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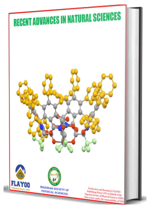

Litho-structural study and depth estimation of Shaki area of Southwestern, Nigeria using high resolution aeromagnetic data

O. M. Adedokun[a], O. P. Oladejo[b], K.O. Suleman[c], K. N. Alao[a], E. O. Adeniyi[a], H. Otobrise[d], O. Adedokun[a,*], L. A. Sunmonu[a]

[a] *Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria*
[b] *Department of Physical Sciences Education, Emmanuel Alayande University of Education, Oyo, Nigeria*
[c] *Department of Physics, School of Basic Sciences, Nigeria Maritime University, Okerenkoko, Nigeria*
[d] *Department of Physics, Lead City University, Ibadan, Nigeria*

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ABSTRACT

Little studies have been carried out in the investigation of some geological faults associated with seismic activities in Nigeria; probably due to the fact that Nigeria is believed to be sitting on a seismically safe African plate. However, the nation has experienced series of tremors in the last few decades. Hence, there is a need to investigate the lithological structural trends in some parts of Southwestern Nigeria to determine the tectonic stability of the study area. This research therefore investigates the litho-structural trends and the overburden thickness around Shaki area, Southwestern, Nigeria. High resolution aeromagnetic data (HRAD) of Shaki (sheet 199) was obtained from the Nigeria Geological Survey Agency; it was processed, enhanced, and interpreted using Geosoft Oasis Montaj 6.4.2 data processing and analysis software package. The depth to basement analysis were done using Euler Deconvolution (ED), Radially Average Power Spectrum (RAPS) and Source Parameter Imaging (SPI) to evaluate the depth to basement of the investigated area. Results of the estimated depth to basement obtained from ED, RAPS and SPI revealed 136-6155 m, 0.2-0.65 m, 96-3229 m. Thus, based on the results obtained from the investigated area, the basement of the area is relatively shallow compared to sedimentary basement area. In conclusion, the faults in the area are responsible for the earth tremor experienced around Shaki in August 2021. Thus, the area could be further probed using seismic refraction method.

1. INTRODUCTION

The earth's structure is essentially composed of several components: the crust, the top-most solid component of the mantle that makes up the lithosphere and which is also known as tectonic plate;the inner core, and the outer core. Every layer has a different chemical and physical makeup that can affect life on Earth's surface. Shifting plates as a result of mantle disturbance brought on by variations in core temperature can result in earthquakes and volcanic eruptions. These natural threats alter our surroundings, and occasionally, inflict catastrophe on human lives and property [1]. A fault is any general discontinuity or planar fracture that has occurred as a result of considerable displacement caused by

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[*] Corresponding author Tel. No.: +234-703-1195-750.
e-mail: `oadedokun@lautech.edu.ng` (O. Adedokun)

movements of the rock mass inside the volume of the rock [2]. Plate tectonic processes cause numerous faults in the Earth's interior, the degree of faults activities can be important for determining the risk of seismic shaking and tsunamis to the nearby infrastructure and humans.

One of the world's most serious hazards has been earthquakes [3]. An earthquake is a complicated natural event that occurs when a fault ruptures and releases sudden energy. It is a strong ground motion. The strength of the seismic event is described using several intensity scales and the observed impacts of ground motion [3]. Even though Nigeria is not located on a known seismic region, tremors were recorded at Dan Gulbi, Kano, Lupma, Abuja, Kombani Yaya, Yola, Gembu, Abeokuta, Oyo, Ibadan, Akure, Shagamu, Ijebu-Ode, Lagos, Okitipupa, and Warri between 1933 and 2006 [4, 5]. One of the most recent occurrence was reported in Shaki in Oyo State, Nigeria in August 2021 with magnitude ranging between 3.0 and 6.0 based on the Modified Mercalli Intensity Scale. These tremors events suggest that Nigeria may not be as seismically inactive as previously believed.The only seismic occurrences that were instrumentally documented were those that occurred at Ijebu Ode in 1984, at Ibadan in 1990, and at Jushi-Kwari in 2000. Their surface wave magnitudes range from 3.7 to 3.9, their local magnitudes values range from 3.7 to 4.2, and their body wave magnitudes ranges from 4.3 to 4.5 [4]. The theory behind the Earth's tremor in Nigeria is that they are caused by Earth movements connected to fractures flowing NE-SW and weak spots that reach into the country from the Atlantic Ocean [6, 7]. According to Onuoha (1988) [8], the earthquakes were caused by plate boundaries partially reactivating. According to regional stress models developed by Sykes [9], Johnston and Kanter [**?**], and Zoback (1992) [11], stresses may have accumulated along plate boundaries and may have moved toward the center of the plate, potentially causing intraplate tremors, particularly in faults that already existed.

On the global scale, The Pacific, Indian, Atlantic, and other oceans are the sites of the epicentres of the majority of earthquakes.Certain earthquakes cause tsunamis, which can cause great damage, particularly to coastal communities and their inhabitants. Research has demonstrated that all significant earthquakes that occur in the ocean have the potential to produce tsunamis, even though subduction zones are known for producing them [12, 13]. Consequently, tsunamis may occur in coastal regions of any nation; their severity is based on the movement of the boundary lithospheric plate.

Regional-scale subsurface lithological characterization can be conducted using a suite of geophysical survey methods, including seismic reflection and refraction, gravity, electrical resistivity and electromagnetic induction, and magnetics [14–17]. In this study, magnetic method was employed using aeromagnetic data to determine the lithological stability and the overburden thickness of area around shaki a basement complex in the Southwestern part of Nigeria using Euler deconvolution, Power spectrum and Source parameter imaging depth estimation technique to comprehend the mechanism behind Earth tremors in the area and hence tectonic stability of the region.

1.1. DESCRIPTION AND GEOLOGICAL SETTING OF THE STUDY AREA

The study area falls within latitude 8° 13' 48" – 8° 40' 12" N and Longitude 3° 12' 0" – 3° 23' 24" E on the Basement Complex of the Southwestern, Nigeria (Figure 1). One of the largest towns in Oyo State, which is made out of Pre-Cambrian Basement rocks, is Shaki. Crystalline and metamorphic rocks that are more than 550 million years old make up the majority of the Basement Complex in southwest Nigeria. The crystalline Migmatite-Gneiss, low to medium-grade metasedimentary, the younger granites that are found within the basement complex, and Pan-African granitoids (older granite) are the three categories of basement rocks found in the Southwest. The rock groups within the study area include gneisses and granite with granite been the predominant rock in Shaki as shown in Figure 2. The structural features displayed by these rocks are folds, joints, foliations, and microfolds with different deformational histories.

2. MATERIALS AND METHOD

The data set utilized was Shaki's total field aeromagnetic data set (sheet 199), which was obtained by Fugro Airborne Survey Limited for the Nigerian Geological Survey Agency during the high-resolution Airborne aeromagnetic survey of Nigeria conducted between 2003 and 2009 [18]. The data set was gridded at a suitable cell size to increase anomaly details and minimize possible noise and latitude effects, and it was leveled, de-cultured, corrected, and recorded for the International Geomagnetic Reference Field (IGRF) [19]. Simplifying the complicated information contained in the original data is a primary objective of data processing, particularly when working with 2-dimensional magnetic field data. Better comprehension and useful geological deductions are made possible by the enhanced data quality that is attained in this manner [20, 21]. One of these simplifications is to create maps where the amplitude of the function that is presented is directly related to a physical characteristic of the rock's underneath, together with other parameters and intrinsic structural traits [22]. The study area's reduced-to-equator residual aeromagnetic intensity (RTE) maps, as shown in Figure 3, were subsequently processed using a variety of data filtering and filtering techniques, such as ED at different spectral indices, RAPS, and SPI using Geosoft Oasis Montaj software.

2.1. EULER DECONVOLUTION

The basement depth of magnetic anomalies was determined by estimating depth using the Euler deconvolution approach. An estimate of the source location and depth is provided by the Euler deconvolution technique for a variety of targets with homogenous sources (dyke, contacts, and sphere cylinder), each of which has a unique structural index. Both the depth estimate method and the border detector are used. Because it only necessitates a minimal amount of prior knowledge regarding the geometry of the magnetic source, it is frequently employed in the interpretation of magnetic bodies. As a result, no knowledge of the magnetization vector is necessary [23, 24]. The foundation of Euler deconvolution techniques is the solution of Euler's homogeneity equation, which is provided as:

$$(x-x_o)\frac{\partial M}{\partial x} + (y-y_o)\frac{\partial M}{\partial y} + (z-z_o)\frac{\partial M}{\partial z} = N(B-M), \quad (1)$$

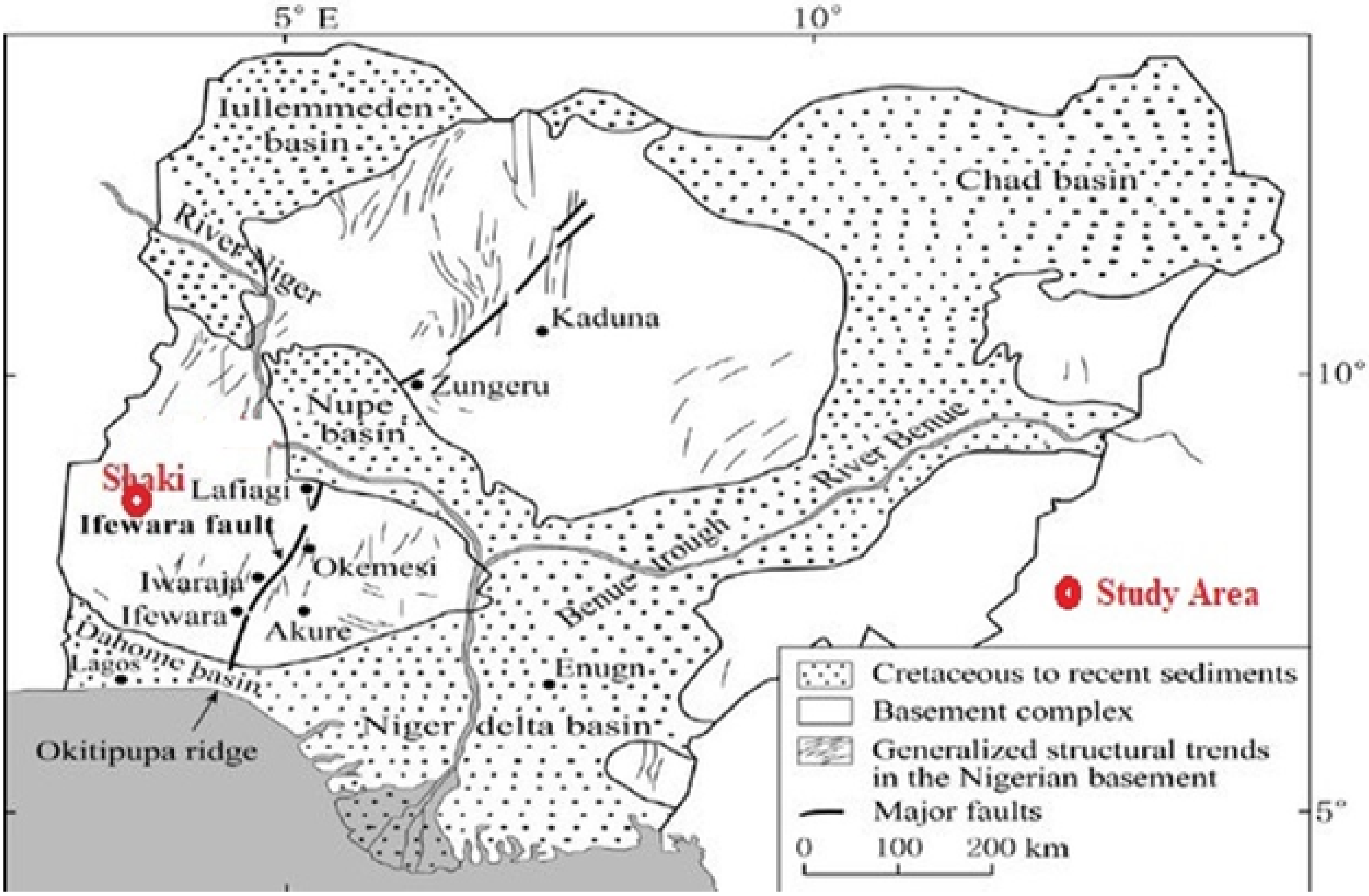

Figure 1. Nigerian map indicating the study region [4].

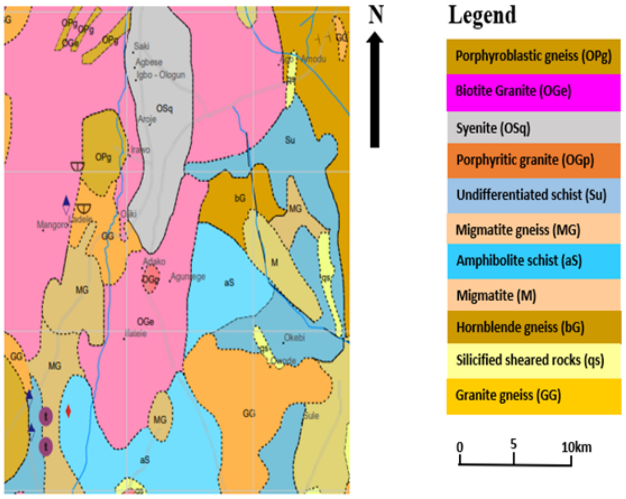

Figure 2. Geological map of the study area.

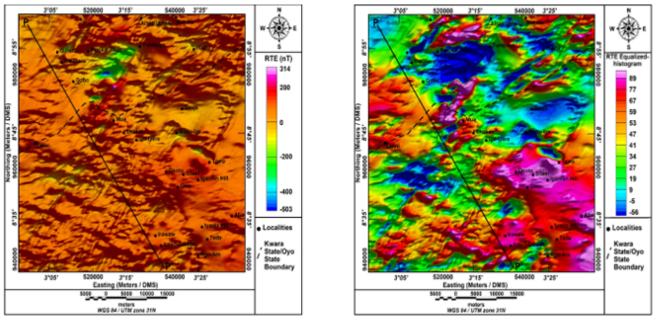

Figure 3. RTE residual aeromagnetic intensity map.

where N is the structural index (SI), $x°$, $y°$, and $z°$ are the positions of the magnetic source that generates the total magnetic field M measured at (x, y, z), and B is the regional value of the total magnetic field.

The structural index, N, is the most important parameter in the Euler deconvolution [23]. The magnetic field and decay rate are related by a homogeneity factor. Essentially, N is a function of the type of magnetic source and quantifies the fall-off rate, or the rate at which the fields vary with distance from the source. We can therefore determine the geometry and depth of the magnetic sources by varying N.

2.2. *SOURCE PARAMETER IMAGING TECHNIQUE*

Thurston and Smith [25] defined the function of source parameter imaging as a quick and powerful technique which can be used for calculation of the depth of magnetic sources. Its accuracy is shown to be ±20% when tests on real datasets with drill hole

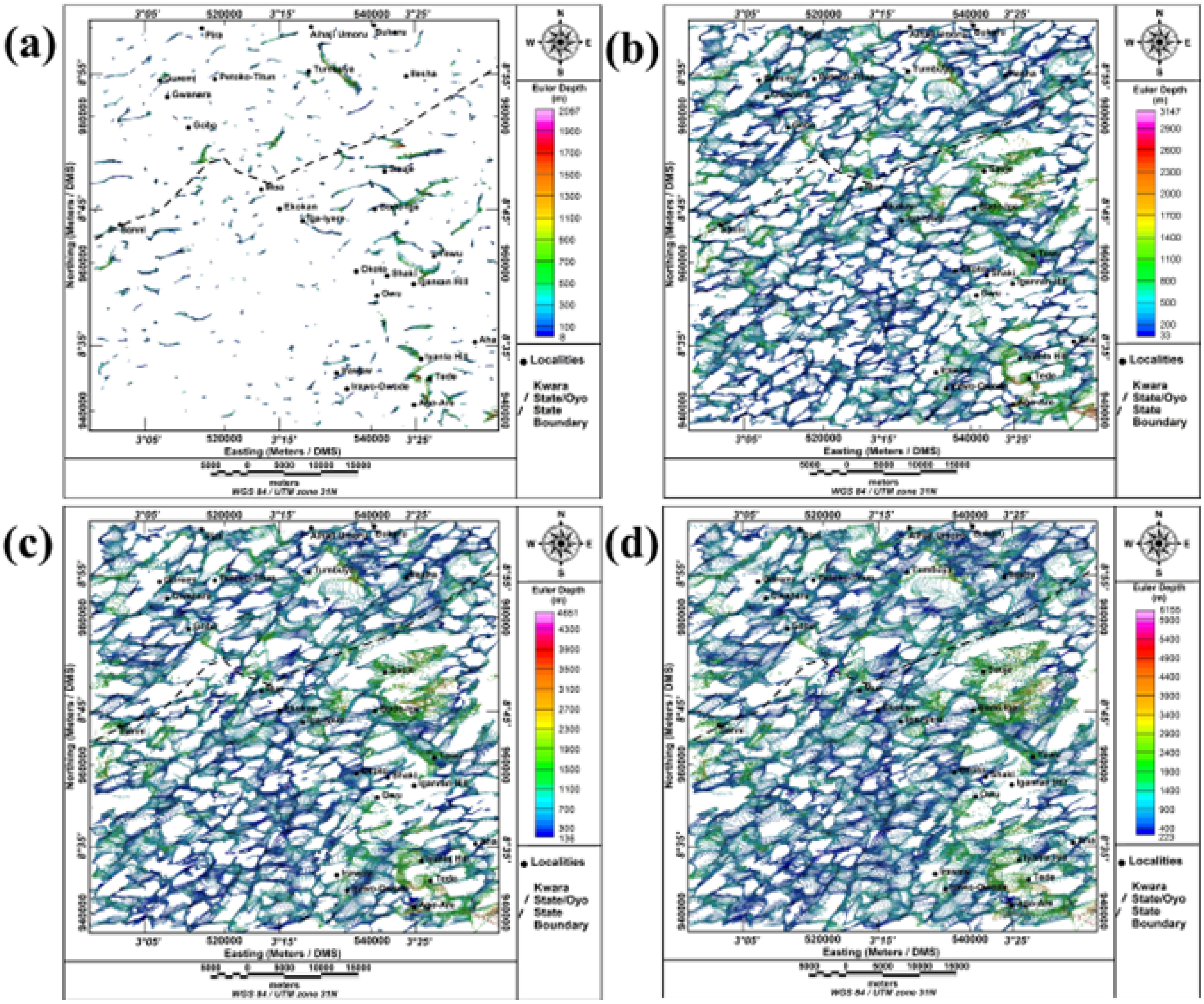

Figure 4. The plot Euler deconvolution at different SI.

control [26]. When compared the SPI method with the spectral analysis method, the SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use, where several blocks and manual fitting of power spectra are required when estimating the sedimentary thicknesses. This makes use of the correlation between the source depth of the observed field and the local wavenumber (k), and it can be computed for any location in a data grid using both vertical and horizontal gradients. The inverse of depth is defined by the local wavenumber's peaks, per the wavenumber theory. Equation 2 displays the local depth (d), as described by Thurston and Smith, [25].

$$d = \frac{1}{k}, \tag{2}$$

where k is the local wavenumber's peak value over the step source. The tilt angle [25] is defined as:

$$Tilt = \tan^{-1}\left[\frac{\partial M}{\partial z}/HDRAD\right], \tag{3}$$

where,

$$HDRAD = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}. \tag{4}$$

2.3. POWER SPECTRUM

A typical set of interfering waves with varying wavelengths and orientations is thought to be the potential field. A power spectrum can be produced by plotting each wavelength's power versus wave number, regardless of the direction. In frequency domain, the distribution of short to long wavelength can be prepared and analyzed across all measured of high to low frequency. It is simple to divide the power spectrum into segments of straight lines, each of which represents the cumulative response of a distinct group of sources at a specific depth. The line segment's slope and depth are directly correlated [27]. The depth of the magnetic sources' basement is thus determined by the slope of each segment [28]. According to equation (2), the radially averaged power spectrum of magnetic data is a function of wavenum-

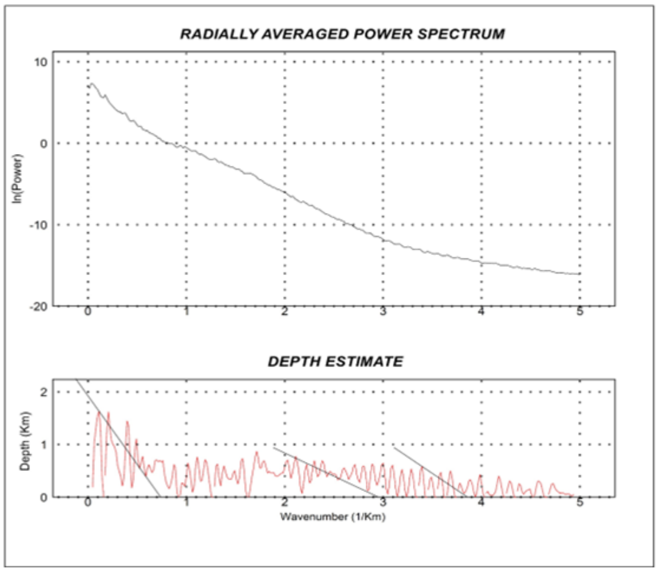

Figure 5. Depth estimate and radially average power spectrum of the study area.

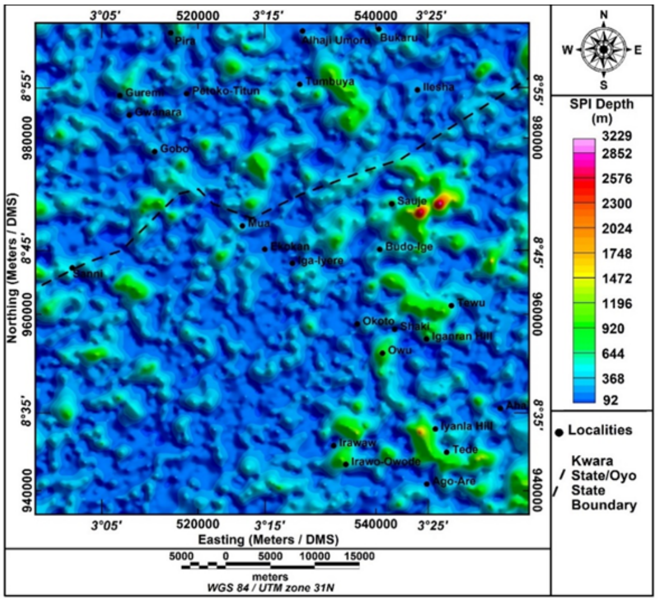

Figure 6. Source parameter image.

ber and is connected to the depth of the basement of the deepest sources [29].

$$K_{max} = \frac{\log Z_b - \log Z_t}{Z_b - Z_t}, \tag{5}$$

where, z_t and z_b stand for depths to top and magnetic basement respectively. K_{max} is a function of wave number and it is expressed in radian per unit distance.

3. RESULTS AND DISCUSSION

3.1. ESTIMATION OF DEPTH TO BASEMENT

The ED, RAPS, and SPI techniques were used to assess the depths to the top of the study areas. Solutions to ED at various Structural Index (SI) values of 0.0, 1.0, 2.0, and 3.0 were presented for the study area. The Euler solution of SI value of 2.0 and 3.0 reveal good match which is as a result of clusters around some notable anomalies, thus, 0.0 and 0.1 values for Shaki are not solutions and hence rejected.

Table 1. Summary of basement depth of the study area.

S/N	Shallow depth (m)	Deep Depth (m)
	Euler Deconvolution	
1.	136-223	4651-6155
	RAPS	
2.	0-400	600-1600
	SPI	
3.	920	3230

On Euler Solution map (Figure 4), the Euler solutions value of SI at 2.0 and 3.0 reveals good match which is as a function of clusters around some notable anomalies. These are seen in Figures 4c and 4d as clusters along the orientations of strikes and lineaments on the Euler map of Shaki, which produce from SI = 2.0 and SI = 3.0 beneath Shaki. Thus, the depth to basement ranged between 136 and 4651 m for SI = 2.0 (Figure 4c) and 223 – 6155 m for SI=3.0 (Figure 4d). The ED summary of depth to basement is shown in Table 1.

3.2. DEPTH ESTIMATE FROM RADIALLY AVERAGE POWER SPECTRUM

Figure 5 displays the depth estimation curves, which are derived from spectral analysis and the RAPS plots of the study area. The deepest sources' estimated depth is provided by the peaks located in the first segment with the greatest fall, while the shallowest sources' depth is provided by the peaks located inside the segment with the least gradient and these correlates to the depth estimation curve of the area which made of two tangential straight lines segment but with depth range estimation of 0.4 – 1.6 km (deep depth to basement) and 0.2 – 0.65 km (shallow depth to basement) for Shaki. Thus, the estimated depth to basement ranges from 0.2 to 0.65 km. This is a very shallow depth to the top of the magnetic sources, hence thin overburden which account for the area being basement complex. The RAPS summary of depth to basement is shown in Table 1.

3.3. DEPTH ESTIMATION FROM SOURCE PARAMETER IMAGING

From the results obtained in the SPI of the study area as shown in Figure 6, shows that the anomalies vary in depths of shallow to deep sources as 92 to 3229 m beneath Shaki. These results established further that the overburden thickness of the area is relatively low and this is responsible for geological competency of the area. The summary of the SPI of depth to basement is as shown in Table 1.

4. CONCLUSION

In this study, HRAD of Shaki (sheet 199) has been processed, enhanced, and interpreted using Geosoft Oasis Montaj, ArcGIS and Rockwares data processing and analysis software to study the lithology and structural disposition of the study area to determining the stability of the area.

The lithological setting of the study area as shown from the anomaly maps revealed three distinct (low, intermediate, and high) magnetic signatures about -400 to -503 nT; 0 to -400 nT; 0 to314 nT for Shaki. The depths to basement of the lithological stability and overburden thickness of Shaki were examined using the ED, RAPS, and SPI techniques.

The ED and SPI results used are in the same interval of shallower depths compared to that of the RAPS. Thus, the overall depth to basement in the area are relatively shallow, even around the zones that are of low magnetic values. The faults in the area could be as a result of the earth experienced tremor around Shaki in August 2021. Thus, the area could be further probed using seismic method of geophysical investigation.

ACKNOWLEDGEMENT

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DATA AVAILABILITY

The data used for this paper will be made available on request.

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