Vol. 14(4), pp. 30-37, 30 March, 2019
DOI: 10.5897/IJPS2018.4787
Article Number: EB7B02F60571
ISSN: 1992-1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Magnetic source basement depth determination of Ikogosi Warm Water Spring South Western Nigeria and the environ using aeromagnetic data

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Received 2 December, 2018; Accepted 19 February, 2019

Structural features of Ikogosi Warm Spring and its environs have been delineated using qualitative and quantitative interpretation methods. Euler-Deconvolution and local wave number methods were adopted for quantitative and qualitative interpretation of aeromagnetic data sheet 243 by Geological Survey Agency of Nigeria (GSN) in 2008, respectively. Euler solution revealed depth range of -2.98 to -290 m to the magnetic sources, while local wave number method revealed depths to magnetic sources/basements ranging from -2.1 to -1311.4 m of the geologic lineaments in Ikogosi Warm Spring and its environs. Both methods revealed outcrop features characterized by their positive depth values above the mean ground level. Both methods proved efficient way of resolving shallow magnetic source depth giving a very plausible depth of -2.1 m for local wave number and -2.98 m for Euler solution in the area of study.

Key words: Warm-Spring, Ikogosi, lineament.

INTRODUCTION

Ikogosi Warm Spring at Ekiti, South Western Nigeria is believed by many to be a viable geothermal energy source for the generation of electricity which is a major need of the nation for economic growth and all other forms of development which directly or indirectly depend on electricity. This belief is attributed to the fact that natural water is supposed to be cool and not warm or hot as the Ikogosi Warm Spring is. There is need to scientifically study the substructures of the area to understand the structural setting of the area. This information about these substructures and their depths to the surface can be used to suggest the existence of any potential reservoir or fault and fractures in the area.

Location of the study area

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 (Rogers et al., 1969). It lies on the geographic latitude of 7°35′N and longitude 5°00′E (Figure 1) within the central region of the area covered by this study. Located within the Precambrian basement complex of South Western Nigeria, it is at an altitude of 450 to 500 m (Adegbuyi and Abimbola, 1997).

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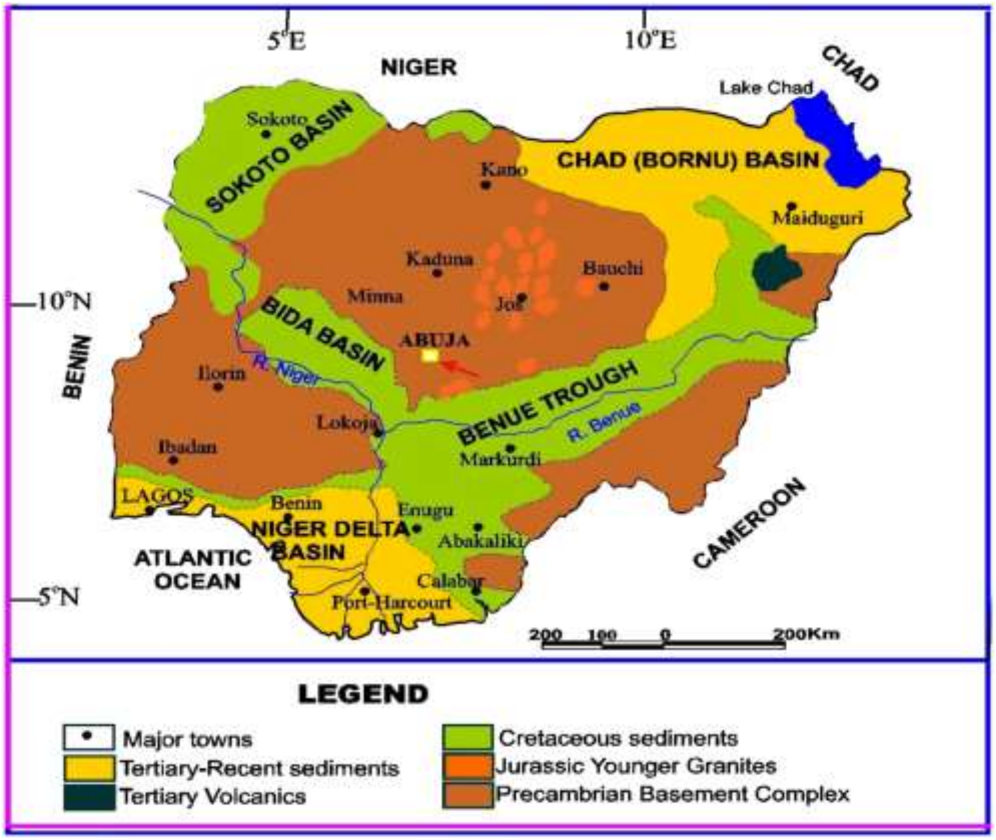

Figure 1. Geological map of Nigeria showing the location of Ikogosi Warm Spring (blue arrow) in the basement complex of Nigeria.Source: Modified from Obaje (2009).

The dominant geology of Nigeria is made mainly by crystalline (Precambrian basement complex) and sedimentary rocks (Cretaceous recent sediments).

The area covered by this study lies approximately between geographic latitudes 7°30′N and 8°00′N and geographic longitude 4°30′E and 5°00′E within the Precambrian of South Western Nigeria. The area is covered by the aeromagnetic map sheet 243 (Ilesha).

Geological setting of the study area

The warm spring temperature is 38°C near the foot of the eastern slope of the north-south trending ridge from a thin quartzite unit within a belt of quartzite which includes quartz-mica schist and granulitic migmatite east of Ilesha. The Okemesi quartzite member is characterized by a North-South trending ridge called the Effon ridge (Elueze, 1988; Oyinloye, 2011). The quartzitic rocks (as shown in Figure 2) are composed of dominant quartz with muscovite, chlorite and sericite occurring in minor proportions (Adegbuyi and Abimbola, 1997). It was suggested that the source of springs in the Effon Psammite formation is associated with a faulted and fractured quartzite band sandwiched between schists (Rogers et al., 1969). Chemical data of Ikogosi shows that quartzite is largely metamorphosed sandstones containing minor arkosic intercalations (Elueze, 1988). On the basis of petrology, a medium pressure Barrovian and low medium pressure types of metamorphism had been suggested for the Precambrian basement rocks in South Western Nigeria (Oyinloye, 2011). It is believed that the intersections of the NNE-SSW epeirogenic belts with the NW-SE fracture trends in Nigeria coincide with the centers of warm springs like the Wikki (Bauchi State) and Ikogosi (Ekiti State) springs (Mbonu, 1990). The issue of the springs is controlled by permeability developed within the quartzite as a result of intergranular pore spaces coupled with fracturing of the relatively competent quartzite (Rogers, 1969).

THEORETICAL BACKGROUND

Geomagnetic field is produced by electric currents induced within the conductive liquid outer core as a result of slow convective movements within it. The behavior of these fields can be characterized by a vector quantity known as magnetization, M. The magnetic induction B, which is composed of the ambient earth's field and

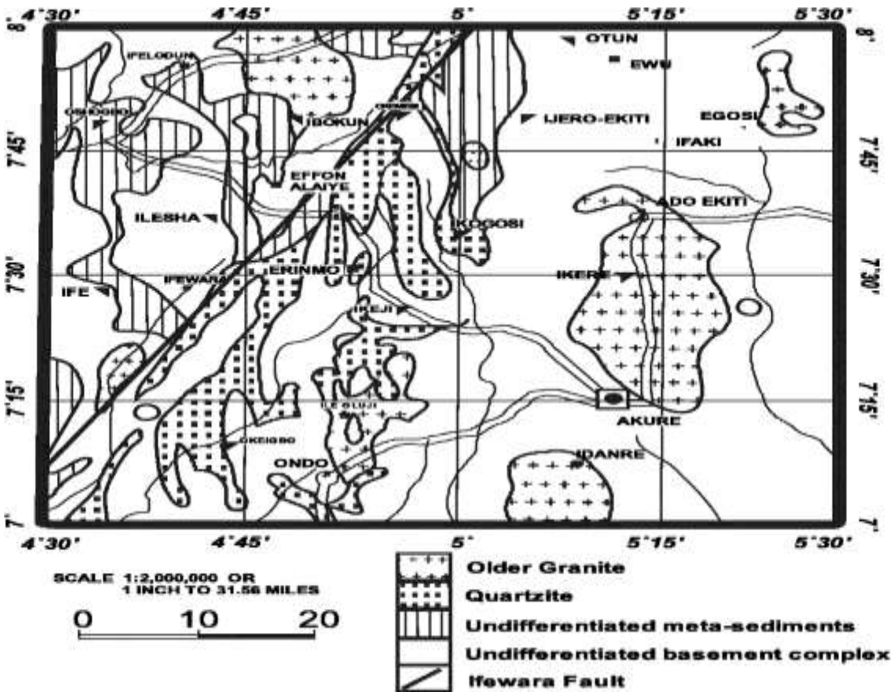

Figure 2. Geology map of Ikogosi Warm Spring and environ.
Source: Adegbuyi and Abimbola (1997).

magnetic material in the subsurface is related to M by:

$$B(R) = \frac{-\mu_o}{4\pi} \int M(R_o).\ddot{\nabla}_o \frac{1}{R - R_o} dV_o \quad (1)$$

where μ is known as permeability of free space and R and R_0 are the observation and source locations, respectively.

The Total Magnetic Field B represents the sum of the magnetizing field strength and the magnetization of the medium:

$$B = \mu_0(1-k)H = \mu\mu_0 H \quad (2)$$

where μ_0 is magnetic permeability of free space (4×10^{-7} H/m), B is also called the magnetic flux density or magnetic induction.

Earth's magnetic field varies between 20,000 nT in the equator and 60,000 nT at the pole (Reynolds, 1997).

Euler De-Convolution

The Euler De-convolution is an interpretation tool in potential field for locating anomalous sources and the determination of their depths by De-convolution using Euler's homogeneity relation (Reid et al., 1990).

The Euler's homogeneity equation relates the magnetic field and its gradient components to the location of the source of an anomaly, with the degree of homogeneity expressed as a structural index (Reynolds, 1997). Euler's homogeneity relationship can be written for magnetic data as:

$$(x - x_0)\frac{dT}{dx} + (y - y_0)\frac{dT}{dy} + (z - z_0)\frac{dT}{dz} = N(B - T) \quad (3)$$

where

$$\frac{dT}{dx}, \frac{dT}{dy} \ and \ \frac{dT}{dz} \quad (4)$$

represent first order derivative of the magnetic field along x-, y-, and z-directions, respectively. Where (x_0, y_0, z_0) is the location of a magnetic source, whose total field magnetic anomaly at the point (x, y, z) is T and B is the regional field. N is structural index and is a measure of the rate of decay of field with distance and assumes different values for different types of magnetic source. The structural index, S.I, depends on the geometry of the source. For a homogeneous point source N = 3, a linear source (line of dipoles or poles, and for a homogeneous cylinder, rod, etc.) N = 2, for extrusive bodies (thin layer, dike, etc.) N = 1, for a contact, vertex of a block and a pyramid with a big height N = 0.

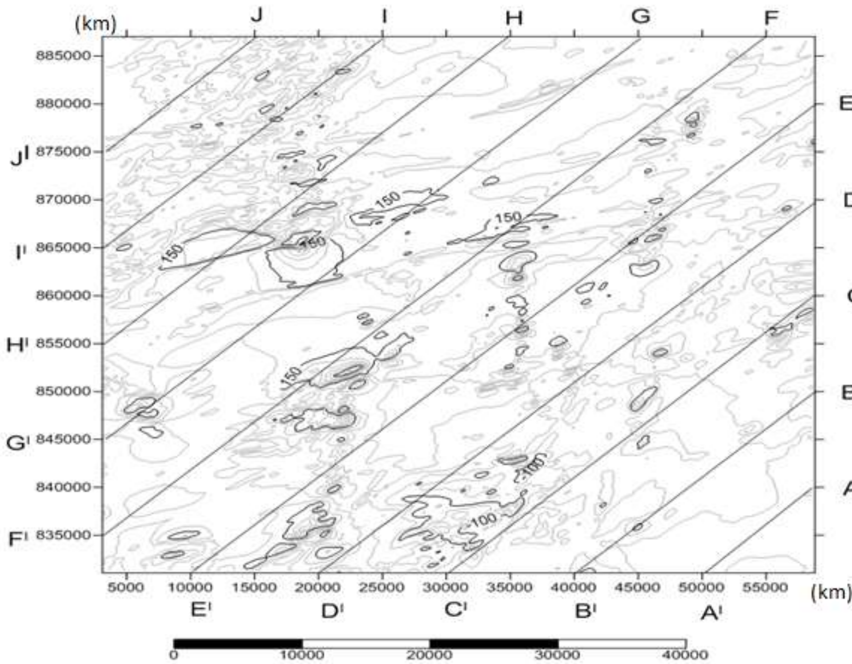

Figure 3. Residual anomaly contour map showing the profile lines in the direction NE-SW.

Local wave number method

This method is based on extension of complex analytical signal to estimate magnetic depths. The method works for 2-D slopping contact or 2-D dipping thin-sheet. For dipping contacts, the maxima of K are located directly over the isolated contact edges and are independent of the magnetic field inclination, declination, dip, strike, and any remanent magnetization.

Depth can also be estimated without assumptions about the thickness of the source bodies. For magnetic field M, the local wave number (Salako, 2014) is given by:

$$K = \frac{\frac{\partial^2 M}{\partial x \partial z}\frac{\partial M}{\partial x} - \frac{\partial^2 M}{\partial x^2}\frac{\partial M}{\partial z}}{(\frac{\partial M}{\partial x})^2 + (\frac{\partial M}{\partial z})^2} \quad (5)$$

The depth is estimated at the source edge from the reciprocal of the local wave number (K).

MATERIALS AND METHODS

A high resolution aeromagnetic data which are part of the airborne geophysical data of Nigeria acquired by Fugro Exploration in 2008 and published by the Geological Survey Agency of Nigeria (GSN) on a total magnetic intensity map scale of 1:100,000 were processed and interpreted to yield the set objectives. The data were leveled, cultural-edited, high frequency noise filtered before further processing. Error correction, spike removal, gridding were carried out prior to other filtering operations to yield the proposed target.

Subsequently, the general description of the survey results and the explanation of the major features called anomalies which can be geological formation and/or structures were discussed. The qualitative interpretation was performed using grids of residual field of the total magnetic intensity, reduction to the equator, upward continuation, horizontal derivatives and CET (Centre for Exploration Targets) analysis maps. The aeromagnetic data were input into the Geosoft Oasis Montaj software that processed them into grids and maps after which the gridded data was contoured on Surfer. The output results were then interpreted qualitatively using the Euler De-convolution and quantitatively using Local Wave Number Method.

RESULTS AND DISCUSSION

Residual anomaly contour map

The residual anomaly contour map was digitized into ten profiles as shown in Figure 3 and profile data were analyzed.

Most of the profiles have both relatively low negative and high positive magnetic anomaly field strengths. Zones with low negative magnetic anomalies are suspected to be the embedded features (faults/fractures) and those with positive anomalies are suspected to be massive quartzite/basement complex embedding the embedded features. The prominent sudden change in the contour over an appreciable distance that trends

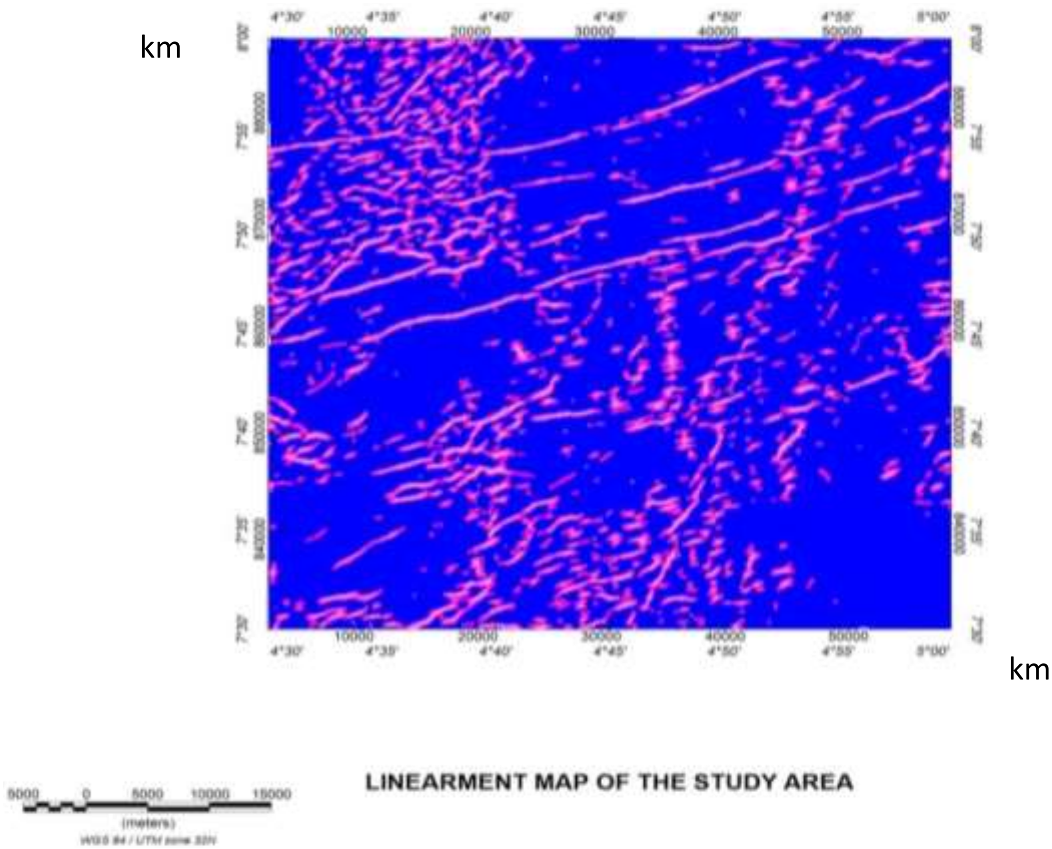

Figure 4. Lineament map of Ikogosi Warm Spring and its environs.

frequently in the south-west direction of the study area implies discontinuity in depth. This could be subsurface major faults.

CET analysis map (Lineament Map)

The map (Figure 4) shows geological features (faulted zones, fractured zones) that are elongated in NE-SW direction. This shows that the majority of the fracture zones and faults are NE-SW in direction although they are of different depths and width. The lineaments bounded from (7°35', 4°55'), (7°35', 5°) to (7°40', 4°55'), (7°40' 5°) (Figure 4) are sandwiched in the quartzite formation of the basement complex of the study area (Figure 2).

Euler-Deconvolution solution

The Euler solution revealed depth range of -290 to 47 m for sources located below and above the mean ground level. The positive depths coincide with regions where sources/basement rocks outcrop on the surface while the negative depths coincide with depth to magnetic sources/ basement rocks.

The Ikogosi Warm Spring region with location (7°35'30''N,4°58'45''E) and (7°35'45''N,4°58'54''E) has features with depth range of -2.98 to -290 m with the shallowest anomaly source (basement) having a depth of -2.98 m.

Prominent clustering of lineaments was obtained on the Lineament map (Figure 4) between (7°30'N, 4°40'E) and (7°40'N,5°E) showing definite magnetic trends within the Ikogosi Warm Spring and its environs. These linear features trending NE-SW are suspected fractured/faulted zones with depths in between -2.98 and -290 m if it is superimposed on the depth contour plot (Figure 6).

With the aforementioned information and the range of depth values obtained, it coud be suggested that the linear trending features (fracture or fault or both) rimmed by basement complex existing in the shallow and deep basements of Ikogosi Warm Spring and its immediate neigbhourhood interface the spring outlet and act as channels for movement of warm ground water from profound depths to the spring outlet (Figure 5).

The Euler depth solution grid was digitized at the Ikogosi Warm Spring location {(7°35'30''N,4°58'45''E) and (7°35'45''N,4°58'54''E)} on the map. The digitized depth data were krigged to give Figure 6. This plot shows

Figure 5. Ikogosi Warm Spring source.

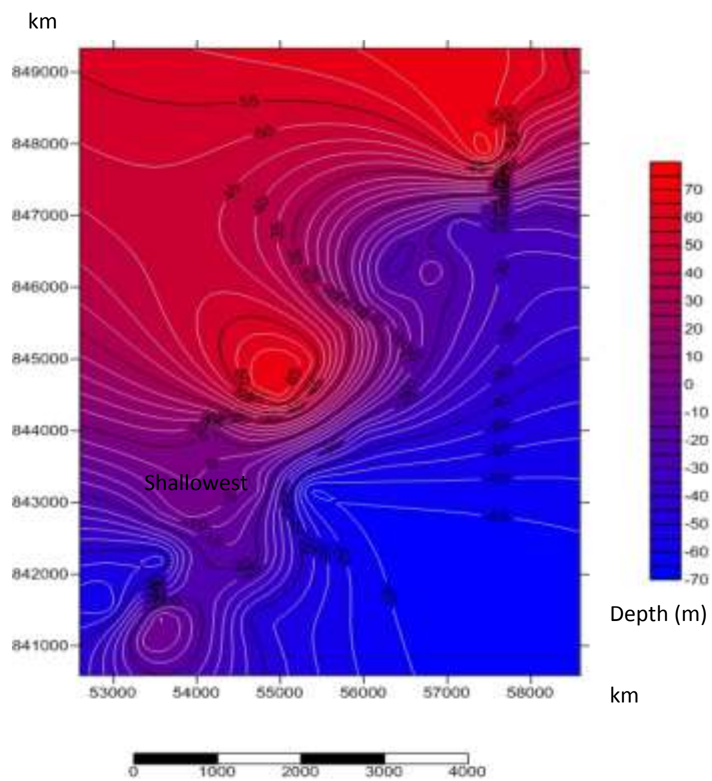

Figure 6. Depth countour plot from Euler-Deconvolution grid of Ikogosi Warm Spring.

that the shallowest depth is between 0 and -5 m which is inline with the shallowest depth of this region earlier suggested.

Local wave number solution

The Local wave number solution revealed depths range

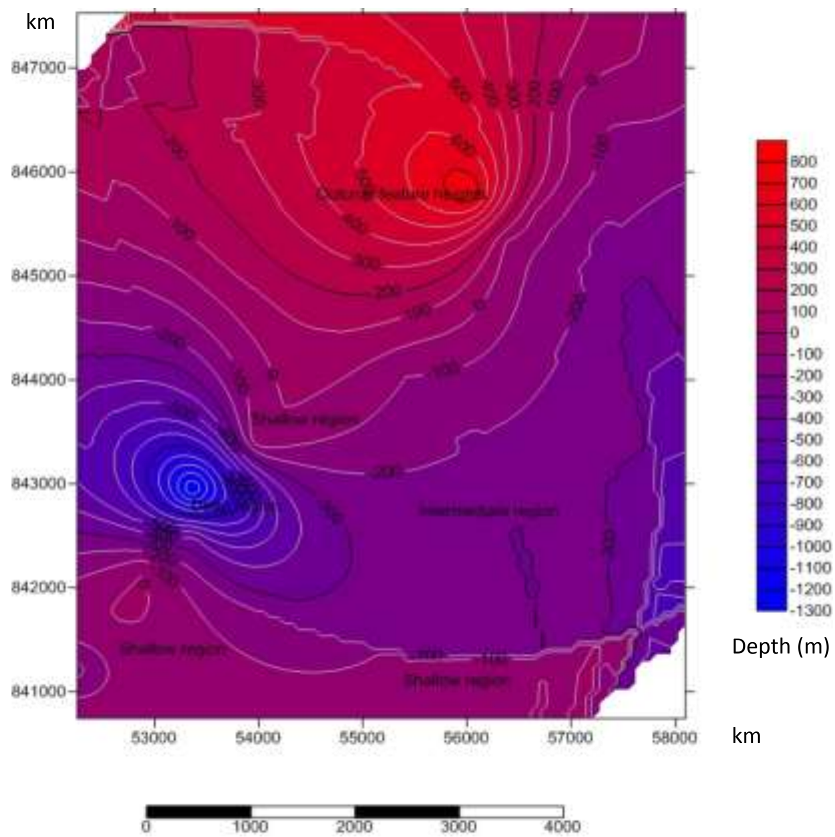

Figure 7. Depth countour plot from local wave number grid of Ikogosi Warm Spring.

of -1311.4 to 2403 m for sources located below and above the mean ground level. The positive depths coincide with region where basement rocks outcrop on the surface while the negative depths coincide with depth to magnetic sources/basement rocks

The local wave number solution revealed depths to magnetic sources/basements ranging from -2.1 to -1311.4 m. So the shallowest magnetic source in the area of the study has a depth of -2.1 m and the deepest-seated magnetic source has a depth of -1311.4 m.

The local wave number depth solution grid was digitized at the Ikogosi Warm Spring location {(7°35'30''N,4°58'45''E) and (7°35'45''N,4°58'54''E)} on the map. The digitized depth data were grided to give Figure 7. This plot shows that the shallowest depth is between 0 and -100 m which encompasses the shallowest depth as suggested.

This finding revealed shallowest depths to magnetic sources compared to depths to magnetic sources (quartzite) which ranged from 50.9 to 227.7 m suggested by Ojo et al. (2011).

The depths suggested in other authors' works on this area presented curie depths associated with the intense temperature that causes surface manifestation of heat.

Conclusion

The analysis of aeromagnetic data from this region revealed lineaments which could be fracture or fault or both have been delineated with trends mapped out to be elongated in the NE-SW directions. Both methods used have proved efficient for resolving well for shallow magnetic source depth giving a very plausible depth of -2.1 m for local wave number and -2.98 m for Euler solution in the area of study. But local wave number solution resolved very well for deep-seated magnetic sources by yielding the least depth value of -1311.4 m. Both methods also have revealed heights of outcrop features characterized by their positive depth values above the mean ground level.

These estimated relatively shallow magnetic sources in the area of study could be an indication of magma intrusion which solidified to form a basement rock and thus has several implications on geothermal resources and tectonic activities in the area. The heat flow in the tectonically active region is enough to cause surface manifestation of geothermal resource.

It is also suspected that the probable fractured/faulted zones mapped out may have acted as channels for movement of warm deep water from profound depths to the surface and the spring outlet is on a lineament interface.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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