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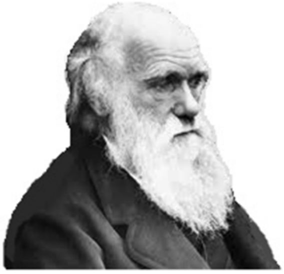

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Assessment of Geothermal Energy as an Alternative Source of Clean Power in Ikogosi Using Aeromagnetic Data

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ABSTRACT

Heat is a form of energy, and geothermal energy is the heat that is stored inside the earth, which when transferred to the surface can be used by humans. Power and heat is a huge asset to any country due to its wide usage to improve the economy and well being of his people. The Aeromagnetic data of Ado-Ekiti Sheet 244 was subjected to spectral analysis with the aim of assessing the geothermal potential of the study area and environs. The software used for processing and interpretation are Oasis Montaj, Surfer 13. The Curie point depth values ranges from (7.0 - 15.0) km, the geothermal gradient values ranges from (36 - 81) °C/km and the heat flow values ranges from (95.0 - 205.0) mW/m^2. The NW edge covering hosts the highest anomalous values of heat flow and geothermal gradient with corresponding shallowest values of Curie point depth Generally, for a viable geothermal reservoir, a heat flow range of 80 - 100 mW/m^2 is recommended, hence it can be inferred that every region on the study area could be considered as having good prospect with high heat flow above 80 - 100 mWm^{-2}.

Keywords**:** Geothermal, Aeromagnetic, Curie point, Spectral Analysis

1. INTRODUCTION

Heat is a form of energy, and geothermal energy is the heat that is stored inside the earth, which when transferred to the surface can be used by humans. Uses for geothermal energy range

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from its direct use with no transformation, to the generation of electricity using geothermal power plants. Even though a huge amount of thermal energy is stored inside the earth, only a fraction of it is usable for mankind [1]. Given that geothermal energy is a renewable resource, it may be considered a solution for the environmental and energy shortage issues the world currently faces [2].

There are certain regions that are attractive for the generation of geothermal electricity; these are generally thermally active areas in the crust of the earth, near the boundaries of the tectonic plates.

The use of geothermal energy for the production of electricity has faced a number of obstacles, such as limited technical and scientific capabilities for the exploration and development of these resources, the large investments and high risks involved in exploration, and non-application of regulatory frameworks on the development and use of such resources by the entities responsible for promoting and managing such projects. These factors have led to very slow progress in the performance of pre-feasibility studies for the use of these resources.

One of the most important steps in solving the world's energy problems and reducing climate change is the switch to clean and sustainable energy systems. Because of its high dependability, low environmental effect, and ability to generate base-load electricity, geothermal energy has become a competitive alternative among renewable energy sources [3]. Geothermal energy is available 24/7, making it a reliable and effective power source in contrast to solar and wind energy, which are impacted by weather variations [4].

The Earth's internal heat, which is mostly trapped in subterranean rocks and fluids, is captured by geothermal energy. The intricacy of subsurface geology, however, makes it difficult to explore and evaluate geothermal resources effectively. In order to solve this, geophysical methods like aeromagnetic surveys have emerged as essential resources for geothermal exploration. By measuring changes in the Earth's magnetic field, aeromagnetic surveys can identify important subsurface features like intrusive bodies, faults, and fractures that are frequently connected to geothermal systems [5]. By lowering exploration risks and enabling more accurate identification of high-potential geothermal zones, these techniques offer crucial insights into the geological framework [6].

In order to better understand subsurface structures and thermal anomalies, this study focuses on evaluating the geothermal energy potential using aeromagnetic data. An effective, economical, and non-invasive method of locating promising geothermal reservoirs is provided by the incorporation of aeromagnetic techniques into geothermal exploration, which advances clean energy technology.

It has been demonstrated that the success rate of geothermal exploration is increased when aeromagnetic data is integrated with other geophysical and geological techniques. For example, by mapping magnetic anomalies linked to geological structures or volcanic activity, aeromagnetic techniques aid in the delineation of heat sources and fluid channels, which are essential elements of geothermal systems [7]. Additionally, the accuracy and dependability of subsurface imaging have increased due to developments in data processing and interpretation methods like 3D modeling and spectrum analysis, which makes aeromagnetic surveys essential in contemporary geothermal prospecting [8].

With a focus on its use in locating and describing geothermal reserves, this study attempts to evaluate the potential for geothermal energy using aeromagnetic data. Through the use of aeromagnetic surveys, this study advances clean energy technology and addresses the growing demand for sustainable energy solutions.

1. 1. Hydrogeology of the Study area

Surface water and groundwater are two major sources of water but spring water results when groundwater travels through a network of cracks and fissures until it reaches the ground surface. The hydro-geology and drinking water quality of the warm spring water source on the outskirts of the agrarian town of Ikogosi-Ekiti in South-Western Nigeria for recreational and drinking purposes had been a major source of interest in the past decades. Drinking water contamination with different chemicals and heavy metals, released from different anthropogenic sources has become a global concern. It is important to establish a comprehensive and detailed database of the minerals and chemical present in the water so as to serve as a baseline for future environmental impact assessment of any developmental project in the spring. An attempt was made earlier to determine the physical and chemical properties of the water from the source. They concluded by attributing its ordinariness and the measured water temperature to the normal geothermal gradient of the area. This finding could be corroborated by geological/radiochemical studies on the abundance and potentials of Hot Dry Rocks (HDR) around the spring area. Circulation of groundwater has a potential filtering effect and also offers the possibility of water pollution through weathering of the basement rocks. Chemical species such as Co, Ci, Ca, Mg, Na, K, Fe which have some salutary health effect as well as toxin such as Pb, Cd could easily be introduced into the water through leaching.

1. 2. Location and Geology of the study area

Ikogosi warm spring is located in Ikogosi, South western Nigerian Basement Complex. It is bounded toward the South region and South East by migmatite and toward the north is porphyritic schist and the North East is mixture of schist and phyllites. It is underlain by three rock units; quartz schist, quartz mica schist, and quartzite (Fig. 1). At the basal part of the spring where the cold and hot springs meet, the quart mica schist covers the area. The grains of the mica and quartz are very fine. Moving upward the outcrop of Ikogosi warm spring, the quartz grains become coarse and coarser grains until it eventually become quartz mineral 100% with schistose foliation with general trend of NNW-SSE , dip direction of ENE, and their dip varies from 42º to 76º. The minor trend of the foliation occurs along NNE-SSW direction with dominant trend running NNW-SSE. Moving farther upward the outcrop, the rock unit transits to quartz schist. At the climax of the outcrop, the rock quartz schist mixed with quartzite. There is a fault that cut across the three rock units into the aquiferous layer in Ikogosi to form spring. The spring has its origin from afar off about almost 1km where people are not allowed to access. It is covered with thick forest and giant bush. The topographic elevation varies from 470m in the valleys to 550m on the hills.

Background of Ikogosi: The Ikogosi Warm Spring is located in the southwestern part of Ekiti State of Nigeria. It is situated between lofty steep-sided and heavily wooded, north-south trending hills about 17 miles (approximately 27.4 km) east of Ilesha, and about 6.5 miles (approximately 10.4 km) southeast of Effon Alaye [9]. It lies on the geographic latitude of 7°35'N and longitude 5°00'E within the central region of the area covered by this study. Located within the Precambrian basement complex of southwestern Nigeria, it is at an altitude of 450 to 500 m [10]. The dominant geology of Nigeria made mainly by crystalline (Precambrian basement complex) and sedimentary rocks (Cretaceous recent sediments) are also represented. The Ibadan and Ijebu Ode locations of seismicity are closest to the study area.

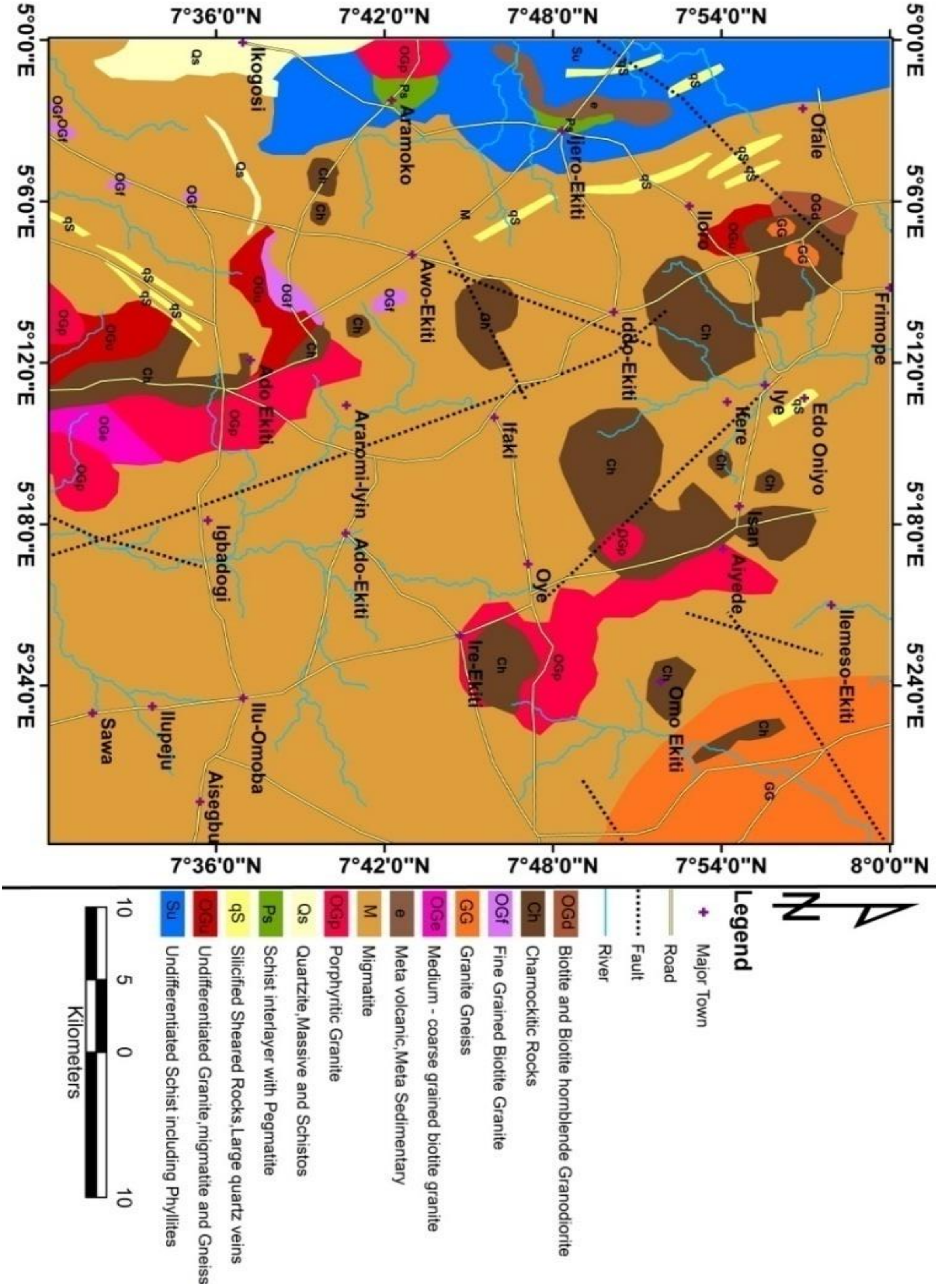

Fig. 1. Geological map of the study area.

The area covered by this study lies approximately between geographic latitudes 7°00,N and 8°00,N and geographic longitude 4°30′E and 5°30′E within the Precambrian of southwestern Nigeria.

The area is covered by the aeromagnetic map sheet 243 (Ilesha), 244 (Ado-Ekiti), 263 (Ondo) and 264 (Akure) spanning an area of approximately 12,400 km2. [10] performed an extensive research on the energy resource potential of the Ikogosi Warm Spring area using the technique of Instrumental Neutron Activation Analysis (INAA). They investigated the radiochemical contents of uranium (U), thorium (Th) and potassium (K) in a surface rock collection from the area and predicted the source of the warm spring's heat to be radioactive probably acquired by meteoric water at depth from thorium-bearing zones of the quartzite host rock of the spring. Samples of the warm spring water and host quartzite rock collected from Ikogosi area were analysed for the fluid physio-chemical characteristics and rock radioactivity in a bid to predict the source of water and the associated heat content [11].

The results were almost similar with predictions made about radioactivity and high geothermal gradient responsible for the heat of the Ikogosi Warm Spring. [12] investigated the pattern of radiogenic heat production in rock samples of southwestern Nigeria while [13] carried out hydro chemical analysis on water samples from the Ikogosi Warm Spring in southwestern Nigeria. Earlier studies of the warm spring have been restricted to geological and geochemical investigations, [14] carried out an investigation of the geological structure beneath the Ikogosi Warm Spring in southwestern Nigeria using integrated surface geophysical methods.

They integrated vertical electrical sounding (VES) and magnetic methods in the immediate vicinity of the Ikogosi Warm Spring with a view to delineate its subsurface geological sequence and evaluate the structural setting beneath the warm spring. They used inverse magnetic models and geoelectrical sections to delineate fractured quartzite/faulted areas within fresh massive quartzite at varying depths. It was deduced that the fractured/faulted quartzite may have acted as conduit for the movement of warm groundwater from profound depths to the surface while the spring outlet was located on a geological interface (lineament). The present study attempts to determine the depths to the top and bottom of the magnetized crust and to characterize the heat flow within the Ikogosi Warm Spring area using Curie point depth (CPD) estimates from spectral analysis of aeromagnetic data. Results will be invaluable to electricity generation companies in Nigeria, especially now that alternative sources of power generation in Nigeria are being explored. The CPD is known as the depth at which the dominant magnetic mineral in the crust passes from a ferromagnetic state to a paramagnetic state under the effect of increasing temperature. For this purpose, the basal depth (depth to the bottom) of a magnetic source from aeromagnetic data is considered to be the CPD [15].

1. 3. Magnetic Measure of Geothermal Exploration

Surveys of the spatial changes in the strength of the magnetic field over the surface of the earth have been used as a method for geophysical exploration for many years. Magnetite is the most common ferromagnetic mineral and so, in most cases, the magnetic permeability is controlled by the presence of varying amounts of magnetite and related minerals in the rock. The magnetic method has come into use for identifying and locating masses of igneous rocks that have relatively high concentrations of magnetite. Strongly magnetic rocks include basalt and gabbro, while rocks such as granite, granodiorite and rhyolite have onely moderately high magnetic susceptibilities. The magnetic method is useful in mapping near-surface volcanic rocks that are often of interest in geothermal exploration, but the greatest potential for the method lies in its ability to detect the depth at which the Curie temperature is reached. Ferromagnetic materials exhibit a phenomenon characterized by a loss of nearly all magnetic susceptibility at a critical temperature called the Curie temperature. Various ferromagnetic minerals have differing Curie temperatures, but the Curie temperature of titano-magnetite, the most common magnetic mineral in igneous rocks, is in the range of a few hundred to 570 °C. The ability to determine the depth to the Curie point would be an ability to determine the depth to the Curie point isotherm as well.

For magnetic field observations made at or above the surface of the earth, the magnetization at the top of the magnetic part of the crust is characterized by relatively short spatial wavelengths, while the magnetic field from the demagnetization at the Curie point in depth will be characterized by longer wavelength and lower amplitude magnetic anomalies. This difference in frequency characteristics between the magnetic effects from the top and bottom of the magnetized layer in the crust can be used to separate magnetic effects at the two depths and to determine the Curie point depth. The magnetic field of the earth is of a complex nature because of its dipolarity. The inducing magnetic field has a dip angle that varies from place to place over the surface of the earth, and this feature introduces a complexity into the patterns of anomalies that are recorded. This problem has long been recognized in the analysis of magnetic data, and a procedure has been developed to recompute the magnetic profile map for a vertical inducing field using the actual observed magnetic map. This first step in processing magnetic data is termed the conversion of the magnetic map 'to the pole', or to the form it would have for a vertical inducing field.

1. 4. Aeromagnetic Method of Geothermal Exploration

High-resolution aeromagnetic surveys can be used to define major regions of coherent structure in the Earth's crust [16]. Since rocks commonly retain magnetism that originates from the time of their formation, magnetic anomaly data provide a unique opportunity to infer geologic processes not readily observed through other geophysical quantities. One common example of this is seafloor spreading, indicated by a series of magnetic stripes, originating from the mid-ocean ridge.

1. 4. 1. Definitions of Terms

Centroid Depth: The centroid is the geometric center of the fault area, and the centroid depth is the average depth at which the seismic moment is distributed. In geology, a fault is a fracture or a discontinuity in the Earth's crust along which there has been displacement of the rock masses on either side of the fracture. Faults can range in length from a few centimeters to thousands of kilometers and can extend from the surface to great depths within the Earth. The two types of fault are dip slip (relative movement of rock masses along a vertical or steeply inclined plane) and strike slip (relative movement of rock masses along a horizontal plane).

Depth to Basement: Depth to basement is a term used in geology and geophysics to describe the depth at which the underlying basement rock or the transition from sedimentary rocks to crystalline basement occurs. The basement rock is the oldest and most stable layer of rock that makes up the Earth's crust and is typically composed of igneous and metamorphic rocks. The basement rock often has a higher density.

Curie Depth: The Curie depth is a term used in geophysics to describe the depth at which rocks lose their magnetic properties due to the Curie temperature. The Curie temperature is the temperature at which a material loses its permanent magnetization and becomes paramagnetic. In the Earth's crust, the magnetic minerals in rocks are aligned with the Earth's magnetic field as the rocks cool and solidify. As the rocks approach the Curie temperature, the magnetic minerals lose their alignment, and the rocks lose their magnetic properties.

Geothermal Gradient: Geothermal gradient is the rate at which the Earth's temperature increases with depth in the subsurface. The geothermal gradient varies from place to place depending on factors such as the local geology, the tectonic setting, and the heat flow from the Earth's interior. Celsius per kilometer (°C/km),

Heat Flow: Heat flow is the movement of thermal energy from the Earth's interior towards the surface. The heat flow is driven by the temperature gradient between the Earth's interior, which is much hotter than the surface, and the cooler outer layers of the planet. The heat flow varies depending on factors such as the geology, tectonic activity, and thermal conductivity of the rocks in the subsurface. Heat flow can be measured directly using heat flow meters, which are placed in boreholes drilled into the Earth's crust.

2. MATERIALS AND METHODS

The materials used in the spectral analysis are High resolution aeromagnetic data sheet 244, thermometer, GPS , Matlab software, Geosoft Oasis Montaj Software.

The Nigerian Geological Survey Agency provided the aeromagnetic data (Sheets) used for this research. The data was obtained as part of the NGSA-sponsored nationwide aeromagnetic survey in 2009 and the data were collected along a series of 200-meter-spaced NE SW flight lines with an average flight elevation of about 80 meters, with tie lines every 500 meters.

Using the International Geomagnetic Reference Field (IGRF), 2005, the geomagnetic gradient was removed from the data. Also, the data was made available in the form of grids with a scale of 1:100,000. The total area covered in this study is approximately 55 by 55 km^2, extending from Latitude 7° N to 7°30’ N and Longitude 6° E to 6° 30’ N.

This study's procedures include creating a Total Magnetic Intensity (TMI) map with OASIS MONTAJ software, separating regional and residual anomalies, dividing the residual map into eight overlapping blocks, performing spectral analysis on each block, evaluating the depth to the magnetic source with spectral analysis, and estimating the geothermal gradient and heat flow.

2. 1. Using the Fourier series

A Fourier series is an expansion of a periodic function f(x) in terms of an infinite sum of sines and cosines in the equation below. Fourier Series makes use of the orthogonally relationships of the sine and cosine functions.

The formula for the Fourier series of the function f(x) in the interval [-L, L], i.e. $-L \leq x \leq L$ is given by:

$$f(x) = A_0 + \sum_{n=1}^{\infty} A_n \cdot \cos\left(\frac{n\pi x}{L}\right) + \sum_{n=1}^{\infty} B_n \cdot \sin\left(\frac{n\pi x}{L}\right)$$

Here,

$$A_0 = \frac{1}{2L} \cdot \int_{-L}^{L} f(x)\,dx$$

$$A_n = \frac{1}{L} \cdot \int_{-L}^{L} f(x)\cos\left(\frac{n\pi x}{L}\right)dx, \quad n > 0$$

$$B_n = \frac{1}{L} \cdot \int_{-L}^{L} f(x)\sin\left(\frac{n\pi x}{L}\right)dx, \quad n > 0$$

A_0 = This term represents the average value (or the DC component) of the function over the interval [−L,L].

A_n = These coefficients represent the amplitude of the cosine components of the Fourier series.

B_n = These coefficients represent the amplitude of the sine components of the Fourier series.

L is the half-period of the function f(x)

The above Fourier series formulas help in solving different types of problems easily. A Fourier Series has many applications in mathematical analysis as it is defined as the sum of multiple sines and cosines. Thus, it can be easily differentiated and integrated, which usually analyses the functions such as sine waves which are periodic signals in experimentation. It also provides an analytical approach to solve the discontinuity problem. In calculus, this helps in solving complex differential equations.

2. 2. Fast Fourier Transform

The "Fast Fourier Transform" (FFT) is an important measurement method in the science of audio and acoustics measurement. It converts a signal into individual spectral components and thereby provides frequency information about the signal. FFTs are used for fault analysis, quality control, and condition monitoring of machines or systems. The FFT is an optimized algorithm for the implementation of the "Discrete Fourier Transformation" (DFT). A signal is sampled over a period of time and divided into its frequency components. These components are single sinusoidal oscillations at distinct frequencies each with their own amplitude and phase. This transformation is illustrated in the following diagram. Over the time period measured, the signal contains 3 distinct dominant frequencies.

2. 3. Oasis Montaj

The concept of an integrated environment for earth science data processing and analysis emerged from over three decades of software development and is implemented in the Oasis Montaj software platform. It is the result of a long-term vision that reflects the fast pace of today's professional work environment and the significant changes in data processing over the past thirty years: An order of magnitude increases in data volumes, Increase in digital data availability and connectivity, Shift in processing from office to in situ (or field) environments, Replacement of proprietary software with commercial solutions.

By design, the Oasis Montaj software platform meets specific needs which are; Unicode support enables the interaction and visual representation of files using non-ASCII characters in them, project Explorer tool enables users to browse as well as open any 'project' item, enhanced metadata capabilities enable the 'properties' of the items displayed in the Project Explorer to be accessed using the Metadata tool, file locations are displayed in a popup dialog when you mouse over an item in the Project Explorer, description tools enable users to add descriptive text to the items displayed in the Project Explorer, light table' capability provides individual transparency settings for both raster images and vector line work for every group or layer on a map, seequent ID based licensing enables you to securely sign in using your Seequent ID and access all of your Geosoft desktop applications and online services, including updates, VOXI Earth Modeling subscriptions, support resources through MySeequent, and Azure Maps services, the DAP (Data Access Protocol) technology enables you to access very large spatial datasets residing on an internet server (or locally on a personal computer).

The Geoscience Data Service powered by DAP is a new web interface for you to connect to the Geosoft Public DAP Server and search for global geoscience datasets by keyword or location, connecting you to your data and information via dynamic linking – a unique technology for graphically connecting data, profiles and maps in a single desktop environment, addressing high-volume processing requirements, delivering focused solutions to specific Earth Science problems, multiple monitor support that allows you to extend your Oasis montaj workspace across multiple monitors, shortcut toolbars access directly within the maps, grids, databases, map templates, and the 3D files you are working on.

3. DATA PRESENTATION AND DISCUSSION

3. 1. Data Presentation

Table 1. The Centroid depth, depth to basement, curie depth, geothermal gradient and the heat flow estimation

Blocks	Longitue (x) Deg	Latitude (y) Deg	Centroid Z_O (km)	Depth to basement, Z_t (km)	Curie depth, Z_b (km)	Geothermal Gradient °C/km)	Heat Flow (mWm^{-2})
A	5.125	7.875	4.59	1.5	7	74	186
B	5.207	7.875	4	0.9	7	81	205
C	5.291	7.875	4.71	1.0	8	62	170
D	5.375	7.875	5.6	0.89	10	55	139
E	5.125	7.625	4.15	0.92	7	79	194
F	5.205	7.625	6.48	1.38	11	53	125
G	5.291	7.625	8.03	1.68	14	38	99
H	5.425	7.625	8.15	1.16	15	36	95
Average			5.7138	1.1788	9.875	59.75	151.625

Theory of method

Calculation of Curie-Point Depth, Geothermal Gradient and Heat Flow.

The centroid depth is calculated from the low wave number part of the scaled power spectrum

as $In\left[\frac{P(k)^{\frac{1}{2}}}{k}\right]$= A$-^{|k|}$ Z_0 (1)

where,

In is the natural logarithm
A is a constant
P(k) is radially power average spectrum
K is the wave properties magnetization and its orientation
Z_0 the depth to the centroid to the magnetic source

For the high wave number part, the lower spectrum can be related to the top of the magnetic sources by a similar equation:

$In\left[\frac{P(k)^{\frac{1}{2}}}{k}\right]$ = B$-^{|k|}$ Z_t (2)

where B is a constant
Z_t is the depth to the top of the magnetic sources
The depth of the bottom of magnetization Z_b

$Z_b = 2Z_0 - Z_t$ (3)

Summarily, the depth to the base of the magnetic source (the Curie point depth) is calculated in four steps

(i) Calculate the radially averaged power spectrum of the magnetic data in each window
(ii) Estimate the depth to the top of the magnetic source (Z_t) using the high wave number portion of the magnetic anomaly power spectra
(iii) Estimate the depth to the centroid of the magnetic source (Z_0) using a lower wave number portion of the magnetic anomaly power spectra.
(iv) Calculate the depth to the base of the magnetic source (Z_b) using

$Z_b = 2Z_0 - Z_t$. The value of the Z_b is the Curie point depth/DBMS.

The geothermal gradient is

$$\frac{dT}{dZ} = \frac{\theta}{Z_b} \qquad (4)$$

Therefore, the geothermal gradient in relation to the heat flow q. (Nsikak et al 2000; Obaje et al 2009) q = k $\theta°Cd$ (5)

where,
q is the heat flow
$\theta°C$ is curie temperature
d is curie depth point
k is thermal conductivity

The surface temperature is Θ°C and dT/dZ will remain constant provided there are no heat sources or heat sinks depth. The Curie temperature depends on magnetic mineralogy. For example, although the Curie temperature of magnetite (Fe_3O_4) is at approximately 580 °C, an increase of Titanium (Ti) contents of titanomagnetite (Fe_2-xTixO_3) will cause a reduction of the Curie temperature.

A curie temperature of 580 °C and thermal conductivity of 2.5W m^{-1} $°C^{-1}$ which is the average thermal conductivity for igneous rocks will be used in the study as standard [17] we then calculate the value for K the geothermal gradient in the study area using the empirical relation between Curie point, Curie temperature and geothermal gradient. Heat flow estimates on the crust can thus be made using depth and thickness information.

The Curie point temperature at which rocks lose their ferromagnetic properties connects thermal models and models based on magnetic source analysis. Temperature influences the magnetic susceptibility and strength of the materials that make up the crust [18]. Magnetic ordering becomes loose at temperatures above the Curie point, and both induced and remanent magnetization disappear, while temperatures above 580 °C cause ductile deformation in the materials [19].

The basic relation for conductive heat transport is based on the assumption that the direction of the temperature variation is vertical and the temperature gradient dT/dZ is

q = -k (dT/dZ) (6)

where q is heat flow and k is thermal conductivity. The Curie temperature θ°C can also be defined as:

θ^0C = (dT/dZ) d (7)

where d is point depth (as obtained from the spectral magnetic anomaly).

The reasons why Fig. 3 and Fig. 4 are identical is stated below

Because geothermal gradient and heat flow are closely coupled through the thermal conductivity of the Earth's subsurface materials, the graphic is the same for both interpretations. Furthermore, here is why again;

Relationship Between Geothermal Gradient and Heat Flow

Heat flow (q) is calculated using Fourier’s Law of Heat Conduction:

$q = k \cdot G$

where:

q = heat flow (measured in mW/m²)
k = thermal conductivity of the subsurface material (W/m·K)
G = geothermal gradient (temperature change per unit depth, °C/km).

If the thermal conductivity (k) is relatively uniform across the region, variations in geothermal gradient (G) will directly correspond to variations in heat flow (q).

Identical Patterns in the Diagram

Either heat flow values or geothermal gradient values are represented by the color-coded contours. If k is constant throughout the study region, the geographical distribution of high and low values will be the same since heat flow is proportional to the geothermal gradient.

For example: High heat flow areas (e.g., in the red zones) correspond to areas with a steep geothermal gradient and Low heat flow areas (e.g., in the black zones) correspond to areas with a shallow geothermal gradient.

Uniform Thermal Conductivity Assumption

It is frequently assumed in regional studies that there is little variation in the underlying materials' thermal conductivity throughout the studied area. As a result, heat flow and geothermal gradient are directly proportionate, producing contour maps with the same patterns.

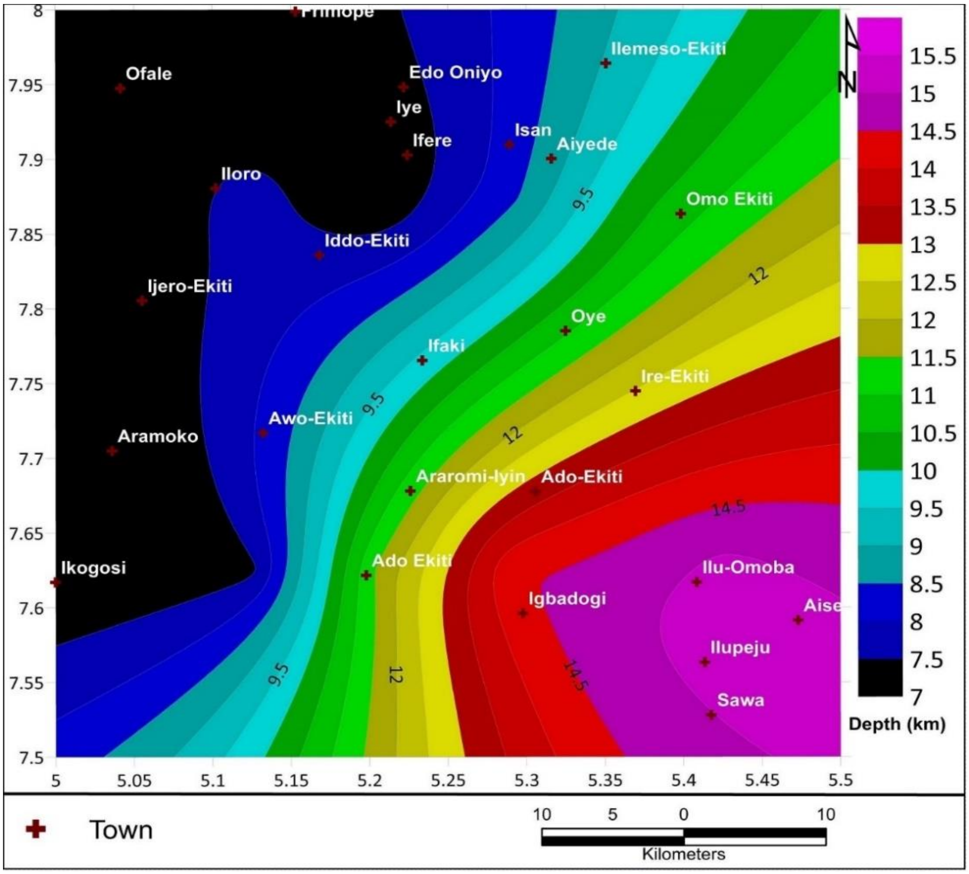

Fig. 2. CPD Contour map of Sheet 244 corresponding to Ado-Ekiti

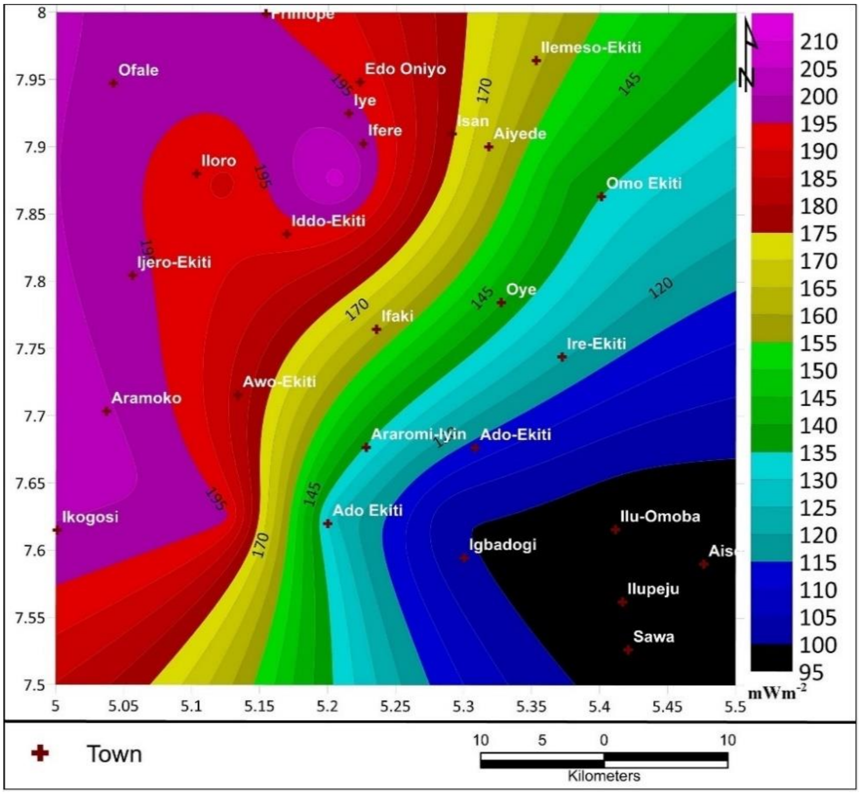

Fig. 3. Geothermal gradient contour map of Sheet 244 corresponding to Ado-Ekiti

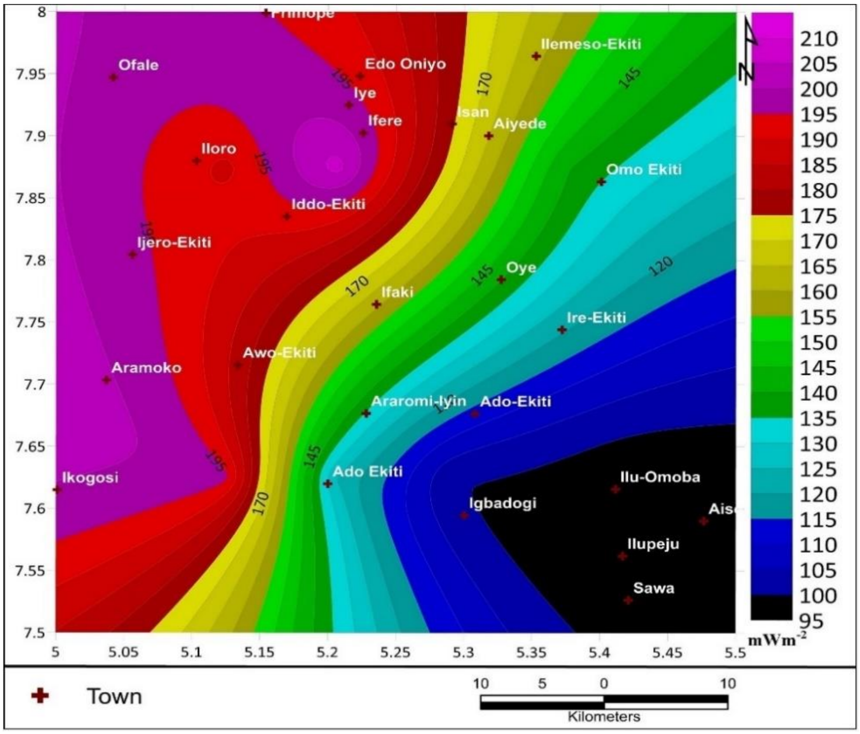

Fig. 4. Heat flow contour map of Sheet 244 corresponding to Ikogosi

Relationship Between Geothermal Gradient and Heat Flow

Heat flow (q) is calculated using Fourier's Law of Heat Conduction:

$$q = k \cdot G$$

where:

q = heat flow (measured in mW/m^2)
k = thermal conductivity of the subsurface material (W/m·K)
G = geothermal gradient (temperature change per unit depth, °C/km).

If the thermal conductivity (k) is relatively uniform across the region, variations in geothermal gradient (G) will directly correspond to variations in heat flow (q).

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Uniform Thermal Conductivity Assumption

It is frequently assumed in regional studies that there is little variation in the underlying materials' thermal conductivity throughout the studied area. As a result, heat flow and geothermal gradient are directly proportionate, producing contour maps with the same patterns.

3. 2. Discussion of Data Presentation

The temperature of the surface manifestation of the Ikogosi spring was found to vary along the direction of spring flow from the apex to downstream. The temperature was observed to be 66 ºC which is the maximum temperature at the apex where quartzite and quartz schist occur. As the spring flows down, the temperature drops gradually to 43 ºC.

The Aeromagnetic data of Ado-Ekiti (Sheet 244) was subjected to spectral analysis with the aim of accessing the geothermal potential of the study area and environs. The Curie point depth values was estimated to range from (7.0 - 15.0) km, the geothermal gradient values ranges from (36 - 81) °C/km and the heat flow values ranges from (95.0 - 205.0) mW/m^2 (Table 1).

The NW edge covering Ofale, Iye, Ifere, Iddo-Ekiti, Ijero-Ekiti, Aramoko, and Ikogosi hosts the highest anomalous values of heat flow and geothermal gradient with corresponding shallowest values of Curie point depth (Figs 2-4).

Generally, for a viable geothermal reservoir, a heat flow range of 80 - 100 mW/m^{2}is recommended, hence it can be inferred that every region on the study area could be considered as having good prospect of the study area with high heat flow above 80 - 100 mWm^{-2}.

Spectral Analysis

Results: The average Curie point depth for the Ikogosi warm spring area is 15.1 ± 0.6 km and centers on the host quartzite rock unit. The computed equivalent depth extent of heat production provides a depth value (14.5 km) which falls within the Curie point depth margin and could indicate change in mineralogy. The low Curie point depth observed at the warm spring source is attributed to magmatic intrusions at depth. This is also evident from the visible older granite intrusion at Ikere - Ado-Ekiti area, with shallow Curie depths (12.37 ± 0.73 km).

Results indicate that the area is promising for further geothermal explorations.

4. CONCLUSION

The temperature of the surface manifestation of the Ikogosi spring was found to vary along the direction of spring flow from the apex to downstream. The temperature was observed to be 66 ºC which is the maximum temperature at the apex where quartzite and quartz schist occur. As the spring flows down, the temperature drops gradually to 43 ºC. The Aeromagnetic data of Ado-Ekiti (Sheet 244) was subjected to spectral analysis with the aim of accessing the geothermal potential of the study area and environs.

The Curie point depth values was estimated to range from (7.0 - 15.0) km, the geothermal gradient values ranges from (36-81) °C/km and the heat flow values ranges from (95.0 - 205.0) mW/m^2. The NW edge covering Ofale, Iye, Ifere, Iddo-Ekiti, Ijero-Ekiti, Aramoko, and Ikogosi hosts the highest anomalous values of heat flow and geothermal gradient with corresponding shallowest values of Curie point depth (Figs 2-4).

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