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Depth to Magnetic Sources Using Spectral Analysis of High Resolution Aeromagnetic Data Over Machina and Environs, Northeastern Nigeria

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Abstract

Analysis of high resolution aeromagnetic data over Machina and its environment shows areas of low total magnetic intensity contour values are hosts to thicker overburden sediments and near surface intrusive rock bodies reside over high total magnetic intensity contour regions. Positive and negative residual anomaly values depict the presence of basic and acid rock units; however, the acid rocks dominate over the basic components. Major linear features of the residual anomaly are oriented along the NE – SW direction. Some linear features however, cross cut the major lineaments along the NW – SE, N –S, and E – W directions. A NW – SE cross section of the residual anomaly shows irregularity of the bedrock floor. The negative residual anomalies are underlain by granite rocks, while the positive values are within the domain of basic intrusive. Determination of the magnetic source depth revealed depths to the top of the deeper and the shallower sources ranging from 0.6 – 2.0 km and from 0.4 - 0.9 km respectively. Thicker sedimentary covers are underlain by basement rocks while; shallower magnetic horizons are composed of intrusive igneous bodies. Maximum sedimentary thickness of 2.0 km in the study area might not be adequate enough for hydrocarbon maturation and accumulation. Segment directional histogram data shown on rose diagram exhibits strike directions along the E – W, NE – SW, NW – SE, NNE – SSW and NNE – SSW. Most of the fracture lines dip at angles lower than 10 degrees. The north dipping direction group of lineaments is prevalent. Orientations of the structural elements are in conformity with the dominant regional structural grain of the country. Cross- cutting of the lineaments may be related to the geothermal energy in the area as higher interconnected lineaments are associated with higher geothermal energy. Rugged terrain reliefs might have resulted from the effects of tectonic and structural evolution in the area. Variability of the dip angles is associated with non-uniform framework of the forces of deformation on the rocks and/or differential responses of the rocks to the stress imposed on them.

Keywords: magnetic source, spectral analysis, deformation, lineament, orientation, dip and dip direction, Groundwater, hydrocarbon.

1. Introduction

Analysis of aeromagnetic data plays integral parts in mapping the depth to magnetic basement that underlie sedimentary covers. It is also important in defining the basement topography and delineating structural features of economic importance.

Unlike the sedimentary areas within the basin where successful boreholes have proved viable for groundwater yields, majority of the boreholes drilled in Machina have been abortive, probably due poor level of understanding of the geological conditions of the area which is a function of how the site is investigated, how the geophysical data are collected, assimilated, interpreted and communicated prior to drilling. Poor groundwater yields can also be accounted for in terms of the effects of basement relief and presence of buried intrusive bodies, where water is readily lost through some routes.

Fractures and faults are prominent features in the continental and oceanic lithosphere, where they are often associated with tectonic activity. The style of deformation changes with depth due to changes in temperature and confining pressure. The upper structural level (0 - 15 km) is the domain of brittle deformation. Stylolitic joints result through stress induced dissolution along irregular surfaces which is triggered by stress concentration at the contact between the grains. These features are oriented in space by their strikes, dips and dip directions. The orientation of the fractures is based on the state of stress within the rock, both stress difference and orientation of the principal stresses and the frequency or spacing of fractures is based on the properties of the rocks in which the fractures were formed. The fact that the rock is fractured is critical in itself but more importantly, when these fractures intersect in a certain way they can be utilized in mineral, hydrocarbon and groundwater exploration studies.

The structural patterns of both the planar and the linear structures in Nigeria are along the N – S, NE – SW, NW – SE and sometimes E – W trends (Wright, 1976; Oluyide, 1988; Udoh, 1988; Olasehinde and Awojobi, 2004). The local lineaments are mostly defined by joints that developed during the exhumation of the rocks following erosion of the overburden and/or from expansion and contraction due to compression and cooling. The joints often formed networks that cross-cut each other.

When the surface geology is buried underneath an in-situ blanket of weathered rocks aeromagnetic images can reveal information on the nature of the subsurface geology and deeper structures. Exploration work has been on in the Chad Basin of Nigeria with the aim of expanding the national exploration and production base of hydrocarbon reserves so as to add to the proven reserves. Increased efforts to explore for new reserves has necessitate the interpretation of the high resolution aeromagnetic data over part of Machina and its environs to determine the depth to the magnetic basement, the basement topography and the orientation of the fractures and their frequencies for possible mineral deposits, hydrocarbon and groundwater accumulation.

The study area lies within latitude 13°00' - 13°30' N and longitude 10°00' - 10°30' E (Figure 1). It is bounded by the Republic of Niger to the north, Jigawa State to the west, Bauchi State to the south and Borno State to the east.

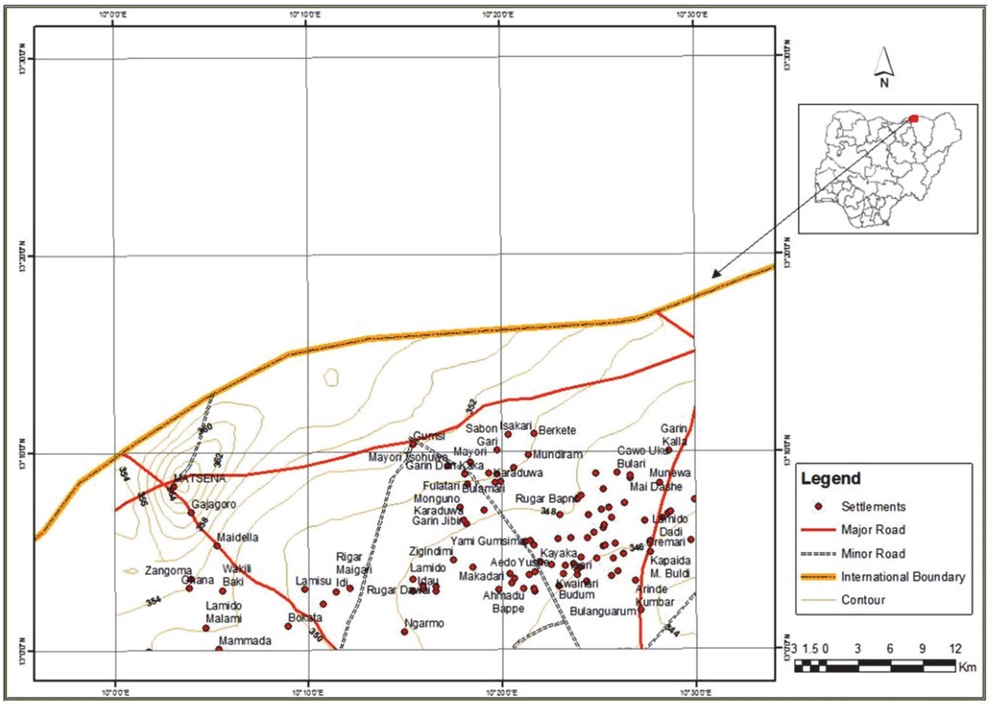


Figure 1. Location map of the study area

1.1 General Geology

The area is primarily comprised of sediments of the Chad Basin and therefore the geology of the study area shown in Figure 2 can be treated alongside that of the Chad Basin. The oldest sediment in the basin is the Bima Sandstones which was deposited unconformably on the Precambrian Basement Complex (Barber, 1965). An extensive transgression during the late Cenomanian-Turonian led to deposition of a limestone/shale series of the Gongila Formation. These series of beds are overlain by the Fika Shale of Turonian–Senonian age. Towards the end of the Cretaceous, the Gombe Sandstone was deposited. The end of the Cretaceous period was marked by folding. The folded Cretaceous beds were partly eroded, thereby creating an erosion surface at the base of the Tertiary deposits

(Barber and Jones, 1960). The Kerri-Kerri Formation was deposited on the erosion surface of the Gombe Sandstone during the Palaeocene. Sedimentation of the Kerri-Kerri Formation was followed by a period of uplift and erosion (Matheis, 1989). The Chad Formation which includes quaternary sediments rests unconformably on the Kerri-Kerri Formation and younger beds.

Few outcrops of discordant, high-level Jurassic Younger Granite intrusions taught to be the northern extension of the North Central Nigeria Younger Granites Complexes occur in the area. The Younger Granite rocks transgressed all units of the basement complex. Granites and Rhyolites underlay major parts of the province. Intermediate and basic rocks occur. Jacobson *et al*. (1958) and van Breeman and Bowden (1973) assigned Pan African age to the Older Granites and accompanying metamorphism of the basement.

Volcanic rocks in the complexes have either been obliterated by later granite intrusions or eroded to an extent that their original pattern of distribution is conjectural. Many of the smaller granite intrusions represent upper, flat-lying roof sections of ring intrusions and, some of these are remarkably shallow in comparison with their lateral dimensions.

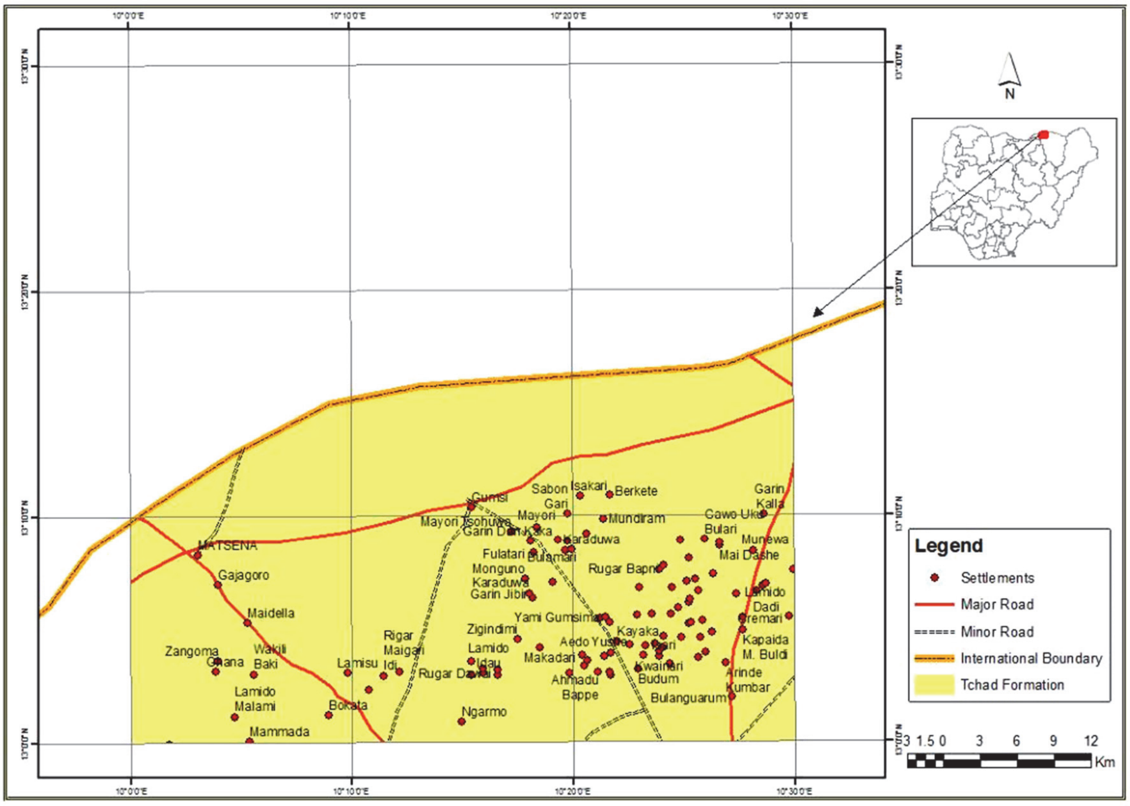


Figure 2. Geologic map of the study area

2. Methods

Aeromagnetic data for this study (Figure 3) was acquired in 2010 by Fugro Airborne Survey Services for Nigeria Geological Survey Agency. The data was acquired using magnetometers (3x Scintrex CS3 Cesium vapour). The survey was conducted along NW - SE flight lines and tie line along NE - SW direction with 500 m flight line spacing, Terrain clearance was 80 m and line spacing was 2 km. Magnetic data recording interval during the survey was 0.1 seconds.

Application of the power spectrum method to potential field data is used to derive the depth to geological features in gravity and magnetic basement. The depth factor invariably dominates the shape of the radial averaged power spectrum of the potential field. The techniques involves dividing the residual blocks into 8 spectral cells of 12.5 km by 12.5 km and each signal was widowed 15 minutes by 15 minutes.

Oasis Montaj software was used to transform the residual magnetic data into the radial energy spectrum for each block. Plots of log of energy and the frequency (Nwosu et al, 2013) have shown that the log-power spectrum of the source has a linear gradient whose magnitude depends on the depth of the source. For the plots, series of points which fall on one or more straight line segments represent bodies occurring within particular depth range (Kasidi et al, 2016). Line segments in the higher frequency range are from shallower sources and lower harmonics are representatives of deeper sources. The gradients of the shallower and deeper sources give their respective mean depths to the top of the anomalous bodies.

3. Results

3.1 Total Magnetic Intensity Field

The total magnetic intensity map of the area is given on Figure 3. The lowest values are at the northeast, the southeast and the southwest of the mapped area. The northeast and southeast features are oriented along NE – SW direction while, the NW – SE is the orientation of the southwest anomalous structure. The highest values of the total magnetic intensity cover almost half of the area. Most of these values are located around the north central to the southeast regions. Few are found at the extreme southwest axis and the northern border of the study area with Niger Republic. These structures are aligned along the NE – SW direction.

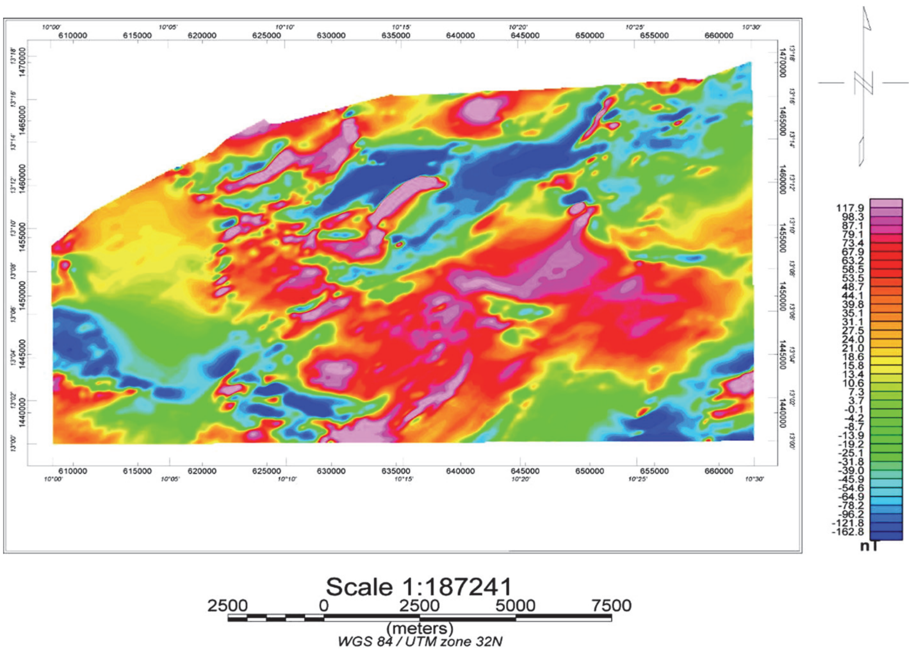


Figure 3. Total Magnetic intensity map

3.2 Residual Anomaly

The residual anomaly map (Figure 4) obtained after subtracting the regional magnetic field from the total magnetic intensity field contains negative and positive values ranging from about –13 nT to about 11 nT. The negative values dominate the area while the positive values are subsidiary. Apart from few parts of the area where the residual anomaly trends along the NW – SE direction, the NE – SW is the main structural pattern of the residuals. Profile section of the residual anomaly shows rugged topography floor; some regions developed more structures than others.

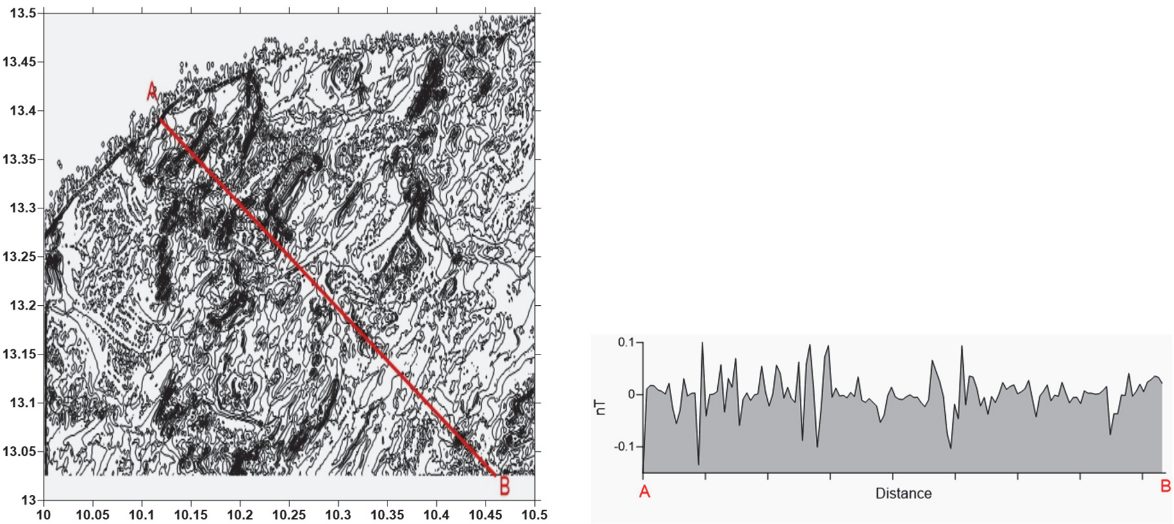
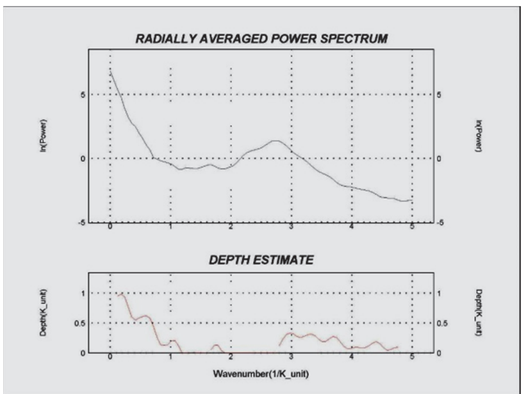


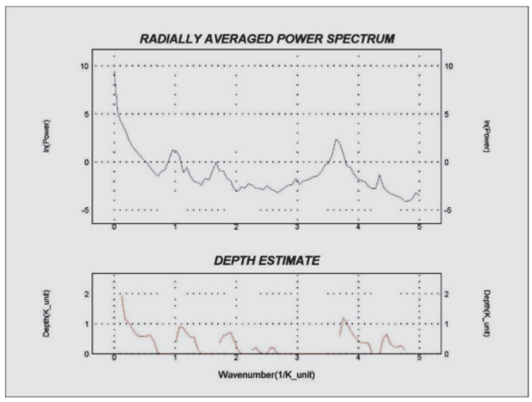
Figure 4. Residual anomaly map

3.3 Radially Averaged Power Spectrum

Figure 5 presents radially averaged power spectra together with estimated depths of four blocks. The results gave two sources of depth levels (Table 1) depicting contributions from deeper sources (0.6 – 2.0 km) and shallower sources (0.4 – 0.9 km).



Block 5



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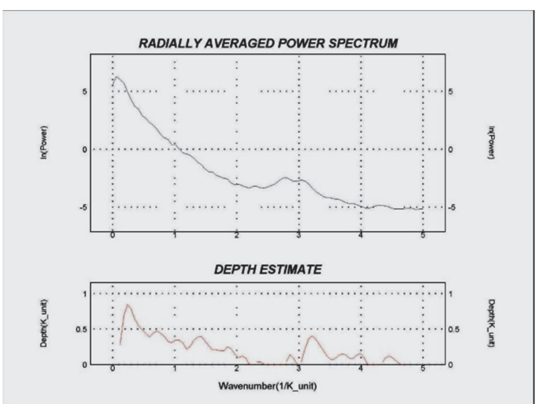

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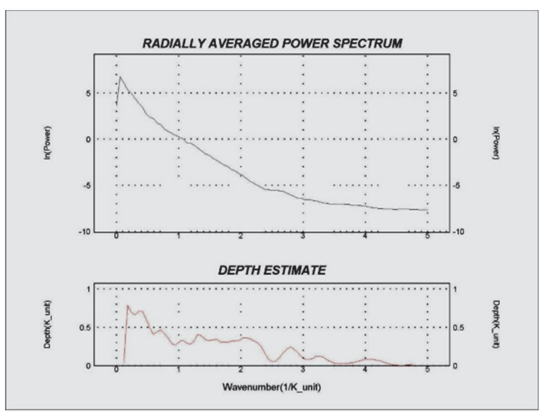


Block 15

Figure 5. Spectral energy for four blocks

Table 1. Estimated depth to deep and shallow magnetic sources

Block No.	*Deep Magnetic Source (D1) km*	*Shallow Magnetic Source (D2) km*
5	1.0	0.6
6	1.8	0.5
7	2.0	0.9
8	0.6	0.4
9	0.6	0.4
10	0.7	0.4
11	0.9	0.8
12	0.6	0.5
13	1.4	0.4
14	1.0	0.5
15	0.8	0.7
16	0.9	0.7
Total	12.3	6.8
Average	1.025	0.567

3.4 Analysis of Lineaments

Structural features derived from the residual anomaly map are shown on Figure 63, the lineaments main trend is the NE – SW direction. Some linear features oriented along the NW – SE, N –S, and E – W directions cross cut these major directional lineaments.

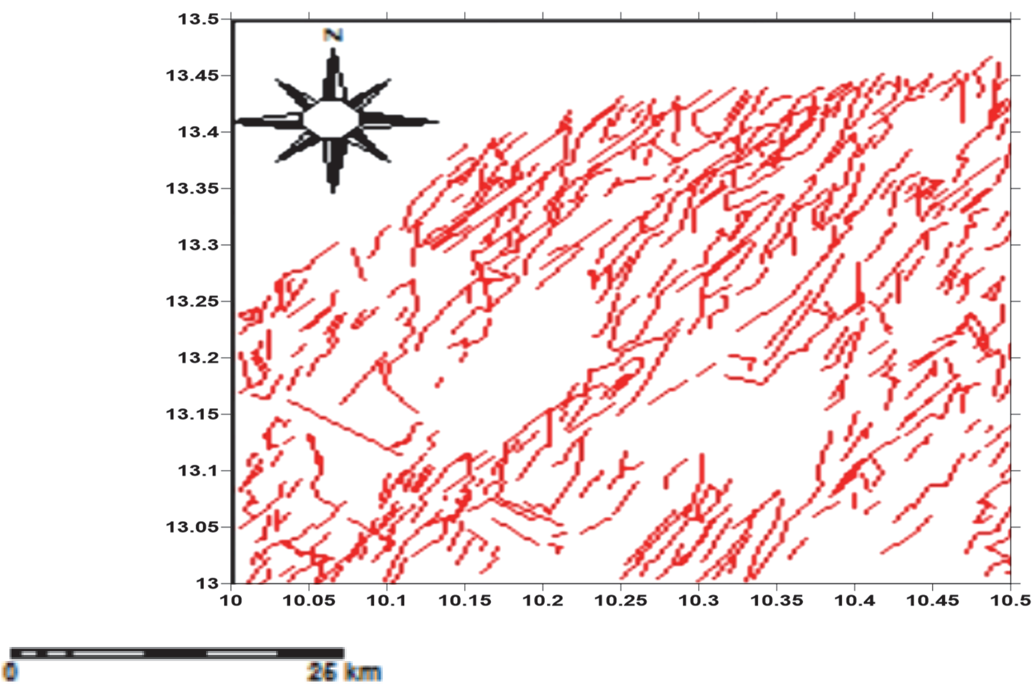
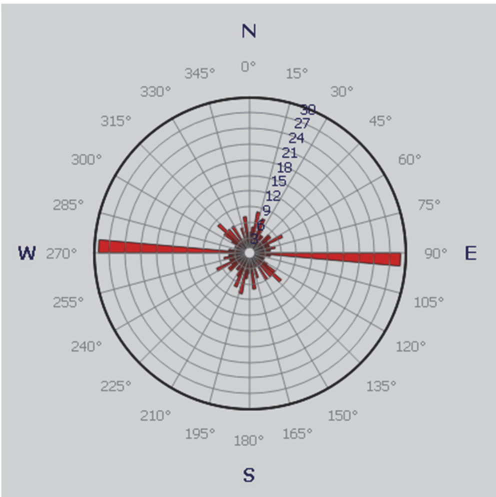


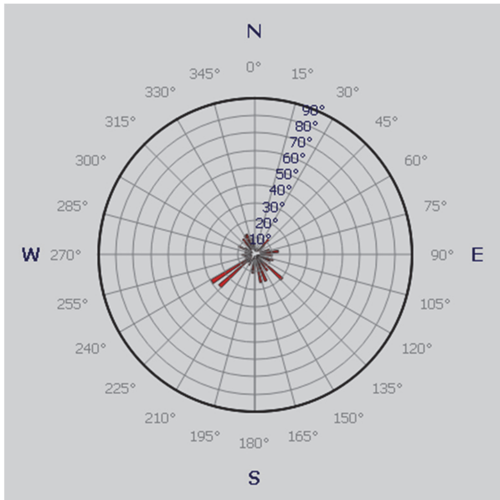
Figure 6. Lineaments extracted from residual anomaly map

3.5 Rose Diagram

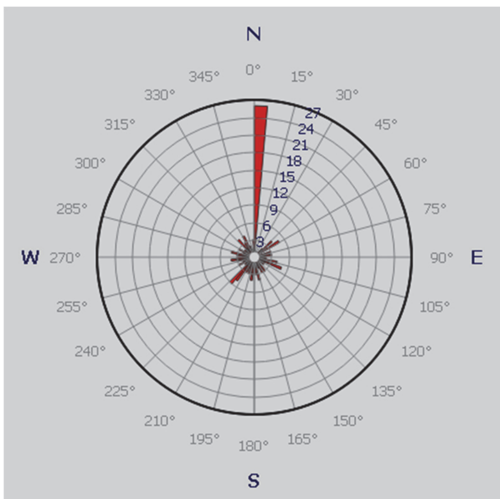
Rose diagrams play significant roles in indicating the strike directions, dips and dip directions of fractures. The orientation data of the dependable tables of segment directional histogram obtained during fracture analysis is summarized on rose diagrams in Figure 7, where the trend and/or strike, dip and dip direction of the fractured data specifying the size of the angular sampling were organized into class intervals of 5. The number of fracture orientations that occupied each class size provides scaled controls for a family of concentric circles. The bar length is controlled by the number of points from the selected data column.

The main structural trend exhibited by the rose diagram in Figure 7a is the E – W direction. Next in quantity are the NE – SW and the NW – SE linear lines. The NNE – SSW and NNE – SSW lineaments contain the smallest groups. Majority of the fracture lines (Figure 7b) dip at angles of 10º or less. However three groups of lineaments' dip angles are between 20º and 30º. One of such class of lineaments is oriented along the SES direction and the other two class are oriented along the SWS direction. In Figure 7c the fracture lines groups dip almost along all geographical coordinates, however, the north dipping direction group is prominent and conspicuous.





(a) Strikes directions (b) Dips angles



(c) Dip directions

Figure 7. Rose Diagram of the Lineaments

4. Discussion

The lowest values on the western part of the total magnetic intensity probably host thicker overburden sediments. The northeastern, the central and the western parts where these values are high may be housing near surface intrusive rock bodies. The negative residual values which dominate the area are underlain by acid rocks probably of granitic composition, and the positive residual values may suggest intrusive igneous bodies of basic composition.

Depth determination of the magnetic sources suggests two main sources of depth levels. The deeper sources have thicknesses of the overburden sediments from 0.6 – 2.0 km. These features are interpreted as consisting of basement complex rocks. Shallower magnetic horizons of the spectra probably indicate the presence of intrusive igneous rocks (Alkali and Kasidi, 2016). The depths to the top of these sources range from 0.4 - 0.9 km. These features probably suggest intrusive igneous bodies which near the surface. Structural features derived from the residual anomaly show majority of the lineaments aligning along the NE – SW direction. Some linear features however, cross cut the major directional lineaments along NW – SE, N –S, and E – W directions. The orientation data of the dependable tables of segment directional histogram shown on the rose diagram exhibited the main striking direction along the E – W direction. Other striking directions are the NE – SW, NW – SE, NNE – SSW and NNE – SSW linear lines. Most of these fracture lines dip at angles below 10^o, however three groups of lineaments' dip angles are between 20^o and 30^o. The fracture lines dip more or less in all directions but dips towards the northern direction prevails over other dip directions.

Orientations of the structural elements are in conformity with the dominant regional structural grain of the country. Cross-cutting of the lineaments may be correlated to the geothermal energy that produced such intersections. Where higher geothermal energy is involved, the quantity of the interconnected lineaments is likely to be higher than those of the surrounding rocks. Unevenness of the topography relief of the bedrocks resulted from the effects of tectonic and structural evolution in the area. Variations in the angles of dip may indicate non-uniformity on the state of stress within the rock and/or the different response of the rocks to the intensity of the tectonic force (Alkali, 2013).

In hydrocarbon exploration, residual maps play key roles in identifying the presence of intrusive, lava flows and igneous plugs, which are areas to be avoided in exploratory exercise. Intrusive are however, not completely detrimental to the hydrocarbon as they could also provide the geothermal energy requirement for the maturation of petroleum source rocks. The presence of intrusive may also serve as hydrocarbon traps or reservoir rocks (Schutter, 2003). Problems arises when more geothermal energy is released than required, which may lead to the over maturation of source rocks. In this case, temperature window for hydrocarbon generation could be exceeded, thus affecting the quantity to be generated.

The results revealed maximum sedimentary thickness of 2.0 km at the study area. Sedimentary thickness of 3.0 km and above is only sufficient for hydrocarbon maturation and accumulation (Nwogwugwu et al, 2017), therefore the results from this study might not be adequate enough for hydrocarbon maturation and accumulation. Structures revealed on the area may serve as indicators for mineral and groundwater targets. With the lingering problem of acquiring groundwater yields in Machina and environs, areas with the deeper sources can serve as potential locations for groundwater accumulations given proper assimilation of geophysical and subsurface conditions within the areas.

5. Conclusion

Areas of intrusive should be approached with caution in hydrocarbon exploration as they are likely to release more geothermal energy than required for the maturation of petroleum source rocks and their presence may also serve as hydrocarbon traps or reservoir rocks. Sedimentary thickness of 3.0 km and above is only sufficient for hydrocarbon maturation and accumulation, therefore the maximum sedimentary thickness of 2.0 km revealed in the area might be inadequate for hydrocarbon maturation and accumulation. Structures delineated on the area may serve as targets for mineral and groundwater exploration.

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