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Radiogenic Heat Production from Well Logs in Part of Niger Delta Sedimentary Basin, Nigeria

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Abstract- The radiogenic heat produced from radioactive elements has been investigated in some parts of Niger Delta sedimentary basin. The heat production was computed from gamma ray logs for three oil producing wells. The major lithology observed in the gamma ray log is alternation of sand and shale. The computed value ranges between0.35 to 2.0μWm^{-3} for well 1, 0.34 to 1.78μWm^{-3} for well 2 and 0.24 to 2.0μWm^{-3} for well 3. The average radiogenic heat production ranges between 0.3 to 1.93μWm^{-3}. It was observed that the heat production within the sand lithology ranges from 0.24 to 0.7μWm^{-3}.Whilethe computed value for the shale lithology ranges from 0.8 to 2.0 μWm^{-3}. The high radiogenic heat production in shale was as a result of high concentration of radioactive elements. The sandstone zone was deficient of radioactive elements and this resulted in the low value. The plot of depth against radiogenic heat production was scattered and it also showed an increase with depth. The increase was due to high shale lithology at greater depth of the Agbada Formation and the shale in the Akata Formation. A linear relationship was established for the radiogenic heat production and the product of gamma ray and density logs for the study Area. The relationship can be used if gamma ray spectral logs are not available.

Keywords: radioactive elements, heat production, well logs, niger delta, radiogenic heat.

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I. Introduction

Geothermal data have been used widely by geoscientists to provide information on temperature variations within the earth and thermal history of a sedimentary basin. Thermal history of a sedimentary basin is very important in the analysis of the organic compound maturity. The maturity of organic compound can be described as a gradual process which involves the release of hydrocarbons from buried organic materials (Beards more and Cull, 2001; Deming, 1994). Of the heat observed flowing out through the surface of the Earth about 40% originates within the outer crust (Pollack and Chapman, 1977). The heat produced by radioactive isotopic decay forms the dominant part, but there are also contributions from the friction of in traplate strain and plate motions, and heats from exothermic, metamorphic, diagenetic and other processes (Hamza and Beck, 1972).

Most heat flow analysis of sedimentary basins do not take into account the contribution from radioactive elements. Heat generated by the decay of naturally radioactive elements in the earth's crust contributes significantly toterrestrial heat flow. Therefore the amount of heat flow in a basin should be constrained with the radiogenic heat production in order to provide a better understanding of the total heat budget (Biicker and Rybach, 1996).. Heat is generated in rocks through the radioactive decay of unstable isotopes that release energy in the form of alpha, beta and gamma particles, neutrinos and antineutrinos through the decay of radioactive elements such as uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). Rocks are transparent to neutrinos and antineutrinos such that most of the energy from these particles is lost into space. However, the surrounding rocks absorb the kinetic energy associated with the other particles which is later converted to radiogenic heat (Rybach, 1986).The energy released by the decay of the uranium isotope is far greater than that released by thorium, which in turn is greater than that of potassium. However, the relative contributions of each isotope to the total heat generation are of the same order of magnitude due to their relative abundance in crustal rocks. Radiogenic heat production can be estimated from the natural gamma spectrometer (NGS) and/or gamma ray logs. The natural gamma spectrometer records the total count and frequency distribution of gamma rays and uses the data to estimate the absolute abundance by mass of each gamma-producing element in the rocks. The results are generally output as three logs - URAN (ppm uranium), THOR (ppm thorium) and POTA (percentage potassium). The gamma-ray energy spectrum emitted from a rock is the sum of the individual characteristic spectra of the radiogenic components. The objectives of this research are to determine the radiogenic heat generation in some hydrocarbon exploratory oil wells and to establish a relationship between radiogenic heat production and the product of gamma ray and density logs in part of Niger delta sedimentary basin.

II. Summary of the Geology of the Niger Delta

The study area is located within the Niger Delta sedimentary basin. Figure 1 is a map of the Niger Delta showing study area. The Niger Delta is the youngest sedimentary basin within the Benue Trough system. Its development began after the Eocene tectonic phase (Ekweozor and Daukoru, 1994; Doust and Omatsola, 1990). Up to 12km of deltaic and shallow marine

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sediments have been accumulated in the basin. The Niger and Benue Rivers is the main supplier of sediments.

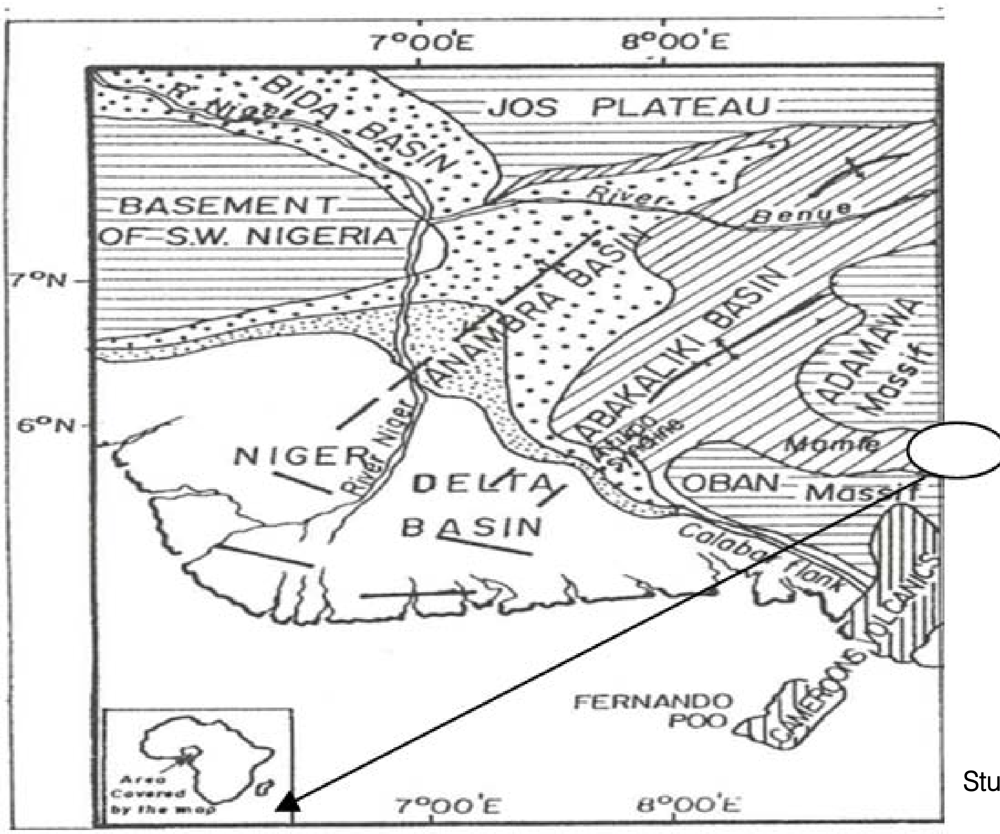

Figure 1 : Map Of Nigeria Showing Niger Delta And Study Area

The tertiary section of Niger Delta is divided into three Formations (Fig. 2.) representing prograding depositional facies that are distinguished based on sand – shale ratios (Short and Stauble, 1965). The Formations are Benin, Agbada and Akata Formations (Ekweozor and Daukoru, 1994;Kulke, 1995). The Benin Formation is the youngest of the Delta sequence. It outcrops in Benin, Onitsha and Owerri provinces in Niger Delta area. It consists mainly of sand and gravels with thickness ranging from 0 - 2100m. The sands and sandstones in this Formation are coarse – fine and commonly granular in texture and partly unconsolidated. Mostly found in the Benin formation are feldspars, hemalites, lignite streak and limonite coatings. Very little oil has been found in the Benin formation, and the formation is generally water bearing. It is the major source of portable water in the Delta area (Doust and Omatsola, 1990).

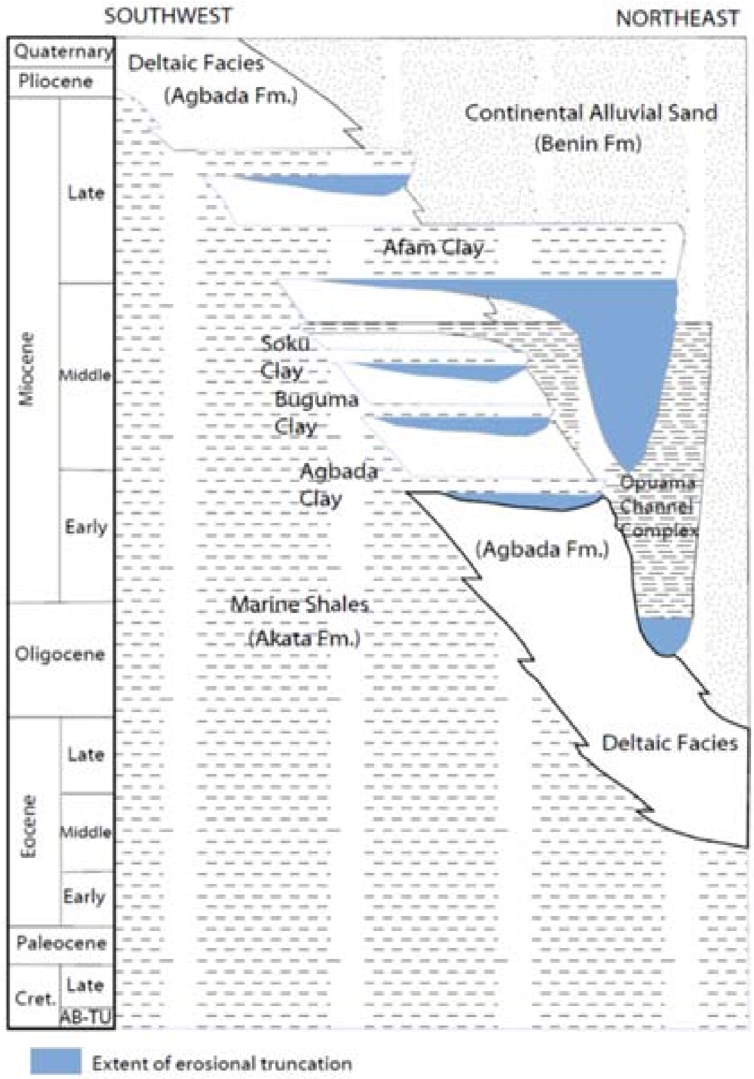

Fig.2 : Stratigraphic setting of Niger Delta showing the three formations of Niger Delta (modified after Doust and Omatsola,1990)

The Agbada Formation is the major host of Niger Delta hydrocarbon and it consists of alternation of sandstones and shale. The deposition of Agbada Formation began in Eocene and continues into Pleistocene. In the lower portion, shale and sandstone beds were deposited in equal proportions. However, the upper portion is mostly with only minor shale interbed. Its thickness ranges from 300m – 4500m (Short and Stauble, 1965).

The Akata Formation forms the base of the transgressive lithologic unit of the Delta complex. It is of marine origin and it is made up of thick shale sequence (potential source rock), turbidite sand (potential reservoir in deep water) and minor amount of clay and silt (Avbovbo, 1978). Beginning in the Paleocene and through the recent, the Akata Formation was formed when terrestrial organic matter and clays were transported to deep water areas characterised by low energy conditions and oxygen deficiency. The approximate range of thickness is from 0 – 6000m and the formation crops out subsea in the outer Delta area but rarely seen onshore. The formation outlies the entire Delta, and is typically overpressured.

III. Materials and Methods

The quantity of heat generated by radioactive elements is a function of the quantities present, their rate of decay and the energies of emission. According to Beardsome and Cull (2001), the radiogenic heat generation A is related to the natural gamma ray spectrometer (NGS) as

$$A = 10^{-3} * \rho * (96.7C_u + 26.3C_{Th} + 35.0C_K) \qquad (1)$$

Where,

A = Radiogenic heat production (μWm^{-3})

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C_u = Concentration of Uranium in parts per million

C_{Th}= Concentration of thorium in parts per million

C_K= Concentration of potassium in percentage

ρ = Density in gcm^{-1}

The applications of equation 1 for the computation of heat production in sedimentary basin by the decay of radioactive elements depend on the availability of spectral gamma ray data. Most time these data are not available and therefore an alternative formula has to be applied. Rybach (1986) obtained a relationship between radiogenic heat production by radioactive substances and gamma ray intensity of the samples. The relationship was further modified by Biicker and Rybach (1996) as

$$A = 0.0158(GR - 0.8) \quad (2)$$

Where

GR = gamma ray value (API)

The gamma ray reading is related to the naturalgamma ray spectral values (Beardsmore and Cull, 2001) by the equation

$$GR = X(Potassium + (0.13Thorium) + (0.36Uranium)) \quad (3)$$

Where X is proportionality constant (though not really constant) and it depends on the distance into the rock that the well log tool is able to detect. The distance is also a function of the rock density, energy of the emissions and the tool type (Serra, 1984).The value of A can be related to the gamma ray (GR) value by combining equation 1 and 3 as;

$$A = 0.035\rho(GR)(\frac{Y}{X}) \quad (4)$$

Where

Y =Potassium + (0.751Thorium + 2.76Uranium)/(Potassium + 0.13Thorium + 0.36Uranium) (5)

= Radiogenic factor

Equation 4 can also be written as

$$A = K\rho(GR) \quad (6)$$

Where

$$K = 0.035 * \left(\frac{Y}{X}\right) = A/(GR * \rho) \quad (7)$$

The radioactive heat generation in the sedimentary succession was determined from total gamma-ray logs available from three wells using equation 1. Attempt was also made to determine the value of K from available density and gamma ray logs for the study Area. The logs were obtained from Agip Oil Producing Company, Nigeria.

IV. Result and Discussion

To obtained accurate value and overall understanding of the heat flow in a sedimentary basin and the temperature gradient, the amount of heat generated by the sediments themselves is an important component, which needs to be calculated and quantified. Clastic sediments can provide reasonable amount of the total heat flow where sediment basins are deep. The depth of the gamma ray logs used for this work ranges between 1000 to 3000 metres. The depth of the density log varies between the depth 1900 – 2700 metres for wells 1 and 3 respectively while the depth is 1200 -3000 metres for well 2.The major lithology observed in the gamma ray logs are sand, shale and sandy shale. The gamma ray value ranges between 20 - 160 API while the density log reading varies between 1.7 – 2.5g/cm^3.

The heat values were computed for the total length of the wells where there is gamma ray readings. The plots of the computed radiogenic heat versus depth for the three wells are shown in Figures 3-5. The values ranges from 0.35 to 2.0 μWm^{-3}for well 1, 0.34 to 1.78μWm^{-3} for well 2 and 0.24 to 2.0μWm^{-3} for well 3. The average radiogenic heat production ranges between 0.3 to 1.93μWm^{-3}. Due to the scattered nature of the values, it was not possible to fit a trend to the plots. This is an indication of the complex variation of the radiogenic heat production with depth. The low heat generation with value ranging from0.24 to 0.7 μWm^{-3} is due to sand lithology. The maximum heat generation occurred in the Shale lithology with values ranging from 0.8 to 2.0 μWm^{-3}. The high radiogenic heat production in shale is expected because of its high concentration of radioactive elements. The value in sand lithology also corresponds to the low radioactive element associated with it. Similarly the low and high radiometric heat production observed in the wells can be attributed to the alternation of sand and shale lithology in the Agbada Formation.

From equation 5, the value of k was computed from the radiogenic heat and the available gamma ray and density logs in the corresponding well. The plot of k versus well depth is shown in Figures 6-8 for the three wells. The value of K ranges from 0.006 to 0.008 with a mean value of 0.007 for the three wells. The graphs show that the value of K is constant with depth. The implication of this constant value is that a plot of the radiogenic heat production versus the product of gamma ray and density will approximate a straight line with a mean gradient of 0.007. Therefore the general equation for radiogenic heat production from gamma ray and density logs (equation 6) for the Niger Delta is given as

$$A = K\,(\rho x\ GR) \quad = 0.007(\rho xGR) \qquad (8)$$

The gradient of A versus RHOB x GR is dependent only on the relative proportions of the radioactive elements in the sediment. The radiogenic heat production is high at greater

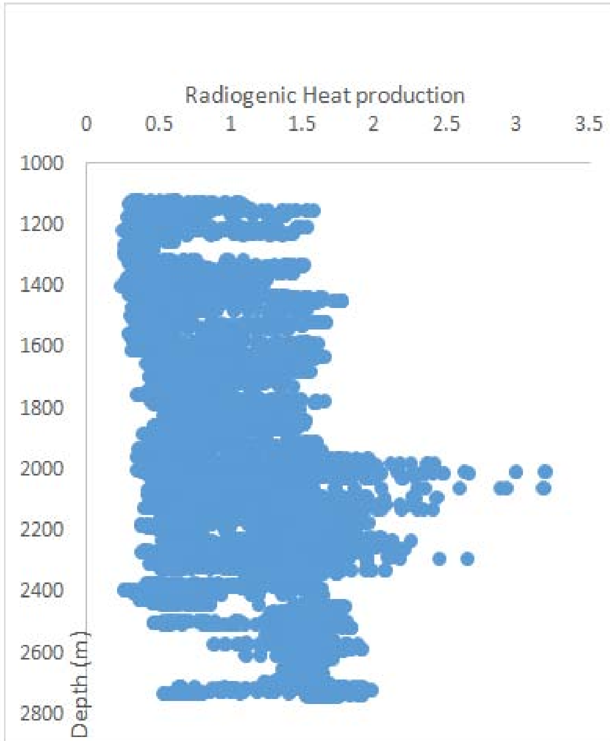

Fig. 3 : Plot of depth versus radiogenic heat production for well 1

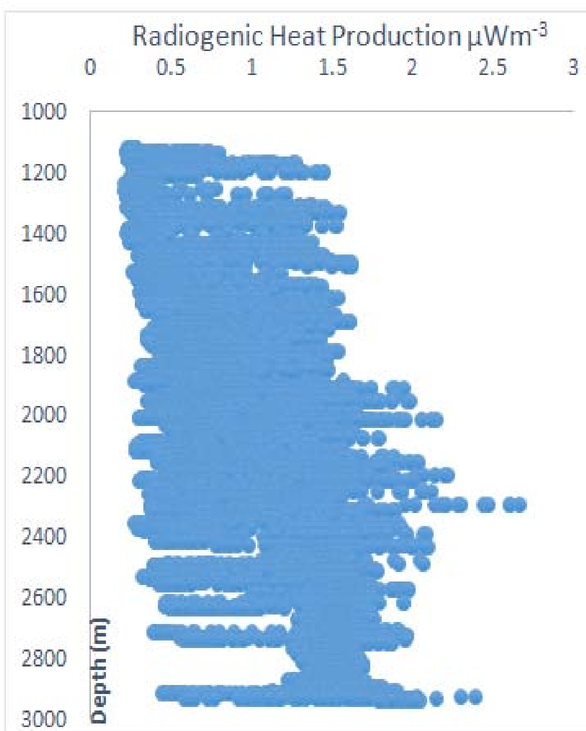

Fig. 4 : Plot of depth versus radiogenic heat production for well 2

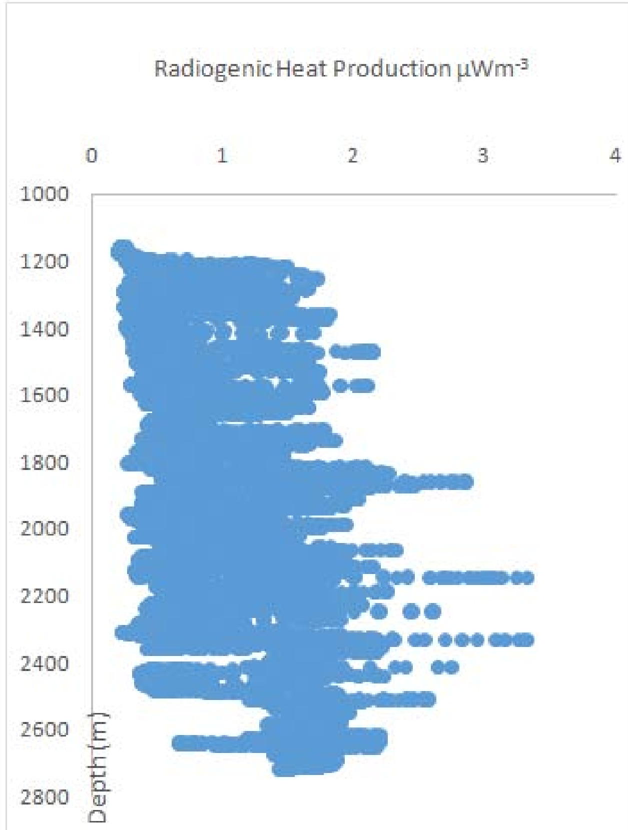

Fig. 5 : Plot of depth versus radiogenic heat production for well 3

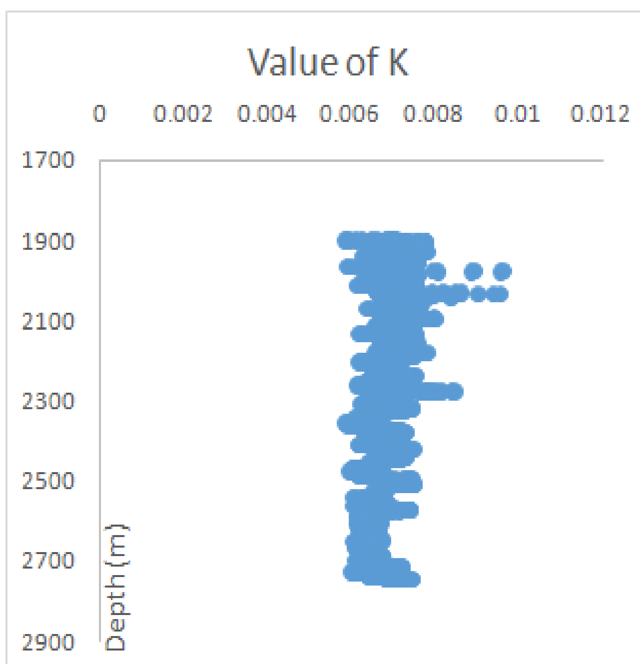

Fig. 6 : Plot of depth versus K values for well 1

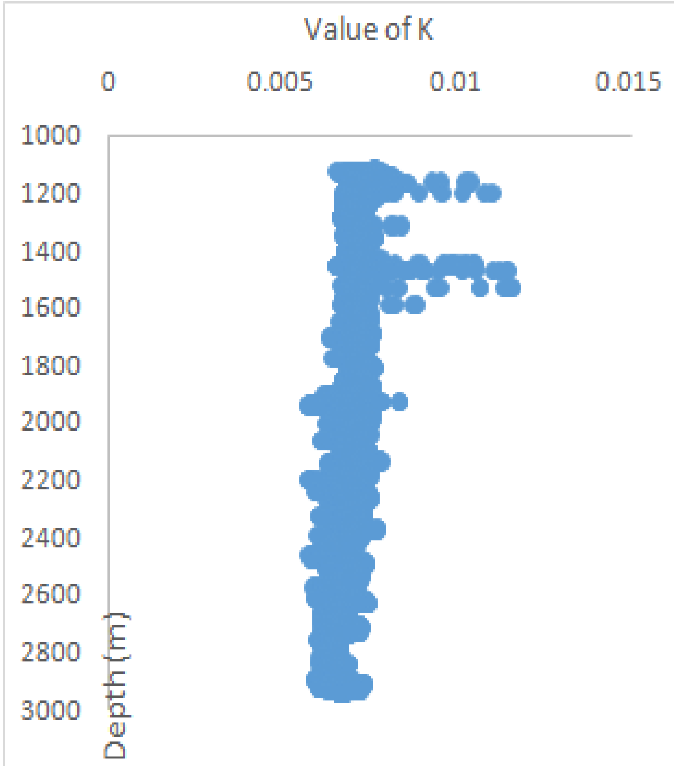

Fig. 7 : Plot of depth versus K values for well 2

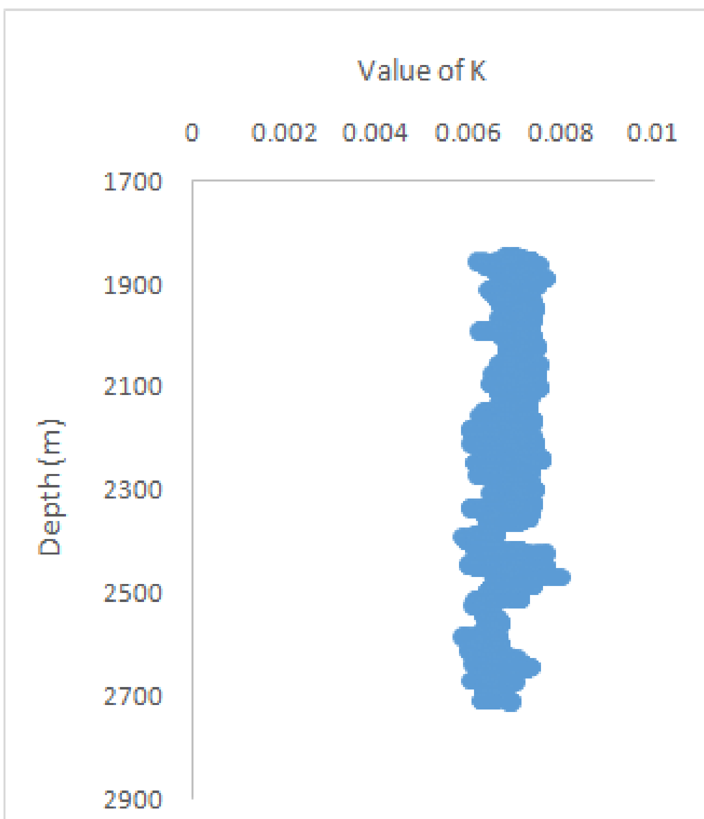

Fig. 8 : Plot of depth versus K values for well 3

Depth in the graph. This can be attributed to high shale lithology toward the base of the Agbada and top of the Akata Formations in the Niger Delta.

Comparison of the computed radiogenic heat flow for the study area (part of the Niger Delta) shows that the value is consistent with that obtained for other basins. For example, the radiogenic heat production classification by Ehinola et al., (2005) is equivalent to 1.688 μWm^{-3} for low generation sediments and greater than 3.37 μWm^{-3} for high generation sediment. Keen and Lewis (1982) observed that the heat generation from sediments of continental margin of Eastern North American ranges between 0.3 $\mu Wm^{-3}$for limestone to 1.4-1.8 μWm^{-3} for shale. According to Zhang (1993), the heat generated for Cenozoic and Mesozoic lacustrine sediments in Chinese basins ranges from 1.02-3.28 μWm^{-3}. Furthermore, the radiogenic heat production estimated from the concentration of the radioactive elements obtained from log data ranges between 0.17 and 1.90 $\mu Wm^{-3}$with an average of 0.90 for Chad Basin, Nigeria (Ali and Orazulike, 2010). Similarly, Chapman and Polack (1975) obtained radiogenic heat production ranging from 0.96 to 1.8 μWm^{-3} for Precambrian site on the exposed West African Craton.

IV. Conclusion

Heat generated as a result of the decay of naturally radioactive elements in the earth's crust contributes significantly to terrestrial heat flow. Heat production estimated from gamma ray logs in part of Niger Delta ranges between 0.24μWm^{-3} and 2.0μWm^{-3}. The average radiogenic heat production ranges between 0.3 to 1.93μWm^{-3}. The computed radiogenic heat production in this study area correlated very well with the results from other basin. The relationship established for the radiogenic heat production and the product of gamma ray and density logs can be used if gamma ray spectral logs are not available. Further research in radiogenic heat production should be based on natural gamma ray spectral.

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