GEOLOGIC ANALYSIS AND INTERPRETATION OF AEROMAGNETIC DATA: AN EXAMPLE FROM THE ANAMBRA BASIN, SOUTH-EASTERN NIGERIA

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ABSTRACT

This study focuses on geologic analysis and interpretation of an area bounded by Latitudes 5^0 56′ 30″ N and 6^0 02′ 30″ N and longitudes 7^0 19′ 59″ E and 7^0 28′ 00″ E in the South-eastern part of Nigeria, using airborne magnetic data. The objective was to investigate the lithologic and structural framework and hence predict the priority targets for exploration of geo-resources in the area. The method adopted involves analysis of spatial derivatives of the Total Magnetic Intensity (TMI) and the Bouguer Anomaly data combined with geology and topographic data. To that effect, data analysis involving comparative analysis of computer screen and hard-copy images and generation of maps for first vertical derivative, reduction-to-pole, analytical signal, SPI Depth to magnetic sources, Bouguer anomaly and topography for quantitative and qualitative interpretation was carried out. Qualitative interpretations through structural synthesis and lithological identification reveal regional faults with structures trending in various directions, and a high density trend, suggesting very thick piles of overburden sediments. Quantitative interpretations based on geologic cross-section on all relevant data indicate presence of dense sediments as well as variations in basin thickness and elevation. Lithologic characterization indicates that the work area cuts across formations with coal beds. Thus, the major target of viable geo-resources in this area is coal. It is recommended that ground geophysics be carried out in order to fully unravel the position, spread and geometry of coal seams as well as other suspected metallic minerals within the study area.

Keywords: *Total Magnetic Intensity; Bouguer Anomaly; Aeromagnetic surveys; Magnetic susceptibility;*

1.0 INTRODUCTION

Mapping of appropriate stratigraphic horizons and identification of suitable structures, such as faults, folds, intrusions etc, are important aspects of the interpretation of magnetic data. Knowledge of the forms of anomalous responses due to different source geometry is fundamental in the estimation of magnetic source boundaries. Diagnostic structural and stratigraphic signatures for mineralization are not always diagnostic, resulting in occurrence of many similar but unmineralized zones.

This study focuses on geologic analysis and interpretation of a portion of the Anambra Basin to investigate the litho-structural framework and possible mineralization within the area using airborne magnetic data set for deterministic results. It is anticipated that lithologic and structural integration and analysis should enable the identification of priority targets for mineral exploration. The area covers the Nigerian Geological Survey Agency's (NGSA) sheets 301, 302, 312 and 313 within a base map of 1:100,000, in South Eastern region of Nigeria. The method adopted involves analysis of spatial derivatives of the Total Magnetic Intensity (TMI) and the Bouguer Anomaly data combined with geology and topographic data.

1.1 Location of Study Area

The study area is bounded between Latitudes 5^0 56′ 30″ N and 6^0 02′ 30″ N and longitudes 7^0 19′ 59″ E and 7^0 28′ 00″ E in Anambra and Imo state boundary, Anambra Basin, south eastern Nigeria. The Area is surrounded by the Nnewi, Ufuma, Akokwa, Ihube, Nkwuli and Uruala towns and villages (Figure 1).

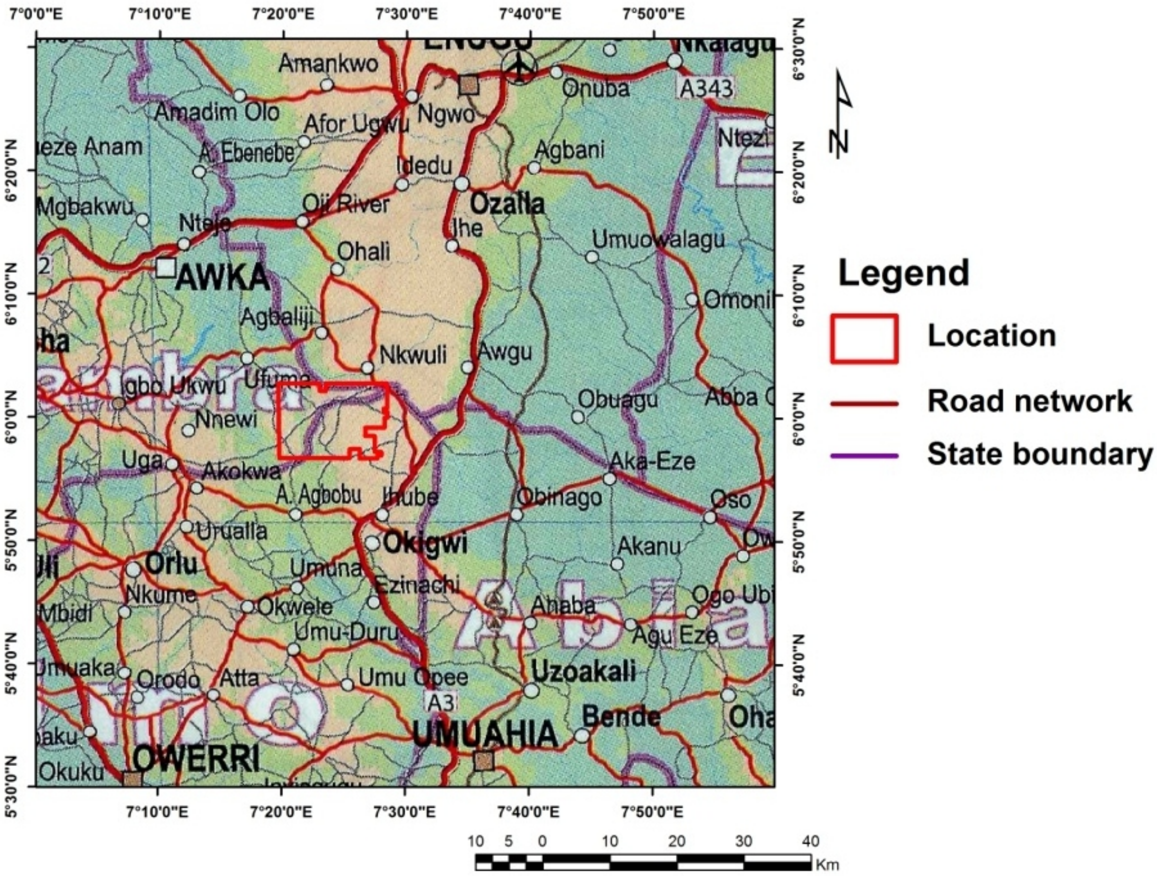

Figure1**:** Location map of study area

1.2 Geophysical Background and Stratigraphy

1.2.1 Geophysical Background

Aeromagnetic surveys measure the total intensity of the Earth's magnetic field from an aircraft as it follows a regular pattern of flight lines. The measured magnetic-field data are processed to remove time-varying external fields and are corrected for noise from aircraft movements. The effects of Earth's primary magnetic field are removed to produce "magnetic anomaly data" which isolate subtle variations related to geology (Grauch and Drenth, 2009). These subtle variations are produced by the distribution of magnetic minerals (normally magnetite) in the ground. The distributions are commonly related to particular rock types. Thus, analyzing the magnetic-field measurements to determine this distribution gives clues to subsurface geology.

In this work, most of the analysis is applied to gridded data and depicted as coloured relief images, in which individual features are referred to as "anomalies". Anomalies are loosely defined by areas that contain increasing values that culminate in relative maxima (a "high") or decreasing values that culminate in relative minima (a "low"). The range of values of an anomaly define its "amplitude" (always a positive number), and the areas of steep decrease or increase (sides of the anomaly) are anomaly "gradients."

Magnetic properties of rocks and sediments measured as "magnetic susceptibility" are

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determined by the quantity of magnetic minerals, their mode and age of their formation, and their thermal and geochemical history (Hansen et al, 2005). Mafic and ultramafic igneous and metamorphic rocks typically contain the greatest abundance of magnetic minerals (high magnetic susceptibilities), and sedimentary rocks and sediments typically contain the least abundance (Reynolds et al., 1990).

1.2.2 Stratigraphic Setting of the Study Area

The roughly triangular Anambra sedimentary Basin in Southeastern Nigeria covers about 40,000 Km^2. It covers eastern Niger Delta, the River Niger, the Calabar flank and a southern extension of the Benue Trough (Onu, 2017). It was formed after the Santonian tectonic pulse, dating back to 84 million years. The Stratigraphic succession is characterized by a cycle of sedimentary sequence that started in the Upper Cretaceous times and ended in the Tertiary times. Upper Cretaceous (Campanio-Maastrichtian) sediments have the following sequences from base to the top: Nkporo Group, Mamu Formation, Ajali Formation and Nsukka Formation. The Tertiary sediments are the Palaeocene Imo Formation and Oligocene-Miocene Ogwashi-Asaba Formation.

Nkporo Group: The Nkporo Formation and its lateral equivalents, the Enugu Shales, the Afrikpo Sandstone and the Owelli Sandstone overlie an unconformity and occupy the basal beds of the Campanio-Maastrichtian sequence of the Anambra Basin. The facies of Nkporo Group overlie an unconformity and comprise the lowest stratigraphy units of the Anambra Basin.

Mamu Formation (Lower Coal Measures): The parallic sequence of Mamu Formation constitutes the lower part of the Enugu cuesta. The formation consists of distinctive assemblage of sandstones, siltstones, mudstones and sandy shale with coal seams at several horizon (Obaje, 2009), about 100m thick and it is Maastrichtian in age (Umeji, 2002). Its lithofacies characteristically form low lying topographic features consisting of dark carbonaceous fissile shales, mudstone, sandstones, limestone and impersistent coals and marl with coating of sulphur and numerous pecks of benthonic foraminifera.

Ajali Formation: The shoreline sequence of Ajali Formation consists of medium to coarse grained, sub rounded quartz-arenites (Nwajide, 2013). They are characteristically high cross bedded and unconsolidated with little clay matrix. It is about 400m thick.

Nsukka Formation: This overlies the Ajali Formation and consists of an alternating succession of sandstones, dark shales and sandy shale with thin coal seams at various horizons (Nwajide, 2013). It also contains fragments of nodular ironstones. Most resistant portions of the formation stand out high in relief some hundreds of metres above ground level due to differential erosion.

Imo Shale: The formation unconformably overlies Nsukka Formation. It consists predominantly of thick dark or bluish-grey shales, claystone, siltstone, ironstone and occasionally interbedded with sandstone intercalation.

Ameki Formation: This formation with its lateral equivalent Nanka Formation consists of highly fossiliferous grey-green sandy clays with calcareous concretion and white clayey sandstone (Nwajide, 2013). The formation is made up of two lithological groups: the lower portion consisting of fine to coarse sandstone and interrelationships of calcareous shale and thin, shelly limestone while the upper part has coarse cross-bedded sandstones, bands of fine, grey-green sandstone and sandy clay.

Ogwashi-Asaba Formation: The formation consists generally of alternation of seams of lignite with clay. It is often difficult to separate the Ogwashi-Asaba Formation and the Ameki Formation in boreholes.

2.0 MATERIALS AND METHODS

A high resolution aeromagnetic data windowed from the National grid with other data set, including Bouguer Anomaly data, topographic map and geological map was used to analyze and interpret the subsurface geology of the study area. The flight parameters of the aeromagnetic data are: Flight line spacing of 500m; Tie line spacing of 2km; Terrain clearance of 80m; Flight direction along NW-SE and Tie line direction along NE-SW. Using industry-standard processing tools, the original Total Magnetic Intensity (TMI) grid was processed, filtered and transformed to other grids such as First Vertical Derivative, Analytical signal, SPI depth etc, and as well, relate and overlay various layers of information, such as geology, magnetic and topographic data.

2.1 Data Analysis and Map Generation

Several interpretation methods were applied with the goal of enhancing the signature of structures, lithologies and estimating the depths to the magnetic contrasts along the structures. Analytical approach involves comparative analysis of computer screen and hard-copy images including maps of the aeromagnetic data, first vertical derivative (1VD), reduction-to-pole (RTP), analytical signal (ANSIG), SPI Depth to magnetic sources map, geological maps, Bouguer anomaly map, SRTM map and other relevant data for detailed quantitative and qualitative study. Being a combination of both regional and residual signatures, the TMI enabled the identification of structures, trends and domains of varying intensities and frequencies (Figure 2). Near surface features such as late-stage dykes, veins, contacts, cultural sources were removed from the regional data, thereby generating the first vertical derivative. This clearly identifies vertical features and therefore maps out lineaments effectively (Figure 3).

Further, derivatives were combined to create analytic signal data, in which the shape of structures is independent of inclination/ declination of the induced magnetic field. The data helps to generate maxima directly over discrete bodies and their edges, which can clearly define different Lithological units (Figure 4). Depth to basement grid of the sheet was created using the local wave number method (Figure 5). The study area is underlain by piles of sediments with average thickness of 1.5km but some deep pockets of sediments may be up to 2km and beyond. In order to detect the lateral contrast in magnetic anomaly, the Bouguer anomaly data was generated, which enables the prediction of the total anomalous mass responsible for an anomaly (Figure 6). For the description of elevation and terrain of the study area, the Shuttle Radar Topography Mission (SRTM) map was generated. This clearly distinguishes the surface structures like drainages, ridges and horizons (Figure 7). The RTP aeromagnetic data, computed from a grid of the total-field magnetic data, are displayed in Figure 8. These data sets as shown in figures 2-7 were analyzed in order to define the following:

a) Surface structures
b) Boundaries of magnetic units
c) Structures dislocating or affecting the morphology of magnetic units
d) Depth and attitude of magnetic units
e) Any superposition of magnetic units
f) Lithological units
g) Chemical changes

A structural synthesis relating distribution of inferred lithologies and structure are recognized by the following features (Figure 8):

a) Offsets of apparently similar magnetic units
b) Sudden discontinuities of magnetic units
c) An abrupt change in depth to magnetic sources
d) A linear narrow magnetic low caused by weathering along a fault plane oxidizing magnetic minerals to non-magnetic minerals (joints can have a similar magnetic expression)
e) A linear magnetic high, which may be discontinuous in nature due to magnetic minerals precipitated in the fault plane.

Lithological unit identification (Figure 9) can be based on a combination of:

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a) Correlations with outcrop geology and drill hole data
b) Correlation with radiometric data- different radioelement concentrations can indicate particular lithologies
c) Correlation with other data set
d) Amplitude of response can indicate possible lithology for example
e) Chemical change. Discordant changes in magnetic intensity within a magnetic unit can indicate modification of magnetic properties by contact or regional metamorphism, alteration and weathering.

3.0 RESULTS AND DISCUSSION

3.1 Data Interpretation of Results

The results of data generation and analysis are as shown in Figures 2 to 9. Based on qualitative interpretation, long wavelength signatures observed from the TMI is interpreted to be a clear indication that the area under investigation is within a sedimentary basin (thick pile of sediments on basement in the area). Alternation of both high and low intensity observed from the map indicates variations in composition of lithology. High intensity, long wavelength signature observed (Figure 2) may be an indication of deeply buried ferromagnesian (mafic) materials. The vertical derivative map in Figure 3 reveals some fainted structures at depth, suspected to be regional faults. Even though the study area appears to have been penetrated by only one regional fault, the area is in the centre of deep tectonic activity with structures trending in various directions such as NW-SE, NE-SW and E-W.

A later intrusion of a rock body rich in ferromagnesian mineral is indicated within the study area. This is corroborated with information from analytic signal map (Figure 4) where long frequency, high intensity signature are observed. There exists a high density trend from northeast to the centre study area evidenced by the Bouguer anomaly map (Figure 6), suggesting very thick piles of overburden sediments, some of which may have undergone compaction and lithification. Digital elevation model reveals high topography from the north-central to the southeast and from the west to south of the study area as suggested by the SRTM (Figure 7). Quantitative interpretation was accomplished by drawing a section in NW-SE direction across the title on all relevant data. High amplitude signature of 31nT was recorded just at the centre of the area, indicated by cross hair on the map (Figure 10a) and represented by line indicator at the profile section (Figure 11a), indicating a presence of high intensity materials. Magnetic value of 0.049nT recorded on analytic signal map (Figure 10b); with high amplitude signature observed from the profile section (Figure 11b) is relatively high.

High amplitude signature of 15mGal recorded at the point indicated by cross hair (Figure 10c) and corroborated by the profile section Figure (Figure 11c) reveal presence of dense materials or sediments. However, 1387.93m recorded just at the point where the cross hair is located on the SPI map in Figure 10d and low amplitude indicated by trough along the profile (Figure 11d) shows that this point is among the deepest along this section.
A value of 284m recorded on the SRTM along the section is relatively high against the background values, as the cross hair on the profile section falls on one of the crests of the profile (Figure 10e, Figure 11e).

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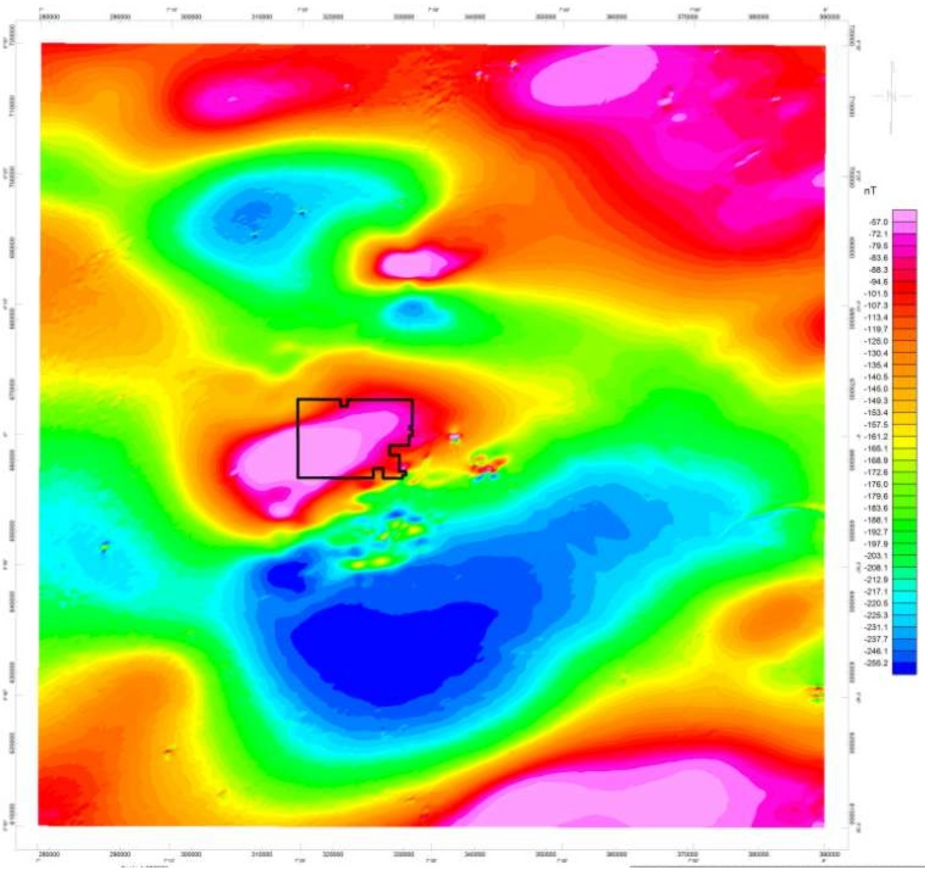

Figure 2: Total Magnetic Field Intensity Map; reduced to the equator inverse.

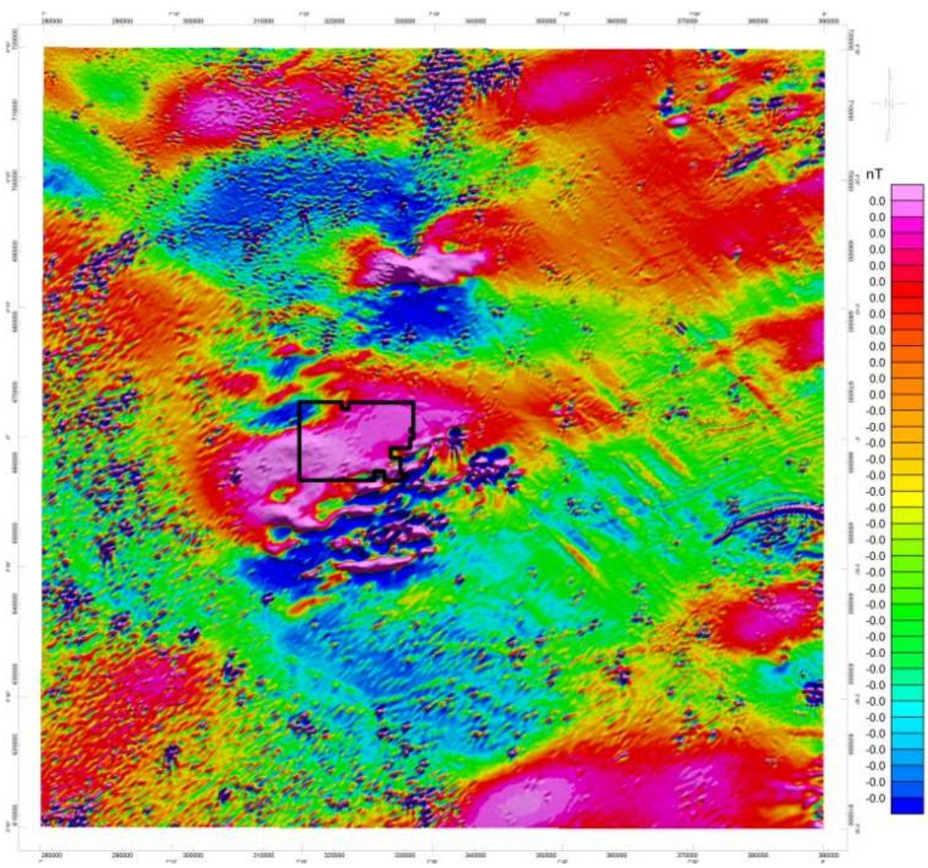

Figure 3: First Vertical Derivative Map.

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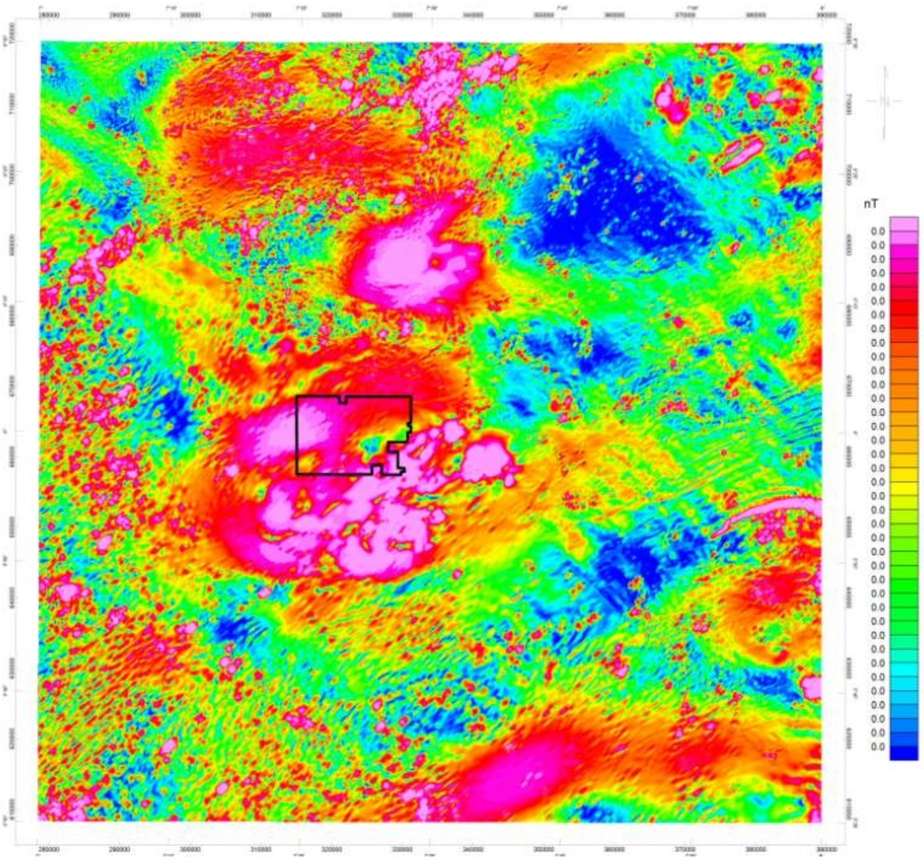

Figure 4: Analytic Signal Ma.

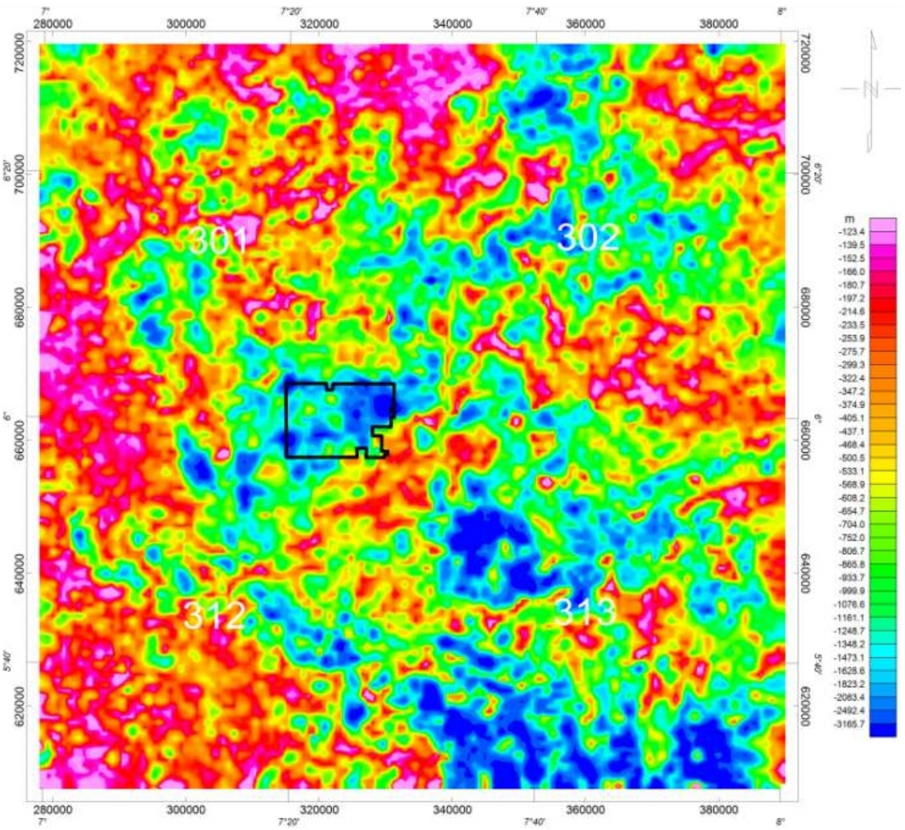

Figure 5: Depth to Basement map.

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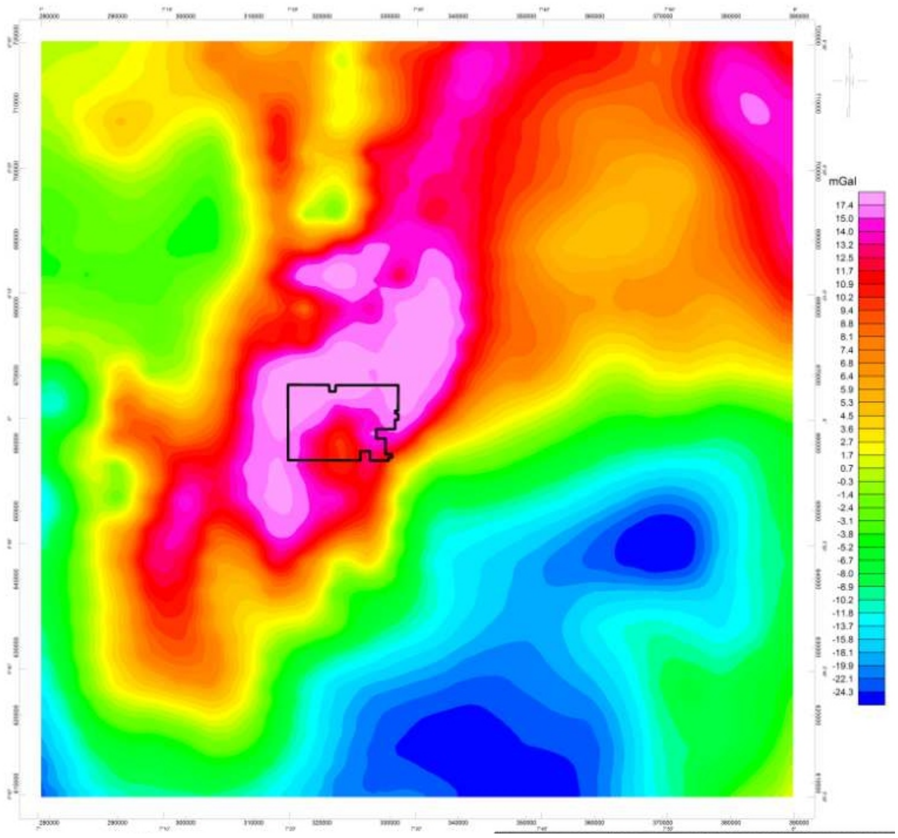

Figure 6: BouguerAnomaly map.

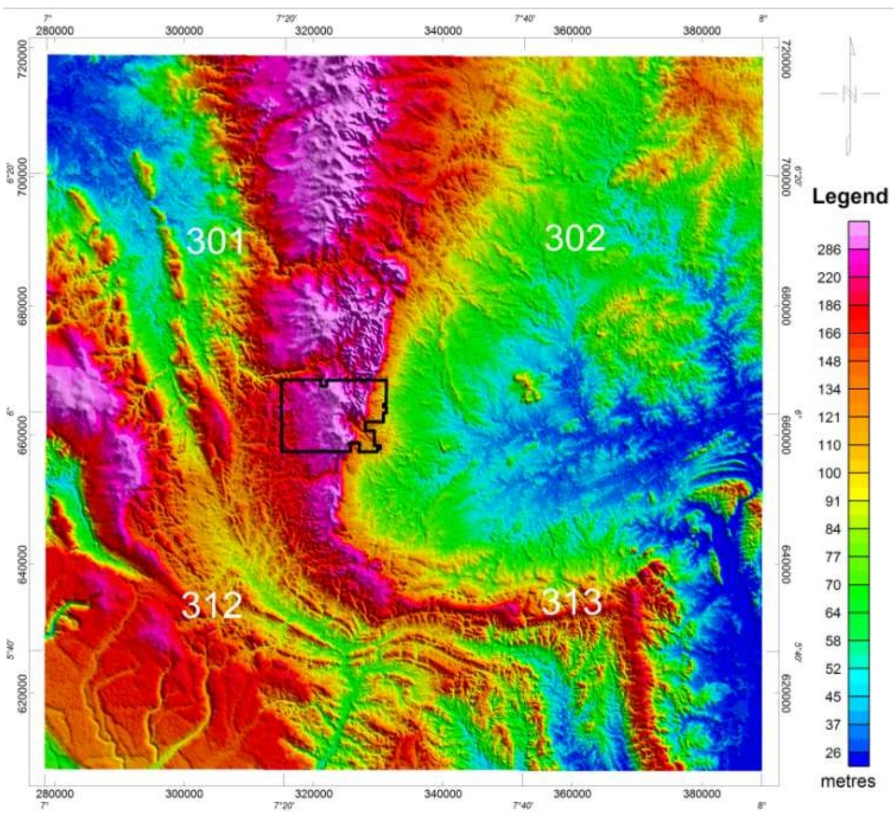

Figure 7: Shuttle Radar Topographic Mission (SRTM).

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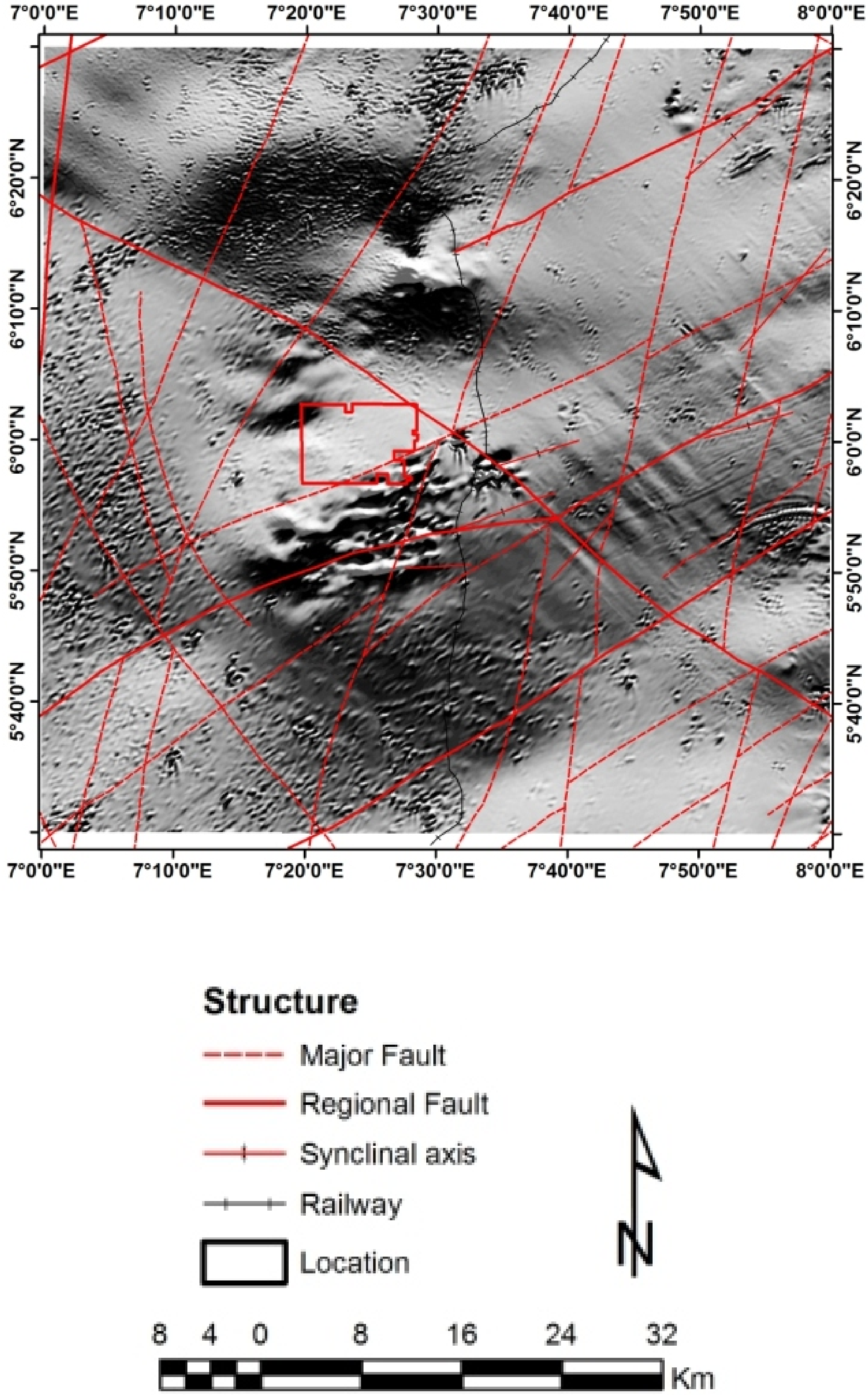

Figure 8: First vertical derivative of the reduced-to-pole (RTP) and associated structural interpretation.

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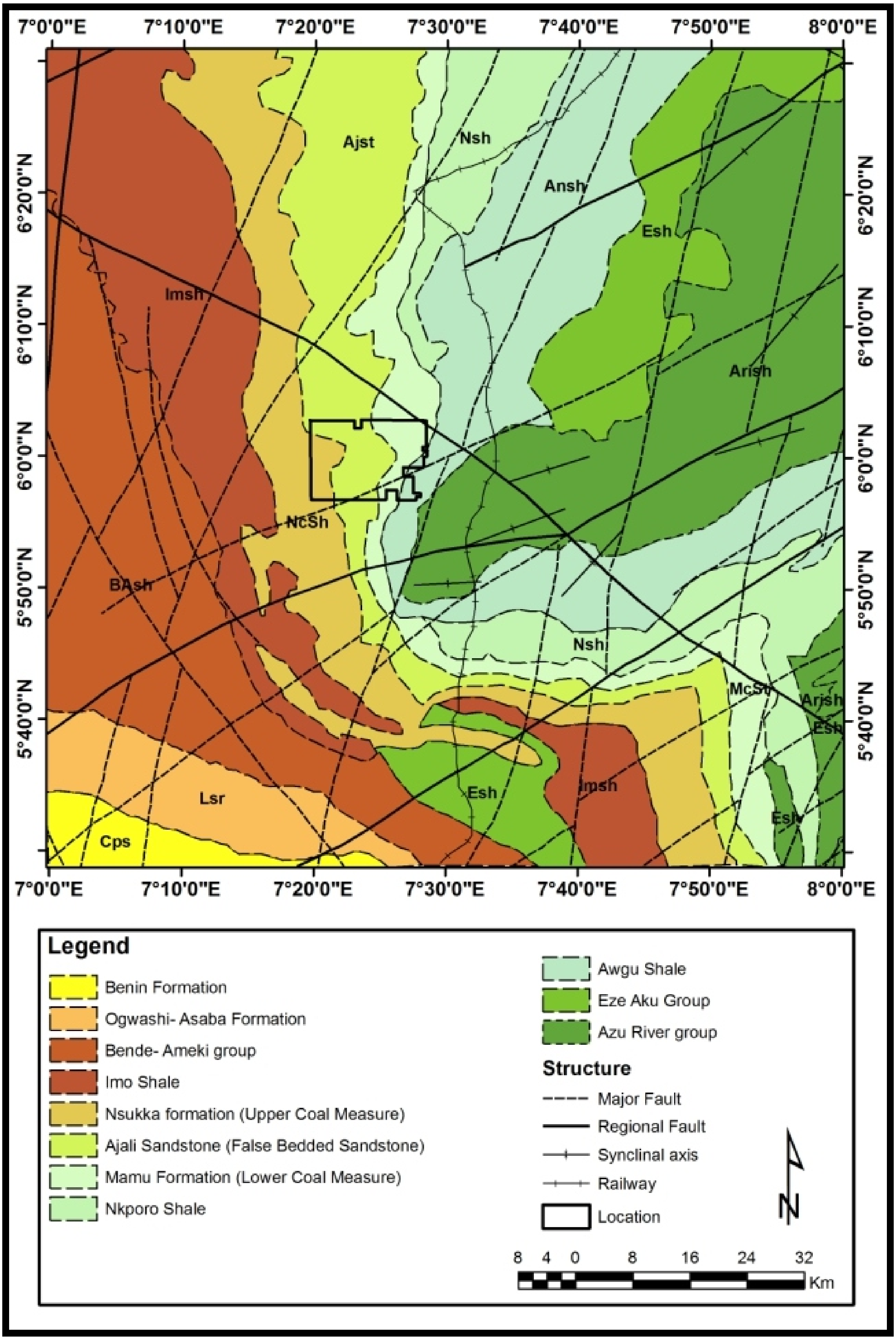

Figure 9: Lithological and structural interpreted map of the area.

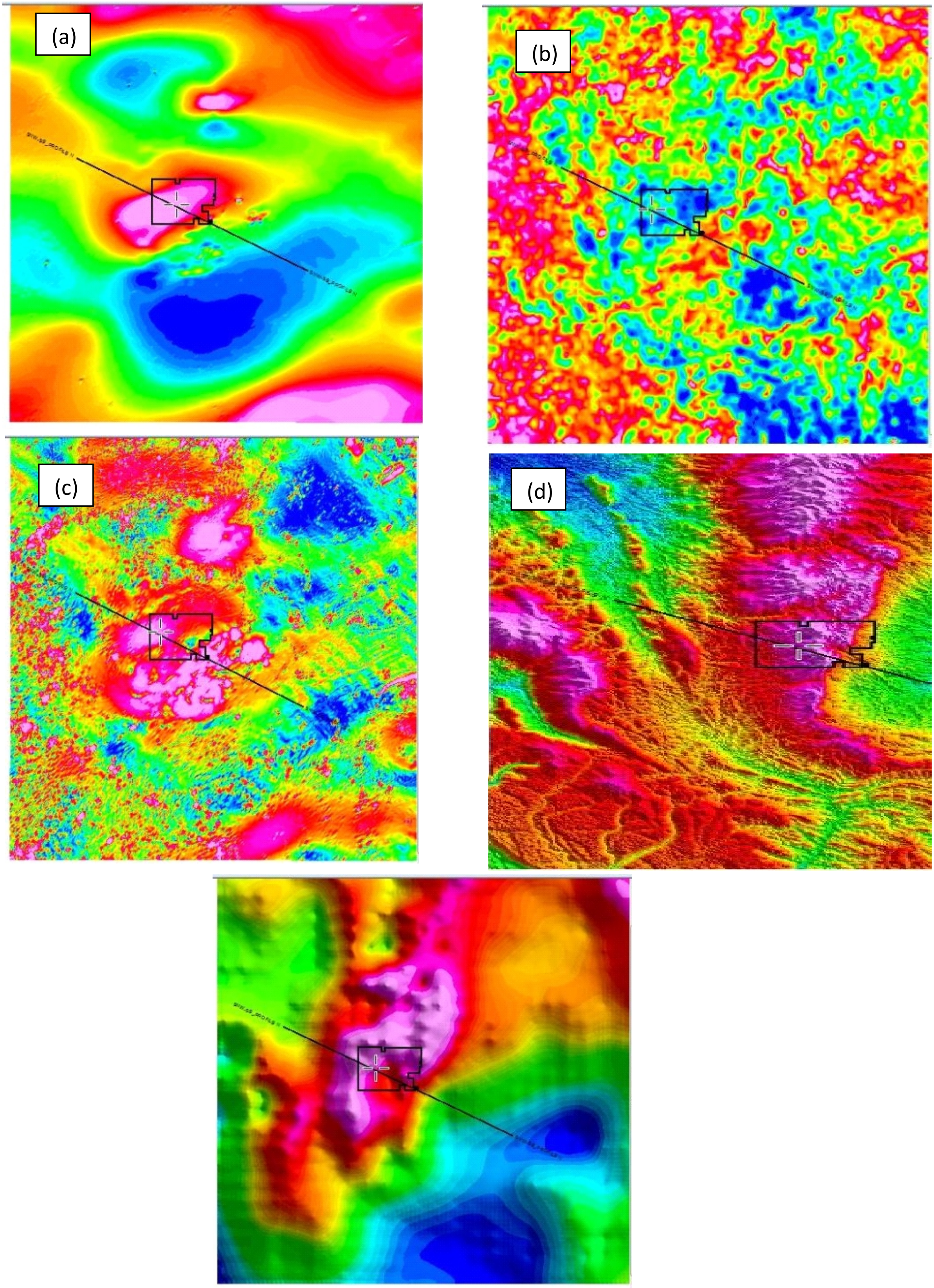

Figure 10: Detailed interpretation by profiling in the NW-SE direction across the study area on all relevant data. (a) NW-SE cross-section on TMI (-31.6). (b) NW-SE cross-section on ASIG (0.0499. (c) NW-SE cross-section on Bouguer map (15.07). (d) NW-SE cross-section on SPI-Depth (-1387.93). (e) NW-SE cross-section on SRTM (elevation at 284.77).

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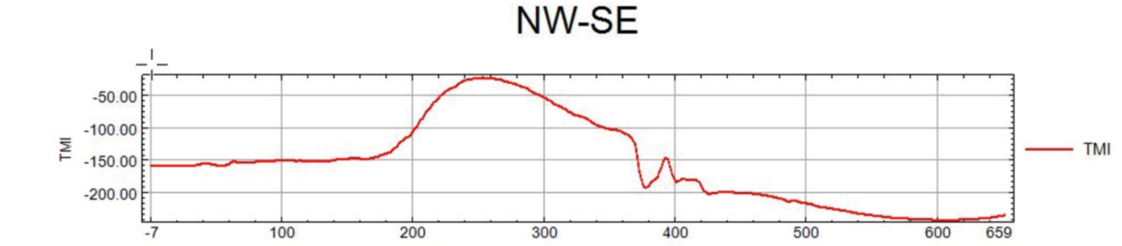
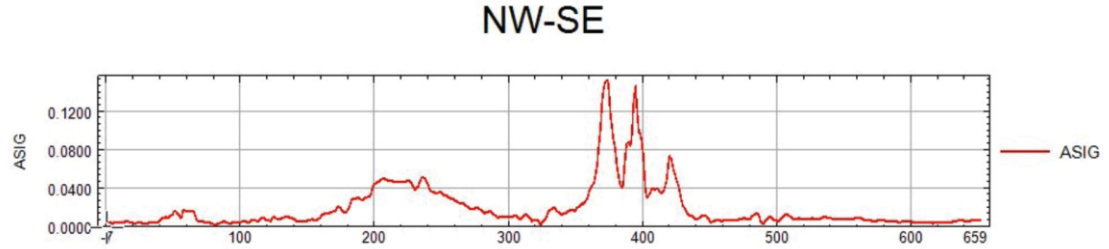
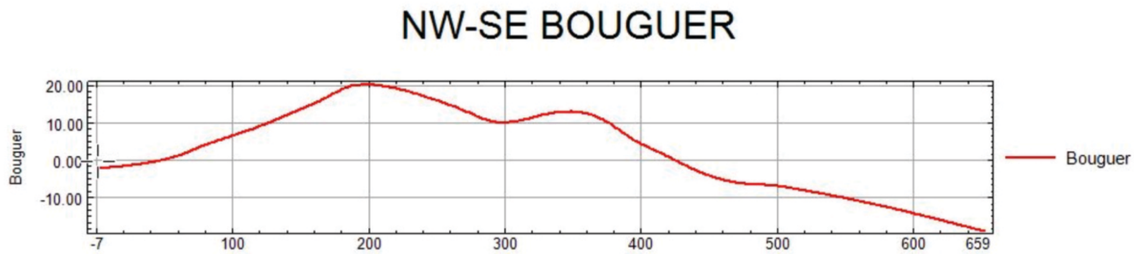


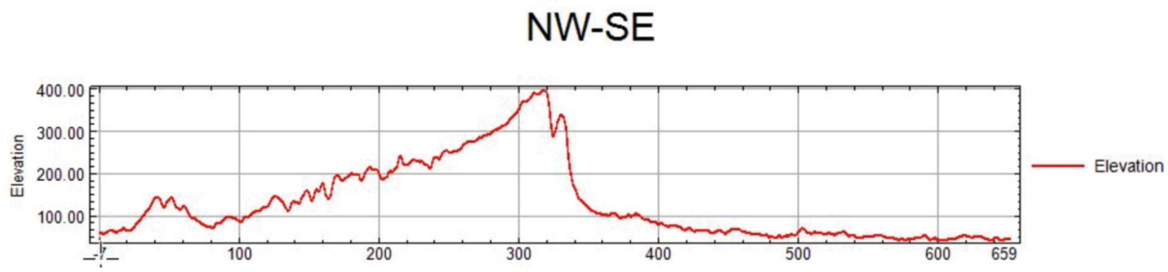
(a) TMI



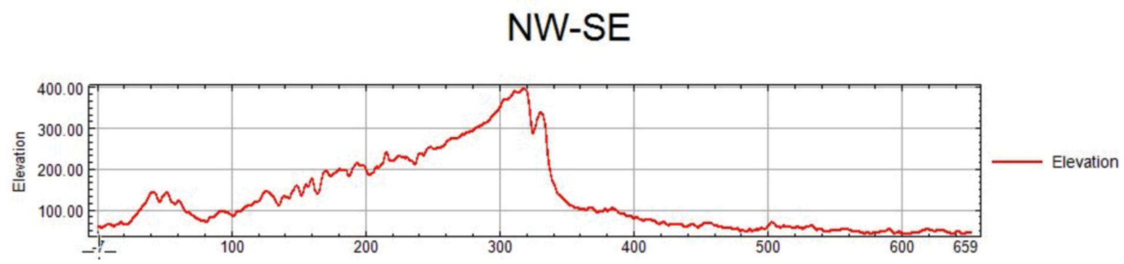
(b) ASIG



(c) Bouguer



(d) Depth



(e) SRTM

Figure 11: Summary of interpretation of the NW-SE profile along all the aeromagnetic data in stacked section. (a) TMI; (b) ASIG; (c) Bouguer; (d) Depth; (e) Elevation profiles.

In terms of lithologic characterization within the study area, outcrop of Nsukka formation (Upper Coal measure) appearing at the western part, Ajali sandstone at the middle and Mamu formation at the eastern flank are observed (Figure 9). Although, some formations of lower Benue trough such as Asu River group and Eze Aku group, Tertiary formations such as Ogwashi Asaba, Bende-Ameki and Benin formation are identified within the Sheet, the area only cuts across Mamu, Ajali and Nsukka formations. Thus, the major mineralization around this area is likely to be coal. This is because Mamu and Nsukka are the two major hosts of coal and lignite in Anambra Basin.

3.2 Discussion of Results

The results of analysis and map generation for the total magnetic field Intensity, first vertical derivative, analytic signal, depth to basement and Bouguer anomaly are as shown in Figures 2-7. Figure 8 displays the result of structural interpretation, while Figure 9 shows the result of a structural synthesis relating distribution of inferred lithologies and structure. Interpretations of the across-section of the area based on all relevant data are indicated in Figures 10a-e and 11a-e.

Looking the total magnetic field intensity (TMI) results, high amplitude, long wavelength were observed, implying lithologies that are at depth rich in ferromagnesian materials. The result of the analytic signal showing moderately high amplitude (crest) implies that intrusive ferromagnesian materials are present. Bouguer anomaly interpretation, showing high amplitude implies very thick piles of sediments (Overburden). Depth to basement analytical result show very low amplitude (trough) and therefore implies deep magnetic source (Basement).

Limitations of the results come during the interpretation process, owing to assumptions relating magnetic properties of rocks to geologic units. The linear anomalies, where they are isolated from other magnetic sources may be offset from the surface expression of faults for several reasons (Grauch and Hudson, 2007) amongst which are: (1) the magnetic contrast may be related to sedimentation near the fault rather than to offset material at the fault zone, or (2) the surface evidence of faulting has migrated away from the fault zone at depth because of erosion or subsequent sedimentation. In addition, even where faults are expressed magnetically, the sense of fault offset (which side is down) cannot be determined from the magnetic data alone. For corroborative, ground geophysical survey preferably 2D seismic or resistivity profiling or both will be required to be carried out around the areas with sufficient thickness and across the fault zone to fully unravel the position, spread and geometry of seam as well as ore of suspected metallic mineral in the area.

4.0 CONCLUSIONS

High-resolution aeromagnetic data were analysed and interpreted to delineate the lithologic and structural framework and as well, identify possible mineralization target within the area. Analysis of spatial derivatives of the Total magnetic Intensity and the Bouguer Anomaly data combined with geology and topographic data has enabled a litho-structural interpretation of the whole area. Analysis and interpretation of the derivatives such as the first vertical derivative (1VD), analytical signal, Depth to basement, Bouguer anomaly, SRTM map show consistent results.

A major regional fault trending northwest–southeast was interpreted to have cut the area at the lower south eastern corner of the area. This fault is evident on the Analytic signal data and was interpreted to contain some ferromagnesian minerals even though at depth.

Fault interpretation was accomplished by synthesizing interpretative maps derived from several different analytical methods, along with preliminary depth estimation (Figure 8). Several northwest-southeast striking faults in addition to the major northwest-southeast trending fault interpreted are proposed mainly on the basis of differences in regional magnetic values.

Lithologic characterization indicates that the work area cuts across Mamu, Ajali and Nsukka

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formations, with both Mamu and Nsukka known to be hosting coal and lignite in the Anambra Basin. Thus, the major target for geo-resources is coal within the thicker sediments in the area (Figure 9).

It is recommended that ground geophysics preferably 2D seismic or resistivity or both be carried out in order to fully unravel the position, spread and geometry of coal seam potential as well as ore of suspected metallic mineral within the study area.

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