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Magnetic data analysis for potential geothermal energy development: Case of Ikogosi warm spring, Ekiti, Southwestern Nigeria

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ABSTRACT

A surface geophysical investigation involving ground magnetic technique was carried out in Ikogosi warm spring situated in Ekiti South-western Nigeria using a high resolution Proton-precession Geometric Magnetometer model G-856 AX to measure total components of magnetic intensity of the area with the aim of giving details of the subsurface geological structure and evaluating the structural setting beneath the warm spring for probable geothermal energy exploration. Total field magnetic measurements data were acquired along twelve (12) N-S profiles. The Magnetic data interpretation applied was able to depict fractured and faulted areas within fresh massive Quartzite at varying depths beneath all the profiles. Profile 12 has the highest amplitude of 748 nT while profile 3 has the lowest amplitude of 81.1 nT. The magnetic anomaly obtained varied between a minimum negative peak value of -235.9 nT and a maximum positive value of 748 nT. The approximate depth to basement rocks ranges between 8 to 14 m. The magnetic contour, 3-D surface, 1-Grid, Image Maps showed that the magnetic anomalies are as a result of Hot dry rocks present in the study area which contributes to the temperature of the spring. Also the highly mineralized area is between profile 1 and 4. It was deduced that the fractured/faulted quartzite may have acted as channel for the movement of warm groundwater from high depths to the surface.

1.0 Introduction

Geothermal energy can be described as the heat generated within the earth which could be exploited for human use. Geothermal resources are generally associated with tectonically active region which are generated as a result of temperature difference between the different parts of the asthenosphere (below the lithosphere) where convection movement are formed. This slow convection movement is said to be maintained by the radioactive elements and heat from the deepest part of the earth [10]. Nigeria reveals a significant geothermal potential for high and low temperature geothermal system. The geological structure of Nigeria influences geothermal exploration extent within each geological province. Sedimentary basins in Nigeria have been explored for hydrocarbons for several decades, thus the oil companies collected large subsurface temperature data basis. But not much is known about geothermal conditions within Nigerian Precambrian crystalline province. Interest in studying geological structure by the integration of geophysical methods has been proven to have the capability of accurately characterizing geothermal reservoirs and exploration. Considering these geological and structural conditions in Nigeria, three major areas have been identified for geothermal resource development namely; The Ikogosi warm spring located in Ekiti State, the Wikki spring in Bauchi and the Rafin rewa spring located in Plateau. Besides these major areas, minor geothermal resources may exist in other parts of the country where fault related proofs may occur as surface expression [8, 10].

In order to validate these conditions, there is a need to carry out geophysical surveys for data acquisition because geophysical data has been proven to have the capability of accurately characterizing geothermal reservoirs and exploring for new ones as long as more than one method is being considered for interpretation.

Different data provides different levels of accuracy, from heat anomalies, structural elements. By correlating different data sets, it is possible to decipher which ones are showing geothermal. In particular, the identification of geological lineaments is considered to be a valuable tool for recognizing geological structure and indicating deformation mechanics [4, 5, 11]. This research work therefore attempts to characterize the subsurface geological layers and structures beneath the Ikogosi geothermal system using the magnetic geophysical method for geothermal energy utilization. The magnetic survey was carried out in the Ikogosi Warm Spring. The magnetic method of geophysical exploration involves measurements of the direction, gradient, or intensity of the Earth's magnetic field and interpretation of variations in these quantities over the area of investigation. Magnetic surveys can be made on the land surface, from an aircraft, or from a ship. Most exploration surveys made today measure either the relative or absolute intensity of the total field or the vertical component.

1.1 Theory of Magnetic Methods

The source of the earth's magnetism is assumed to be the liquid outer core. This cools outside and it leads to the material becoming denser and sinking towards the inside of

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the outer core and new warm liquid matter rising to the outside. Thus, liquid metallic matter generates convection currents which move through a weak cosmic magnetic field that subsequently produce induction currents. It is this induction current that generate the earth's magnetic field [18]. Crystals with magnetic minerals are the major content of most rocks of the earth's crust. Thus, most rocks contain some certain amount of magnetism which usually have two components; induction by the magnetic field present while taking measurement, and remnant which formed during geologic history [15]. However, the ground magnetic study is used for detail mapping in order to understand the subsurface geology of an area. The technique requires measurements of the amplitude of magnetic components at discrete points along traverses distributed regularly throughout the survey area of interest. In ground magnetic study, three components are examined which are horizontal, vertical and total components. The vertical components and the total components were mostly used in the past studies to delineate faults, fractures, depth to magnetic basement and other geological structures [7,9].

$$\nabla . A = 4\pi\vec{\nabla}.\vec{J} \qquad (1)$$

Equation (1) is the required potential equation within regions occupied by magnetic bodies.

When a magnetic field is applied to a material it responds by becoming magnetised (*M*); such magnetisation is a measurement of magnetic moment per unit volume of material. The field applied to the material is called the applied field (*H*) and is the total field that would be present if the field were applied to a vacuum. This applied field (*H*) is related to magnetic induction (*B*) which is the total flux of magnetic field lines through a cross-sectional area of the material, considering both lines of force from the applied field and from the material's magnetisation. *B*, *H* and *M* are related by equation (1) in S.I. units.

$$B = \mu_0(H + M) \qquad (2)$$

The constant μ_o is the permeability of free space ($4\pi \times 10^{-7} Hm^{-1}$) which is the ratio of *B/H* measured in a vacuum. Magnetic susceptibility *(k)* is another important parameter demonstrating the type of magnetic material and the strength of that type of magnetic effect, such as magnetic permeability, μ_o. The relationship between magnetic induction B, magnetising force H and susceptibility k, as given by Reynolds [16] is:

$$B = \mu_0 H (1+k) \qquad (3)$$

where *B* is in tesla, μ_0 is free space permeability, *H* is given in amperes/metres and *k* is dimensionless in SI units.

1.3Background and Geological Settings of Study Area

The Ikogosi Warm Spring is located in the southwestern part of Ekiti State of Nigeria (Figure 1). It is situated between lofty steep-sided and heavily wooded, north-south trending hills about 27.4 km east of Ilesha, and about 10.4 km southeast of Effon Alaye [17]. It lies on the geographic latitude of 7°35′N and longitude 5°00′E (Figure 1).The area covered by this study lies approximately between geographic latitudes 7°35′30″ N and 7°35′45″ N and geographic longitude 4°58′45″E and 4°58′54″ E . The spring is a low enthalpy system, with temperature being around 38.6 ^{0}C as at last average measurement of morning, afternoon and night readings for the past six months. The temperature of the spring increases when the surrounding is cooler especially in the morning and night periods. The geothermal system discharges a virtually constant volume of water all year round. It is a popular national tourist attraction.

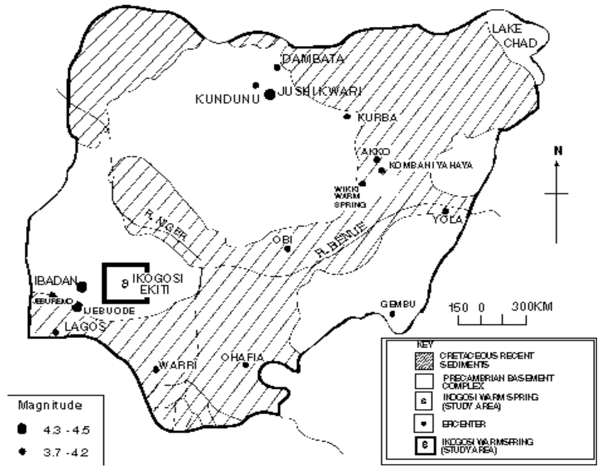

Figure 1. Location Map of Ikogosi Warm Spring in the basement complex of Nigeria [2].

The Ikogosi area is underlain by south-western Nigeria's basement complex rocks. The basement complex rocks can be classified [14] into the migmatite gneiss-quartzite complex; slightly migmatised to non-migmatised metasedimentary and metaigneous rocks; and members of the older granite suite. The study area is underlain by a group of slightly migmatised to non-migmatised para-schists and meta-igneous rocks. This group contains rocks which have been previously described as being younger or newer metasediments: the Effon Psammite formation and the associated epidiorite schist and amphibolite complex. The Effon Psammite formation [3] comprises quartzites, quartz schists and granulites which occur largely east of Ilesha and run for nearly 180 km in a NNE-SSW direction. There are three varieties of quartzite in the study area (Fig. 2); these include massive quartzite, fissile quartzite and mica schist/quartz schist.

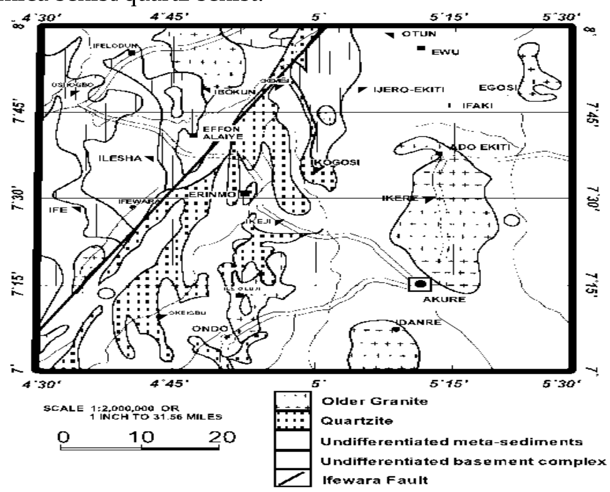

Figure 2. Geological map of the study area [1].

Figgeological features such as faults and shear zones are concealed; however fractures can be identified on a number of few outcrops along river valleys and on hill tops/slopes. The study area is of rugged terrain (Figure 10) with undulating hills and thick vegetation. The topographical elevation determined varies from less than 473m in the valleys to 533m on the hills (Figure10).

2.0.Methodology

2.1Data Acquisition and Processing

The major instruments used for the magnetic survey are the Geometrics 856 Proton precision Magnetometer and Garmin Global Positioning System (GPS) navigational equipment for geographical coordinate measurements while the magnetometer measures the Earth's total magnetic field in gamma (nanotesla, nT). The magnetic survey was carried out within the vicinity of the warm spring's area. The horizontal profiling was adopted for the magnetic method and twelve (12) N-S traverses of 180 points were established covering about 55 m by 75 m. The station interval (profile-profile separation) is 5 m while the distance between lines is 5 m intervals to achieve the best result of near-surface geological features, such as faults and fractured zones. The observed magnetic field data was corrected for diurnal variations and offset by subtracting the regional magnetic field from magnetic field measurements taken along the profiles.

$$\Delta r(residual) = \Delta T(corrected\ field\ data) - \Delta R(regional\ value) \quad (4)$$

The Microsoft Excel package was used to obtain the regional ΔR values for the total component of the magnetic intensity. The residual Δr values were obtained (equation 4) by subtracting the regional ΔR values from the corrected field data ΔT. The value on the line was taken from the original (raw data) value to obtain either positive or negative values, which depicts anomaly in the data. The corrected magnetic data were used to prepare each magnetic profiles and Golden software was used to get the contour, topography, grid, 3D surface and image maps for the study area (Figures 9-13). The magnetic data developed were processed so as to prepare the dataset for interpretations. The magnetic profiles were also used to estimate the approximate depth to the magnetic anomalies and heat source. The peak points (positive or negative) on the magnetic profile plots (Figures 3-8) are taken as reference points for the results of the depth estimation in the table provided (Table 1).

For accuracy during measurement, the best method is to adjust the sensor in the same direction at each station when taking readings. On each profile, a tangent was drawn to the point of maximum slope, using a right-angled triangle construction; also a second line with half the same slope was drawn. The horizontal distance (S) existing between these two tangents is a measure of the depth to the magnetic body. The method of obtaining the above horizontal distance (S) is known as Peter's half slope method. The estimate depth (d) to the top of the magnetized body can be calculated using equation 5, where (S) is the horizontal distance between half-slope tangents and *k* is a constant [13].

$$d = kS \quad (5)$$

where: *d* is the depth, *S* is the horizontal extent of the tangent and $1.2 \leq k \leq 2.0$. For this work, $k=2$ was used.

3.0 Results and Discussion

The negative and low magnetic peak profiles represent typical anomalous signatures in low-latitude magnetic regions (around the equator where Nigeria is located) [6, 12]. Comparing these 'lows' from profile-to-profile may define a fault line zone or magnetic mineral-bearing fault zone. Figure (9) shows the contour map for the study area. Since quartzites are metamorphic rocks having relatively low magnetic susceptibility, magnetic anomalies were assumed to have resulted from magnetic materials contained within the fractured quartzite/faulted zones relative to the fresh massive quartzite bedrock.

Contour lines that are widely spaced imply shallow slope, which is an area with lower magnetic susceptibility. The prominence of sudden change in the contour over an appreciable distance, which trends frequently in the south-west direction of the study area, implies discontinuity in depth, possibly subsurface major faults.

The 3D surface and Image maps (Figure 12 and 13) have been able to show the location and signatures of the magnetic reserves in the study area. The vector map (Figure 11) suggests appreciable magnetic minerals that cause unusual changes in the direction of magnetic field and clearly highlights different changes in the direction of the magnetic field, which suggests that the target location where the magnetic source is more significant appears within that region of the map, and such area indicates the presence of fracture. Some of the graphs (Figures 3-8) and maps for the whole study area (Figures 9-13) instead of individual profiles and maps are presented in this paper to minimize space. The selected graphs are presented because they clearly have distinct magnetic signatures (Figures 3-8). Table 1 presents and determines the estimated basement depths to top and center of anomaly. Profile 12 has the highest amplitude of 748 nT followed by profile 9 and profile 7 with 746.7 and 705 nT, respectively (Figures 8, 6 and 5). It was also observed that the minimum depth is 8 m which indicates near-surface feature and maximum depth of 14m (Table 1). High residual points (Figures 3-8) are suspected area with near surface rocks with appreciable magnetite content. Points on profile 3, (Figure 8) are suspected to be fractured because of the wide gap between two peak points. Low residual points (Figures 8 and 12) are suspected area with non-magnetic minerals or contact between rocks. Two anomalous zones were marked out at the southern part of the survey area, across Profiles 1 and 2 and on the north-eastern part, across Profiles 11 and 12 (Figures 7 and 8). Magnetic anomaly amplitude for these two identified anomalous zones ranged between -235.9 and -679 nT. The area having high magnetic intensity correlated to intensely fractured/faulted quartzite block (Figure 9), having an approximately north-easterly trend. The spring outlet was located at the interface between the low and high magnetic intensity zones.

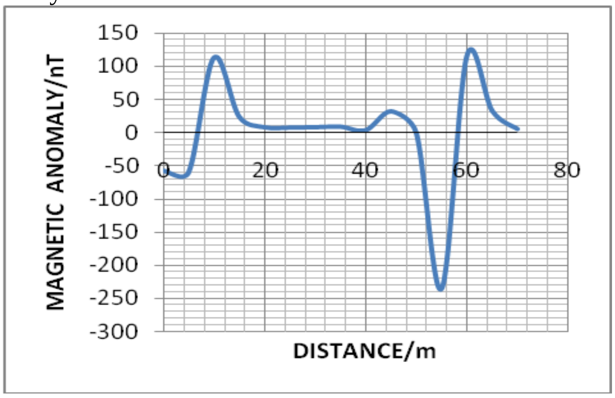

Figure 3. Corrected Magnetic Field Plot for Profile 1.

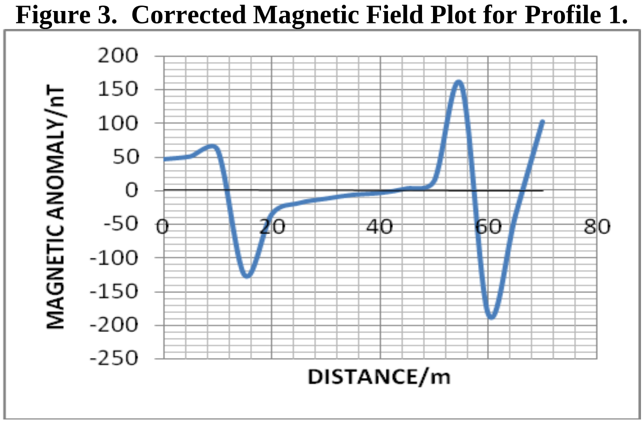

Figure 4. Corrected Magnetic Field Plot for Profile 2.

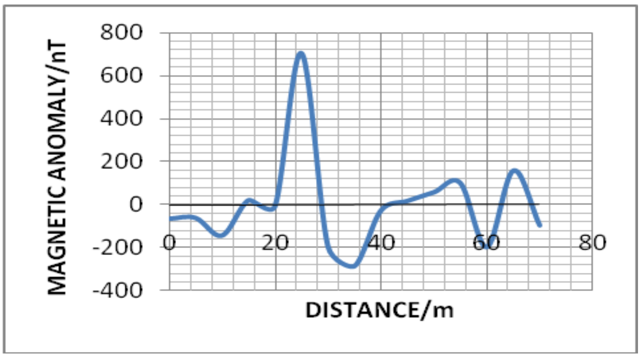

Figure 5. Corrected Magnetic Field Plot for Profile 7.

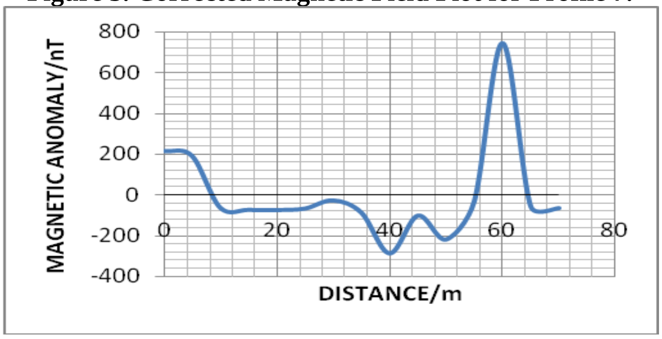

Figure 6. Corrected Magnetic Field Plot for Profile 9.

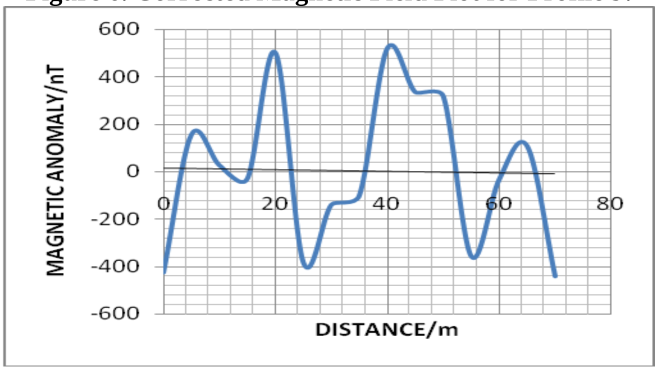

Figure 7. Corrected Magnetic Field Plot for Profile 11.

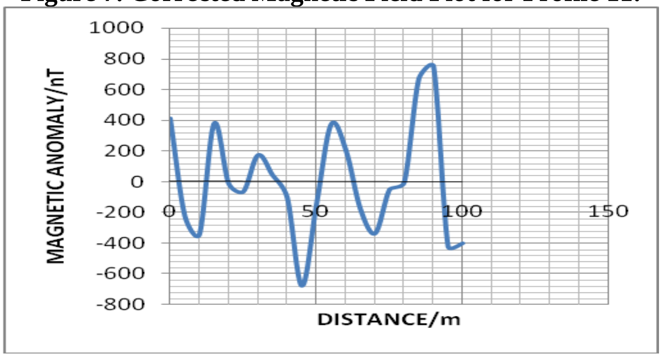

Figure 8. Corrected Magnetic Field Plot for Profile 12.

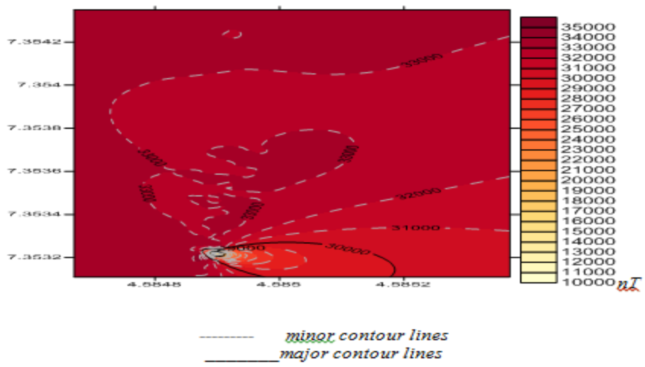

Figure 9. Magnetic contour map for study area showing the variation of the magnetic anomalies.

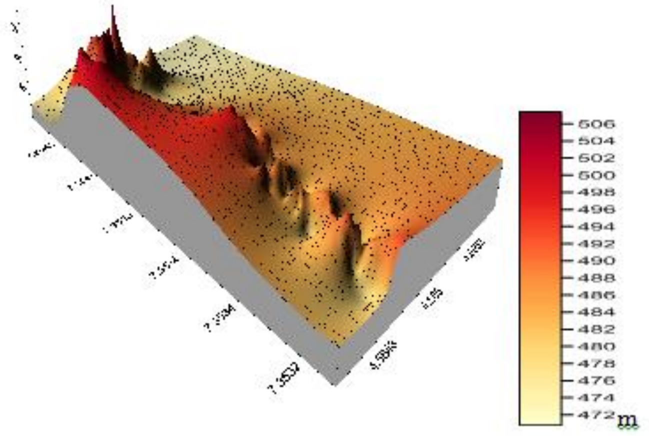

Figure 10. 3D Elevation map of study area showing attenuating topography.

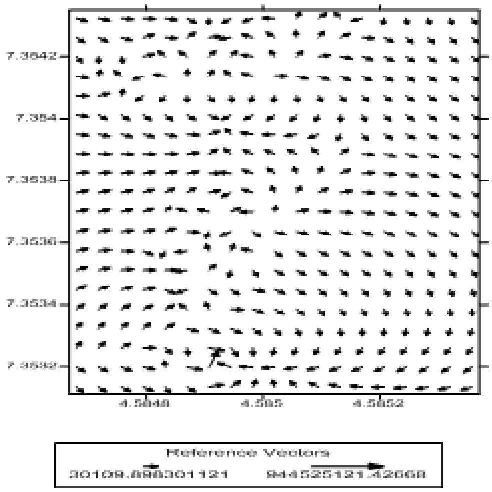

Figure 11. 1-Grid Vector Map for Study Area.

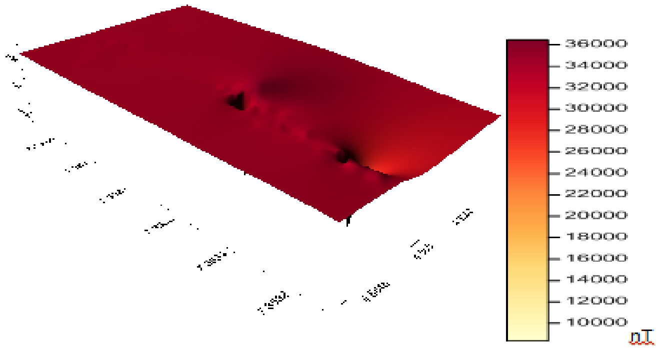

Figure 12. 3D Surface Map of Study Area.

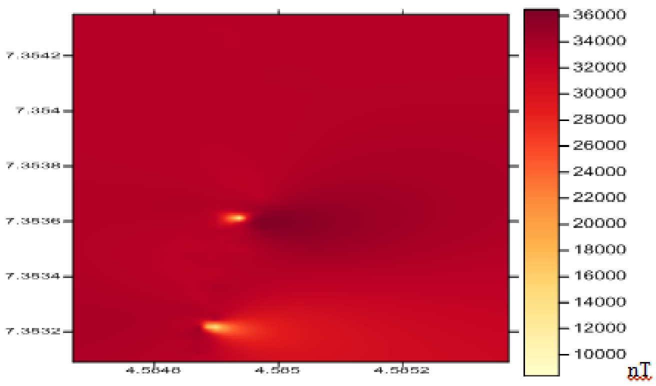

Figure 13. Image Map of study area.

Table 1. Estimated Depth to Anomaly Sources using the Slope Methods.

	Peak 1/m	Peak 2/m	Peak 3/m	Peak 4/m	Amplitude/nT		Average Depth/m
					Low	High	
Profile 1	10	8	12	10	-235.9	115.3	10
Profile 2	10	8	8	-	-184.9	156.5	8.7
Profile 3	10	6	-	-	-51.5	81.1	8
Profile 4	14	-	-	-	-233.1	158.7	14
Profile 5	10	-	-	-	-53.4	164.6	10
Profile 6	6	8	10	-	-570	387	8
Profile 7	10	12	10	-	-286	705	10.7
Profile 8	12	10	12	10	-286	222	11
Profile 9	10	10	-	-	-216.9	746.7	10
Profile 10	10	12	10	10	-459	518	10.5
Profile 11	8	8	8	10	-442	518	8.5
Profile 12	10	12	10	10	-679	748	10.5

4.0 Conclusion

The magnetic data have been able to identify the fractured and quartzite/faulted zone as a result of the magnetic minerals contained in it. It was suspected that the fractured/faulted quartzite may have acted as conduits for the movement of warm groundwater from deep depth to the surface. The depth to magnetic sources estimated in this research and its correlation with the faulting systems provides information about the geodynamic activities around Ikogosi warm spring. The estimated depth to magnetic anomaly which is probably an indicative of magma intrusion is relatively shallow and thus has several implications on the geothermal resources and tectonic activities in the area. The heat flow in the area is high enough to cause the surface geothermal manifestation. It can be concluded therefore from the interpreted data supported by existing literature and other field observations that the manifestation of hot spring in Ikogosi is largely supported by the presence of faults and that the area is promising for further geothermal exploration.

Hence, there is a need for further study in the area using more advanced approach and application of other geophysical methods such as seismic, electrical, radiometric and remote sensing so as to have a better understanding of the geothermal settings for possible exploration and drilling activities.

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