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Evaluation of the geothermal potential of Okigwe and environs using aeromagnetic method

Ijeh, Boniface I.[1], Ahamefule, C. Y.,[2] Azunna, Daniel E.[3*], Onyebere, Blessing C.[4] and Anyadiegwu, Faustinus C[4]

[1]Applied Physics and Renewable Energy Program, Department of Computing Sciences, Admiralty University, Ibusa, Delta State, Nigeria
[2] Department of Physics, Gregory University, Uturu, Abia State, Nigeria.
[3] Department of Physics, Clifford University, Owerrinta, Abia State, Nigeria.
[4]Department of Physics, Michael Okpara University of Agriculture, Umudike Abia State
[*]Corresponding Author's E-mail: azunnad@clifforduni.edun.ng

Abstract
Investigation of geothermal potential in Okigwe embraced the use of aeromagnetic methods. Okigwe is found between the latitudes of 5˚ 56ʹ 24ʺ N and 5˚ 42ʹ 19ʺ N and the longitudes of 7˚ 12ʹ 58ʺ E and 7˚ 24ʹ 02ʺ E. The LGA is bordered to the North by Orumba South LGA in Anambra and Umunneochi LGA in Abia, to the East by Isikwuato LGA in Abia, to the South by Umuahia North LGA also in Abia and to the West by Onuimo and Ideato North LGA̕s in Imo State. The aeromagnetic data sheet 312 which covers Okigwe and its environs was used in the study and it reveals the presence of both magnetic sources and non-magnetic sources as inferred from the total magnetic intensity values ranging from -61.3 nT – 182.9 nT. The magnetic analyses done include regional anomaly, residual anomaly, reduction to equator, analytical signal, vertical derivatives, source parameter imaging and tilt derivative which show a result range of -198.4 nT to – 161.4 nT, -19.4 nT to 16.6 nT, -49 nT – 167.8 nT, 0.003 nT to 0.04 nT, -3.4 x 10^{-5} nTm^{-1} to 1.5 x 10^{-5} nTm^{-1}, 0.0947 km to 2.27 km and -1.4^0 to 1.1^0 respectively indicating the presence of magnetic bodies in the study area. Spectral analyses were also done with the study area being divided into 25 spectral blocks to obtain deep depth and shallow depth of the magnetic sources, Curie depth, geothermal gradient and heat flow for each of the spectral blocks and an average was thereafter obtained. It was observed that the study area has geothermal potential with a geothermal gradient range of 80 ^{0}Ckm^{-1} to 170 ^{0}Ckm^{-1} and an average value of 125.67 ^{0}Ckm^{-1}. From the study it was inferred that Okigwe has magnetic sources with a Curie depth of about 4.7 km and has geothermal heat potential and it is most likely to be a zone for mineral exploration as well as geothermal sources.

Keywords: Geothermal Gradient, Okigwe, Heat Flow, Curie Depth, Aeromagnetic Data.

1.0 Introduction

Geothermal gradient can be defined as the rate at which temperature increases with increasing depth beneath the earth's surface as expressed in equation 1 (Arndt, 2011).

$$\gamma = dT/dz. \qquad (1)$$

where γ = geothermal gradient, T = temperature gradient and z = depth

The magnitude of the geothermal gradient depends on; the rate at which heat is produced at depth, the dynamics of the systems in addition to conductivity of rocks (Arndt, 2011). The geothermal gradient is calculated in ^{0}C/m (or K/km) and it has average values ranging from 0.045 – 0.065 ^{0}C/m on a continental scale (Aniko and Elemer, 2017).

Geothermal resources provide essential insights into the sustainable energy source generated by the Earth's internal heat (Elbarbary *et al*., 2018). Measurements indicate that regions with significant geothermal energy exhibit an anomalously high temperature gradient and heat flow, suggesting that geothermally active areas are associated with shallow Curie point depths (Azunna, Nwokoma & Anyadiegwu, 2021). Aeromagnetic method provides viable and reliable means of determining the structural characteristics of rock formations, the geophysical assessment of mineral deposits, hydrocarbon potential, and geothermal resources in a region. This is important because magnetic surveys locate magnetic ore bodies that are buried because of the magnetic susceptibilities of the ores. It can detect these bodies at a depth of tens of kilometers within the earth's crust though it is limited by the depth where minerals that are magnetic attain their Curie point thereby ceasing to be ferromagnetic (Azunna *et al.,* 2021, Grant, 1985). This Curie point depth thus is a determining factor in considering the geothermal gradient of any given area (Brooks et *al.,* 1999). Some of the previous studies on heat flow and geothermal gradient can be seen in the works of Akpabio *et al* (2003), Akpabio *et al* (2013), Adedakpo et al (2013), Anomohanam (2013), Odumodu & Mode (2014), Chukwueke *et al* (1992), Etim *et al* (1996) and Ogagarue (2007).

1.1 Aim and Objectives

The ongoing rise in demand for hydrocarbons and other minerals has resulted in the continuous depletion of Nigeria's non-renewable hydrocarbon reserves. This increased extraction underscores the need for further research into other inland basins with hydrocarbon potential, particularly the Sedimentary Basin, within the country (Hamiche *et al.*, 2016). Thus, by studying the total intensity aeromagnetic anomaly map, this research hopes to estimate both the Curie point depth and geothermal and mineralogical potentials of Okigwe and nearby areas. Addressing these objectives could potentially resolve issues related to power generation and boost revenue. The specific objectives of study are to:

i. generate the Total Magnetic Intensity map of the area from the digital data.
ii. map the lineament/structures from the Magnetic data which are possible host of mineralization by using the derivatives and other edge detection methods, such as horizontal gradient magnitude and also to map near surface intrusions within the area which are associated with mineralization.
iii. determine the Curie Point Depth, Heat Flow, and Geothermal gradient within the area so as to identify areas with geothermal resource.

1.3 Geology of the study area

Okigwe is situated between latitude 5˚56' 24" N and 5˚42' 19" N and longitude 7˚12' 58" E and 7˚24' 02" E. On the North, the Afikpo North LGA of Ebonyi State is surrounded by Orumba South in Anambra State and Umunneochi in Abia State. The LGA is to the East by Isikwuato, to the South by Umuahia North and to the West by Onuimo and Ideato North LGA's of Imo State. The different geologic and rock structures in Nigeria are sorted into three: The Basement complex, younger granites and sedimentary Basins. The site of the study is found within the Lower Benue Trough which is a subtrough of the Benue Trough included in the larger Sedimentary Basins. The Sokoto Basin, Niger Delta Basin, Dahomey Basin, Chad Basin and Bida Basin are also included in Figure 1. The Abakaliki anticlinorium and the Afikpo syncline in the Lower Benue Trough, the Lamurde anticline and Dadiya syncline in the Upper Benue Trough, the Giza anticline and the Obi syncline in the Middle Benue Trough all resulted from such deformation (Obaje, 2009). The Lower Benue Trough includes areas around Enugu, Awka, Okigwe, Abakaliki, and Nkalagu, the first three make up the Anambra Basin which is logically part of the Benue Trough (Akande and Erdmann, 1998).

This part of the Lower Benue Trough under study is comprised of 10 formations (Figure 1), the oldest of these formations belong to the Albian age Asu River Group deposited in the first sedimentary cycle which comprises mostly of Shales with localized sand stones, silt stones, and limestone (Olade, 1975), and is found in the Abakaliki-Afikpo Basin and Mfamosing in the Calabar Flank. The Bende-Ameki formation, found at the bottom of the sequence, is the youngest and includes Nanka sands of upper to middle Eocene age. Sandstones, shales and lignite layers are what you get in the Ogwashi-Asaba formation which tops the Nanka formation. Such units are referred to as tertiary and make up the pro-Niger delta Eocene to recent sequence as described by Fatoye and Gideon (2013).

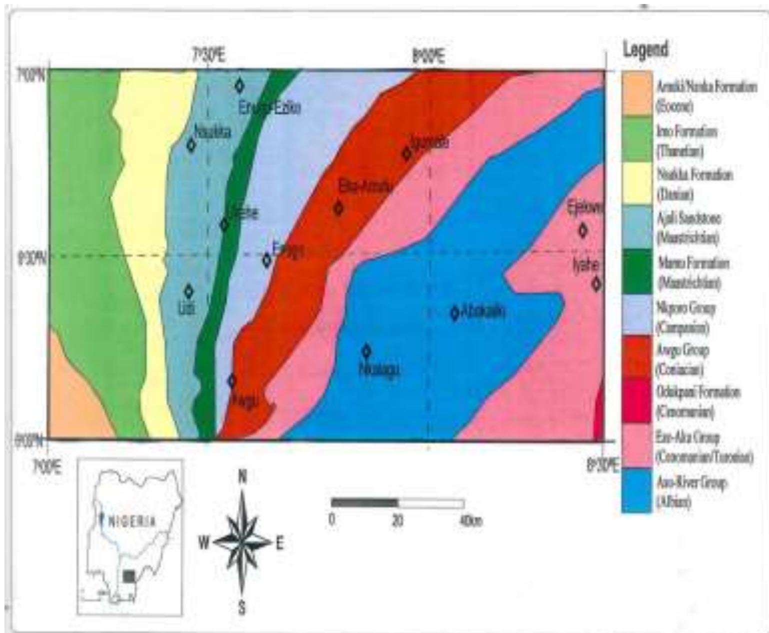

Figure 1: Geology map of the study area (Redrawn after Offodile, 1976).

2.0 Materials and Method

Information from secondary airborne magnetic data from Okigwe Sheet 312, available from the Nigerian Geological Survey Agency, was used for this research. There are important procedures in data processing to turn raws measurements into useful information about geology. In the beginning, the raw measurements were processed to subtract out diurnal influences, aircraft vibrations and different keyboard errors. Following this, data is adjusted using the International Geomagnetic Reference Field (IGRF) to find and separate out the anomalies from the standard field. Corrected data points are interpolated to make a continuous grid for easy viewing and analysis. By performing spectral analysis, we convert spatial information into frequency levels to find out the wavelengths present and locate the depth of any magnetic sources. To do this, we perform a Fourier transform on the data from spatial magnetic measurements, turning it into the frequency domain. The next step is to study the power spectrum to learn how energy is present at different wavelengths. From reviewing the slope of the power spectrum, the Vegas Graben Project team estimated the depths of the magnetic sources needed for exploration.

Assessing what comes out at the surface allows us to guess the heat flow and the direction of temperature changes underground, needed for geothermal exploration. You can see an anomaly by first studying the pole, regional and residual maps. Source parameter imaging and spectral analysis are used next to determine the depth of magnetic sources, where the magnetic properties in Okigwe and its vicinity are found.

3.0 Results and Discussion

This study examines Okigwe and its locale and the findings of the aeromagnetic research are explained and analyzed through the use of Total Magnetic Intensity (TMI), Source Parameter Imaging (SPI), reduction to equator, regional and residual magnetic anomalies, vertical derivative, analytical signal and the tilt derivative.

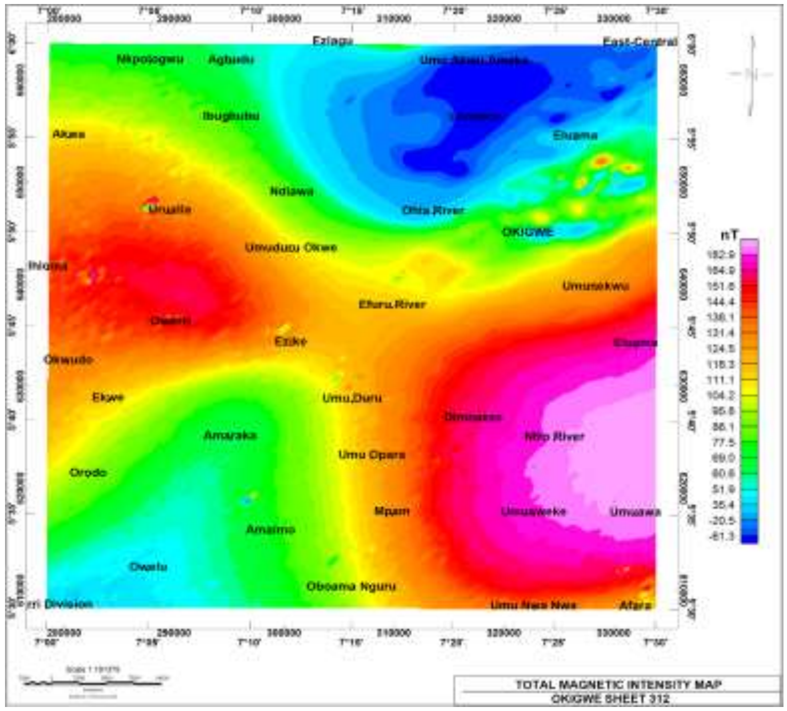

Figure 2: Total Magnetic Intensity Map of the Study Area

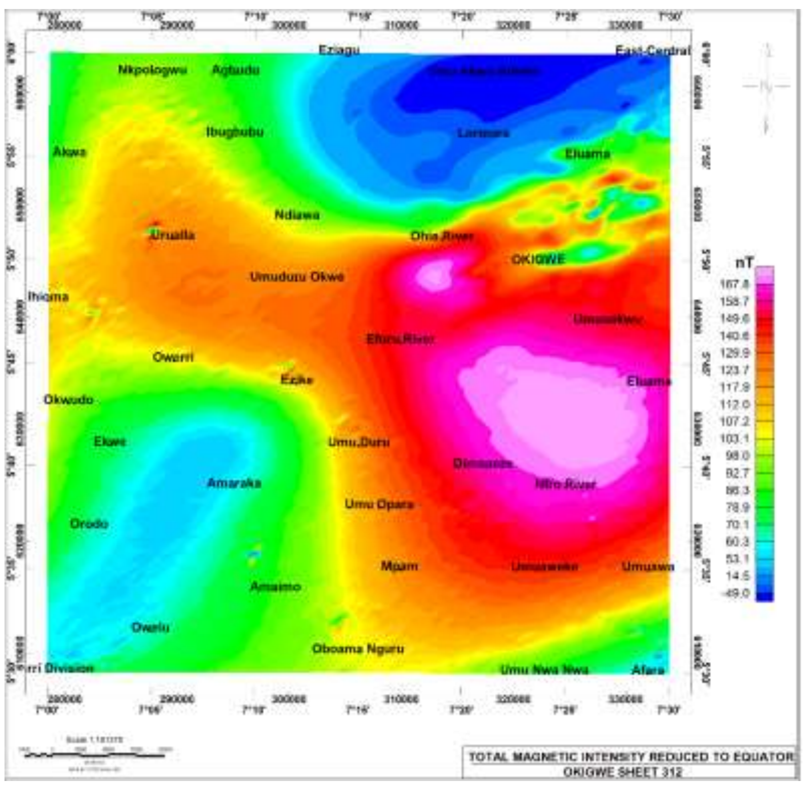

Figure 3: TMI Reduced to Equator

3.1 Total Magnetic Intensity

The TMI of the study area is shown in Figure 2. The study area has magnetic anomalies ranging from -61.3 nT – 182.9 nT. When the TMI is reduced to equator (Figure 3), it shows a magnetic anomaly ranging from -49 nT – 167.8 nT. The reduction to the equator enables us to centre structures and anomalous bodies over their exact positions. The mineralization process reduces noise, so the higher and lower magnetic results can be better delineated. The study area's southeastern area has the largest magnetic anomaly, but the northernmost section has the least. Therefore, Eluama, Dimnaeze, Umuaweke, Umuawa, Owerri and Uruala will more likely have more igneous rocks due to their high magnetic anomalies while Eluama, Umu Akwu Ameke, Lormora are more likely to have sedimentary basins. Okigwe is comprised of both magnetic sources and sedimentary basins due to its mixed magnetic responses of both positive and negative magnetic responses in the TMI map.

3.2 Regional Magnetic Anomaly

The regional anomaly of the study area shows the areas with deep seated magnetic bodies. They are obtained through low pass filters with long wavelength and low frequency responses. From the regional magnetic anomaly map in Figure 4, deep seated magnetic bodies have magnetic anomalies ranging from -198.4 nT to – 161.4 nT implying that the magnetic sources are deeply seated hence the weak negative anomaly in regional anomaly map where she Southern and Nothern parts of the study area have high negative magnetic anomalies while the central and southeast areas have low negative magnetic anomalies.

Comparing the regional magnetic anomaly with the TMI, it can be observed that the magnetic sources in Umuawa, Eluama and Owerri are more deeply seated than the magnetic sources in Okigwe, Umuaweke and Dimnaeze.
The residual anomaly map shown in Figure 4.4 on the other hand shows areas whose magnetic sources are sshallow seated with short wavelengths and high frequency responss obtained using high pass filters. The sshallow lying magnetic bodies has a magnetic anomalies ranging from -19.4 nT to 16.6 nT where Okigwe, Umu Akwu Ameke, Amaraka and lomara areas have high magnetic anomalies whereas Eluama, uruala and Owerri areas have low magnetic responses.

It can also be observed that from the residual anomaly and the TMI maps, Okigwe, ezikem Amaraka, Ekwe and Oboama Nguru areas may have magnetic sources that are shallow in depth. This is complinat with physical observations where there are highlands and outcrops of igneous rocks in some parts of Okigwe.

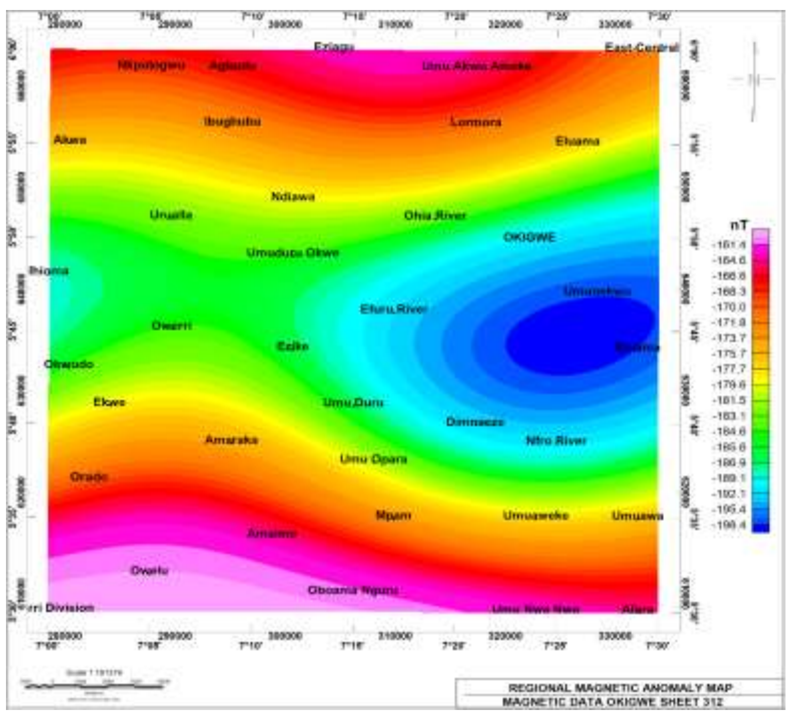

Figure 4: Regional Anomaly Map of the Study Area

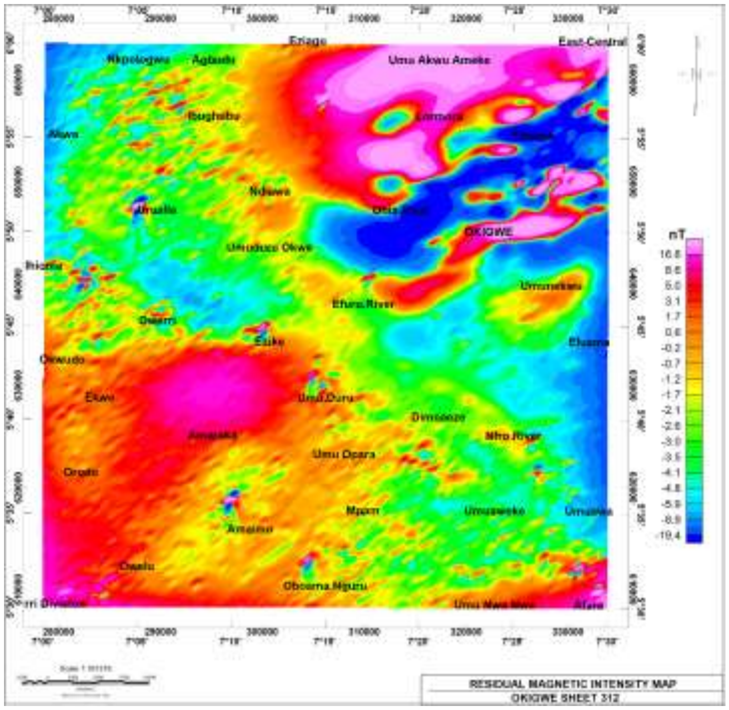

Figure 5 Residual Magnetic Anomaly of the Study Area

3.3 Vertical Derivative

Derivatives of magnetic signals suppress responses arising from regional anomalies while enhancing high frequency and short wavelength signals associated with low lying residual magnetic anomalies and shows how the magnetic anomalies varies with depth. From Figure 6, the first vertical derivative is more in the southeast and northwest regions of the study area while it is less in the northeast and southwest regions of the study area with a range of -3.4 x 10^{-5} nTm^{-1} to 1.5 x 10^{-5} nTm^{-1}.

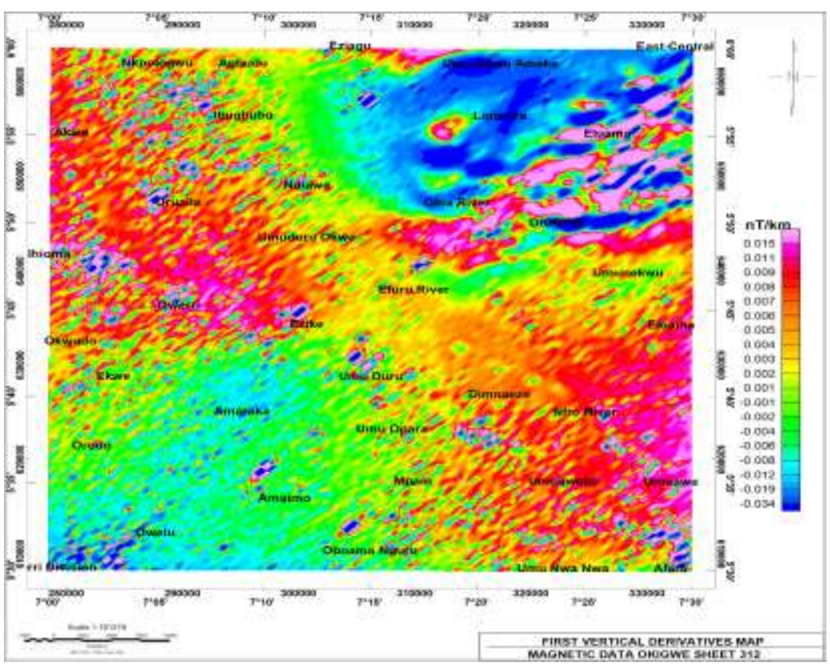

Figure 6: First Derivatives Map of the Study Area

3.4 Analytical Signal

The analytical signal filters are used to locate the edge of remanent magnetic anomalies and centres anomalies over their causative bodies. The analytical signal map of the study area is as shown in Figure 7 where the magnetic responses are between 0.003 nT and 0.04 nT. The Northeastern part of the study area has more of the remanent magnetic anomalies while the southwest areas have the lower remanent magnetic anomalies. It can be inferred Lormora, Umu Akwu Ameke and Okigwe all have remanent magnetic sources.

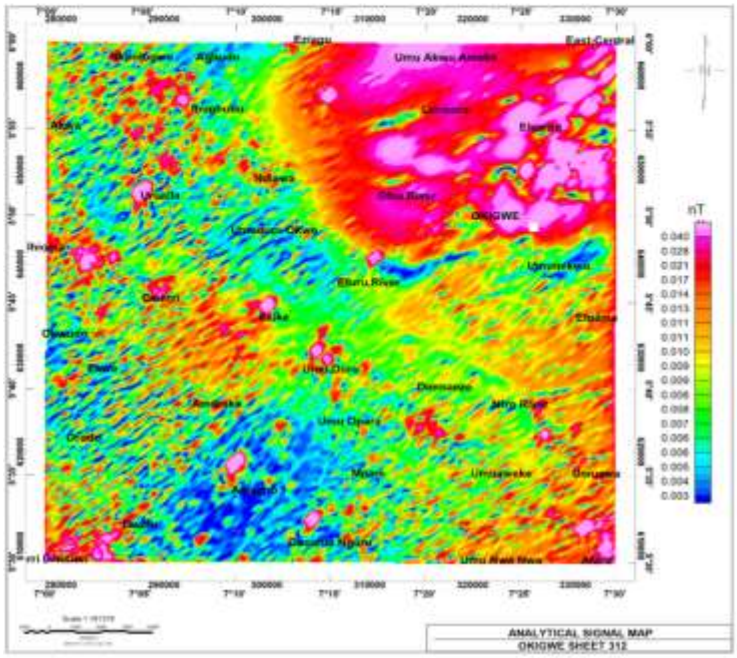

Figure 7: Analytical Signal Map of the Study Area.

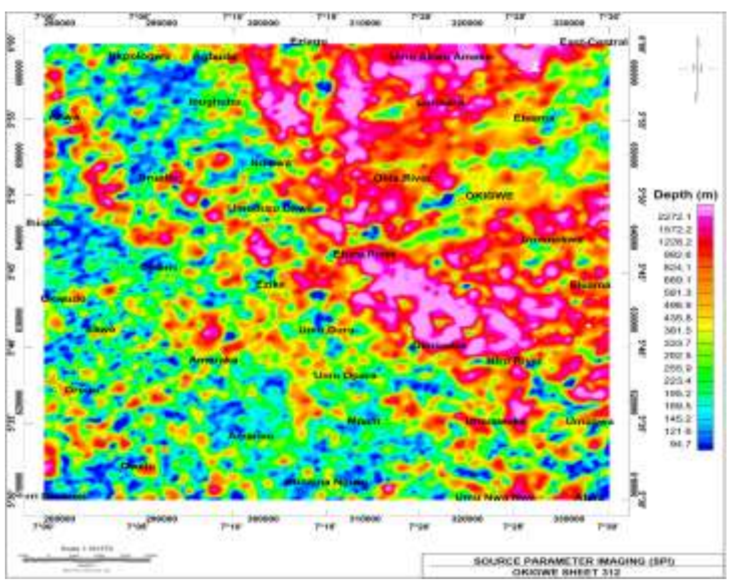

Figure 8: Source Parameter Imaging (SPI) of the Study Area

3.5 Source Parameter Imaging

The SPI shows the depth to the magnetic basement as shown in Figure 8. The depths of the magnetic sources range from 0.0947 km to 2.27 km. The deepest northeast areas such as Okigwe, Lormara, Umunekwu have the greater depth to magnetic bodies while areas like Oboama Nguru and Owerri have lesser depth to magnetic sources.

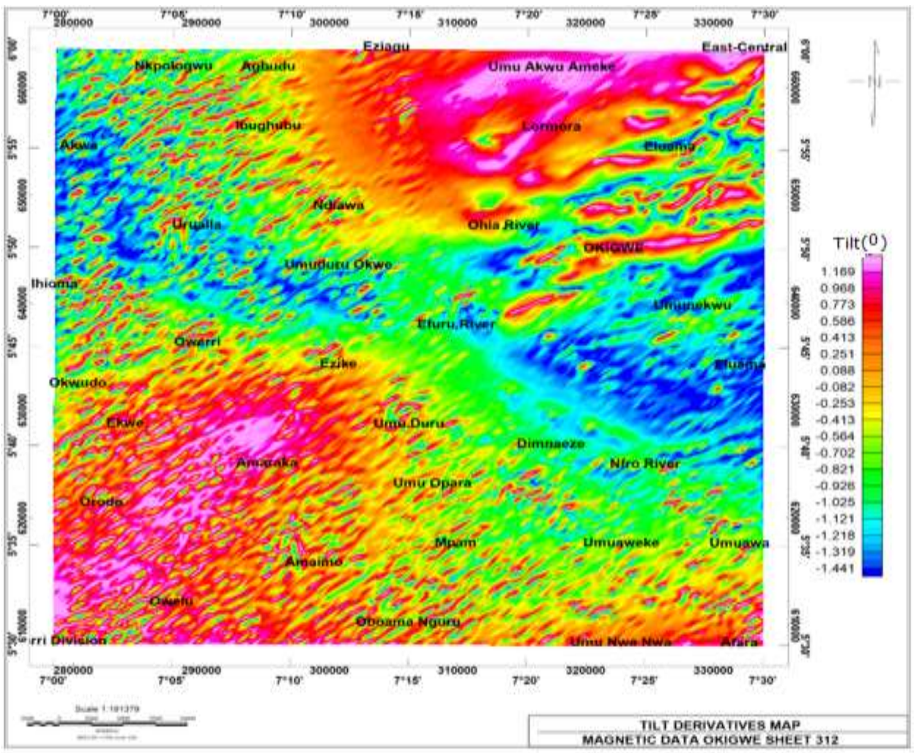

Figure 9: Tilt Derivative Map of the Study Area

3.6 Tilt Derivative

Shallow basement features and mineral targets can be outlined using the tilt derivative and its total horizontal derivative. This figure is created by taking the arctangent of the vertical derivative to the total horizontal derivative of all the data. Based on Figure 9, the tilt derivative of the magnetic sources ranges from -1.40 to 1.10, indicating that the sources are tilted by ±10 degrees away from the horizontal. Therefore, the signal peak from below the deeper body is about equal to the peak above shallow body areas and these two are directly above where the bodies are.

3.7 Spectral Analysis

The whole study area was assigned as 25 spectral blocks where each block was 18.5 km wide and 8.5 km high, as depicted in Figure 10. This was essential for measuring longer-wavelength vibrations to study pressures up to about 10 km deep. For each spectral cell, a plot of the logarithm of energy against frequency was generated and the gradient of the graph provided the columns in Table 1 for each of the 15 data sets.

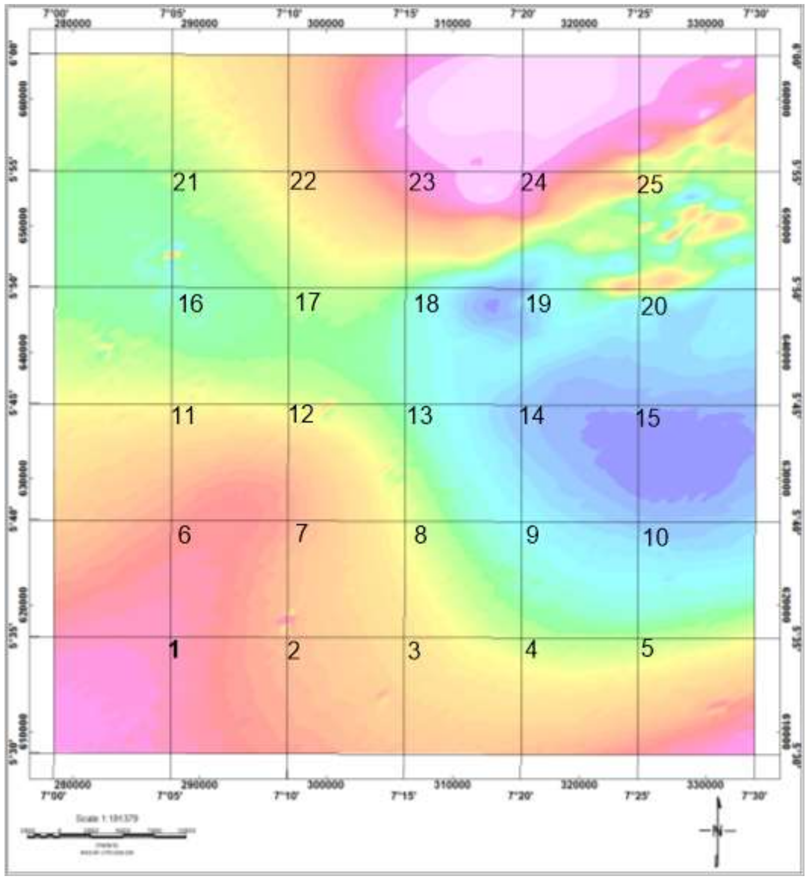

Figure 10: Spectral Blocks of the Study Area

Table 1: Result from Spectral Analysis

SP Block	Mid Longitude (Dec.deg)	Mid Latitude (Dec.deg)	Deep Depth D1 (m)	Shallow Depth D2 (m)	Curie Depth Point (m)	Currie Depth (km)	Geothermal Gradient ($^{O}C/km$)	Heat Flow (mW/m^2)
1	7.08333	5.58333	2688.361	459.302	4917.42	4.91742	117.948	351.2492
2	7.16666	5.58333	2309.253	298.169	4320.337	4.320337	134.2488	399.7929
3	7.25000	5.58333	3788.497	418.266	7158.728	7.158728	81.01998	241.2775
4	7.33333	5.58333	2875.312	452.301	5298.323	5.298323	109.4686	325.9975
5	7.41666	5.58333	2510.169	482.550	4537.788	4.537788	127.8156	380.6348
6	7.08333	5.66666	2722.212	309.152	5135.272	5.135272	112.9444	336.3483
7	7.16666	5.66666	2553.953	331.106	4776.80	4.77680	121.4202	361.5893
8	7.25000	5.66666	2685.945	348.846	5023.044	5.023044	115.4678	343.8632
9	7.33333	5.66666	2502.142	288.490	4715.794	4.715794	122.9910	366.2671
10	7.41666	5.66666	2850.946	325.699	5376.193	5.376193	107.8830	321.2757
11	7.08333	5.75000	2390.275	267.548	4513.002	4.513002	128.5176	382.7253
12	7.16666	5.75000	2144.100	313.185	3975.015	3.975015	145.9114	434.5241
13	7.25000	5.75000	3137.343	264.084	6010.602	6.010602	96.49616	287.3656
14	7.33333	5.75000	2686.498	302.271	5070.725	5.070725	114.3821	340.6298
15	7.41666	5.75000	2481.438	219.431	4743.445	4.743445	122.2740	364.1320
16	7.08333	5.83333	2228.889	363.608	4094.17	4.09417	141.6649	421.8779
17	7.16666	5.83333	2224.789	290.972	4158.606	4.158606	139.4698	415.3411
18	7.25000	5.83333	2525.529	316.023	4735.035	4.735035	122.4912	364.7787
19	7.33333	5.83333	2328.849	398.771	4258.927	4.258927	136.1845	405.5576
20	7.41666	5.83333	2780.041	354.601	5205.481	5.205481	111.4210	331.8118
21	7.08333	5.91666	2536.194	429.877	4642.511	4.642511	124.9324	372.0487
22	7.16666	5.91666	1860.111	249.930	3470.292	3.470292	167.1329	497.7218
23	7.25000	5.91666	2015.979	303.894	3728.064	3.728064	155.5767	463.3075
24	7.33333	5.91666	2221.133	293.900	4148.366	4.148366	139.8141	416.3663
25	7.41666	5.91666	2220.328	418.473	4022.183	4.022183	144.2003	429.4285
Average			2530.731	340.018	4721.445	4.721445	125.6671	374.2365
Maximum			3788.497	482.55	7158.728	7.158728	167.1329	497.7218
Minimum			1860.111	219.431	3470.292	3.470292	81.01998	241.2775

3.8 Depth Analysis, Geothermal Gradient and Heat Flow

The findings of the spectral analysis are shown in Table 1. The depth of the magnetic sources goes as far as 3.79 km, but the average is at 2.5 km. The shallow depth (D2) is between 0.219 km and 0.48 km, averaging 0.34 km. Figures 11 and 12 provide the 3D depth view and a contour map, respectively. The deepest magnetic readings in the study area are found in the south, showing two craters with max depths of 3.8 km and 3.3 km. The depth within Okigwe where the magnetic sources form is approximately 2.8 km. From the shallow depth map shown in Figure 13, the shallow magnetic sources are more in the northeast, southern and northwest areas with Umunnekwu and Eluama areas having the shallowest magnetic sources.

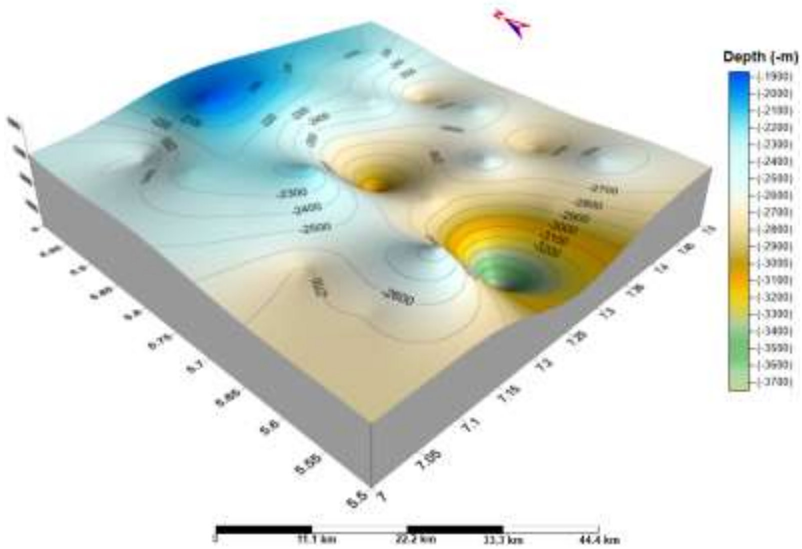

Figure 11: 3D Deep magnetic source depth variation (D_1)

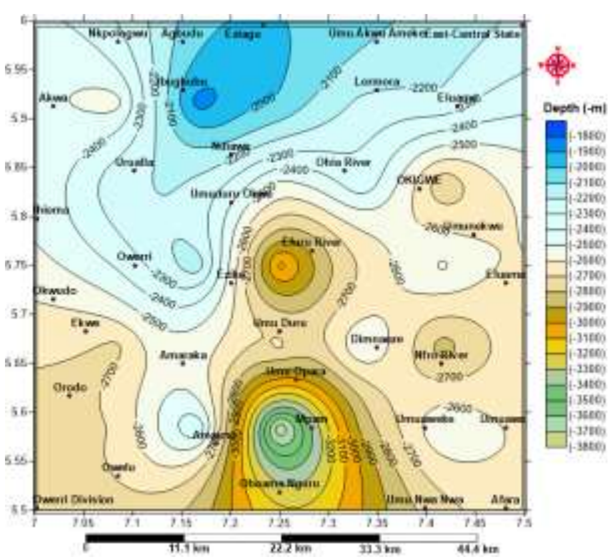

Figure 12 Map of the deep magnetic source depth variation (D_1)

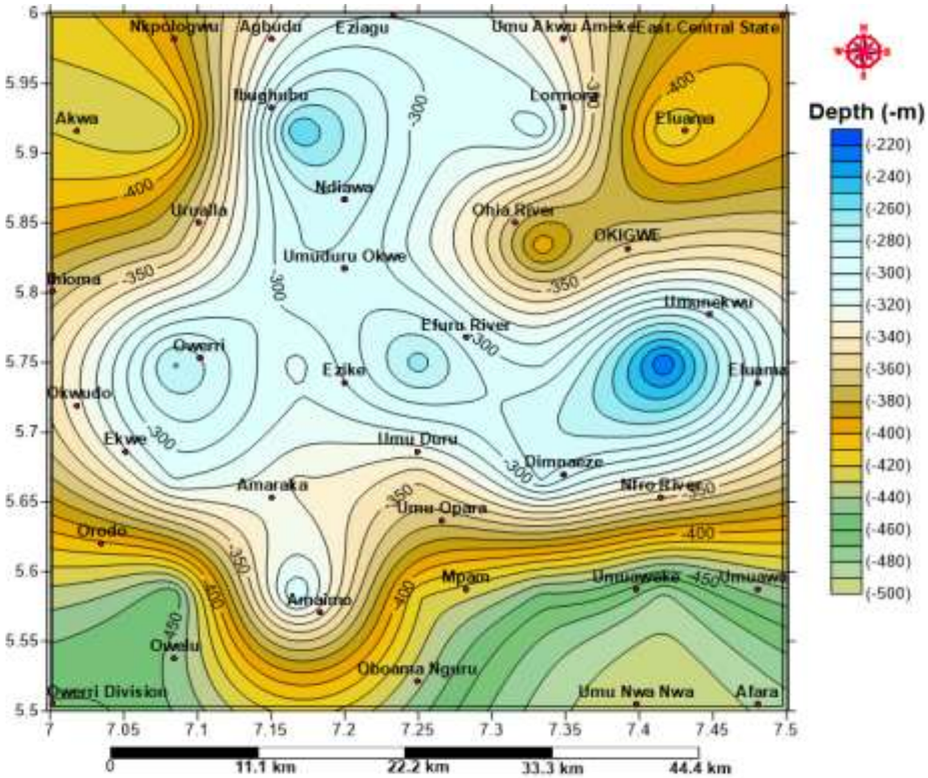

Figure 13: The Shallow magnetic source depth variation (D_2)

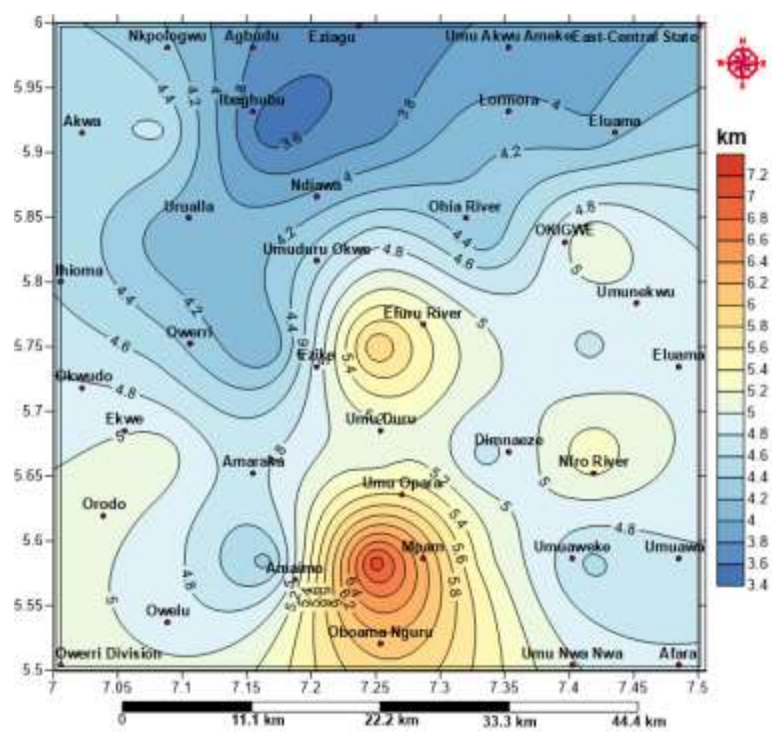

Figure 14: The Currie depth map over the study area

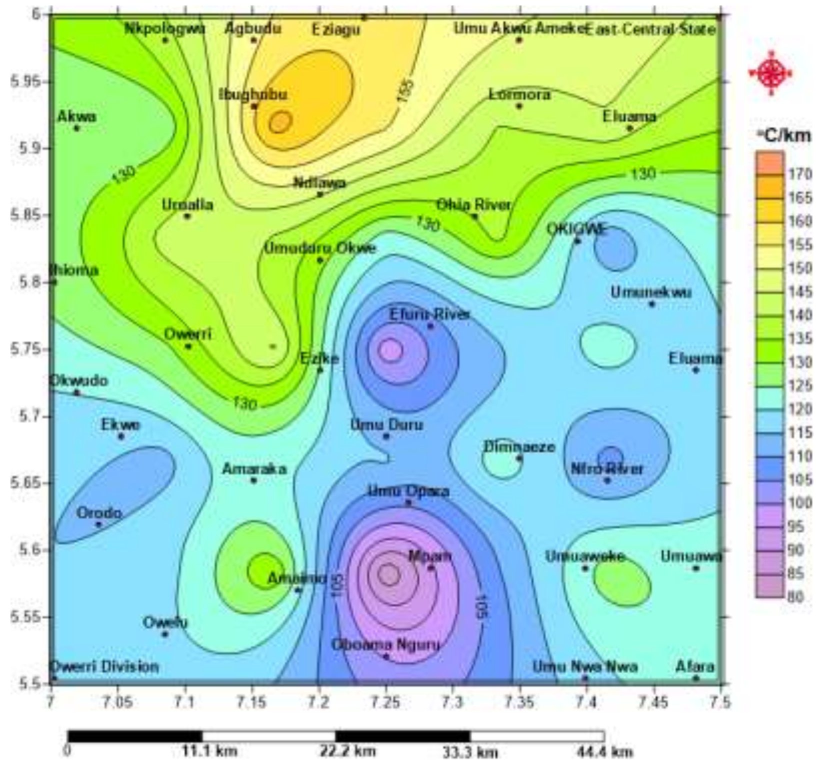

Figure 15: The geothermal gradient map over the area

The Curie depth map in Figure 14 indicates that the loss of magnetism in magnetic rocks in the study area is related to increases in temperature from 3.4 km to 7.2 km. The magnetization of the Michaud sources disappears at 5.2 km depth in Okigwe. Meanwhile, the highest depth for a magnetic material to lose its magnetization due to temperature measurements occurred at Mpam and Oboama Nguru. Figure 15 of the geothermal gradient map shows that geothermal heat transfer in the study area is between 80 ^{o}Ckm^{-1} to 170 Ckm^{-1}, with the least happening at the south end. Okigwe area, our research covers, has a high geothermal gradient of 110 Ckm^{-1} which indicates it might offer more geothermal energy than the Oboama Nguru area located to the south. The values of heat flow in the study area (Figure 16) follow the same pattern as the geothermal gradient and range from 240 mWm^{-2} to 500 mWm^{-2}. further analysis suggests that sediments are likely in the south due to the lower heat flow. In the vector diagram for heat flow seen in Figure 17, we observe that Okigwe, Ezike, Niro River and Mpam are four more likely areas for a geothermal resource or mineral since they are the meeting points were heat travels from high to low temperatures. The findings from my observations correspond with what other researchers working in the same field have said as found in Azunna et al. 2020, Azunna et al. 2021, Ijeh et al., 2019, Obi and Obeten 2017, Olawale and Temitayo 2020.

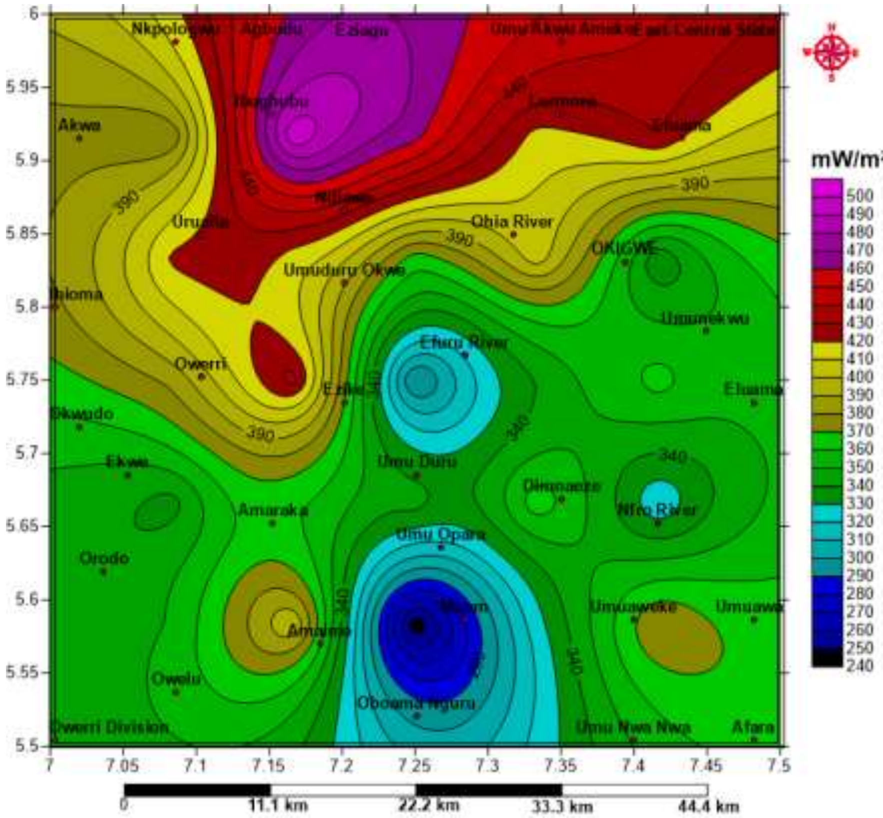

Figure 4.16: The heat flow map over the area.

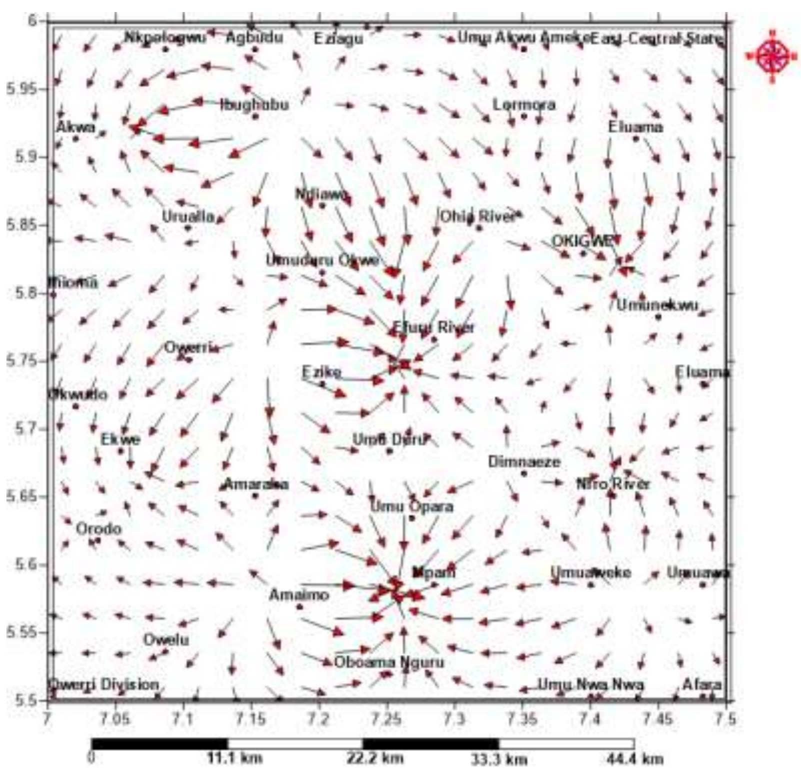

Figure 17: The vector diagram of the heat flow

4.0 Conclusion

This study applied high resolution aeromagnetic sheet 312 to examine the geothermal potential of Okigwe and nearby areas. The data chosen produced an anomaly map for Total Magnetic Intensity that was also moved to the equator. The area covered by the study, including Okigwe, showed mixed magnetic behavior, suggesting that there are probably both sedimentary and basement rocks present. Leaning on these maps, we figured out that the shallower magnetic sources are more concentrated in Okigwe when compared to other places in the study area. The analysis of the remanent magnetic part in Okigwe from the signal map showed that the vertical derivatives had values between -3.4 x 10^{-5} nTm^{-1} to 1.5 x 10^{-5} nTm^{-1}. As seen in the source parameter imaging, depths of the magnetic sources range from 0.0947 km to 2.27 km and the magnetic bodies in Okigwe are observed to have the greatest depth of all studied. By using 25 spectral blocks, the regions of both the magnetic source's deeper and shallower layers were studied with averages of 2.5 km and 0.034 km respectively. Average values were found for the Curie depth, geothermal gradient and heat flow in the study area: 4.7 km, 125.7^{O}C/km and 374.2 mW/m^2. From the facts presented, Okigwe and its localities are suitable for mineral and geothermal energy exploration as they have magnetic sources, geothermal gradient and heat function convergence.

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