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Full Length Research Paper

Determination of geothermal gradient and heat flow distribution in Delta State, Nigeria

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Geothermal and heat flow distribution study was carried out at eighteen locations in Delta State, Nigeria using field data obtained from temperature logging and thermal conductivity measurements. The study shows that the geothermal gradients for the area ranges from a minimum of 25.47°C/km to a maximum of 31.16°C/km and a mean geothermal gradient of 28.64°C/km. This result indicates that the geothermal gradient falls within the range interval typical of the gradients commonly encountered in tectonically inactive areas. The study also shows that the heat flow ranges from 38.93 to 89.59 mWm^{-2} with a mean heat flow of 62.70 mWm^{-2}. The study reveals that the heat flow and geothermal gradient of the study area decreases southward toward the ocean. This implies that fluid migration path is to the south of the study area.

Key words: Heat flow, geothermal gradient, temperature, thermal conductivity, bottom-hole temperature.

INTRODUCTION

Geothermal gradient is the rate of increase in temperature per unit depth in the earth due to the outflow of heat from the centre (Lowrie, 1997). The temperature gradient between the centre of the earth and the outer limits of the atmosphere is about 1°C/km^{-1} on the average (Lowrie, 1997). Geothermal gradients are very useful indicators of subsurface temperature distribution. A geothermal gradient is one of the most frequently used parameters in logging geophysics (Kutasov and Eppelbaum, 2009) and it is useful in the understanding of regional and subregional tectonics. It is also useful in the assessment of geothermal resource potentials of an area (Nwankwo and Ekine, 2009; Kutasov and Eppelbaum, 2010).

Borehole temperature measurements are important in several areas of underground resource investigation and management. In mineral exploration, it aids the detection of massive minerals while in hydrogeology, temperature variations can be a key element in the understanding of groundwater flow. Departures from the geothermal gradient are usually indicators of fluid movement. They tend to be proportional to the mass flow rate of the liquid present. The differential temperature curve is used to accentuate the occurrences of changes.

Some temperature studies in the Niger Delta area have made use of bottom-hole temperatures (Nwachukwu, 1976). For instance, Akpabio and Ejedawe (2001) used the linear extrapolation between ambient and bottom hole temperature to develop a geothermal gradient map of the Niger Delta. Approximate temperature at various depths in different parts of an area can be estimated from such single trend and temperature gradient maps (Bayram et al., 2011). Isotherm maps derived from the temperature plot from the Niger Delta indicate that temperature of 150°C can be obtained over much of the Niger Delta at a depth less than 5 km (Akpabio and Ejedowe, 2001).

When the depth of investigation is limited, the temperature recorded will be that of the fluid surrounding the sensor and it should be representative of the temperature of the surrounding rock formations. The sub-surface temperature increases in a very irregular manner in relation to depth. On the average, it increases by 1°C for every 30 m (Nwankwo and Ekine, 2009). This is known as the geothermal degree which varies from one place to another depending on topographic conditions, present rock types and geological history of the region.

Measured subsurface temperature from open-hole log is always lower than the true formation temperature. During the drilling of wells, a large quantity of mud is circulated in the borehole to facilitate the drilling, evacuate the cuttings and stabilize the hole. The influence of this circulation and other drilling effects like

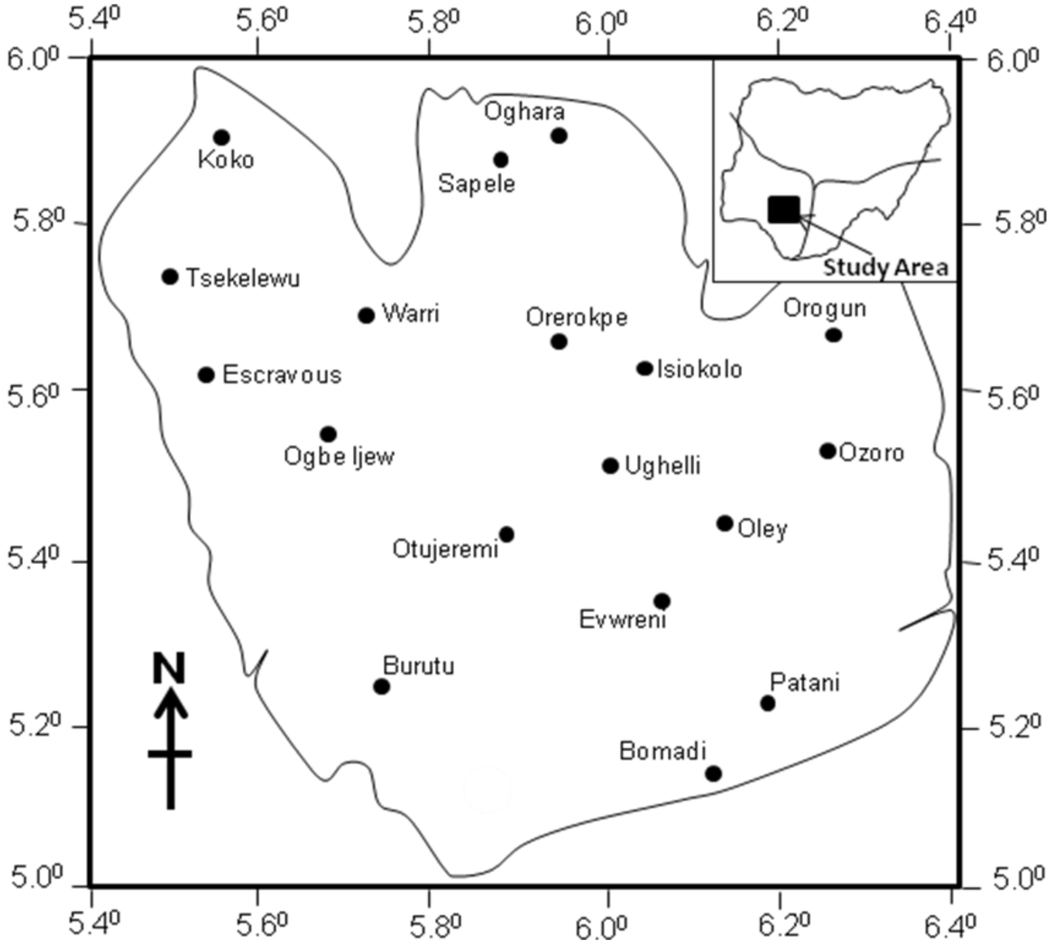

Figure 1. Location map of the study area.

thermal properties of the drilling fluid, nature of heat exchange between borehole and the well, duration of drilling and non equilibrium temperature at the time of temperature measurements on the formation were reasons why bottom hole temperature data was rarely used in geophysical studies in the past. Several methods to correct this pitfall have been proposed by many authors, such as the correction made by Davies et al. (2007).

It is a well established fact that temperature increases with depth in the earth. This is an indication that heat is generated at depth and transferred through rock and sediment layers to the surface. By assuming a linear relationship of temperature and depth, the geothermal gradient is determined.

Four different methods are employed in determining thermal gradients, depending on the characteristics of primary data. These are designated as the conventional (CVL), conventional bottom temperature (CBT), aquifer temperature (AQT) and geochemical (GCL) methods (Gomes and Hamza, 2005).

Temperature distribution is one of the primary factors controlling hydrocarbon generation, sediment diagenesis and migration of hydrocarbons including other pore fluids (Awad et al., 2011). The temperature distribution of the area could also be a potential source of electricity generation which will be cost effective as compared to other sources. This study is therefore carried out to determine the heat flow distribution of the area. The study will also estimate the thermal conductivity and the thermal gradients in the area. This will enable the various authorities to effectively monitor and harness the geothermal potentials of the area for the good of all Nigerians.

MATERIALS AND METHODS

The study area

The study area is the oil rich state of Nigeria known as Delta State (Figure 1). It consist of eighteen locations which are Oghara, Koko, Sapele, Tsekelewu, Warri, Escravos, Ogbe-Ijaw, Otujeremi, Burutu, Bomadi, Patani, Evwreni, Oleh, Ozoro, Ughelli, Isiokolo, Orogun and Orerokpe. The area is located within latitude 5.0 to 6.0°N and longitude 5.4 to 6.4°E and consists mainly of thick friable sands with intercalation of clay beds, silts and coarse to fine grained

Table 1. Record of geothermal gradient and heat flow values from the various wells.

Location name	Location symbol	Temperature gradient (°C km^{-1})	Thermal condition 'K' ($W/m^{-1}K^{-1}$)	Heat flow (mWm^{-2})
Bomadi	A	25.47	2.21	56.32
Burutu	B	26.52	1.54	40.84
Escravos	C	29.04	2.52	73.18
Evwreni	D	27.61	1.41	38.93
Isiokolo	E	29.11	2.01	58.51
Koko	F	31.00	2.89	89.59
Ogbe Ijaw	G	28.06	2.36	66.09
Oghara	H	31.16	2.73	84.10
Oleh	I	27.84	1.49	41.48
Orerokpe	J	29.32	2.37	69.49
Orogun	K	29.14	2.35	68.48
Otujeremi	L	27.47	1.42	39.01
Ozoro	M	27.54	2.14	58.94
Patani	N	27.26	2.07	56.43
Sapele	O	30.50	2.76	84.18
Tsekelewu	P	30.18	2.83	85.41
Ughelli	Q	28.20	1.51	42.58
Warri	R	30.17	2.49	75.12

sandstones (Okwueze and Offong, 1992).

Field measurement of temperature

The procedure adopted in the measurement of temperature involves the use of the Schlumberger Auxiliary Measuring Sonde (AMS) with high sensitivity sensor known as the logging tool. The logging tool was lowered into the borehole and the temperature of various depth intervals determined in a process called continuous temperature logging method. The instrument was lowered in a slow and continuous process so that the temperatures are not altered due to agitation of the fluid when the cable and the probe pass through it. The instrument thus measured the temperature of the formation at various depth intervals. This was carried out for all the eighteen wells in the study area.

Determination of geothermal gradient

The quality consideration of the available data set are, in part, related to the characteristics of the methods used for determining gradients, which in turn depend on the nature of availability of primary temperature data. In this study, the measured temperature was plotted against the corresponding depth interval for all the wells as shown in Figure 2 and a linear least square fitted to the set of data (Anomohanran, 2004; Gomes and Hamza, 2005). The gradient of the fitting represents the geothermal gradient. A summary of geothermal gradient obtained by this method is provided in Table 1.

Determination of thermal conductivity

Soil/rock samples were collected from all eighteen wells in the study area, and were subjected to conductivity test in the laboratory. The determination of the thermal conductivity of the samples was carried out using the probe method. In using this method, the soil sample was placed inside a control furnace which produced the base temperature for the test. A certain amount of current was passed through the heater in the furnace for a period of time during which the temperature of the heater surface took on a characteristic form. First, the temperature rose rapidly and as the heat begins to soak in, the rate of rise became constant. When the thermal front reached the outer boundary of the sample, the rise in temperature began to slow down gradually until it eventually stop altogether (Norden and Forster, 2006). The record of the temperature and the time was taken. From the straight line portion of the rate curve (temperature versus time), the thermal conductivity was calculated.

Determination of heat flow

The heat flow was determined in this study by employing the conventional method of heat flow. Heat flow Q_z is usually calculated as a product of the linear least square estimate of gradient $\Delta T/\Delta D$ and the mean of thermal conductivity ρ.

This process is described by the equation (Lowrie, 1997):

$$Q_Z = \frac{\rho \Delta T}{\Delta D}$$

where Q_z is the heat flow per unit area in the vertical direction, ρ is the thermal conductivity and $\frac{\Delta T}{\Delta D}$ is the geothermal gradient.

A summary of the heat flow values obtained by the conventional method is shown in Table 1.

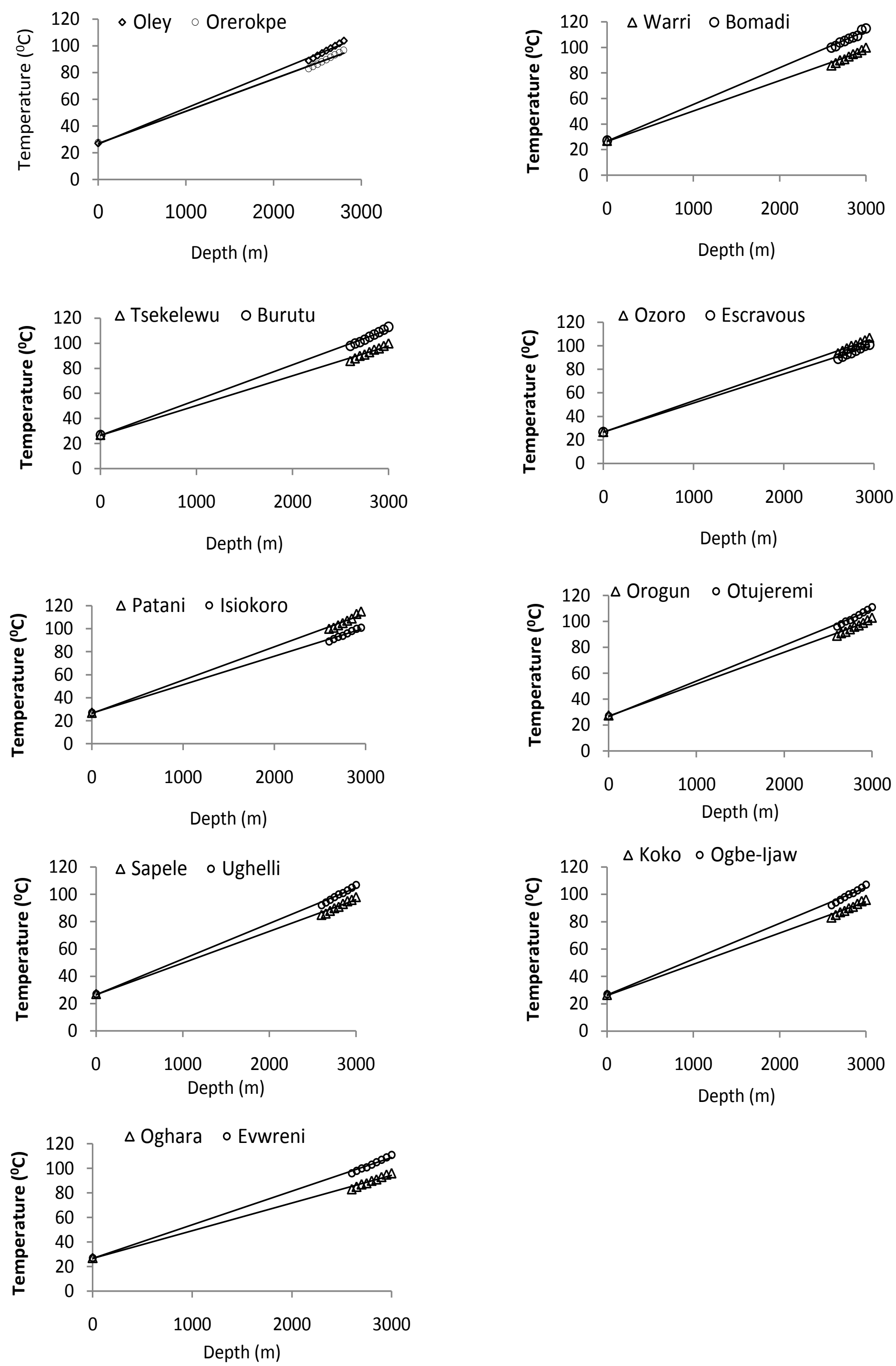

Figure 2. Temperature variation with depth of the various wells.

RESULTS AND DISCUSSION

The record of geothermal gradient and the thermal conductivity determined from this study is presented in Table 1. The plot of temperature against depth for each of the 18 wells is as shown in Figure 2. The plot shows the relationship between these two parameters and the gradient of the graph represent the thermal gradient which is also shown in Table 1. Figure 3 is the contour map of the geothermal gradient of the area while the heat flow distribution for the area is as shown in Figure 4. The study shows that the geothermal gradient for the area

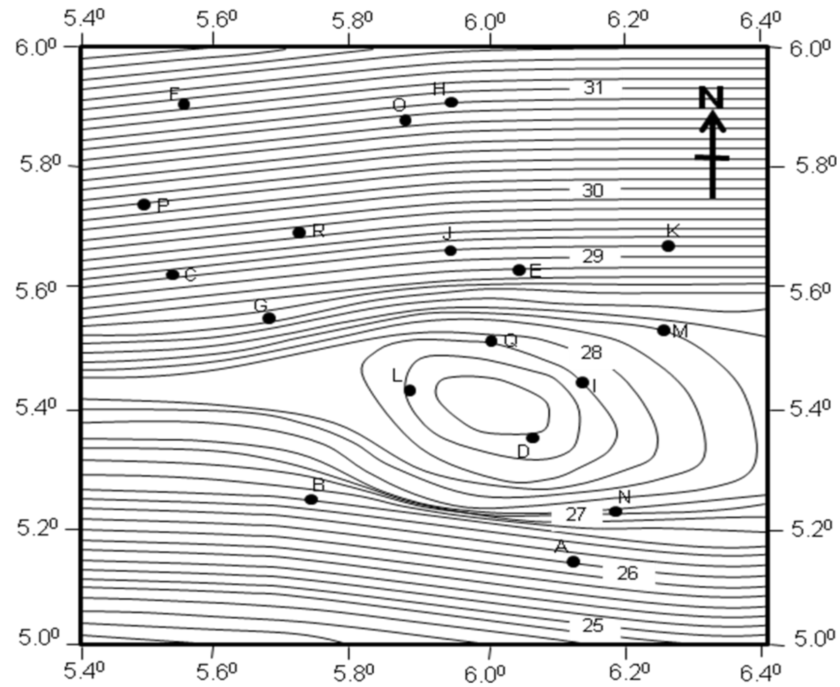

Figure 3. Contour map showing the geothermal gradient of the area.

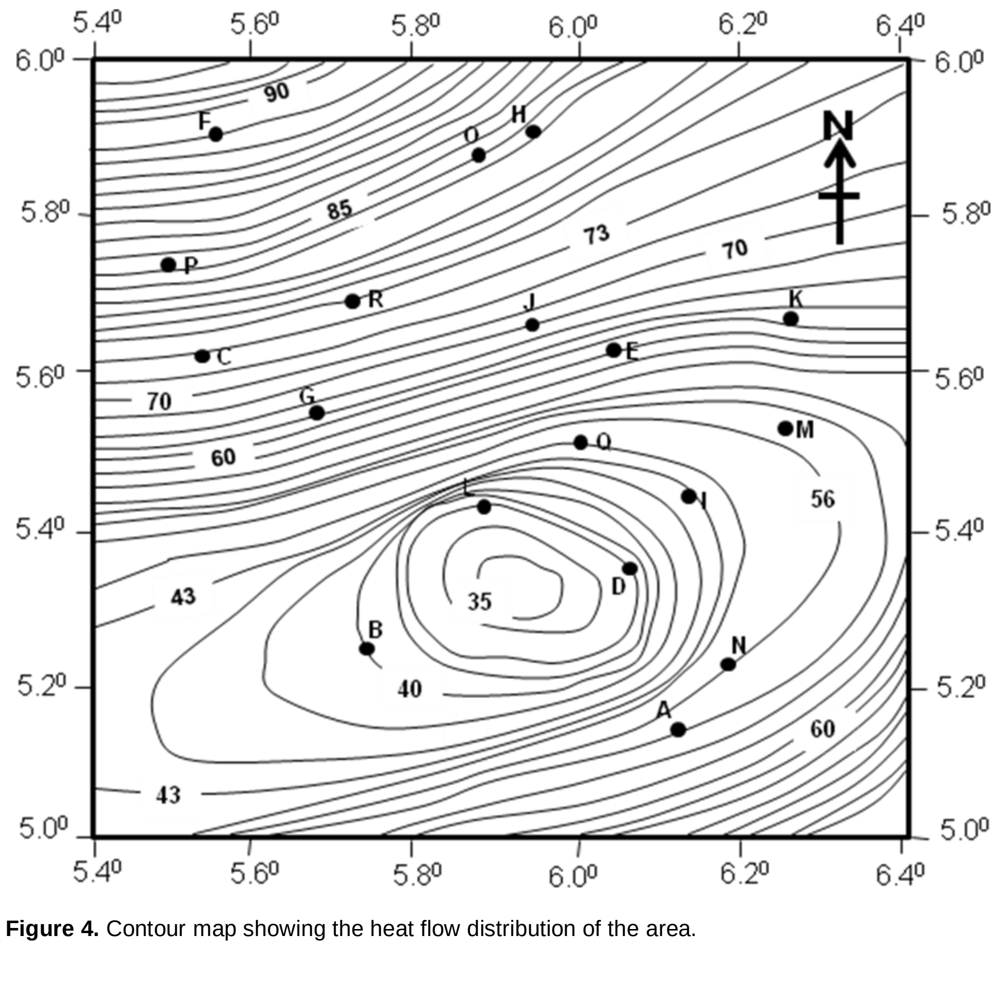

Figure 4. Contour map showing the heat flow distribution of the area.

ranges from a minimum of 25.47 to a maximum of 31.16°C km^{-1}. These range falls within the range interval typical of the gradients commonly encountered in tectonically inactive areas (Gomes and Hamza, 2005). This result conforms to earlier work carried out in the Niger Delta by Akpabio and Ejedawe (2001) which shows that the thermal gradient ranges from 26.2 to 29.5°C km^{-1}. The result is also in close relation with a study carried out in the northern part of Nigeria by Nwankwo et al. (2009) which shows that the thermal gradient of the Chad Basin of Nigeria using bottom hole temperature method ranges from 30 to 44°C km^{-1}. On the other hand, the heat flow for the study area ranges from 38.93 to 89.59 mWm^{-2}. This range according to the work of Gomes and Hamza (2005) may be considered as typical of continental crust. This is an indication of an enormous energy potential which can be utilized for many purposes, including electricity generation. The geothermal gradient contour map shows that the thermal gradient decreases southward. The contour maps of the heat flow pattern decreases from north west of the study area to a minimum at the centre and thereafter begin to increase south eastward toward the ocean. This pattern shown in the figure represents the pattern of fluid movement in the area. This fact clearly indicates that the utilization of the energy potential of the area will be optima if cited in the northern part of the study area. It also points to the fact that hydrocarbon migration path is to the south of the study area. This is the reason why more wells are expected southward of the area.

Conclusion

This work has shown that the heat flow and geothermal gradient of the study area decreases southward toward the ocean which is indicative of hydrocarbon flow direction in the area. The average geothermal gradient is 28.64°C km^{-1}, while the mean heat flow of the area is 62.70 mWm^{-2}.

REFERENCES

Akpabio IO, Ejedawe JE (2001). Temperature Variations in the Niger Delta Subsurface from Continuous Temperature logs. Global J. Pure Appl. Sci., 7:137-142.

Anomohanran O (2004). The use of third degree polynomial for accurate conversion of Seismic time to depth and vice versa. J. Niger. Assoc. Math. Phy., 8: 241-246.

Awad FG, Sibanda P, Narayana M, Motsa SS (2011). Convection from a semi-finite plate in a fluid saturated porous medium with cross-diffusion and radiative heat transfer. Int. J. Phys. Sci., 6(21): 4910-4923.

Bayram AF, Gultekin SS, Sogut AR (2011). Specifications of thermal waters and their classification on the base of neural method: Examples for Simav geothermal area, Western Turkey. Int. J. Phys. Sci., 6(1): 43-51.

Davies MG, Chapman DS, Wagoner TMV, Armstrong PA (2007). Thermal Conductivity Anisotropy of Metasedimentary and Igneous Rock. J. Geophys. Res., 112, B05216.

Gomes JJ, Hamza VM (2005). Geothermal gradient and heat flow in the State of Rio De Janeiro. Brazilian J. Geophy., 23(4), 325-347.

Kutasov IM, Eppelbaum LV (2009). Estimation of geothermal gradients from single temperature log-field cases. J. Geophys.Eng., 6(2): 131-135.

Kutasov IM, Eppelbaum LV (2010). A new method for determining the formation temperature for bottom-hole temperature logs. J. Petro Gas Engr., 1(1): 001-008.

Lowrie W (1997). Fundamentals of Geophysics, Cambridge University Press, UK.

Nwachukwu SO (1976). Approximate geothermal gradients in Niger Delta Sedimentary Basin. AAPG Bulletin, 60(7): 1073-1077.

Nwankwo CN, Ekine AS (2009). Geothermal gradients in the Chad Basin, Nigeria, from bottom hole temperature logs. Int. J. Phys. Sci., 4(12): 777-783.

Nwankwo CN, Ekine AS, Nwosu LI (2009). Estimation of the heat flow variation in the Chad Basin Nigeria. J. Appl. Sci. Environ. Manage. 13(1), 73-80.

Norden B, Forster A (2006). Thermal conductivity and radiogenic heat production of sedimentary and magmatic rocks in the North East German Basin. AAPG Bull., 90: 939-962.

Okwueze EE, Offong AO (1992). Seismic Refraction investigations of the foundation conditions of the rock/soil in parts of Akwa Ibom State of Nigeria. J. Phys., 4: 114-124.