Identification and Interpretation of Structures in Parts of Southern Benue Trough and the Anambra Basin Using High-Resolution Geophysical Data for Hydrocarbon Prospecting

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ABSTRACT

High-resolution geophysical data covering parts of the southern Benue Trough and the Anambra Basin were acquired and interpreted to aid investigation into structures associated with hydrocarbon generation and occurrences within the basins. The geophysical data investigated both surface and subsurface characteristics of sediments present in the basins. Sediment packages together with their thicknesses, extent and structures housed were examined. Nine sheets of aeromagnetic and radiometric data were acquired and processed, to produce grids and maps, and interpreted. Aeromagnetic data was used to decipher sedimentary rock thicknesses, lineaments and trends, structures and magnetic intensities of rocks present, while radiometric data was used in detecting formation boundaries, rock types, and structures. Sediment thicknesses were determined using the Source Parameter Imaging (SPI) method. The sediment thicknesses obtained varied from 168.78 to 2627.95m, with the deepest sections occurring in the Anambra Basin. High lineament density trending mostly in the NE-SW direction were observed more in the southern Benue Trough than in Anambra Basin. Magnetic intensities are almost equal in both basins. Formation boundaries, drainage patterns, shear zones, horst and graben, rock types, faults, folds, fractures, metamorphosed areas, and intrusions within the study area were clearly delineated from maps generated. Structures such as folds, fractures, faults, metamorphosed areas, intrusions, horst and graben, ridges, shear zones, are prominent within the southern Benue Trough. Results obtained in this study, shows that both basins have enough sediment thickness and structures which will serve as migration pathways and traps for hydrocarbon but numerous intrusions present in the southern Benue Trough reduces its chances for hydrocarbon prospectivity compared with the Anambra Basin. Intrusions provides geothermal energy required for maturation of source rocks but in large quantity leads to overmaturation of source rocks as temperature window for hydrocarbon generation would be exceeded.

Keywords: High-resolution, Aeromagnetic, Radiometric, Hydrocarbon, Prospectivity.

INTRODUCTION

Basins with excellent petroleum system potentials are the target for exploration and production of hydrocarbon and its by-products. To estimate these potentials, proper identification and interpretation of structures housing hydrocarbon are important steps in the geological survey for hydrocarbon exploration and production. High-resolution geophysical data comprising of aeromagnetic and radiometric data of parts of the southern Benue Trough and the Anambra Basin were applied in identifying the structural features which characterize the area, and further interpreted. Aeromagnetic surveys measure the magnetic field associated with magnetic minerals in rocks while the goal of radiometric survey is to detect and map natural radioactive emanations (ɣ-ray) in the earth's surface (Halder, 2013). These geophysical methods allow the mapping of subsurface geology to determine geological structures present as structures present will provide the major elements that influences production performance (Shepherd, 2009). It is also an addition to already existing aeromagnetic and seismic data for the Benue Trough where key structural styles similar to the Niger Delta giant field have been found (Orife and Avbovbo, 1981; Okosun, 1995; Olugbemiro *et al.,* 1997; Okiwelu *et al.,* 2012; Irumhe et al., 2019). Thus, this work is focused on identifying and interpreting structural features existing in parts of the southern Benue Trough and the Anambra Basin, from high-resolution geophysical data as the abundance or paucity of them will influence hydrocarbon accumulation and production.

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GEOLOGICAL SETTING

The Benue Trough and Anambra Basin are part of an extensive West and Central African Rift System which resulted from crustal stretching of the African plate (Nwajide, 2022) (Figure 1). This crustal stretching or splitting-up began in the early Cretaceous (Obaje, 2009). The trough is a failed arm of the Cretaceous Rift-Rift-Rift (RRR) system, while the other two arms continued to spread during the break-up of Gondwana giving rise to south Atlantic Ocean (Petters, 1978; Grant, 1971). Major structural trends within the Benue Trough are in the NE-SW directions (Benkhelil, 1982). During the Santonian, there was intense compression and folding of the basin. Sediments within the basin were displaced westwards resulting to the formation of the Anambra Basin (Obaje, 2009). The depositional axis of the Benue Trough was shifted into the Anambra Basin and accumulation of sediments derived from the Abakaliki anticlinorium began (Nwajide, 2022). The Anambra Basin is an almost triangular shaped embayment which covers about 3000km, with a total sedimentary thickness of approximately 9,000m, and is considered to be the youngest formation of the Benue Trough (Online Nigeria, 2011).

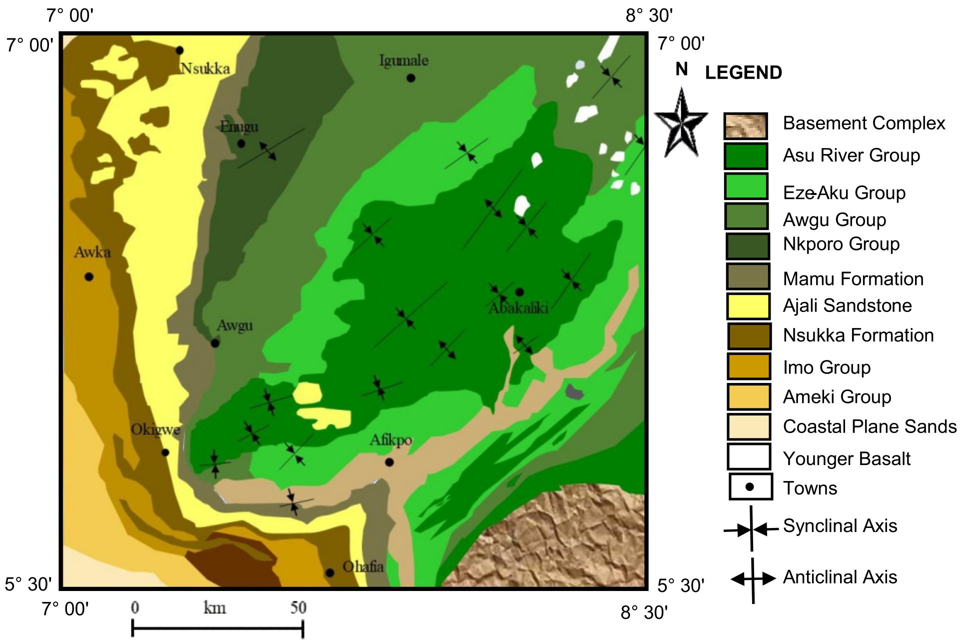

Figure. 1: Geologic map of the study area (After Nigerian Geological Survey Agency Map, 2006).

were used in detecting the geologic structures present in parts of these basins. Fugro Airborne Surveys conducted the geophysical survey, while Paterson, Grant and Watson Limited (PGW), carried out the processing and preliminary interpretations. The trend of the survey is the NW-SE flight line direction which is perpendicular to the axis of the Benue Trough. The flight line spacing is 500m, tie line spacing is 5, 000m and elevation is 80m.

The data was further processed using Geosoft® Oasis MontajTM (Standard edition version 6.4.2 (HJ)), Microsoft packages, ArcGIS and MatLab 7.5, to merge and generate the grids and maps used. The grids and maps were interpreted by application of appropriate filters. Aeromagnetic maps interpreted are Total Magnetic Intensity (TMI) which shows how strong or weak any magnetic field is; Derivative maps (1VD = First Vertical Derivative, and Tilt-Derivative) enhances shallow sources and sharpen edges of anomalies; Lineament map shows distinctive shapes or lines; Analytic Signal (AS) shows magnetic source location; and Source Parameter Imaging (SPI) gives depth ranges to various magnetic sources. Structures delineated with the aeromagnetic maps are faults, fractures, folds, horst and graben, shear zones,

MATERIALS AND METHOD

Dataset used is part of the new high-resolution digital dataset acquired between 2005 and 2009 by the Nigerian Geological Survey Agency (NGSA). The data covers some parts of the southern Benue Trough and the Anambra Basin, between Lat. 5°30'E – 7°00'E, and Long. 7°00'N – 8°30'N. Nine sheets of aeromagnetic and radiometric data

intrusives and extrusives. This method has been used in the geological mapping of several basins (Oha *et al.,* 2016; Eze *et al.,* 2019; Irumhe et al., 2019; Ishola *et al.,* 2020).

Distribution of radioelement on the earth's surface has been reported by several authors such as Dickson and Scott (1997), and was later revised by the International Atomic Energy Agency (IAEA, 2003). The method has also been used to measure radiometric signatures and geologic mapping of different basins (Youssef and Elkhodary, (2013); Ademila *et al.,* 2018; Eze *et al.,* 2019). The radiometric maps interpreted are Potassium, Thorium and Uranium concentration maps. It was further used to determine geologic boundaries, drainage and rock types.

RESULTS AND DISCUSSION

Colour maps with their legends were generated both for the aeromagnetic and the radiometric maps (Figures 2 and 3). Within these maps, structures were delineated and interpreted. The TMI map shows more structures in the southern Benue Trough than in the Anambra Basin (Figure 2A). These structures include folds, horst and graben, and shear zones. The derivative maps comprising of 1VD and tilt-derivative, show intrusives, extrusives, faults and folds of higher density in the southern Benue Trough (Figures 2B and C). From the lineament map, higher lineament density is observed within the southern Benue Trough (Figure 2F). The predominant structural trend is in the NE-SW direction, with minor N-S and E-W

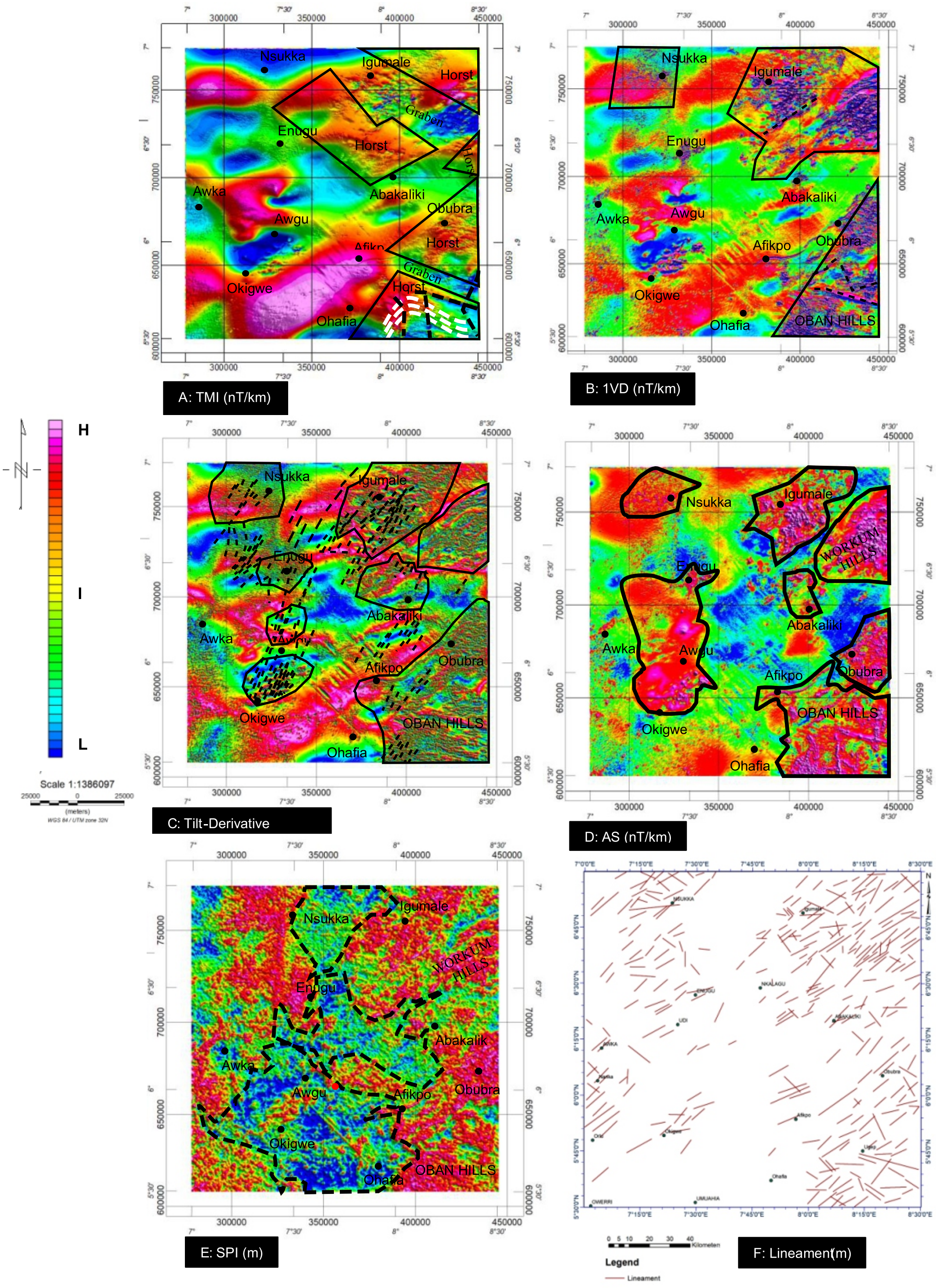

Figure 2: Aeromagnetic maps used (A) TMI (B) 1VD (C) Tilt-Derivative (D) AS (E) SPI (F) Lineament.

directions. This is in agreement with published works that identified the NE-SW direction as the major trend within the Benue Trough (Chukwu-Ike, 1981; Ajakaiye *et al.,* 1986). The Analytic Signal shows higher concentrations of magnetic source within the southern Benue Trough (Figure 2D). Also, areas with intrusives are clearly seen. This method has been used in identifying important features of oil field structure in Toqui-Toqui and Mana Fields, Tolima, Colombia (Martínez-Gómez, and José-María, 2017). Sedimentary thicknesses obtained using the SPI method has its deepest parts in deep blue colour with values ranging from 1442.87 to above 2627.95m (Figure 2E). The values of the deepest parts exceed the 1000m recognized as the overburden thickness required for a potential basin if all other petroleum system elements are present (Benkhelil et al., 1989; Hunt, 1996). The intrusives provide geothermal energy needed for source rock maturation while the folds, faults, horst and graben, serve as traps and pathways for migration of hydrocarbon generated from the source rocks.

The radiometric map measures concentration of radioelement and was used in determining rock types, geologic boundaries and drainage pattern (Figure 3). High potassium concentration areas are rich in potassic minerals such as orthoclase, muscovite, and found in unstable areas while areas with low potassium concentrations are poor in potassic minerals and are found in stable areas (Figure 3A). These areas with high potassium concentrations show high degree of intrusives and lots of deformational structures which is supported by the derivative and analytic signal maps, and is noted to be more within the southern Benue Trough. Degree of concentration of potassium within the study area is highest within the southern Benue Trough with about 80% of the area having high concentration of potassium, while the Anambra Basin has predominantly low concentration of potassium. This corresponds with Hoque, 1997, results of quartz arenite being the dominant composition of rocks in the Anambra Basin, while that of the southern Benue Trough is made up of feldspathic arenites. Tectonic

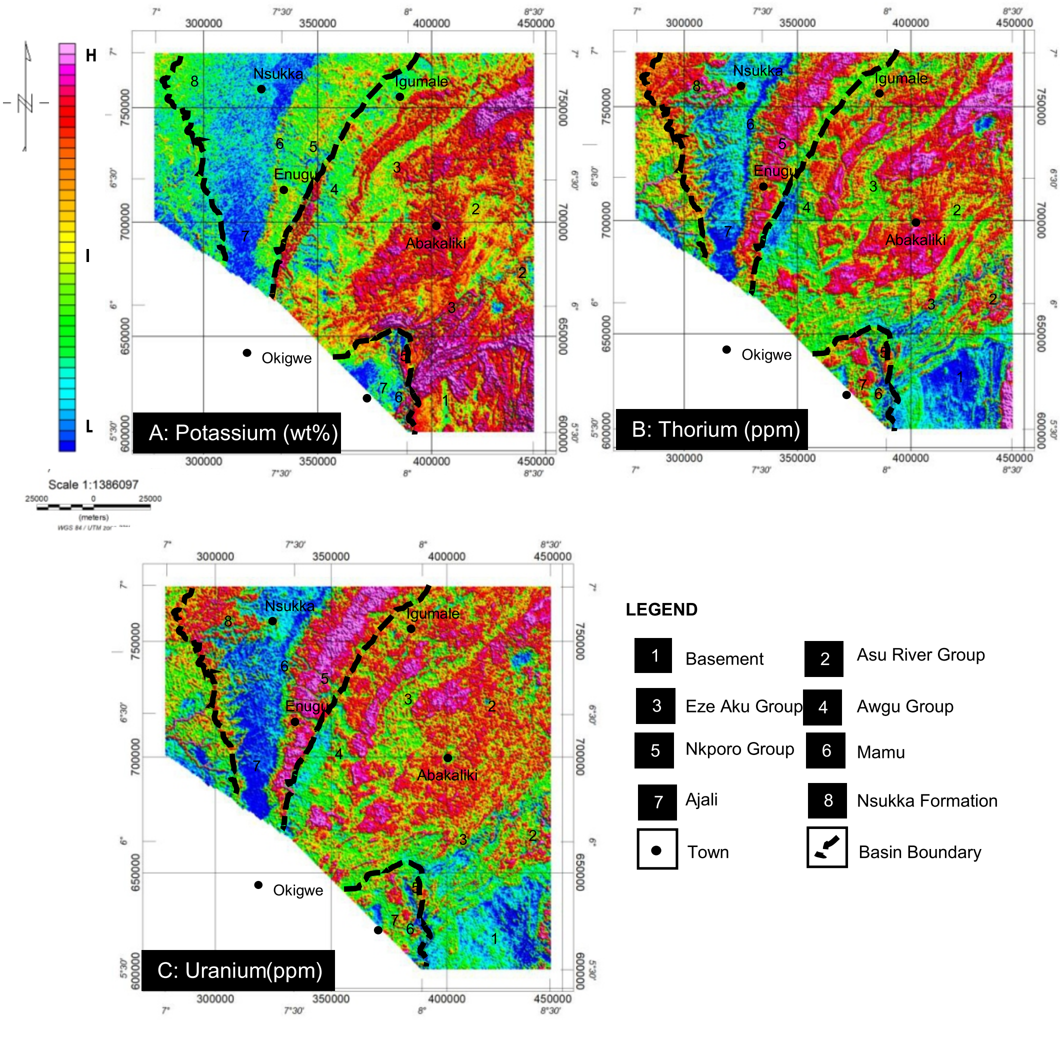

Figure 3: Radiometric maps used (A) Potassium (B) Thorium (C) Uranium concentration maps.

activities of the Santonian might have contributed to high potassic minerals contained in rocks of the southern Benue Trough.

In the thorium map, areas with high thorium concentration indicate rocks rich felsic minerals, while areas with low thorium concentration indicate rocks with high concentration of mafic minerals such as volcanic, magmas and intrusive igneous rocks (Figure 3B) (Shives *et al.,* 1997). Also, rocks rich in thorium are composed of various ferruginous materials at the surface. Structures within the study area were clearly delineated within the thorium concentration map. Geologic boundaries were precisely delineated and formations numbered and named. Structural deformations and the dendritic drainage pattern within the study area were clearly identified.

The uranium concentration map has similar features with the thorium concentration map. Rock types, geologic boundaries and drainage within the study area are clearly distinguished in the uranium concentration map as well. Uranium rich rocks are composed of torbenite and uranite minerals. Rocks rich in uranium minerals are calcrete, calcareous sediments and soils.

CONCLUSION

High-resolution airborne geophysical data was used to generate maps used in identifying and interpreting structures found in some parts of the southern Benue Trough and the Anambra Basin for hydrocarbon prospecting. Aeromagnetic and radiometric maps generated using various software were used in detecting folds, faults, horst and graben, intrusions, extrusions, shear zones, sediment thicknesses, drainage, geologic boundaries and rock types within the study area. Even though intrusions provide geothermal energy needed for source rock maturation, its abundance leads to source rock becoming overmature. Both basins have sufficient sediment thickness and structures for generation, storage and transmission of hydrocarbon.

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