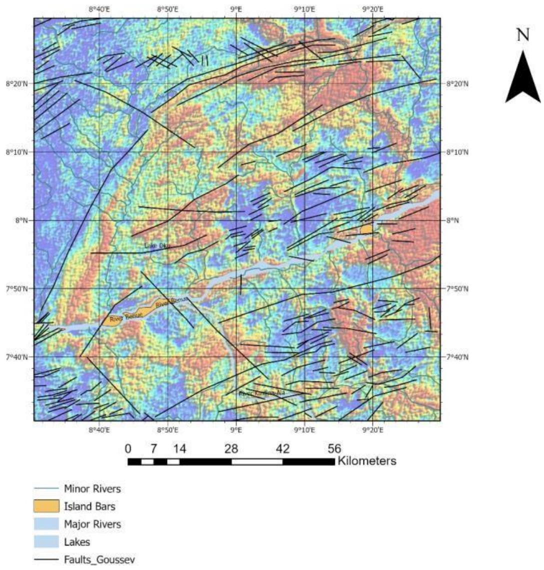


Figure 6a: Map showing the distribution of the element Potassium with faults mapped from the Goussev-filtered TMI map and other geographic features such as rivers, lakes amongothers.

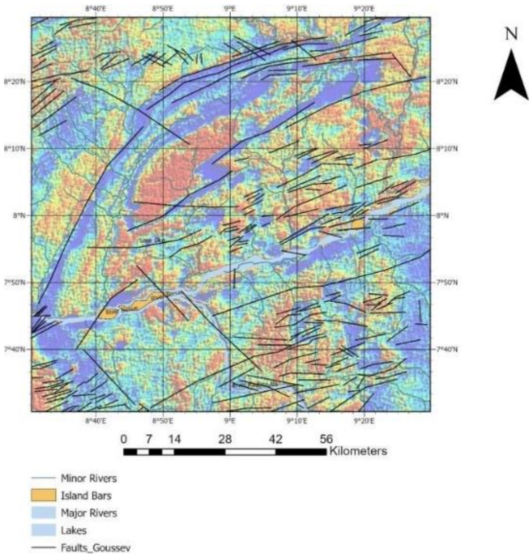


Figure 6b: Map showing the distribution of the element Thorium with faults mapped from the Goussev-filtered TMI map and other geographic features such as rivers, lakes among others.

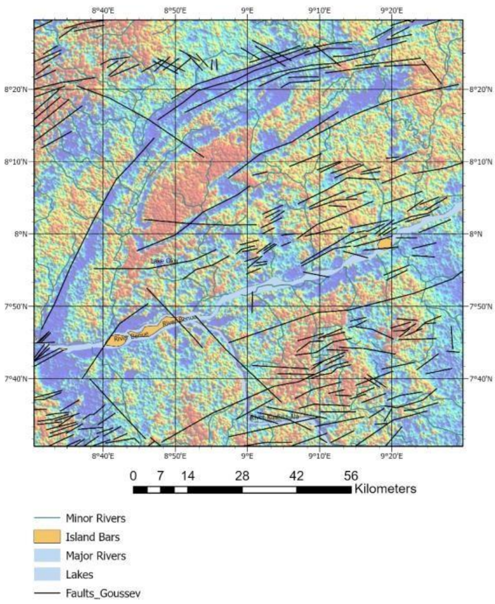


Figure 6c: Map showing the distribution of the element Uranium with faults mapped from the Goussev-filtered TMI map and other geographic features such as rivers,lakesamong others.

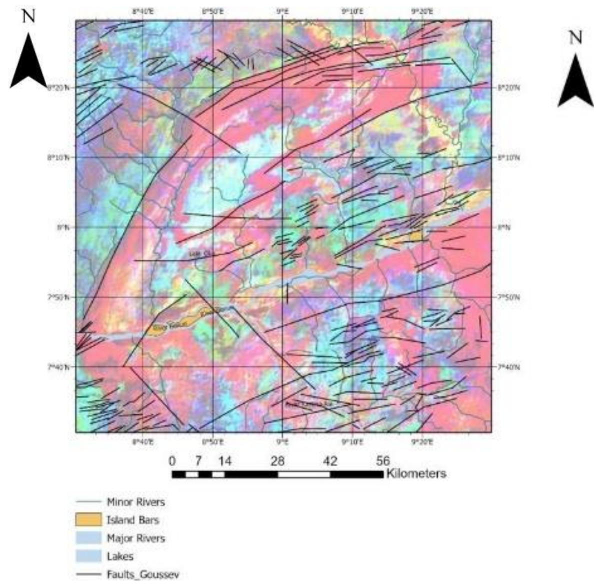


Figure 6d: Aeroradiometric map showing the ternary plot for the surface distribution of elements Potassium, Thorium and Uranium colour shaded with the total countof the three radioactive elements with faults mapped from the Goussev-filtered TMI map and other geographic features such as rivers, lakes among others.

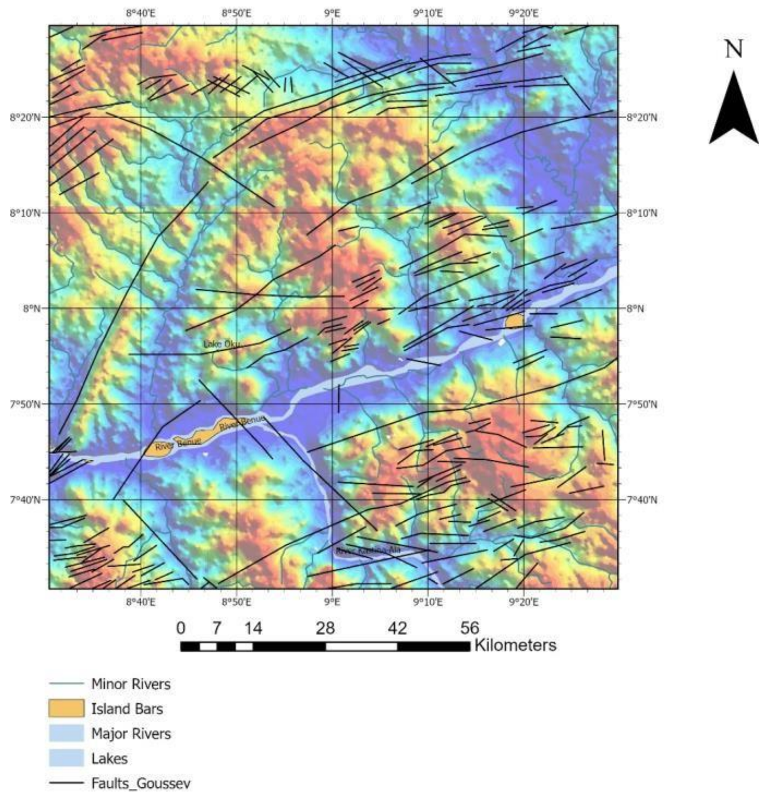


Figure 7: Elevation map for the study area with faults mapped from the Goussev-filtered TMI map and other geographic features such as rivers, lakes among others.

Aeromagnetic Structural View

The aeromagnetic data was compiled as total intensity colour maps. Different filters wereapplied to the data with the results also compiled and presented as colour maps. Other data such as aeroradiometric and topographic data were also compiled into colour maps and shading applied to all the maps to enhance them. Ternary maps were also compiled from the TMI map and its derivative maps and aeroradiometric maps. The TMI map showed geophysical features of interest (figure 8a). The principal magnetic patterns for the area under investigation vary between -400nT to 400nT. The magnetic patterns show a general trend of NE-SW which coincides to the dominant trend of the structures as the study will show. The most apparent magnetic anomalies identified on the TMI map are two magnetic peaks inthe northern and southern parts of the map separated by a magnetic trough. There is also ananomalous magnetic pattern in the southwestern part of the map which appears to be anextension of the northern anomaly that possibly have been shifted and separated by a fault block rotation and movements on the strikes lip or probably oblique faults within the accommodation zone towards the north of the anomaly. The northern feature is about 100 kmlong and occupies an area of about 1600 km and extends even beyond the margins of the areaunder investigation as determined by a TMI map from Adetona *et al*., 2017 and Salako et al., 2019. It shows a closed contour with increasing TMI values and because of its location has been suggested to be structurally a half-graben characteristic of rift basins. The southern feature is also about 100 km long and occupies an area of about 3230 km and extends substantially far beyond the current area under investigation as also determined from the works of Adetona *et al*., 2017 and Salako *et al*., 2019. It is irregular in shape and is defined bythese smaller features suggested to be granitic dykes, the intrusion of which formed smaller fractures and faults. The intervening anomalous zone between these two features is a broad magnetic trough which has been suggested to be a deep structural trough which reflects the changes that are characteristic of rift basins. The broad nature of these three anomalies suggests that they are deep-seated unlike the smaller anomalies correlated to granitic dykes which are narrow. The northern anomaly, however, is narrower than the other two and this has been interpreted that this part of the basin may be part of an uplifted flank which is acharacteristic part of rift basins. These anomalies also correlate positively with anomalies identified on pseudo gravity map derived from the TMI map.

The structural style of the area under investigation interpreted from the TMI maps and itsderivatives and constrained by the elevation map and aeroradiometric maps is typical of riftbasins. Normal faults are the most common structures within rift basins and many normalfaults are deep-seated, involving the crystalline basement (Withjack et al., 2002). We suggestthat this is the case for the area under investigation because of the broad patterns of themagnetic anomalies. Most of the faults are normal probably deep-seated crystalline basementinvolved faultswhich show up as linear features on the TMI-Goussev-filtered map (figure5g). The faults trend in the NE-SW direction (figure 8c) and divide the study area into faultblocks which appear to have been down thrown in the south-east direction parallel to theinferred direction of maximum extensional stress (figure 8b). There is a minority of faults trending in the opposite NW-SE direction, and these have been associated with accommodation in response to the extensional stress. The fault blocks also appear to show ageneral clockwise rotation southward. There are also major strike slip more probably obliquefaults which formed recognizable transfer or accommodation zones. In most locations, thefaults are parallel and orthogonal to the inferred direction of extension, but there are locationswhere the faults overlap and in some locations few faults intersect forming crosslinks. In thenorthern part of the area under investigation, a possible shear zone was identified with closelyspaced parallel normal faults trending parallel tothe dominant structural style. This shearzone formed on what was interpreted to be a basement high on a footwall of a prominent faultblock and this interpretation correlates well with the elevation map. This is because most ofthe moderately high lands found in the study area lie west of this location along the margin oraxis of this shear zone. But this shear zone and areas surrounding it that lie eastwards are lowlands and this was interpreted to be possibly due to movements along the faults which musthave created a local depression that accounts for the low relief of this part of the foot wallblock compared to areas westward of it. The morphology of the topographic relief appears tohave also been controlled by tectonic activities related to the rifting process and the riftevolution. The magnetic pattern associated with the deep trough shows some differentiation with a very deep zone closer to the major or main intrabasin fault separated by a zone of shallower basement from another deep zone that appear to have been affected by localized stress and faulting. The entire area under investigation also shows evidence of mechanical heterogeneity and stress localization which must have influenced the geometry of the faults.The area also appears to have been affected by magmatic process and intrusions which appearas short wavelength magnetic anomalies and this appears to have been limited to the southernportion ofthestudy area.

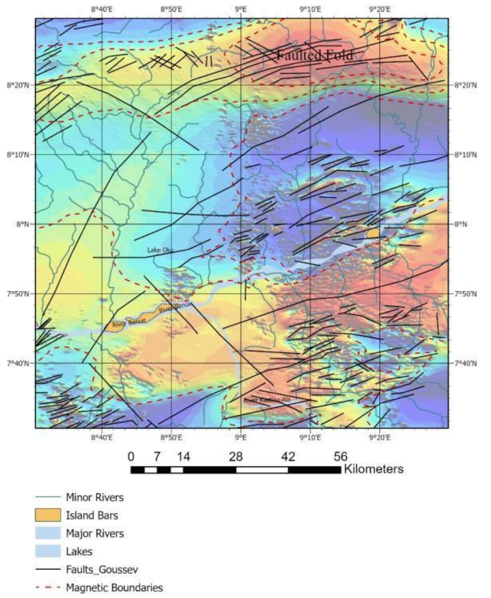


Figure 8a: TMI map showing the anomalous magnetic patterns, inferred probable contacts formagnetic bodies, interpreted faults from Goussev-filtered TMI map and other

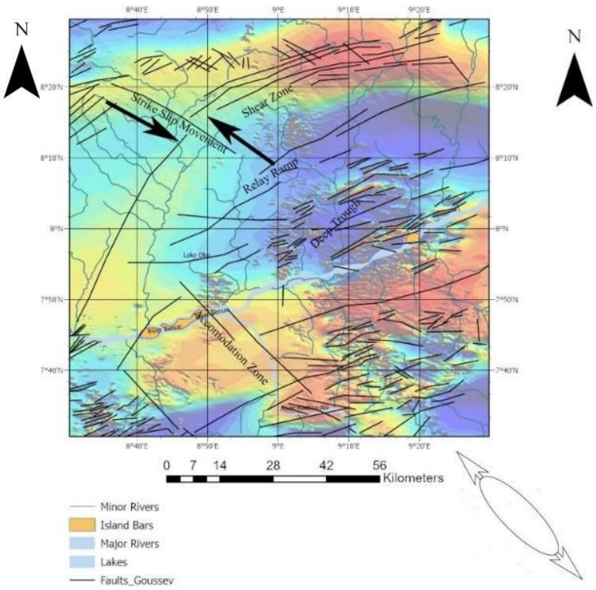


Figure 8b: TMI map with inferred geologic structural components and other geographicfeatures.A strain ellipseindicates theinferred senseof extension

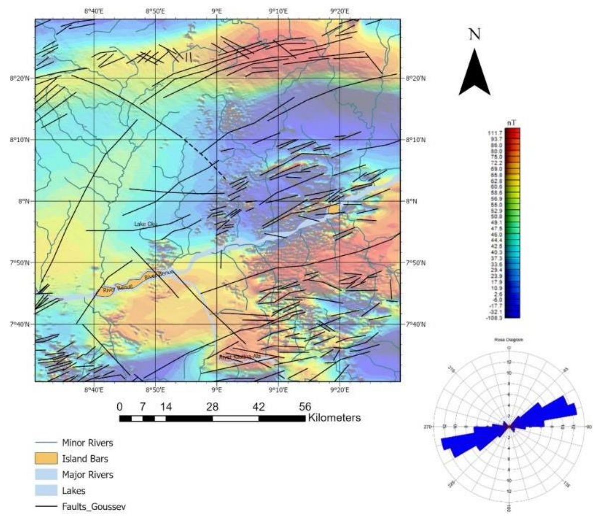
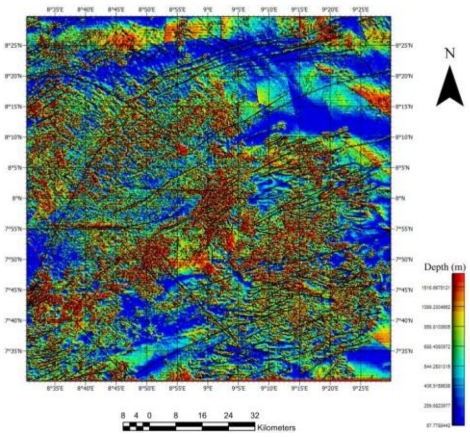


Figure 8c: TMI map overlain on the structural map showing the final result of the aeromagnetic analysis and structural interpretation. The structural trend is also indicated bytherosediagram.

Estimation of Depth to the Magnetic Sources

The results of the estimation of depth to the magnetic sources using the SPI technique revealdepths between the range of 0.033km to 4.69km (figure 9a) which is in close agreement with previous published work in the area such as Nuretal (1994), and Eletta and Udensi (2012). The depths to magnetic sources vary greatly from place to place indicative of a highly variable basement topography which is in agreement with the results of Cratchley and Jones (1965); Effeotor (1974); Ayoola (1978), who determined from out crop studies that the topography of the basement in the Lower and Middle Benue Trough to be irregular (Ofoegbu,1985). This irregular topography is better seen in a 3D plot of estimated depth and the same pattern is observed on the 3D plot of the TMI (Figures 9b and 9c).



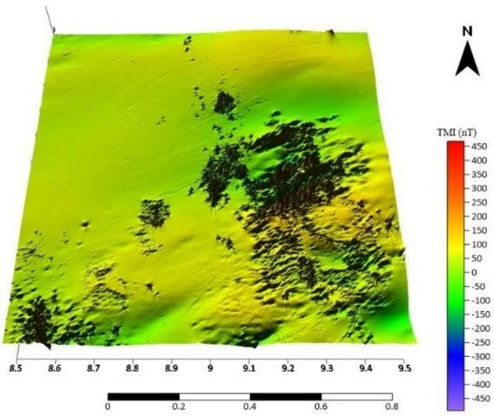


Figure 9a: Estimated depth to magnetic sources

Figure 9b: 3D plot of TMI

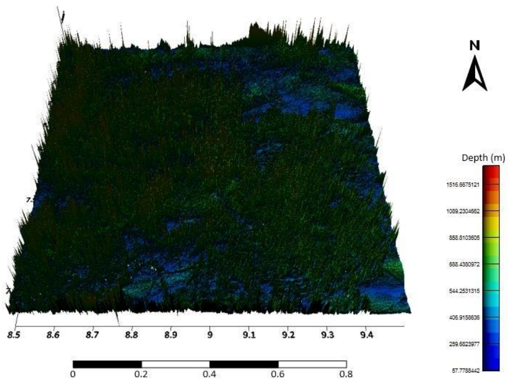


Figure 9c :3D plot of the estimated depth to magnetic sources

Pseudo-2D Modelling of Depth

A single profile A-B was taken across the maps of elevation, TMI and depth to magnetic sources and the profiles stacked vertically and compared to one another. There is an observable close match between the profiles reinforcing the earlier conclusion that tectonicevolution greatly influenced the present-day subsurface and surface geomorphology of the study area. Also, from the profiles, zones of intrabasin high sand lows can clearly be delineated and this is typical of rift basins.

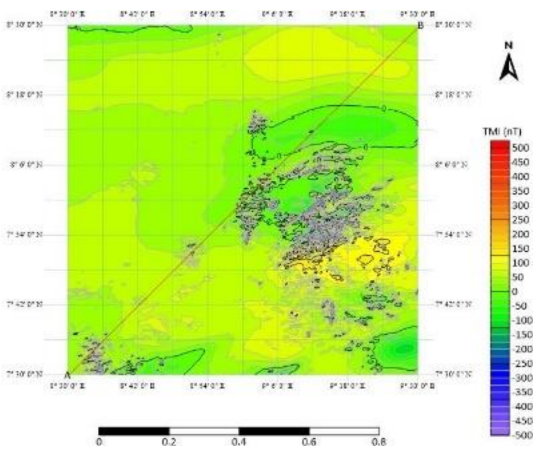


Figure 10a: TMI map showing profile A-B

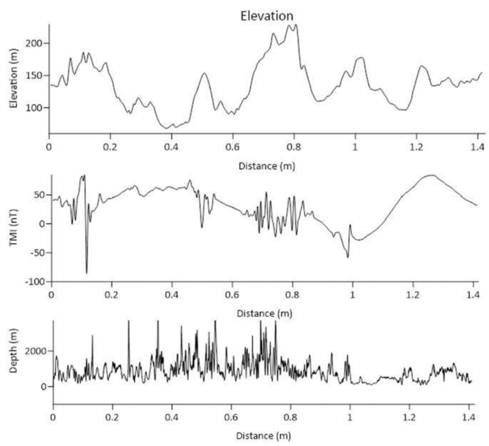


Figure 10b: Stacked Profiles of elevation, TMI and estimated depth to magnetic sources.

Implicationoffindings

The results of this research show the distribution of key subsurface geologic structures andtheir influence on the surface and subsurface geomorphology of the study area. Large and medium scale intrabas in faults were identified from the structural interpretation of aeroradiometric, elevation and aeromagnetic data acquired over the study area. The structuralmap from this study can serve as a tool for future exploration for hydrocarbon and solid minerals within the study area.

Conclusion

The result of the structural interpretation of aeroradiometric, elevation and aeromagnetic data acquired over the study area show that there are numerous intrabasin, large scale and mediumscale normal faults, with two easily recognizable zones of accommodation. Identified from the map interpretation was also a deep trough flanked by intrabasin basement highs. There was also evidence of magmatic intrusions which appear as small wavelength magnetic anomalies on the TMI map. Estimation of depth to magnetic sources using the SPI techniques yielded a depth range of 0.033km for shallow sources and 4.67km for the deeper sources. Map of the estimated depth also indicated highly irregular basement topography. Pseudo-two-dimensional modelling of depth confirmed the conclusion that the tectonic evolution ofthe study area greatly influenced present-day surface and subsurface geomorphology. We hope that the results of this study will be of economic and academic significance. We alsohope that the results of this study will be useful in preliminary studies during the exploration of economic geologic deposits and serve as a motivation for detailed analysis of other portions of the Benue Trough and them a king of accompanying structural maps. We also hope that further studies would be done towards the production of a detailed reliable surfacelithologicmaps forthe entireBenue Trough.

References

Adetona, A.A, Salako, K.A and Rafiu, A.A. (2017). Delineating the Lineaments within the major structures around Eastern part of Lower Benue Trough from 2009 Aeromagnetic data. FUWTrends in Science and Technology Journal, vol.3No.1pp. 175-179.

Al-Badani, A.M and Al-Wathaf, M.Y. (2018). Using the aeromagnetic data for mapping the basement depth and contact locations, at southern part of Tihamah region, western Yemen. Egyptian Journal of Petroleum 27: 485–495.

Ayoola, E. O. (1978). Sedimentology of the Middle Benue Trough, Nigeria. Unpublished Ph.D.Thesis, University of London.

Benkhelil, J. (1986). Structure et evolution geodynamique due bassin intracontinental de laBenoue (Nigeria). These Sciences, Nice, 231p.

Benkhelil, J. (1987). Cretaceous deformation, mag matism, and metamorphism in the Lower Benue Trough, Nigeria. Geological journal, vol.22, thematic issue, pp 467-193.

Benkhelil, J. (1989). The origin and evolution of the Cretaceous Benue Trough, Nigeria. Journ. Afr. Earth Sci. vol. 8, pp. 251–282.

Cratchley, C. R. and Jones, G. P. (1965). An interpretation of thegeologyand gravity anomalies of the Benue Valley, Nigeria. Geophys. Pap. Overseas geol. Surv. London, No. 1.

Effeotor, O.E. (1974).Sedimentological studiesofthe BimaSandstones(Sheets193and 172)
N.E.Nigeria.Unpublished Ph.D. Thesis, University of l,ondon.

Eletta B.E. and Udensi E.E. (2012). Investigation of the Curie Point Isotherm from the Magnetic Fields of Eastern Sector of Central Nigeria. Geosciences, vol. 2, no. 4, pp. 101-106.

Fairhead, J.D. (2015). Geophysical controls on sedimentation within the African Rift Systemsin Frostick, L.E. et al. (eds) 1986, Sedimentation in the African Rifts, Geological Society Special Publication, no. 25, pp. 19-27.

Fairhead, J.D. and Okereke, C.S. (1987). A regional gravity study of the West African rifts System in Nigeria and Cameroon and its tectonic interpretation. In: I.B. Ramberg, E.

E. Milanovsky and G. Qvale (eds.),Continental Rifts-Principal and Regional Characteristics. Tectonophysics, vol. 143, pp. 141-159.

Fairhead, J.D. and Okereke, C.S. (1988). Depths to major density contrasts beneath the West African rift system in Nigeria and Cameroon based on the spectral analysis of gravity data. Journal of African Earth Sciences, vol. 7, no.5/6, pp. 769-777.

Fairhead, J.D. and Okereke, C.S. (1990). Crustal thinning and extension beneath the Benue Trough based on gravity studies. Journal of AfricanEarthSciences, vol. 11, no.3/4, pp. 329-335.

Fitton, J.G. (1980). The Benue Trough and Cameroun Line-A migrating rift system in West Africa. Earth and Planetary Science Letters, vol. 51, pp. 132-138.

Genik, G.J. (1992). Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central Africa Republic (C.A.R). Tectonophysics, vol. 213, pp. 169-185.

Goussev, S. A., Charters, R. A., Peirce, J. W and Glenn, W. E. (2003). Jackpine magnetic anomaly: Identification of a buried meteorite impact structure: The Leading Edge, vol. 22, pp. 740–741.

Guiraud, R., and Maurin, J.C. (1992). Early Cretaceous rifts of Western and Central Africa: an overview.Tectonophysics, vol. 213, pp. 153-168.

Hamza, H., and Graba, I. (2010). Challenges of exploration and utilization of hydrocarbons inthe Sokoto International Journal of Mar. Atmosphere. & Earth Science, vol. 2, no. 1, pp. 41-51.

Jatau, B.S. and Abu, N. (2013). Morphology of parts of the Middle Benue Trough of Nigeria from Spectral Analysis of aeromagnetic data (Akiri sheet 232 and Lafia sheet 231). World Academy of Science, Engineering and Technology International Journal of Geological and Environmental Engineering vol: 7, No. 9.

Kogbe, C. A. 1981a. Attempt to correlate the stratigraphic sequence in the Middle Benue Basin with those of the Anambra and Upper Benue Basins. Earth Evol. Sci., vol. 1, pp. 139 - 143.

Nur, A., Ofoegbu, C.O. and Onuoha, K.M. (1999). Estimation of depth to the Curie point is other min the Upper Benue Trough, Nigeria. Jour. Mining and Geol., vol. 35, no. 1, pp. 53 –60.

Nwogwugwu, E.O, Salako, K.A., Adewumi, T., and Okwokwo, I.O. (2017). Determination of depth to basement rocks over parts of Middle Benue Trough, North Central Nigeria, using high resolution aeromagnetic data. Journal of Geology and Mining Research, vol. 9, no. 3, pp.18-27.

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. Springer Lecture Notes inEarthSciences.ISSN:0930-0317.ISBN:978-3-540-92684-9.E-ISBN:978-3-540-

92685-6.DOI:10.1007/978-3-540-92685-6

Odidi I.G., Mallam A., and Nasir N. (2020). Depth to magnetic sources determination using SPI of aeromagnetic data of parts of central and north-eastern Nigeria: a reconnaissance tool for geothermal exploration in the area. Science World Journal, vol. 15, no. 3,.

Ofoegbu, C.O. (1985). A review of the geology of the Benue Trough, Nigeria. Journal of African Earth Sciences,vol.3, no. 3, pp.283-291,

Offodile, M.E. (1976). The geology of the Middle Benue, Nigeria. Palaentological Institute, University Uppsala, Special Publication 4, pp 1–166.

Offodile, M. E. and Reyment, R. A. 1977. Stratigraphy of the Keana-Awe area of the Middle Benue region of Nigeria. Bull. geol.Inst. Univer. Uppsala 7, 37~6.

Oguadinma, T.C., and Aku, M.O. (2019). Delineation of Sedimentary thickness of Lafia and Environs using aeromagnetic data. World Journal of Innovative Research (WJIR), Vol.7, no2, pp 64-70

Onyishi, G.E., and Ugwu, G. Z, (2019). Source Parameter Imaging and Euler Deconvolution of Aeromagnetic Anomalies over parts of the Middle Benue Trough, Nigeria. American Jour. of Geophysics, Geochemistry and Geosystems, vol. 5, no. 1, pp. 1-9.

Pitkin, J.E. (1968). Airborne Measurements of Terrestrial Radioactivity as An Aid to Geologic Mapping. United States Geological Survey Geophysical Field Investigations Geological Survey Professional paper 516-F, pp F7

Reyment, R.A. (1965). Aspects of the geology of Nigeria.Ibadan University Press, Ibadan.

Salako, A.K. (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, vol. 5, no. 3.

Salako, K.A., Adetona, A.A., Rafiu, A.A., Alhassan, U.D., Aliyu, A., and Alkali, A. (2019). Determination of Sedimentary thickness over parts of Middle Benue Trough, North-East, Nigeria using Aeromagnetic Data. 2nd School of physical sciences Biennial International Conference (FUTMINNA 2019): p. 530-544.

Sorkhabi, R., and Tsuji, Y. (2005). The place of faults in petroleum traps, in Faults, fluid flow,and petroleum traps: AAPG Memoir, vol. 85, pp. 1–31.

Thurston, J.B., and Smith, R.S., (1997). Automatic conversion of magnetic data to depth, dip, and susceptibility contrast using the SPI(TM) method. Geophysics, vol. 62, no. 3, pp 807-813.

Turekian, K. K., and Wedepohl, K. H., (1961). Distribution of the elements in some major units of the Earth's crust. Geol.Soc. America Bull., vol. 72, no. 2, pp.175-191.

Withjack, M.O., Schlishe, R.W. and Olsen, P.E. (2002). Rift basin structure and its influence on Sedimentary Systems. Sedimentation in Continental Rifts SEPM (Society for Sedimentary Geology) special publication No.73, pp.57-81.