Determination of Geothermal Gradient in the Eastern Niger Delta Sedimentary Basin from Bottom Hole Temperatures

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Abstract

The geothermal gradient of the eastern Niger delta have been obtained from bottom hole temperature for 19 exploratory oil wells. The geothermal gradients vary from 13.46^{o}C/km to 33.66^{O}C/km with an average of 23.56^{o}C/km. The geothermal gradients have low values in the northwest-southeast direction and increases seaward and northward. The distribution of geothermal gradient is directly related to the overburden thickness, lithology, tectonic activities (growth faults), and hydrodynamics of the basin. The computed geothermal gradient map could be used in the application of the liquid hydrocarbon -window concept for oil exploration.

Keywords: Niger delta, geothermal gradient, bottom hole temperature, Hydrocarbon

1 Introduction

For more than 50years, oil exploration activity in the Niger delta proliferous province has resulted in the accumulation of thousands of well-log data in which some borehole temperature data have been recorded. Knowledge of subsurface temperature distribution is valuable in understanding the geologic and geophysical processes in this large and important sedimentary basin [1].

Geothermal anomalies have been mapped over several sedimentary basins [2, 3,4]. Knowledge of subsurface temperature and geothermal gradients are necessary for the analysis of reservoir fluid properties as well as plate tectonics interpretation. Temperature is one of the primary factors controlling hydrocarbon generation, sediment diagenesis and migration of hydrocarbon and other pore fluids. The aims of this work are to determine the geothermal gradients in the area and to explain the possible causes of the lateral variation in geothermal gradients and its hydrocarbon implication.

Several factors may be responsible for the lateral variations in the earth's temperature field, resulting in regional variations in geothermal gradients in sedimentary basins. The primary factors that may be responsible for this lateral variation in the geothermal

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gradient may be attributed to lateral and vertical variations in thermal conductivity of the rocks due to variety of causes such as structural configuration (lithology, cementation, degree of compaction, permeability and fluid content); effects of moving fluids (groundwater, petroleum, connate and juvenile water moving upward, meteoric water moving downward through fractures and pore spaces); overburden thickness, endothermic reactions during diagenesis, tectonic activities (e.g. growth fault) and differences in heat flow from the source in the basement beneath the basin.

2 Summary of the Geology of the Niger Delta

The Niger Delta is the youngest sedimentary basin within the Benue Trough system. Its development began after the Eocene tectonic phase. Up to 12km of deltaic and shallow marine sediments have been accumulated in the basin. The Niger and Benue Rivers are the main suppliers of sediments. Three lithostratigraphic units are distinguishable in the Tertiary Niger Delta [5]. The basal Akata Formation which is predominantly marine prodelta shale is overlain by the paralic sand/shale sequence of the Agbada Formation. The Akata Formation is the source rock in the sedimentary basin. The topmost section is the continental upper deltaic plain sands – the Benin Formation. Virtually all the hydrocarbon accumulations in the Niger Delta occur in the sands and sandstones of Agbada Formation where they are trapped by rollover anticlines related to growth fault development [6].

3 Data Collection and Analysis

The bottom hole temperature data used for this study were obtained from the Shell Petroleum Development Company (SPDC). The bottom hole temperatures (BHTs) were recorded at various depths during logging of petroleum exploration wells. These BHTs are lower than the static formation temperatures because of the cooling effect of mud circulation prior to logging. The bottom hole temperatures were obtained from 19 exploratory oil wells in the study area (Fig.1).

Subsurface temperatures normally increase with depth, and the geothermal gradient is a measure of this rate of temperature increase with depth. Assuming a linear relationship of temperature with depth, the geothermal gradient is computed by dividing the difference between the temperature of the formation and mean annual surface temperature by the depth of the formation according to the empirical equation:

$$T_z \quad = \quad mZ + T_o \qquad\qquad 1$$

where

T_z = well bore temperature in ^{o}C at depth Z km

T_o = mean surface temperature in ^{o}C

m = geothermal gradient in ^{o}C /km

The surface (ambient) temperature for the Niger delta is assumed to be 27°C [7, 8]. The geothermal gradient is usually reported as ^{0}C/Km.

Due to non availability of circulation time, time logger on bottom and time since cessation of circulation it was not possible to correct the measured bottom hole temperatures using the Horner techniques or Fertl and Wichmann as cited in [9]. The BHTs were not corrected for the cooling effect of mud circulation because the thermstor use was assumed to probe very deep into the formation and thus measured the in situ temperature.
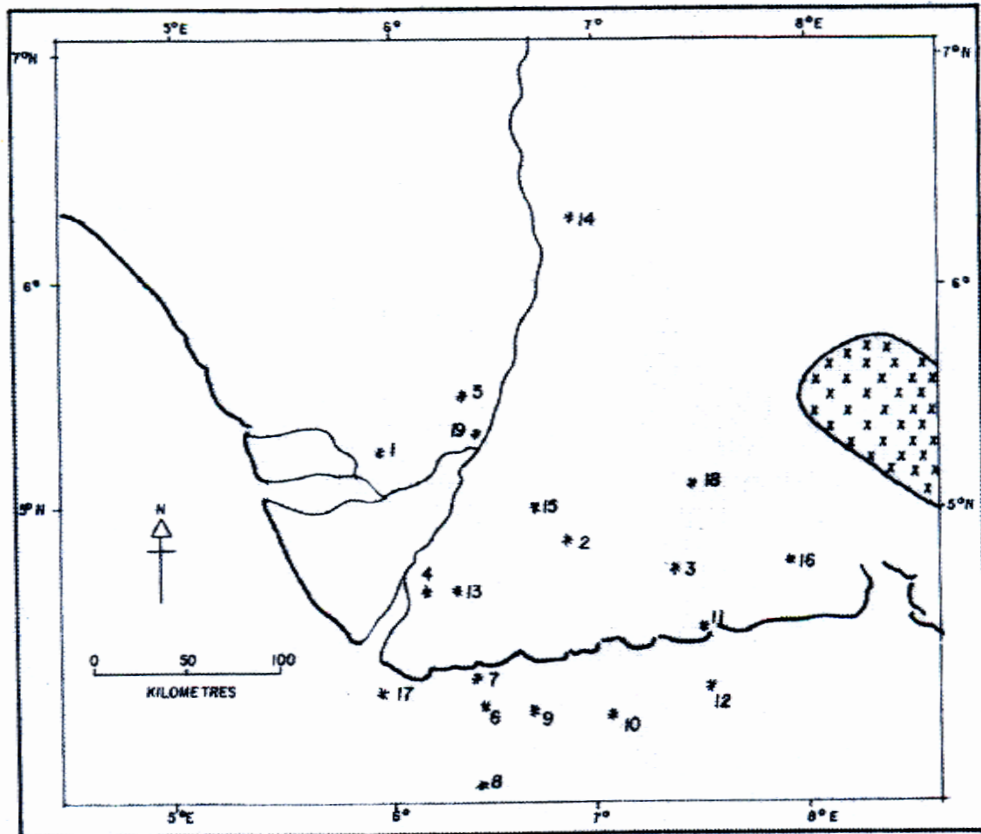

Figure1: The Base map of the study area showing the well locations

4 Results and Discussion

A map of the computed geothermal gradients of the eastern Niger delta is shown in Figure 2. Regional present day geothermal gradient vary from 13.46°C/km to 33.66°C/km with an average of 23.56°C/km. A distinctive feature of the geothermal gradient map is the characteristics low gradient trending in the northwest-southeast direction, which increases both northward and seaward.

The geothermal studies have revealed lateral as well as vertical variation in the temperature fields. These variations may be interpreted as resulting from thermal

conductivity heterogeneities or local variations in basement heat flow. Variation may also result from ground water flow systems.

The regions with low geothermal gradient may be regarded as water recharge zones and high topography. The movement of water in deep aquifers can significantly perturb the local underground temperature distribution. The lithology of the rocks in the subsurface also affects the geothermal gradients. Regions of low geothermal gradients correspond with areas of high sand percentage.
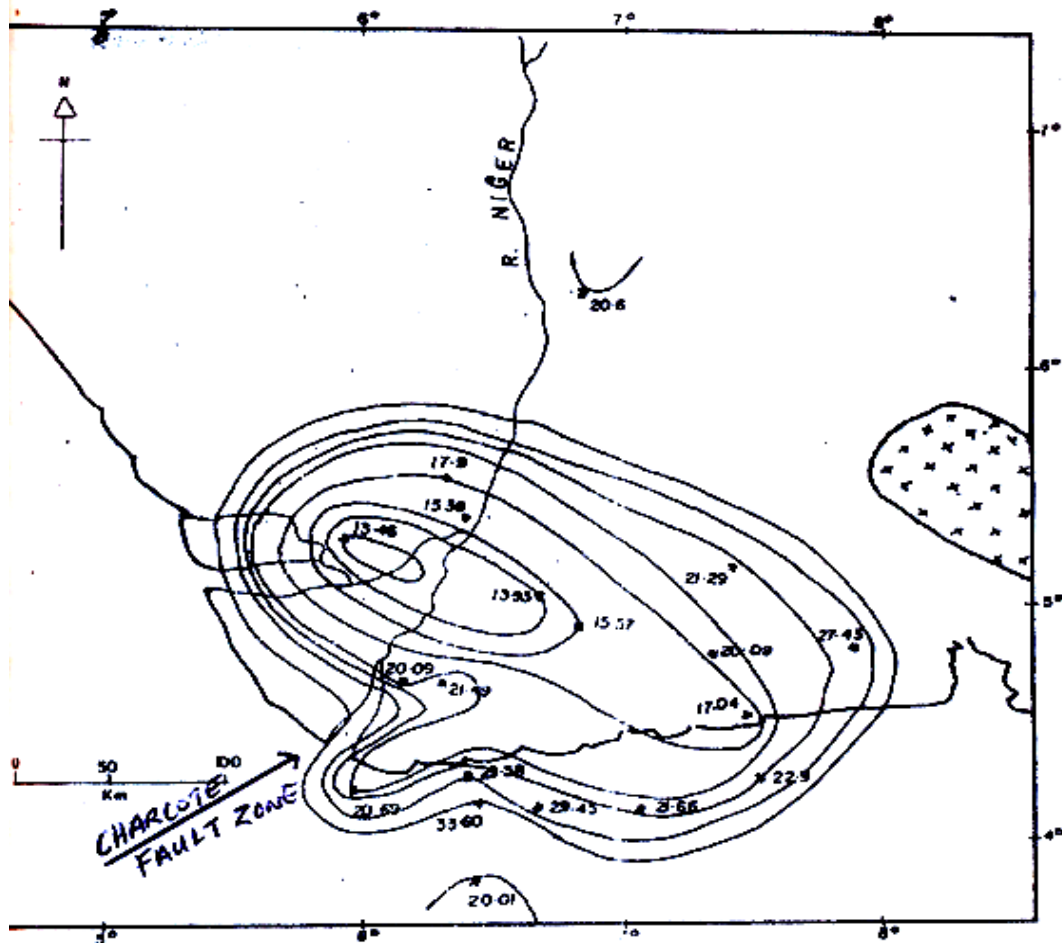

Figure 2: map of the computed geothermal gradients of the eastern Niger delta

Generally, temperature increases with increasing depth to basement. Where the sedimentary section is relatively thick, the rocks act as a heat sink and dissipate the heat generated by radioactive decay in the basement rocks. Over the basement high, a small volume of sedimentary rocks exists, and temperature remains hotter.

The geothermal gradients computed in this work are comparable to the worldwide average 25°C/Km and to those of earlier works carried out in the Niger delta [10,11,12].

The geothermal gradient map may be utilized as an exploration tool. Studies by Pussey cited in [12] indicated that hydrocarbon generation takes place within the temperature interval of 65 to 150°C. Assuming that the present temperatures obtained in this study

represent the maximum values to which the sediments have been subjected, the depths of critical generation and destruction of hydrocarbon in the eastern Niger delta can be calculated on the basis of linear geothermal gradient. Consequently, oil may be generated from a depth range of 2300m to 6860m in well1, 1480m to 4370m in well6, 1530m to 4800m in well8 and 1524m to 4700m in well 17 (Fig.3). This shows that the liquid hydrocarbon window is shallow in wells with high geothermal gradients and deep in well with low geothermal gradients within the study area.
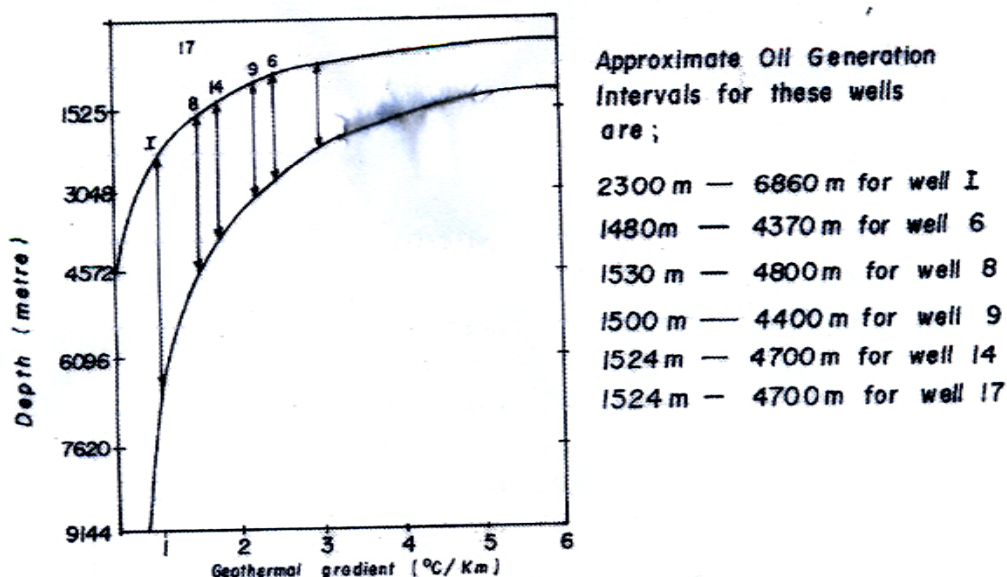

Figure 3: Hydrocarbon-liquid window and theoretical oil prospects in various parts of sedimentary basin

5 Conclusion

The study revealed interesting data regarding the geothermal gradient distribution, depth of potential petroleum source rocks and also throw some light on the petroleum accumulation in the study region.

The regional geothermal gradient varies between $13.46^oC/Km$ to $33.66^OC/Km$ with an average of $23.56^oC/Km$. It has a low value in the northwest- southeast direction and increases both seaward and northward. The major factors responsible for the geothermal gradients variation are lithology, geothermal conductivity, fluid flows, and sedimentary diagenesis and overburden thicknesses.

Present exploration activities in the Niger delta have not been extended beyond 4270m. On the basis of the liquid hydrocarbon window obtained in the study, the theoretically prospective sediment is yet to be explored in most parts of the study area. Thus, there is need to extend drilling programmes below the depth of exploration activity in the basin especially in regions with very low geothermal gradients.

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