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Applying Geophysical Method for Investigation of the Depth of the Mineralization Potential of Ikogosi and Environs Using Aeromagnetic Data

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ABSTRACT

Mineralization refers to the natural process by which minerals are deposited in the Earth's crust. This process occurs when mineral-rich fluids, such as hydrothermal solutions or groundwater, flow through rocks and deposit minerals in the pore spaces or fractures. Mineralization can result in the formation of economic mineral deposits, which are concentrations of minerals that can be extracted and used for industrial, commercial, or other purposes. Ado-Ekiti found in Ekiti Central Local Government area of Ekiti state, is located geographical between Latitude 7°37′23″ N and Longitude 5°13′15″ E. Mineral exploration is capable of sustaining economic growth and industrial development of any nation. Opportunities are available for mining operation which is yet un-tapped, despite the abundance of mineral deposits in the country. The study is investigating the geophysical characterization of the depth of the mineralization potential of ikogosi and environs using aeromagnetic data. The materials applied in this study are the high resolution aeromagnetic data, Oasis montaj, Surfer 8 and matlab software. The high resolution aeromagnetic acquired from the Nigeria Geological Survey Agency (NGSA) sheet 244. Ikogosi falls within the South western Nigerian Basement Complex. It is bounded toward the South East and South region by migmatite and toward the extreme north is porphyritic schist and the North East is mixture of schist and phyllites. It is covered with thick forest and giant bush. The topographic elevation varies from 480m in the valleys to 560m on the hills. The results reveals that the depth to basement of the mineralized zones range from (0.89- 1.68) km.

***Keywords*:** Ikogosi, basement, characterization, topographic

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1. INTRODUCTION

Mineralization refers to the natural process by which minerals are deposited in the Earth's crust. This process occurs when mineral-rich fluids, such as hydrothermal solutions or groundwater, flow through rocks and deposit minerals in the pore spaces or fractures. Mineralization can result in the formation of economic mineral deposits, which are concentrations of minerals that can be extracted and used for industrial, commercial, or other purposes. Mineralization can occur in a variety of geological settings, including volcanic and sedimentary rocks, as well as in hydrothermal systems associated with faults, fractures, and other geological structures. The type and concentration of minerals deposited during mineralization depend on the composition of the fluids, the temperature and pressure conditions, and the host rock properties.

Mineralization is of great economic importance, as it is the process that forms most of the world's mineral deposits, including precious metals, base metals, and industrial minerals. Mineral exploration is the process of identifying areas with potential for mineralization and is a critical part of the mining industry.

Ado-Ekiti found in Ekiti Central Local Government area of Ekiti state, is located geographical between Latitude 7°37′23″ N and Longitude 5°13′15″ E. It is bounded in the north by Ido-Osi and Oye Local Government Areas, in the west by IJero and Ekiti south west, lkere and Emure-Ise-Orun local government areas. Mineral exploration is capable of sustaining economic growth and industrial development of any nation. Nigeria economy depends largely on oil and gas industry at present, why opportunity availed by mining operation is yet un-tapped, despite the abundance of mineral deposits in the country. In most cases, the knowledge about occurrence, mineralogical composition and reserves of mineral are not fully understood [1]. Solid mineral exploration require interpretation of high-resolution airborne data which are usually targeted at delineating possible rocks, zones and structures which can serve as host Analysis of remote sensing data and imageries are efficient in delineating geology structures [2]. Magnetic surveying plays a vital role in delineating metallic and non-metallic minerals, since most minerals are usually deposited along rock contacts or features such as faults or fractures. Since mineralization processes affect concentration of radioelement in rocks, radiometric method, therefore becomes a useful tools in identification of potential mineralized zone. Radiometric surveys are capable of directly detecting the presence of uranium which also assists in locating some intrusive related mineral deposit. The present research therefore focus on the analysis of aeromagnetic and geological study of the Ikogosi schist belt and environs of Nigeria with the aim of delineating structural and geological conditions relating to mineralization within the study area.

1. 1. Aeromagnetic Method of Exploration

Aeromagnetic method is the most costly geophysical tool for mineral exploration. It detects alteration zones that may control the mineralization zones. An aeromagnetic survey (AMS) is an air-borne geophysical survey performed using a magnetometer aboard or towed behind an aircraft. A magnetometer is an instrument used to measure the magnetic field. Aeromagnetic surveys are probably one of the most common types of air-borne geophysical surveys. The applications of AMS in engineering geology include but are not limited to near-surface geological mapping, structural geology mapping, aiding three-dimension (3D) geological subsurface model construction, groundwater study, environmental study, and geologic hazards assessment.

In an aeromagnetic survey, an airplane flying at a low-altitude, carrying a magnetic sensor flies back and forth in a grid-like pattern over an area, recording disturbances in the magnetic field. Height and gridline spacing determine the resolution of the data. Geologic processes often bring together rocks with slightly different magnetic properties, and these variations cause very small magnetic fields above the Earth's surface. The differences in the magnetic field are called "anomalies" [3].

Rocks or soils containing iron and nickel can have strong magnetization and, as a result, can produce significant local magnetic fields. The magnetic minerals contain various combinations of induced and remanent magnetization. At exploration depths, the Earth's primary magnetic field is perturbed by the presence of magnetic iron oxide (magnetite, the most strongly magnetic and the most common magnetic mineral), iron-titanium oxides (titanomagnetite, titanomaghemite, and titanohematite), and iron sulfides (pyrrhotite and greigite) [4]. The remnant magnetization in the earth's magnetic field occurred during the mineral formation process, while the induced magnetization was created by the presence of the earth's magnetic field. The magnitudes of both induced and remnant magnetizations depend on the quantity, composition, and size of the magnetic-mineral grains.

The goal of the magnetic method is to map changes in the magnetization that are, in turn, related to the distribution of magnetic minerals [5]. The magnetometer was invented in 1832 and was designed and constructed to measure the intensity of the Earth's magnetic force [6]. However, development of magnetometers used in exploration, i.e. usable for taking a large number of readings over a given area of interest in a reasonably short period of time, dates only from the invention of the electronic magnetometer during the Second World War [7]. Aeromagnetic surveys were performed, using a Magnetic Anomaly Detector attached to an aircraft, in World War II to detect submarines. The aeromagnetic survey technology was progressively refined with time. In the late 1950s the proton precession magnetometer was invented but, despite on-going refinement of the flux-gate instrument, eventually was replaced in routine survey operations [7].

Magnetic measurements are usually made from low-flying airplanes flying along closely spaced, parallel flight lines. Additional flight lines are flown in the perpendicular direction to assist in data processing. These huge volumes of measurements are processed into a digital aeromagnetic map. Assisted by computer programs, the geophysicist builds a geologic interpretation from the digital aeromagnetic data, incorporating geologic mapping and other geophysical information (gravity, seismic-reflection) [8] Aeromagnetic Survey.

1. 2. Geographical Location

Ikogosi-Ekiti, where the warm spring is located is in Ekiti West Local government of Ekiti State of Nigeria. It is situated in a valley and from the surrounding hills rises the warm spring. The vegetation of this resort centre is a highly thick forest. This natural and rich vegetation is closely maintained and protected from arbitrary deforestation. The area covered by this resort centre is about 31.38 km^2 and it is highly protected from erosion by tall and evergreen trees. These trees also serve as a sort of canopy under which tourists could stay during the dry season and sunny days. The undulating topography of the entire tourist centre and the symmetry of the surrounding hills add more to the aesthetic beauty of this centre.

There is a pass that cuts across the Tourist centre to the equally popular Erinta Water Falls at Ipole Iloro, a few kilometres to the Warm Spring

1. 3. Geology of Study Area

The geology of Ado-Ekiti belongs to the basement complex (igneous rock) rock of South Western Nigeria. Major lithiological rock units are basically crystalline basement rocks. These include coarse grained charnokite, fine grained granite, medium grained-granite and porphyritic biotite-hornblend granite, with superficial deposit of clay and quartzite. Association of the fine-grained charnokite and the porphyritic biotite-horn blend granite suggest a common age [9]. The charnockitic rock is the most abundant in the area. The charnockite ranges in colour from dark-green, to greenish-grey rock with milky quartz and greenish feldspar. The outstanding feature of the coarse grained variety of charnokite rock in Ado-Ekiti is that it is similar to those of [10], described as "bauchite" around Bauchi Nigeria. Other occurrences are in form of small dykes or veins in other granitic rocks. The rock is generally even textured and homogenous with mineral aggregates mainly of biotite and feldspar phenocryst. The superficial deposits are clay, quartzite rumbles and fine sand (SiO_2). The clay is believed to have be formed from the weathering of feldspar mineral present in charnockitic rocks due to alteration of igneous rocks by hydrothermal process and the quartzite rumbles due to high degree of cyclic weathering.

2. LITERATURE REVIEW

The availability of sufficient information of the geology, mineralogy of ore and ore texture assist in the effective design of concentration flow-sheet and development of the area of the minerals. More importantly, these characteristics facilitate setting the proper grinding size to get required liberation and reduce over-grinding, and help out in discovering correct concentration (flotation) constraints to achieve the optimum mineral separation [11].

A vast number of reports of research work had been published over the years on the geological exploration [12], mining survey and metallurgical exploitation (mineral processing and extraction) [13] of numerous mineral deposits discovered across the boundaries of Nigeria. The major focuses of such reports were to develop these mineral for economic applications. Ekiti state is covered with vegetation and rocks that has been formed through the cooling solidification of magma which might have under gone the processes of metamorphic rock formation.

Ekiti is surrounded by rocks that are predominantly granite and believed to have been exposed through several years of erosion activities. Geographically, the terrain of Ekiti and its environs belong to complex basement that are characteristically metaigneous [14]. The quest to search for more industrial minerals in Ekiti state have daily motivated the industrial mineral engineers and geoscientist in finding out some of the economic minerals present in Ekiti rocks.

Intrusive igneous rocks form very good engineering materials, possessing high crushing strength and shearing strength especially when they are fresh and un-weathered, unless they are minutely fractured. They make a good source of concrete aggregate and typical construction materials. Paying much attention to jointing and possible faulting, weathering along fractures, some tests may be necessary before using it for engineering construction. On the other hand, the engineering properties of sedimentary rocks depend largely on the degree of compaction, consolidation and cementation, these, which determine the hardness, crushing strength and shearing resistance (Strength) of the rocks. Metamorphic rocks share structural complexity in both physical and chemical properties and hence, make it impossible to generalize their engineering properties.

2. 1. Geology of Nigeria

Nigeria has a diverse geology that is shaped by a long and complex history of tectonic and geological processes. The country is situated within the West African Craton, which is a stable and ancient geological region that extends across West Africa. Here are some of the key features of Nigeria's geology:

1) Basement complex: The basement complex in Nigeria is a region of ancient rocks that were formed more than 2.5 billion years ago. These rocks are made up of gneisses, schists, granites, and other metamorphic and igneous rocks. The basement complex is an important source of mineral resources, including gold, tin, columbite, and tantalite.
2) Sedimentary basins: Nigeria has several sedimentary basins that are important for the country's oil and gas industry. The most important of these is the Niger Delta Basin, which is one of the world's largest deltas and contains significant oil and gas reserves. Other sedimentary basins in Nigeria include the Chad Basin and the Benue Trough.
3) Younger granites: Nigeria also has younger granites that were formed during the Pan-African orogeny, which occurred between 600 and 500 million years ago. These granites are found in the Jos Plateau, the Keffi-Bida Basin, and other regions of Nigeria.
4) Volcanic rocks: Nigeria has several areas of volcanic rocks, including the Oban Massif, the Biu Plateau, and the Jos Plateau. These volcanic rocks were formed during the Cretaceous period, between 145 and 66 million years ago.
5) Coastal plains: Nigeria's coastal plains are relatively flat regions that are underlain by sedimentary rocks. These plains are important for agriculture and fishing, as well as for oil and gas exploration.

Overall, Nigeria's geology is a rich and diverse resource that has shaped the country's history and economy. The country's mineral resources, oil and gas reserves, and fertile agricultural lands all depend on the underlying geology.

3. MATERIALS AND METHOD

The materials applied in this study are the high resolution aeromagnetic data, Oasis montaj , Surfer 8 and matlab software.

Data used in this research is the high resolution aeromagnetic acquired from the Nigeria Geological Survey Agency (NGSA) sheet 244. The magnetic data analyses involved the processes of editing, application of a gridding routine, and removal of the Earth's main magnetic field through removal of international geomagnetic reference field (IGRF) over the study area. This was followed by application of series of filters in order to improve the edge effects of magnetic anomalies, enhance shallow small-sized geologic features and making smaller anomalies more readily visible in area of strong regional disturbances.

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 to delineate the mineralization zones.

3. 1. Theory of Methods

3. 1. 1. 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

$$\ln [P(k)1/2 / k] = A - |k| Z_0 \quad (1)$$

where In is the natural logarithm, P (k) is the radially averaged power spectrum, k is the wave properties magnetization and its orientation and Z_0 is the centroid depth of the magnetic sources [15]. For the high wave number part, the lower spectrum can be related to the top of the magnetic sources by a similar equation:

$$\text{Ln} [P (k) 1/2 / k] = B - |k| Z_t \quad (2)$$

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 is:

$$Z_b = 2Z_0 – Z_t \quad (3)$$

centroid of the magnetic source (Z_0), Estimate the depth to the top of the magnetic source (Z_t), Calculate the depth to the base of the magnetic source (Zb). The value of the Z_b is the Curie point depth/DBMS [15]

Therefore, the geothermal gradient in relation to the heat flow q. [15, 16]

$$q = k\ \theta°Cd \quad (4)$$

The surface temperature is Θ^0 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 ($Fe_2^{-x} Ti_xO_3$) will cause a reduction of the Curie temperature. A curie temperature of 580 °C and thermal conductivity of 2.5 Wm^{-1} $°C^{-1}$ which is the average thermal conductivity for igneous rocks will be used in the study as standard [15, 16], 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 [17].

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.

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

$$q = -k\,(dT/dZ) \quad (5)$$

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

$$\theta^0C = (dT/dZ)\,d \quad (6)$$

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

3. 1. 2. Oasis Montaj software (OASIS Montaj Viewer and USGS GX Programs)

The Oasis Montaj Viewer is a free software from Geosoft Inc. that allows to view and to share data in grid (.grd) and database (.gdb) file formats. The viewer can also convert grids and export maps as images in various supported formats. In addition, basic plotting profile of the database can also be performed [18]. In this paper, we present the most basic functions of the software in accordance with the need of advanced gravity data processing, i.e. contour shading,filtering etc. The Oasis Montaj Viewer is available for download from Geosoft's website, the latest being the version 8.5. With almost similar functionalities, we use the older version 6.4 for the sake of compatibility with our licensed version. Complementary modules called Geosoft's executables or GX's are provided by USGS. The exact sites for download might be changed, however, they can be easily searched from the internet. After installation of both the Oasis Montaj Viewer and USGS GX's programs, it is necessary to move or to copy the resulting files with the usgs prefix (usgs*.*) into the same directories under the Oasis Montaj Viewer directory.

The directories are designated as /bin, /gx, /omn and /ger, for binaries, GX's, additional menus and error messages respectively. When the Oasis Montaj Viewer is launched,we can create or open a project file. Then, only basic menus are shown. In the GX menu, the Load Menu is used to load an additional menu, e.g. to load USGS's programs menu by selecting the file usgs.omn in the dialog box. Once the USGSV is loaded (V for viewer, otherwise USGS is used for licensed Oasis Montaj) calculations using USGS's GX programs can be performed principle, the installation process is straightforward and the use of the software is clearly explained in the manual.

Only data in the form of grid can be processed by using the Oasis Montaj Viewer. Therefore, we must convert our gravity (or magnetic) data usually distributed arbitrarily in the survey area into a uniform grid by a gridding process. The database (.gdb) and also the grid (.grd) files that can be loaded into the software are proprietary format of Geosoft and can only be created by using the licensed version of the Oasis Montaj. However, a grid file created with the Golden Software's Surfer can also be used as the input of the software, i.e. by specifying the Surfer's grid format in the input dialog. The grid can be directly displayed from the Grid menu and Display Grid sub-menu as shown.

The grid can be first converted to the Geosoft's format by selecting Copy/Convert grid sub-menu and then processed using available menu in USGSV. The grid conversion is usually preferred to avoid specifying the grid format each time we input the data. Once the processes are performed and several grid files are generated, then the grids can be displayed and exported to images with standard formats, i.e. jpg, png, emf etc. These images can be imported again into Surfer or other software for map annotations, since the free or viewer version of the Oasis Montaj does not allowed for a noted map creation.

4. RESULTS AND DISCUSSION

Table 1. Results of the depth to basement, curie depth, and the heat flow

Blocks	X	Y	Centroid	Depth to basement	Curie depth	Geothermal Gradient	Heat Flow (mWm^{-2})
A	5.125	7.875	4.59	1.5	7.68	75	180
B	5.207	7.875	4	0.99	7.01	81	204
C	5.291	7.875	4.71	1.03	8.39	67	171
D	5.375	7.875	5.6	0.89	10.31	56	139
E	5.125	7.625	4.15	0.92	7.38	77	194
F	5.205	7.625	6.48	1.38	11.58	51	127
G	5.291	7.625	8.03	1.68	14.38	39	100
H	5.425	7.625	8.15	1.16	15.14	38.3	95

Table 2. Attitude of the foliation of schist underlying Ikogosi, Ekiti.

S/N	**Strike of foliation**	**Dip direction**	**Dip**
1	330ºNNW-150ºSSE	73ºENE	44º
2	321ºNNW-143ºSSE	73ºENE	42º
3	320ºNNW-142ºSSE	72ºENE	43º
4	340ºNN-160ºSS	74ºENE	41º
5	360ºNN-180ºSS	89ºENE	52º
6	340ºNN-160ºSS	70ºENE	43º
7	345ºNN-165ºSS	75ºENE	40º

8	10ºNNE-143ºSSW	53ºENE	75º
9	20ºNNE-200ºSSW	110ºSSE	61º

Table 3. Water collection Point, rock unit and water temperature along the spring flow in Ikogosi, Ekiti State, Nigeria

S/N	Point along the spring	Condition	Rock unit	Temperature (ºC)	Thermal Resource
1	The top most outcrop	Bushy and restricted	Quartzite	65.0	Hyper thermal
2	About 1/2 km away from source, fenced with brick	Open and accessible	Quartz schist	40.6	Hyper thermal

The hydrogeology of Ikogosi was studied with special attention on the origin of the flow direction, temperature along the flow direction and rock units along the flow direction. The spring occurs in the area as a result of the fault that cut across the rock units (mineralized zones) underlying the area deep into the aquiferous layer. Through the fault, the groundwater flows to the surface at the almost 1/2 km apex of the outcrop away from the restriction limit.

The temperature of the spring varied along the direction of spring flow from the apex to downstream. The temperature was observed to be 65 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 40.6 ºC till it reaches the restricted limits.

Ikogosi falls within the South western Nigerian Basement Complex. It is bounded toward the South East and South region by migmatite and toward the extreme north is porphyritic schist and the North East is mixture of schist and phyllites .It is underlain by three rock units; quartz schist (Fig. 1), quartz mica schist and quartzite (Fig. 1 and 2). At the basal part of the spring where the cold and hot springs meet, the quarzt 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 (Fig. 2), dip direction of ENE, and their dip varies from 42º to 76º as shown in Table 2.

The minor trend of the foliation occurs along NNE-SSW direction with dominant trend running NNW-SSE (Table 2) .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 1 km where people are not allowed to access. It is covered with thick forest and giant bush. The topographic elevation varies from 480m in the valleys to 560m on the hills. The results reveals that the depth to basement of the mineralized zones range from (0.89-1.68) km. Table 1 and Fig. 3 with corresponding high heat flow ranging from (95-204) mWm^{-2}.

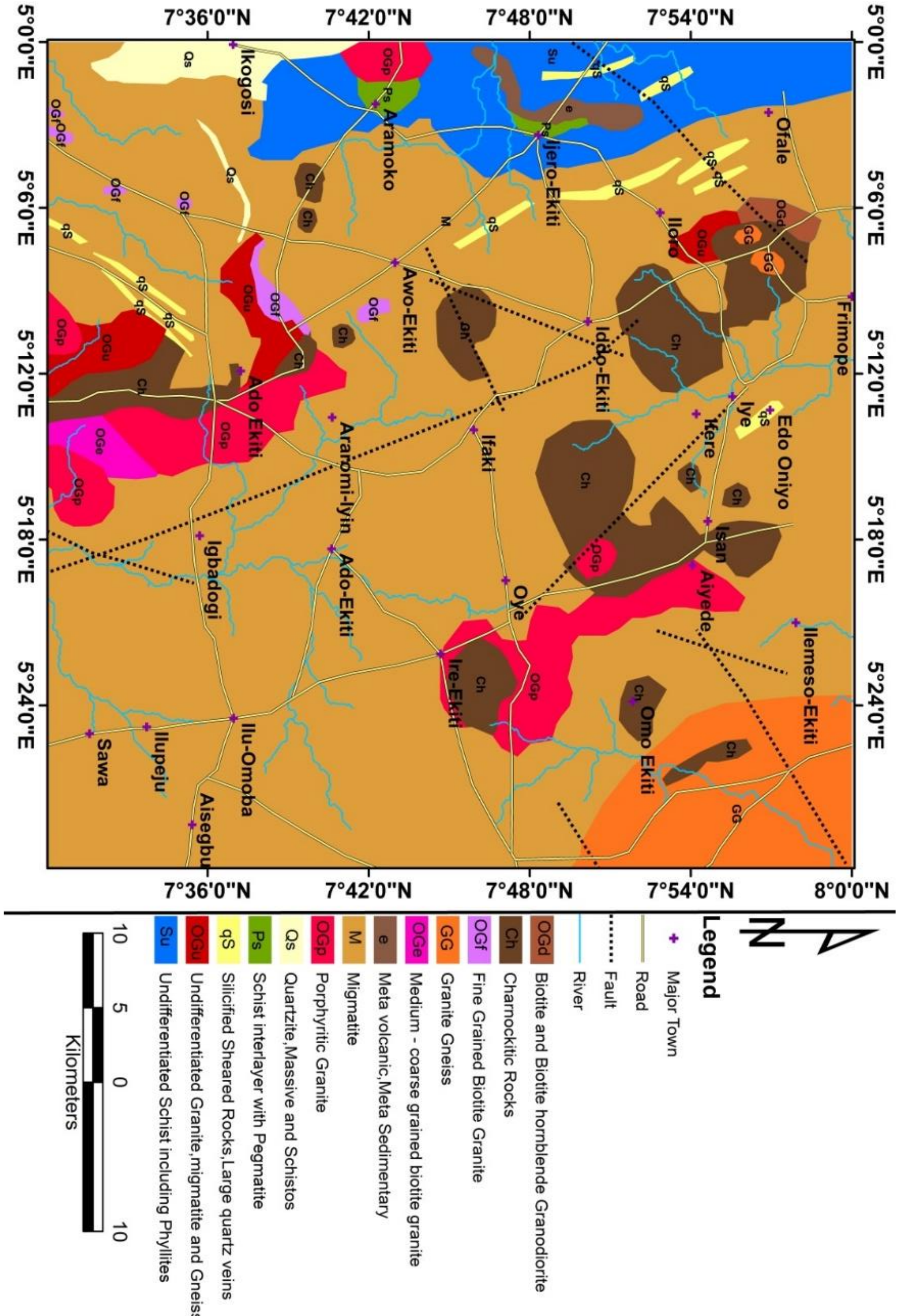

Fig. 1. Mineral distribution in Ikogosi and environs indicating faults/fractures

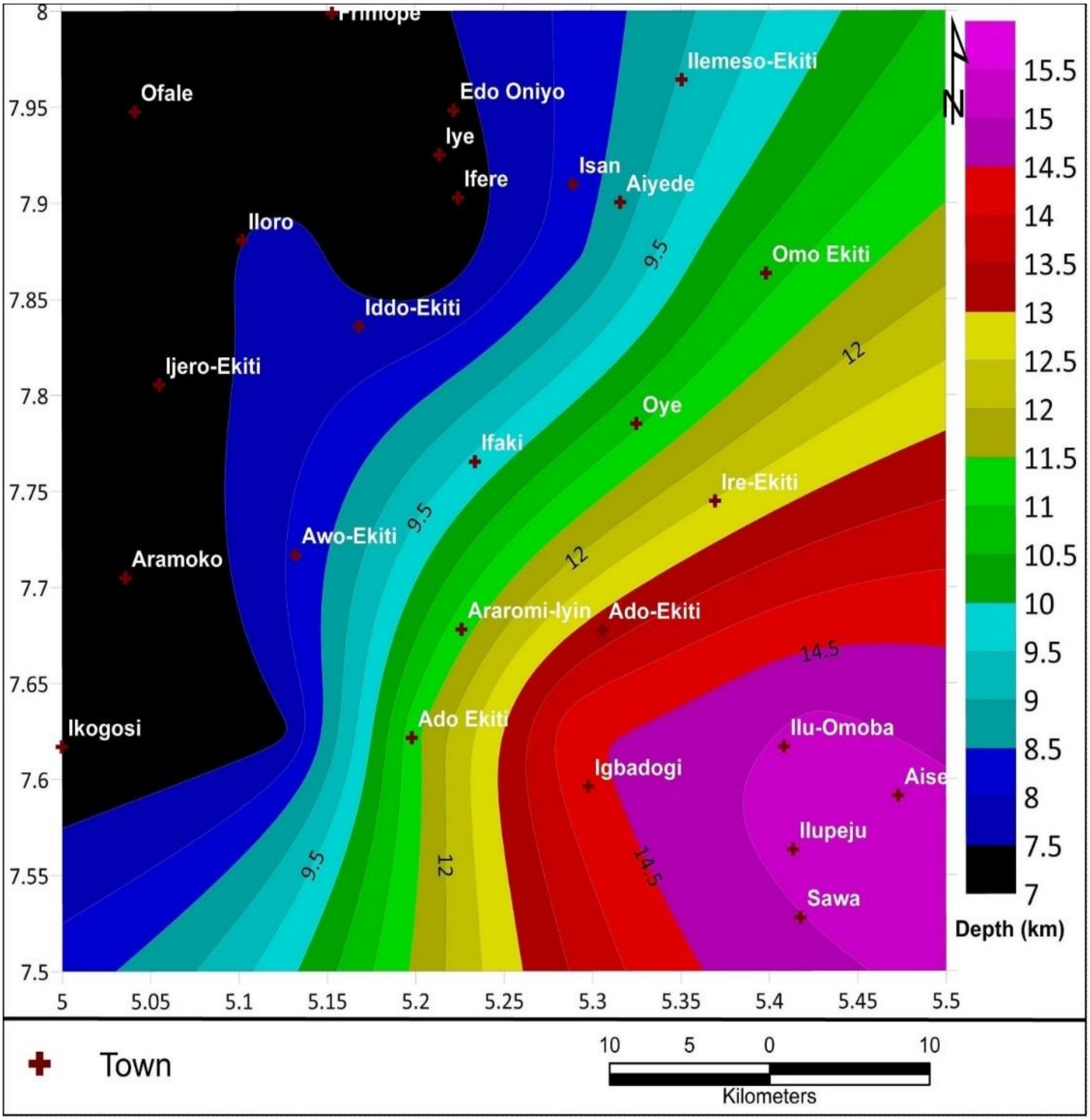

Fig. 2. Geological CPD contour map of Ado Ekiti sheet 244

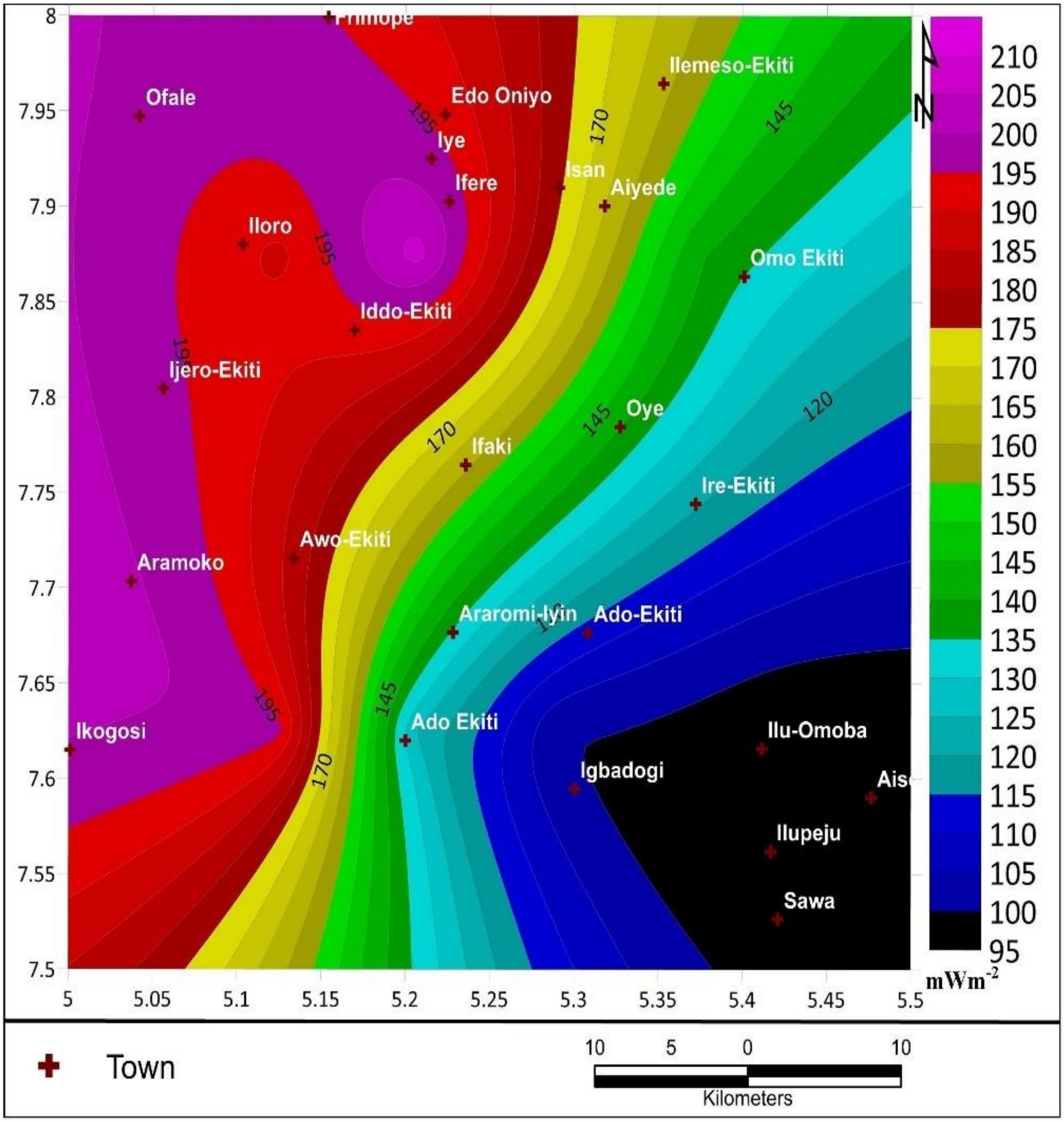

Fig. 3. Heat flow map contour map of Ado Ekiti sheet 244

5. CONCLUSIONS

The results reveals that the depth to basement of the mineralized zones range from (0.89-1.68) km.

Table 1 and Fig. 3 with corresponding high heat flow ranging from (95-204) mWm^{-2} which manifest to the surface of the area of th study. The aeromagnetic analysis showed that Ikogosi and environs is bounded toward the South East and South region by migmatite and toward the extreme north is porphyritic schist and the North East is mixture of schist and phyllites .It is underlain by three rock units; quartz schist (Fig. 1), quartz mica schist and quartzite (Fig. 1). At the basal part of the spring where the cold and hot springs meet, the quartz 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 (Fig. 2), dip direction of ENE, and their dip varies from 42º to 76º as shown in Table 2.

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