Identification of volcanic rocks and their distributions in parts of the Abakaliki Anticline, southern Benue Trough, Nigeria

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Abstract
The study identifies various volcanic rocks and their distribution within the Abakaliki Anticlinorium and environs. This is important due to its role in understanding the evolution of the crustal rocks beneath the southern Benue Trough of Nigeria. To achieve this, a high-aeromagnetic data was acquired by the Nigerian Geological Survey Agency (NGSA) covering a total area of about 3,025 square kilometres. The magnetic susceptibility and the surface reflectance techniques were employed to delineate basement rocks from sedimentary cover. The results from these analyses show that the study area is covered predominantly of low to intermediate magnetic anomalies. These anomalies were interpreted as sedimentary terrains except for the south-eastern portion of the study area that display very high magnetic anomalies. These high magnetic anomalies were linked to the near-surface crustal features observed to be of volcanic rocks as confirmed from ground truthing. The volcanic rocks identified were observed primarily at the SE part of the study area with scattered patches at the NW and NE segments. These volcanic rocks were mainly andesite/diorite of intermediate composition. Few components of mafic (basalt/Gabbro) and felsic (granite/rhyolite) were also observed within the study area. This has great implications for the thermal maturation of hydrocarbon within the study area. Hence, the area with observed volcanic rocks should be avoided when prospecting for hydrocarbons.

1 Introduction

The Earth has magnetic and gravity fields which vary according to the magnetic properties and mass distribution of its interior. In geophysical survey, observed variations in the magnetic and gravity fields can, therefore, be interpreted in terms of possible structures in the Earth's interior that may cause them (Kearey et al., 2002). Both magnetic and gravity field data can be acquired on land, sea, and air. For this study, aeromagnetic data were employed. Aeromagnetic survey is a potential field method of geophysical survey carried out using a magnetometer aboard or towed behind an aircraft. As the aircraft flies, the magnetometer records variations in the intensity of the ambient magnetic field due to the spatial variations in the Earth's magnetic field and the local effect of magnetic minerals in the Earth's crust (Kearey et al., 2002; Telford et al., 1990). Both magnetic and gravity field methods are potential field methods of geophysical survey that uses natural field media unlike seismic that uses artificial field medium. Potential field methods depend on spatial variation of the gravitational, electrical, and magnetic force fields. Generally, potential methods provide significant information on Earth's properties and are simpler to carry out when compared to non-potential methods. The aim of this study was to identify volcanic rocks and their distributions beneath the Abakaliki Anticline from potential field methods. The area is bounded by longitudes 8^{o}00''00'E to 8^{o}30''00'E and latitudes $6^{o}00”00’N$ to $6^{o}30”00’N$ (Figure 1.1). The Abakaliki area and environs is largely drained by Ebonyi Rivers and its tributaries and partly by Cross River on the eastern portion. The drainage pattern is essentially dendritic in nature and the tributaries are perennial, which usually overflow their banks at the peak of the rainy season. Stunted trees and pockets of derelict woodland exist where the lithology has undergone high degree of laterization. Around the study area, typical characteristics of the tropical rain forest, multitude of evergreen trees, climbing plants, parasitic plants and creepers are observed (Ezeh and Anike, 2009).

2 Geological Setting

The Cretaceous Benue Trough is an elongate intracratonic structure of over 1,000 km long and about 250 km wide, developed as a purely rift structure in the Pan-African mobile belt starting from late Jurassic to Cretaceous. Studies have shown the structure to be a set of pull-apart sub-basins or grabens generated by sinistral displacements along a pre-existing zone of northeast-southwest trending transcurrent faults. Transcurrent movements were therefore the principal factor in the formation and subsequent evolution of the trough (Nwajide, 2013). The Benue Trough is sub-divided into northern, central, and southern segments based on tectonic considerations. The Gboko line, which represents a wrench fault demarcates the southern Benue Trough from the central segment, while the northern segment does not have a clear boundary with the central segment (Nwajide, 2013). The southern segment includes mainly the Abakaliki Anticlinorium, a structural unit formed by tightly folded Cretaceous sediments intruded by numerous magmatic rocks (Akande et al., 2002). According to Lehner and De Ruiter (1977), the tectonic framework of the continental margin along the west coast of equatorial Africa is controlled by Cretaceous Fracture Zone (CFZ) expressed as margin and ridges in the deep Atlantic. The fracture zone ridges subdivide the margin into individual basins, and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough, which cuts far into the west African Shield. The trough represents a failed arm of a rift triple junction associated with the opening of the south Atlantic (Tuttle et al., 1999). In the region, rifting started in the late Jurassic and persisted into the Cretaceous. The stratigraphy of the Cretaceous Benue Trough is well documented in Peters (1978). The Aptian pyrocrastics form the basal unit of the Albian-Cenomanian depositional sequence (Peters, 1978). These were overlain by over 3,000 m of sediments of the Albian Asu River Group (Nwachukwu, 1985). These are the dark, micaceous, and sandy-shales and the fine-grained sandstones. These were followed by the Cenomanian Odukpani Formation consisting of sandstones, sandy shales, and fossiliferous limestones observed along the Calabar Flank. During the Turonian and Coniacian times, a thick marine sequence of grey, calcareous, fossiliferous shales were deposited. During this major transgressive phase, the Eze-Aku Shales and the Awgu Shale were deposited. These depositional cycles were interrupted by widespread Santonian events that resulted in folding of the trough’s sediments and were also accompanied by magmatic activity leading to the emplacement of Lead-Zinc mineralization. Following the Santonian tectonism, the sea retreated into the Anambra Basin and the smaller Afikpo Syncline leaving the Abakaliki High separating the two basins. The depositional axis was subsequently displaced, and the Anambra Basin subsided. The Campanian-Maestrichtian sequence includes the shallow marine Nkporo Group, Mamu Formation, Ajali Formation and Nsukka Formation.

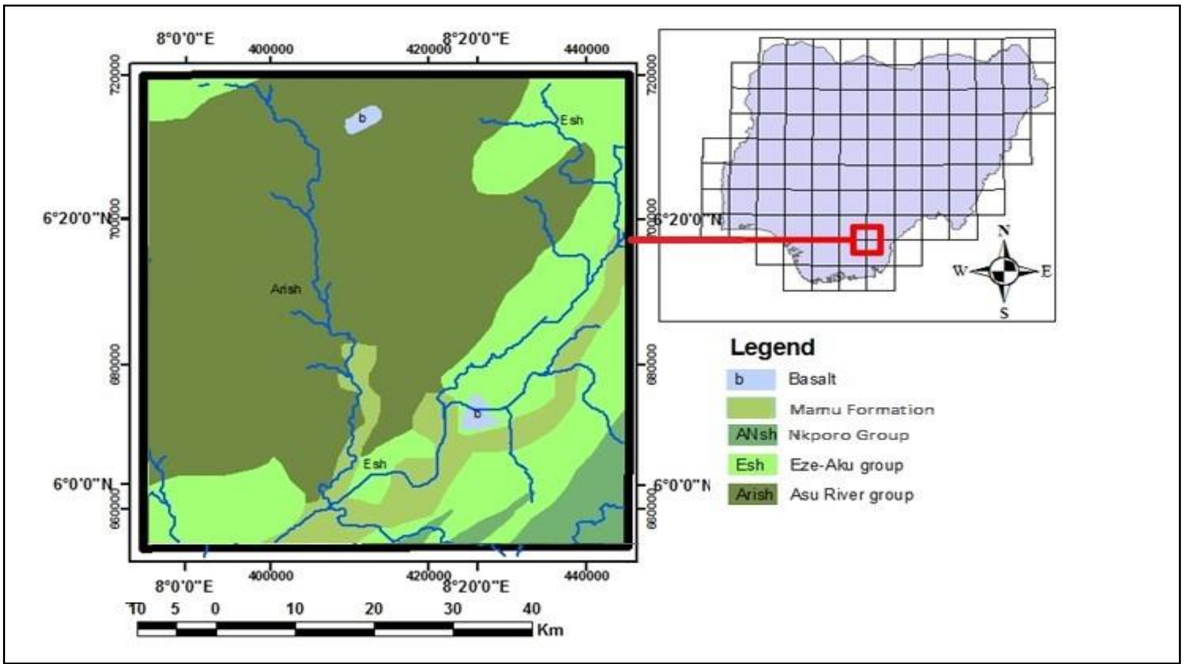

Fig. 1.1 Location and geological map of the study area (NGSA, 2012)

3 Methodology

3.1 Magnetic dataset

In magnetic survey, the geology of the subsurface is being investigated based on changes in the Earth's magnetic field (geomagnetic field) resulting from the magnetic properties of the underlying rocks (Kearey et al., 2002). Although, most rock-forming minerals are non-magnetic, but certain rock types contain sufficient magnetic minerals to produce significant magnetic anomalies. The main purpose of a magnetic survey in geophysical exploration is to measure the geomagnetic field strength over a certain area of interest. At any point above the Earth's surface, it will be the sum of the regional field and the local field produced by the magnetic rocks in that vicinity. The Earth generates a magnetic field as if it were a dipole magnet where lines of force radiate from one magnetic pole converge at the other. The inclination of the magnetic force field changes from vertical at the poles to horizontal at the Earth's equator. The largest constituent (over 80%) of the Earth's field is suggested to have originated in the Earth's outer core from convection of liquid iron (Kearey et al., 2002; Telford et al., 1990).

This aeromagnetic datasets for the study area were acquired for the Nigerian Geological Survey Agency (NGSA) in 2009 by Fugro Airborne Survey Ltd. The preliminary processing on the data was carried out by Paterson Grant and Watt Ltd, Canada. The datasets are produced in digital format. This aeromagnetic dataset was collected and gridded using a bi-directional gridding procedure with a cell size of about 100 m. This is presented as total magnetic intensity map of Abakaliki area and environs (Figure 3.1).

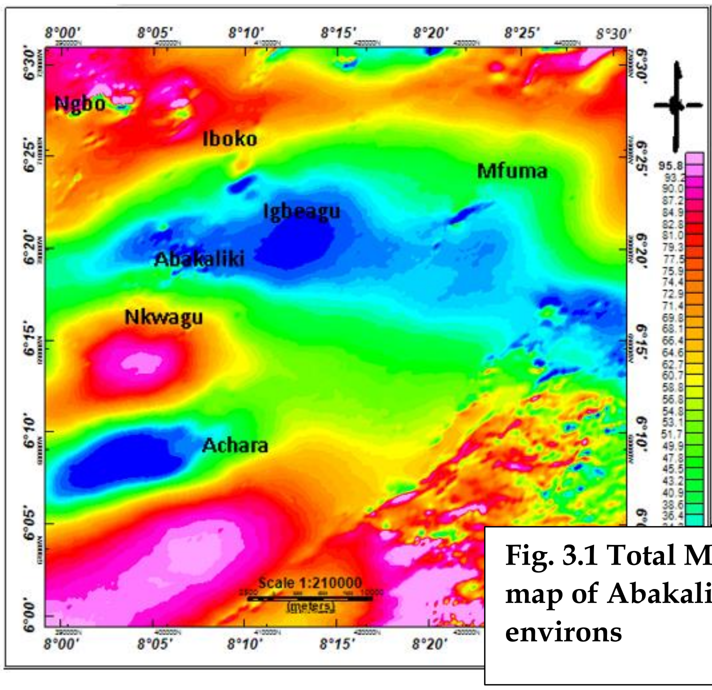

Fig. 3.1 Total Magnetic Intensity map of Abakaliki Area and environs

3.1.2 Magnetic susceptibility

Hinze et al. (2013) defined magnetic susceptibility as a measure of the ease to which a material can be magnetized in the current magnetic field of the Earth. It is the operative physical property for the magnetic method in exploration activities. Magnetic susceptibility of rock depends on its magnetite content. Consequently, basic igneous rocks have high magnetic susceptibilities due to their relatively high magnetite content; acidic igneous rocks and metamorphic rocks have intermediate magnetite content while sedimentary rocks have low magnetic susceptibility due to low magnetite content.

The equation is given as:

k = Ji/H

where

J_i = intensity of magnetization (magnetic moment/volume)

k = magnetic susceptibility of the material

H = magnetic field strength of the Earth

However, $Ji = \dfrac{M}{LA}$

where

M = magnetic moment, L = length and A =cross-sectional area.

J_i is represented by Am^{-1}. In the c.g.s. system intensity of magnetization is expressed in emu cm^{-3} (emu = electromagnetic unit), where 1 emu cm^{-3} = 1000 Am^{-1}.

3.1.3 Magnetic surface reflectance

Magnetic surface reflectance shows variation in the dominant anomaly wavelength and trend between regions. The procedure treats a potential field map as a relief and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle. Subtle, local, and short wavelength are emphasized. The angle used for this study is 45°.

4 Results and discussion

4.1 Results from interpretation of magnetic susceptibility and surface reflectance

The magnetic susceptibility and surface reflectance techniques were employed to identify volcanic rocks within the study area. The results from the evaluation show that the study area is covered predominantly of low to intermediate magnetic anomalies. These were interpreted as primarily sedimentary terrain except for the south-eastern portion of the study area that display very high magnetic anomalies. These high magnetic anomalies were linked to the near-surface crustal features observed to be of volcanic rocks as confirmed from ground truthing. The volcanic rocks identified were observed at the SE part of the study area with scattered patches at the NW and NE segments. These volcanic rocks were mainly andesite/diorite of intermediate composition. Few components of mafic (basalt/Gabbro) and felsic (granite/rhyolite) were also observed within the study area.

The results obtained were compared to the total magnetic intensity map and the geological map of the study area (Fig. 4.1). On the maps, areas of high volcanic rock concentration were highlighted using an outline marker to separate areas of sedimentary cover (Fig. 4.2). The marked area shows similar structural trend of NE-SW observed in the south-eastern part of the study area. These structural trends perhaps link with the Chain and Charcot Fracture Zones in the South Atlantic of Africa to the Cretaceous Benue Trough of Nigeria.

This has great implications for the thermal maturation of hydrocarbon within the study area. The hydrocarbon traps in this region could have been destroyed by these intrusions. Hence, the area with observed volcanic rocks should be avoided when prospecting for hydrocarbons.

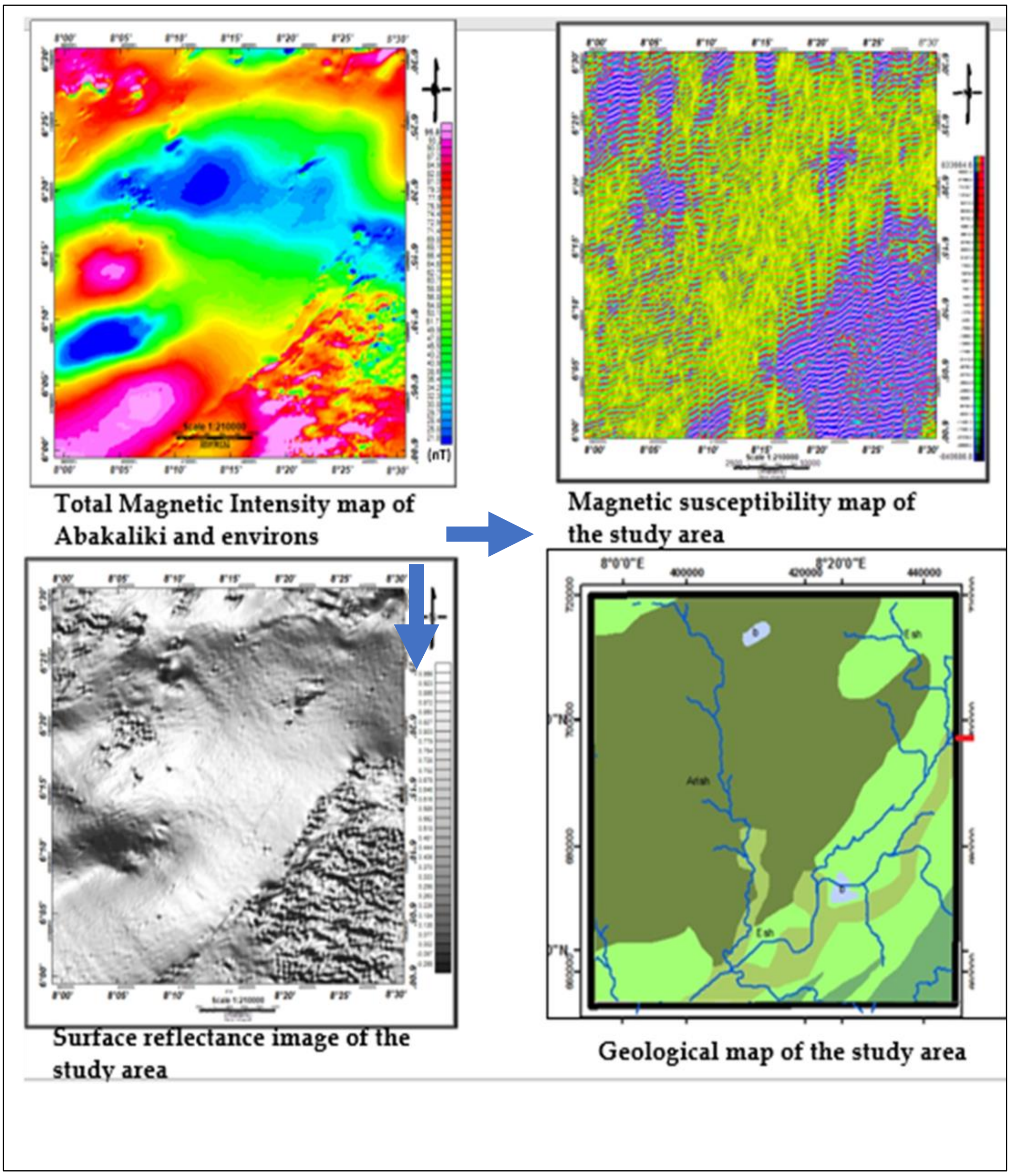

Fig. 4.1. Comparison magnetic susceptibility and surface reflectance maps to the total magnetic intensity and geological maps of the Abakaliki and environs.

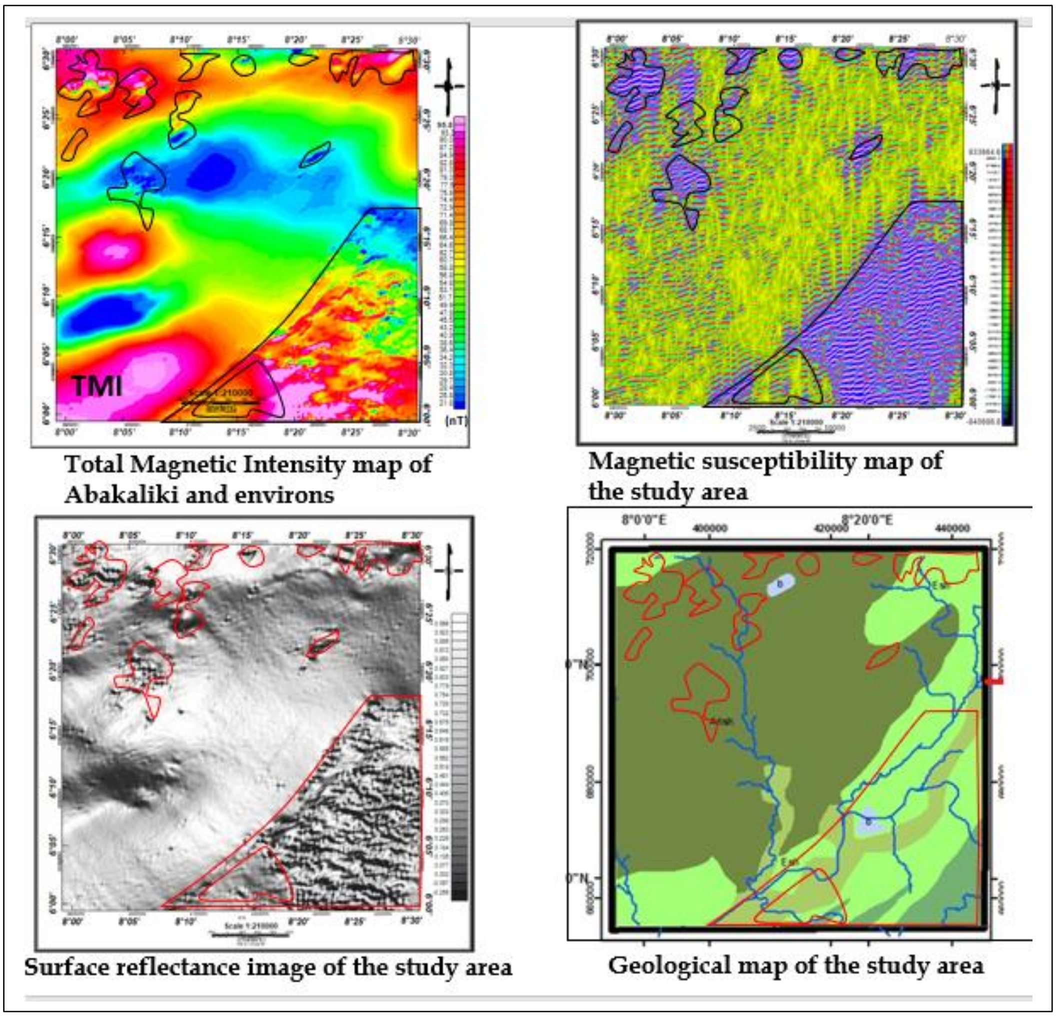

Fig. 4.2. Outline marker highlights areas with volcanic rock concentration as displayed on the magnetic susceptibility map, surface reflectance map, total magnetic intensity map and geological map of the Abakaliki and environs.

5.1 Summary and Conclusions

A high-resolution aeromagnetic data was acquired and analyzed to identify volcanic rocks and their distributions within the Abakaliki Anticline. This is important in understanding the crustal rocks for regional basin exploration. To achieve this a high-resolution aeromagnetic data was acquired by the Nigerian Geological Survey Agency (NGSA) covering a total area of about 3,025 square kilometres. This data was first gridded using bi-directional gridding techniques to generate a total magnetic intensity map as programmed in Oasis Montaj Software. This data was further analyzed using magnetic susceptibility and surface reflectance techniques. These techniques help to display areas of high volcanic rocks which were associated with high magnetic intensity. In geophysical considerations, intensity of magnetization (or the magnetic moment per unit volume) is the operative physical property for the magnetic method in exploration activities. The results from these analyses show that the study area is covered mainly by low to intermediate magnetic anomalies. These were interpreted as mainly sedimentary terrain except for the south-eastern portion of the study area that display very high magnetic anomalies. These high magnetic anomalies were linked to the near-surface crustal features observed to be of volcanic rocks as confirmed from field work. The volcanic rocks identified were observed mainly at the SE part of the study area with scattered patches at the NW and NE segments. These volcanic rocks were mainly andesite/diorite of intermediate composition. Few components of mafic (basalt/Gabbro) and felsic (granite/rhyolite) were also observed within the study area. This has great implications for the thermal maturation of hydrocarbon within the study area. The hydrocarbon traps in this region could have been destroyed by these intrusions. Hence, the area with observed volcanic rocks should be avoided when prospecting for hydrocarbons.

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