Preliminary Evaluation of Geothermal Energy Potential in Western Part of Dahomey Basin, Southwestern Nigeria

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Preliminary evaluation of geothermal energy potential in western part of Dahomey Basin, Southwestern Nigeria

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Summary

Geothermal Energy, Dahomey Basin, Curie Point Depth, Temperature Gradient, Heat Flux

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Introduction

Recently, an active geothermal energy source was discovered in Isheri area (Lasena Water Company) of Ogun state, Southwestern Nigeria. Drillers drilling deep boreholes for "large quantity" groundwater exploitation accidentally intersected an aquifer of very hot water having temperature of between to 72 – 75ºC at a drill depth of 425 m. For geophysicists interested in geothermal energy exploration, such accidental discovery is an indicator of a potentially viable "geothermal energy field" that requires coordinated exploration for proper characterisation and exploitation.

In an effort to fully explore and characterise the geothermal capability of this potential "geothermal field" which is situated in the western part of the Nigerian sector of the Dahomey basin within the Gulf of Guinea, and to make recommendation towards its development for exploitation, geophysical methods involving integration of magnetic and borehole logging methods of geophysical prospecting were deployed to estimate the Curie Point Depth (CPD), temperature gradient and heat flux in the region. This research seeks to reveal how viable it is to embark on geothermal energy exploitation campaign in this area.

Hot springs are known to occur randomly across most regions of Nigeria. Also, temperature data from boreholes drilled by oil explorationists in the sedimentary basins showed thermal gradient values higher than the expected normal in these sedimentary basins (Kwaya and Kurowska, 2018; Olumide *et al.*, 2013). These facts have fuelled the speculations that Nigeria possibly has enormous geothermal energy potential. The aforementioned facts, coupled with the accidental discovery at Isheri area, is opined, should necessitate coordinated geothermal energy exploration which could supplement the use of fossil fuel especially in basins such as the Dahomey basin that has shown significantly less potential in terms of hydrocarbon prospect when compared to the popular, neighbouring Niger delta. While the major aim of this research is to reveal how viable it is to embark on geothermal energy exploitation campaign in the western part of the Nigerian sector of the Dahomey basin, an important objective of the study is to start a coordinated geothermal energy exploration attempt in the area and present verifiable facts which would either concretize or counterfeit the speculations about the geothermal energy potentials of the Dahomey basin.

Based on onsite information obtained from the geologist who supervised the drilling at the borehole point where hot water aquifer was intersected at Isheri, the temperature of water lifted at the depth of 425 m was 73ºC. This translates to a temperature gradient of 171.32 ºC/km or 0.171 ºC/m. The water is artesian in nature, coming out with strong pressure from within the subsurface.

The study area is designated as the western part of the Nigerian sector of the Dahomey basin. It is located around the southwestern corner of Nigeria, starting from close to the Nigerian border with the Republic of Benin and spanning eastwards. It covers an area of 55 x 110 km dimension from Longitude 03º 00'00" E to 04º 00'00" E; and Latitude 06º 30'00" N to 07º 00'00" N. Expressed in the Universal Transverse Mercator Projection system, it falls within the Zone 31N and extends from 500000 mE to 610000 mE; and 718000 mN to 774150 mN with reference to the WGS'84 datum (Figure 1).

The Dahomey basin where the study area is located, is situated in the upper region of the Gulf of Guinea. Tectonically, the region is a passive rifted margin whose framework (rifts) were initiated during the separation of the South American plate from the African plate (Omatsola and Adegoke, 1981; Petters, 1982; Brownfield and Charpentier, 2007). While the major transform fault zones that have been identified within the Gulf of Guinea were the Four North fault zone, St. Paul fault zones, Romanche fault zone and the Chain fault zone (Brownfield and Charpentier, 2007), those that are particularly within the enclave of the Dahomey basin are the Romanche fault zone and the Chain fault zones (Omatsola and Adegoke, 1981; Babalola, 1988; Brownfield and Charpentier, 2007). The transform faults were believed to be related to plate movement from the proximal mid-ocean (Atlantic) ridge

(Kutu, 2013). The Romanche fault appeared to enter into the continent from the offshore through southern Ghana (Kutu, 2013) while the Chain fault zone entered the continent through southwestern Nigeria, cutting through the uplifted expression of the Okiti-pupa ridge (which demarcates the Dahomey Basin from the Niger Delta), and bending westwards into the Dahomey basin sector region of Nigeria (Balogun *et al.*, 2016). According to Balogun and Ojo (2016), Crustal thicknesses from spectral analysis of gravity data presented the crust under the onshore region of the Nigerian sector of Dahomey basin as relatively thin, ranging between 26 and 30 km. Depth to basement in this region is about 1.5 km (Avbovbo, 1980).

Method and/or Theory

The methods adopted involved the integration of magnetic and borehole logging methods of geophysical prospecting to evaluate the Curie Point Depth (CPD), characterise the lithology and delineate the geothermal energy reservoir within the study area. Spectral analysis was performed on the magnetic data and their radial averaged power spectra were interpreted for the depth to the top (Z_T) and depth to the centroid (Z_o) of magnetic sources in order to estimate the CPD. Depth to the base of magnetic sources which invariably corresponds to the CPD was computed using equation 1 below.

$$Z_{CPD} = 2Z_o - Z_T \qquad 1$$

Equations 2 and 3 give the formula used for the computation of the geothermal gradient (∇T) and the heat flux (q) within the study area respectively.

$$\nabla T = \frac{dT}{dZ} \qquad 2;$$

where T is temperature (in ºC) and Z is depth (in m); unit of ∇T can either be in ºC/km or ºC/m

$$q = k\frac{dT}{dZ} = k\frac{\theta_C}{Z_{CPD}} \qquad 3$$

where k is coefficient of thermal conductivity and its unit is in W m^{-1} $°C^{-1}$;

θ_C is the Curie temperature usually given as 580 ℃. Unit of q is Wm^{-2}.

Due to the inverse relationship that exists between crustal magnetism and temperature, shallow CPD would indeed mean that temperature gradient is rather high within the subsurface and this would in turn suggest that such region can be a good geothermal energy prospect.

Wireline logging was also done at the drilled hole where drillers accidentally intercepted hot water (72 – 75ºC) at a depth of 425 m. The suites of wireline logs engaged were the gamma ray, spontaneous potential and resistivity logs (Single Point Resistance, Short Normal and Long Normal). Though the suite of well logs combined were primarily suitable for lithologic identification, they were adopted for this geothermal study so that in addition to lithologic discrimination, they may be observed if probably they may reflect some noticeable, consistent changes in the vicinity of the hot water aquifer where existing physical properties are expected to be influenced by the remarkable change in temperature since there is no access to temperature logs. The basic theories on the principles of wireline logging are well detailed in Passey *et al.*, 1990 and Bassiouni (1994).

Results and Discussion

The CPD, Temperature Gradient and Heat Flux Estimates

The aeromagnetic map of the study area is shown in Figure 2. The result of the spectral analysis performed on the aeromagnetic data showed that the Curie Point Depth (CPD) is generally very shallow in the whole study area, ranging from 1.454 to 3.645 km (Figure 3). The CPD is deepest in the western part (3.645 km) and shallowest at the central part, being just 1.454 km in the area. CPD at the eastern part is moderate (1.831 km) relative to the western and central parts.

The temperature gradient ($\frac{dT}{dZ}$) is generally high in the region, ranging between 159.12 ºC/km to 398.90 ºC/km. The computed temperature gradient values, based on the estimated CPD, are 159.12 ºC/km, 398.90 ºC/km and 316.77 ºC/km in the western, central and eastern parts of the study area respectively (Figure 4). From the theoretical estimation done from the analysis of magnetic data, the geothermal gradient at the region surrounding the Isheri borehole where an aquifer of hot water was intersected at 425 m was evaluated as 398.90 ^{o}C/km which is a value that reflects that the area is a very viable geothermal field. It was noted however, that the value estimated theoretically (i.e. 398.90 ^{o}C/km) was significantly higher than the value of 171.76 ^{o}C/km obtained from the real-time data gotten at the drilling site. This was suggested be due to the fact that the evaluation of geothermal gradient from the real-time data (at the drilling site) relied on heat data derived from hot water (which itself was likely heated through deep circulation of groundwater) and not the direct heat from the subsurface rock or conduit serving as the heat source. It should be noted that the coefficient of thermal conductivity of water is 0.6 W m^{-1} ^{o}C^{-1} (or 0.6 W m^{-1} K^{-1}), a value that is significantly less than the 2.2 W m^{-1} ^{o}C^{-1} (or 2.2 W m^{-1} K^{-1}) which is the value for most earth materials in the subsurface (Pribnow *et al.,* 1996; Shen *et al.,* 2020).

The value of the heat flux obtained from the analysis of the aeromagnetic data ranged from 350.0686 mW/m^2 at the western part, 877.5791 mW/m^2 at the central part to 696.8869 mW/m^2 at the eastern part (Figure 5). The estimated CPD, temperature gradient and heat flux reflected very high geothermal energy potential.

The Borehole Logs

The suite of logs deployed were the Normal Gamma Ray (NGAM), Spontaneous Potential (SP), Single Point Resistivity (SPR), Long Normal Resistivity (LON) and the Short Normal Resistivity (SHN) logs. The integrated interpretation of logs delineated three (3) basic lithologies which were the Clay, Sandy clay/Clayey sand and Sand units which occurred as intercalations (Figure 6). About 60% of the well section is constituted by Clay, about 15% by Sandy clay/Clayey sand and about 25% by sand. The major aquiferrous units in the borehole are the sand units. Four of such sand units were identified within the drilled section and were found to occur at 20 – 30 m, 190 – 225 m, 295 – 350 m and 425 to 450 m.

As expected, relatively high resistivities were observed over the sand units while lower resistivities were observed over the clay/sandy clay/clayey sand units. SP values were lower over the sand units and relatively higher over the clay units. The response of the logs over the sand that constitute the hot water aquifer (at depth between 425 to 450 m) was not different from the response observed over cold water aquifer.

Conclusion

While the whole study area showed very high potential for geothermal energy development, the central part which is where the Lasena Water Company, MTU mini campus and MTU permanent site are located have the greatest geothermal potential (with heat flux approaching 877.58 mWm^{-2}). Therefore, with what is verifiable at Lasena Water Company's site which is where the hot water aquifer was intersected, it is pretty safe to say that geothermal energy is available for exploitation in the study area especially at the central part. When compared with known geothermal provinces in Africa, the study area appears to be viable. The thermal gradient and heat flux values were much greater than the maximum values (34 ^{o}C/km and 72.87 mWm^{-2}) obtained (also from analysis of magnetic data) at the eastern coast of the well explored Gulf of Suez in Egypt which has been classified as a viable geothermal field (Selim and Aboud, 2014). It is also greater than the values obtained at central Cameroon which has a maximum thermal gradient and heat flux of 111.11 ^{o}C/km and 277.77 mWm^{-2} respectively (Mono *et al.,* 2018), and comparable to the value of above 200 ^{o}C/km obtained at the proven geothermal fields of Kenya (Mwawongo, 2013) where geothermal energy is currently being exploited expressly.

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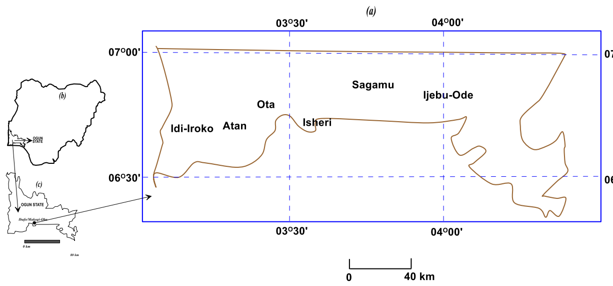

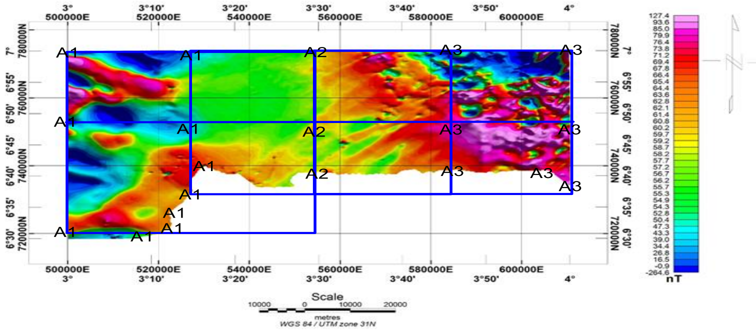

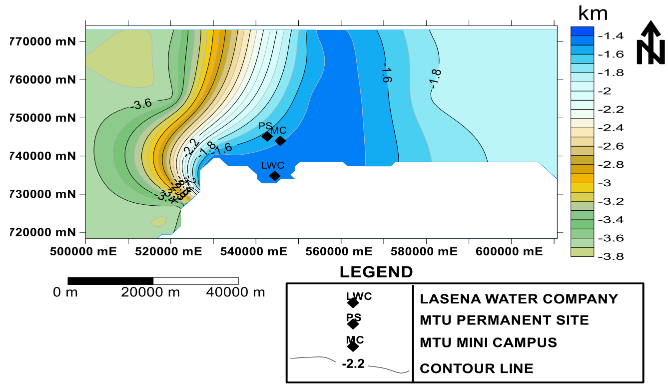

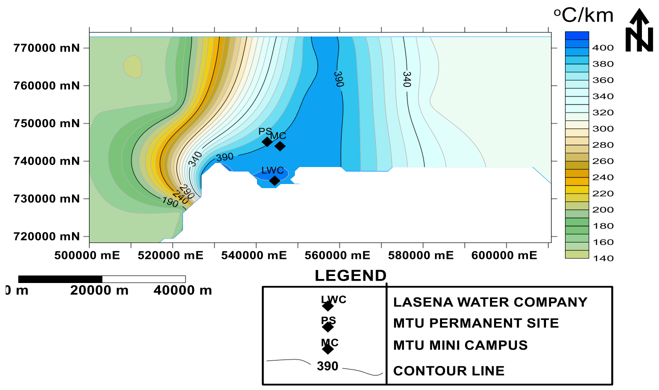

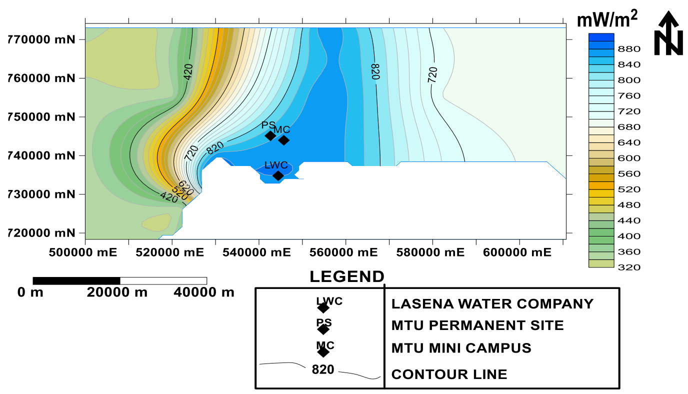

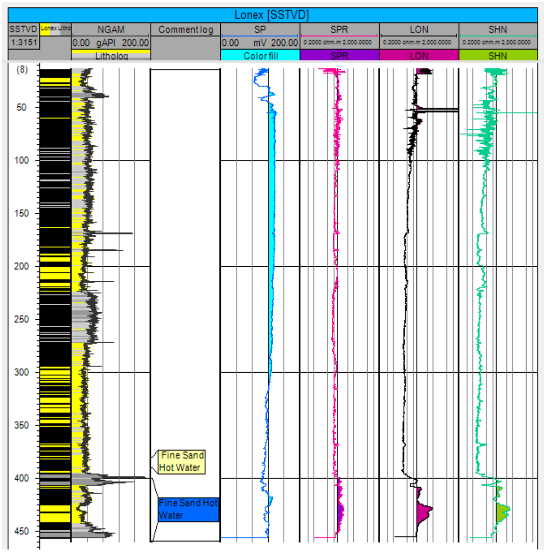

Figure 1 (Top Left): Location Map of the Study Area
Figure 2 (Top Right): Aeromagnetic Map of the Study Area
Figure 3 (Left Middle): Map of the Curie Point Depth
Figure 4 (Right Middle): Map of the Temperature Gradient
Figure 5 (Bottom Left): Map of the Heat Flux
Figure 6 (Bottom Right): Well section showing the response of the wireline logs deployed at the hole where hot water aquifer was intersected at Isheri.