Determination of Geothermal Gradient from Bore Hole Temperature data in Some Parts of the Eastern Niger Delta Basin

E. D. Uko¹, M. A. Alabraba¹, I. Tamunoberetonari¹ and A. O. Oki²*

¹Department of Physics, Rivers State University, Port Harcourt, Rivers State, Nigeria.
²Department of Geology, Niger Delta University, Amassoma, Bayelsa State, Nigeria.

Authors’ contributions
This work was carried out in collaboration between all authors. Authors EDU and MAA designed the study performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author IT managed the analyses of the study. Author AOO managed the literature searches. All authors read and approved the final manuscript.

ABSTRACT
An analysis of Geothermal Gradients in the Eastern Niger Delta basin was done using Bore Hole Temperature (BHT) data from three (3) adjacent oil fields. BHT data was converted to static formation temperature by using the conventional method of increasing measured BHT data by 10% and Geothermal Gradient computed using its simple linear relationship with depth, surface temperature and static temperature at depth. Projections were then made for change in Geothermal gradients at 1km intervals to a depth of 4 km. Results obtained showed significant variations across Idama, Inda and Robertkiri fields with average geothermal gradients of 17.3⁰C/Km, 22.6⁰C/Km and 23.1⁰C/Km respectively. Variation in the geothermal gradients in the area is attributed to lithological control and differential rates of sedimentation during basin evolution. Also, results showed that the Geothermal Gradient in the area are generally moderate and could be a good reason for the occurrence of more oil hydrocarbons than gas in the area.
Keywords: Geothermal gradient; bore hole temperature; hydrocarbons, Eastern Niger Delta.

1. INTRODUCTION

The Niger Delta basin is a major prolific hydrocarbon province in the world. One very important factor controlling the formation and maturation of hydrocarbons in a sedimentary basin is temperature [1-5]. The rate of increase in temperature per unit depth into the earth is known as Geothermal Gradient. This progressive increase can be attributed to the flow of residual heat due to planetary accretion, radioactive decay and core crystallization from the interior of the Earth outwards. Geothermal Gradients are useful indicators of subsurface temperature distribution, it gives insight into the mechanisms of formation of the basin and other geological processes such as rifting, hydrocarbon formation and maturation in sedimentary basins [6-7].

Geothermal Gradients may vary laterally due to changes in thermal conductivity of rocks arising factors such as lithology, porosity, permeability, fluid content, overburden thickness, endothermic reactions during diagenesis and heatflow [5,8].

Temperature data obtained by logging of wells could be used to derive estimates of regional temperature and Geothermal Gradients in an area [9]. The most common temperature data collected during geophysical logging process is the Bore Hole Temperature data (BHT). Several works have been done on study of Geothermal Gradients in the Niger Delta [5,7,8,10-13] this research work determines variations in the Geothermal Gradient of three adjacent oil fields in in the Eastern Niger Delta basin using BHT data.

2. MATERIALS AND METHODS

2.1 Geology of Study Area

The study area is located within latitudes 6° 15’ E and 7° 15’ E and longitudes 4° 15” N and 4° 40” N, it falls within the fresh water swamps of the Niger Delta basin (Fig. 1). The topography of the area is generally low lying with average elevation of 10 m above sea level comprising of silt and clay. The Niger Delta basin comprises of three major lithostratigraphic units, these are the Akata, Agbada and Benin Formations in a gross coarsening-upwards sequence. The Akata Formation is comprised chiefly of shales depicting marine environment of deposition, it is overlain by sandstones with intercalations of shales of the Agbada formation depicting deltaic or transitional environment. The Agbada is overlain by the continental sandstones of the Benin Formation which shows fluvial depositional environment [14-16].

2.2 Study Design

This research makes use of Bottom Hole Temperature data from three (3) adjacent fields in the eastern Niger Delta to determine the variation in the Geothermal Gradient in the area. BHT data are usually acquired before the borehole attains thermal equilibrium. Correction of BHT data to that attained at equilibrium requires information of circulation and shut-in time, these information were not provided for the dataset.

The conventional industry method employed by [17] for BHT data correction, which involves increasing BHT by 10% to obtain static or equilibrium formation temperature was used for this study. Geothermal Gradient was computed using a simple linear relationship (Equation 1);

\[ T = mZ + C \] (1)

which can be rewritten to make Geothermal Gradient subject (Equation 2);

\[ m = \frac{T - C}{Z} \] (2)

Where m is the slope or geothermal gradient, T is the temperature at depth in °C or °F, C is the surface temperature in °C or °F, Z is depth in m or ft. The average surface temperature obtained in Niger Delta from literature is 27°C [3,18-19].

Temperature data was given in Fahrenheit scale, for this study the data was converted to the Celsius scale for convenience of computation (Equation 3);

\[ C = (F - 32) \times \frac{5}{9} \] (3)

Where C is temperature in Celsius and F is temperature in Fahrenheit.

Fahrenheit scale has an interval of 180°F. It starts from 32°F ending at 212 °F, while the Celsius scale starts from 0 and ends at 100°C having an interval of 100°C.
Results of computation of Geothermal Gradient from corrected BHT is presented in Table 1.

3. RESULTS AND DISCUSSION

The results of conversion, correction of BHT data and determination of Geothermal Gradients are presented in Table 1 below.

Using the linear relationship given in Equation 1 ($T = mZ + C$), since the geothermal gradient ($m$) was successfully computed, taking mean surface temperature ($C$) in the Niger Delta as 27°C, the Temperature ($T^°C$) - Depth (Z km) relationship for the wells was then determined (Table 2).

Temperature was then projected at varying depths of 2 km, 3km and 4 km (Table 3 & Fig. 2). Average computed geothermal gradients for wells Idama, Inda and Robertkiri showed values of 17.3°C/Km, 22.6°C/Km and 23.1°C/Km respectively. Values obtained showed agreement with those obtainable from literature [5,7,8,20-22]. Variation in the geothermal gradients in the area is due to lithological variations or differential rates of sedimentation during basin evolution. Regions with low geothermal gradients correspond with areas of high percentage of sands because sands are better thermal conductors than shales, on the other hand higher geothermal gradients are attributed to high shale volume, as such, in the Niger Delta minimal thermal gradients usually tend to coincide with areas of maximum thickness of the sandy Agbada and Benin Formation, while higher thermal gradients occurs at delta fronts where the deeper Akata Formation exerts a stronger influence. Geothermal Gradients variations play a significant role in source rock maturation, areas with low geothermal gradients are associated with immature source rocks and in some cases oil occurrence like parts of the Eastern Niger Delta basin compared to higher gradients to the west where gas is known to occur predominantly.

![Map of the Niger Delta showing study area](image)
Table 1. Geothermal gradient computed from corrected BHT data

| S/No | Well name | Test date  | Depth (ft) | Depth (Km) | BHT (°F) | BHT (°C) | BHT * 110% | Geothermal Grad. (C/Km) | Ave. Geothermal Grad. (°C/Km) |
|------|-----------|------------|------------|------------|----------|----------|------------|------------------------|-------------------------------|
| 1    | Idama-04  | 30-Jan-94  | 11162      | 3.382424242 | 169      | 76.1111111 | 83.722222222 | 16.7696948             | 17.294107                     |
| 2    | Idama-04  | 31-Jan-94  | 9583       | 2.903939394 | 160      | 71.1111111 | 78.222222222 | 17.6388744             |                                |
| 3    | Idama-04  | 22-Feb-95  | 11162      | 3.382424242 | 164      | 73.3333333 | 80.66666667   | 15.8663322             |                                |
| 4    | Idama-04  | 23-Feb-95  | 9583       | 2.903939394 | 166      | 74.4444444 | 81.88888889   | 18.90152701            |                                |
| 5    | Inda-08h  | 15-Apr-12  | 9560       | 2.896969697 | 181      | 82.7777777 | 91.05555556   | 22.11122734            | 22.55656289                   |
| 6    | Inda-08h  | 06-Jun-07  | 9560       | 2.896969697 | 185      | 85        | 93.5        | 22.95502092            |                                |
| 7    | Inda-08h  | 26-Apr-07  | 9560       | 2.896969697 | 185      | 85        | 93.5        | 22.95502092            |                                |
| 8    | Inda-08h  | 18-Feb-07  | 9560       | 2.896969697 | 185      | 85        | 93.5        | 22.95502092            |                                |
| 9    | Inda-08h  | 18-Jan-07  | 9560       | 2.896969697 | 185      | 85        | 93.5        | 22.95502092            |                                |
| 10   | Inda-08h  | 03-Dec-06  | 9560       | 2.896969697 | 185      | 85        | 93.5        | 22.95502092            |                                |
| 11   | Inda-08h  | 22-Jun-06  | 9560       | 2.896969697 | 182      | 83.3333333 | 91.66666667   | 22.32217573            |                                |
| 12   | Inda-08h  | 21-Apr-06  | 9560       | 2.896969697 | 180      | 82.2222222 | 90.44444444   | 21.90027894            |                                |
| 13   | Inda-08h  | 26-Feb-06  | 9560       | 2.896969697 | 180      | 82.2222222 | 90.44444444   | 21.90027894            |                                |
| 14   | Rbk-04    | 29-Sep-85  | 12950      | 3.924242424 | 275      | 135       | 148.5       | 30.96138996            | 25.71857567                   |
| 15   | Rbk-04    | 04-Nov-85  | 12950      | 3.924242424 | 274      | 134.4444444 | 147.8888889 | 30.80566281            |                                |
| 16   | Rbk-04    | 10-Aug-86  | 12950      | 3.924242424 | 224      | 106.6666666 | 117.3333333  | 23.01930502            |                                |
| 17   | Rbk-04    | 17-Aug-86  | 12950      | 3.924242424 | 225      | 107.2222222 | 117.9444444  | 23.17530218            |                                |
| 18   | Rbk-04    | 06-Apr-87  | 12950      | 3.924242424 | 230      | 110       | 121         | 23.95366795            |                                |
| 19   | Rbk-04    | 12-Apr-87  | 12950      | 3.924242424 | 220      | 104.4444444 | 114.8888889 | 22.3963964             |                                |
| 20   | Rbk-05    | 30-Oct-85  | 9850       | 2.984848485 | 240      | 115.5555556 | 127.11111111 | 33.53976311           | 25.84747386                   |
| 21   | Rbk-05    | 08-Aug-86  | 9850       | 2.984848485 | 175      | 79.44444444 | 87.38888889 | 20.23181049            |                                |
| 22   | Rbk-05    | 22-Jul-87  | 9850       | 2.984848485 | 218      | 103.3333333 | 113.6666667 | 29.03553299            |                                |
| 23   | Rbk-05    | 20-Aug-88  | 9850       | 2.984848485 | 140      | 60        | 66          | 13.06598985            |                                |
| 24   | Rbk-05    | 25-Oct-90  | 9850       | 2.984848485 | 190      | 87.77777777 | 96.55555556 | 23.30287648            |                                |
| 25   | Rbk-05    | 16-Oct-92  | 9850       | 2.984848485 | 214      | 101.1111111 | 111.22222222 | 28.21658206            |                                |
| 26   | Rbk-05    | 23-May-93  | 9850       | 2.984848485 | 240      | 115.5555566 | 127.11111111 | 33.53976311            |                                |
| 27   | Rbk-08    | 17-Apr-85  | 12800      | 3.878787879 | 226      | 107.7777778 | 118.55555556 | 23.60416667            | 23.13151067                   |
| 28   | Rbk-08    | 14-Jun-86  | 12800      | 3.878787879 | 208      | 97.7777778 | 107.55555556 | 20.7682917             |                                |
| 29   | Rbk-08    | 08-Apr-87  | 12800      | 3.878787879 | 226      | 107.7777778 | 118.55555556 | 23.60416667            |                                |
| 30   | Rbk-08    | 16-Mar-88  | 12800      | 3.878787879 | 226      | 107.7777778 | 118.55555556 | 23.60416667            |                                |
| 31   | Rbk-08    | 05-Aug-90  | 12800      | 3.878787879 | 225      | 107.2222222 | 117.94444444 | 23.44661458            |                                |
| S/No | Well name | Test date | Depth (ft) | Depth (Km) | BHT (°F) | BHT (°C) | BHT * 110% | Geothermal Grad. (°C/Km) | Ave. Geothermal Grad. (°C/Km) |
|------|-----------|-----------|------------|------------|----------|----------|------------|-------------------------|-------------------------------|
| 32   | Rbk-08    | 17-May-97 | 12800      | 3.878787879 | 227      | 108.333333 | 119.1666667 | 23.76171875             |                               |
| 33   | Rbk-10    | 12-Aug-86 | 12800      | 3.878787879 | 218      | 103.333333 | 113.6666667 | 22.34375              |                               |
| 34   | Rbk-10    | 20-Jul-87 | 12800      | 3.878787879 | 215      | 101.666667 | 111.8333333 | 21.87109375           |                               |
| 35   | Rbk-10    | 18-Mar-88 | 12800      | 3.878787879 | 220      | 104.444444 | 114.8888889 | 22.65885417           |                               |
| 36   | Rbk-10    | 08-Aug-90 | 12800      | 3.878787879 | 225      | 107.222222 | 117.9444444 | 23.4466148            |                               |
| 37   | Rbk-10    | 01-May-93 | 12800      | 3.878787879 | 190      | 87.777777  | 96.55555556  | 17.93229167           |                               |
| 38   | Rbk-12    | 08-Aug-95 | 12800      | 3.878787879 | 224      | 106.666667 | 117.3333333 | 23.2890625            |                               |
| 39   | Rbk-12    | 02-Nov-85 | 10060      | 3.048484848 | 190      | 87.777777  | 96.55555556  | 22.81643472           |                               |
| 40   | Rbk-12    | 19-Aug-86 | 10060      | 3.048484848 | 184      | 84.444444  | 92.88888889  | 21.61365142           |                               |
| 41   | Rbk-12    | 21-Jul-87 | 10060      | 3.048484848 | 118      | 47.777777  | 52.55555556  | 8.383035123            |                               |
| 42   | Rbk-12    | 29-Nov-89 | 10060      | 3.048484848 | 218      | 103.333333 | 113.6666667 | 28.42942346           |                               |
| 43   | Rbk-12    | 21-Jan-93 | 10060      | 3.048484848 | 178      | 81.111111  | 89.22222222 | 20.41086812           |                               |
| 44   | Rbk-12    | 16-Aug-95 | 10060      | 3.048484848 | 202      | 94.444444  | 103.8888889 | 25.22200133           |                               |
| 45   | Rbk-13    | 19-Jul-87 | 9825       | 2.977272727 | 200      | 93.333333  | 102.6666667 | 25.41475827           |                               |
| 46   | Rbk-13    | 18-Aug-88 | 9825       | 2.977272727 | 118      | 47.777777  | 52.55555556  | 8.583545377            |                               |
| 47   | Rbk-13    | 23-Jan-93 | 9825       | 2.977272727 | 170      | 76.666666  | 84.33333333 | 19.25699746           |                               |
| 48   | Rbk-14    | 30-Sep-92 | 14668      | 4.444848485 | 250      | 121.111111 | 133.2222222 | 23.89782747           |                               |
Table 2. Temperature depth relationship for given wells.

| S/No | Well name   | Relationship         |
|------|-------------|----------------------|
| 1    | Idama 4     | $T = 17.30 \ Z + 27$ |
| 2    | Idama 8h    | $T = 22.56 \ Z + 27$ |
| 3    | Robertkiri 4| $T = 25.72 \ Z + 27$ |
| 4    | Robertkiri 5| $T = 25.85 \ Z + 27$ |
| 5    | Robertkiri 8| $T = 23.13 \ Z + 27$ |
| 6    | Robertkiri 10| $T = 21.65 \ Z + 27$ |
| 7    | Robertkiri 12| $T = 21.45 \ Z + 27$ |
| 8    | Robertkiri 13| $T = 17.75 \ Z + 27$ |
| 9    | Robertkiri 14| $T = 23.90 \ Z + 27$ |

Table 3. Temperature variation with depth for given wells

| S/No | Well name   | Relationship         | at 1km (°C) | at 2km (°C) | at 3km (°C) | at 4km (°C) |
|------|-------------|----------------------|-------------|-------------|-------------|-------------|
| 1    | Idama 4     | $T = 17.30 \ Z + 27$ | 44.3        | 61.6        | 78.9        | 96.2        |
| 2    | Inda 8h     | $T = 22.56 \ Z + 27$ | 49.56       | 72.12       | 94.68       | 117.24      |
| 3    | Robertkiri 4| $T = 25.72 \ Z + 27$ | 52.72       | 78.44       | 104.16      | 129.88      |
| 4    | Robertkiri 5| $T = 25.85 \ Z + 27$ | 52.85       | 78.7        | 104.55      | 130.4       |
| 5    | Robertkiri 8| $T = 23.13 \ Z + 27$ | 46.13       | 73.26       | 96.39       | 119.52      |
| 6    | Robertkiri 10| $T = 21.65 \ Z + 27$ | 48.65       | 70.3        | 91.95       | 113.6       |
| 7    | Robertkiri 12| $T = 21.45 \ Z + 27$ | 44.45       | 69.9        | 91.35       | 112.8       |
| 8    | Robertkiri 13| $T = 17.75 \ Z + 27$ | 44.75       | 62.5        | 80.25       | 98          |
| 9    | Robertkiri 14| $T = 23.90 \ Z + 27$ | 50.9        | 74.8        | 98.7        | 122.6       |

Fig. 2. Graph showing projected variation of Geothermal Gradient with depth

4. CONCLUSION

An assessment of Geothermal Gradients in three adjacent oil fields in the Eastern Niger Delta basin showed significant variations. Results showed the average gradients for Idama, Inda and Robertkiri as 17.3°C/Km, 22.6°C/Km and 23.1°C/Km respectively. These results show that
the Geothermal Gradient in the area are generally moderate and could be a good reason for the occurrence of more oil deposits than gas in the area.

COMPETING INTERESTS
Authors have declared that no competing interests exist.

REFERENCES
1. Tissot BP, Welte DH. Petroleum formation and occurrence. Springer-Verlag, New York. 1978; 538.
2. Waples DW. Time and Temperature in Petroleum Exploration: Application of Lopatin’s method to Petroleum Exploration. AAPG Bulletin. 1980; 64:916-926.
3. Uko ED. Thermal modelling of the Northern Niger Delta. Unpublished PhD Thesis. Rivers State University, Rivers State, Nigeria; 1996.
4. Nwankwo CN, Ekine AS. Geothermal Gradients in the Chad Basin, Nigeria from Bottom Hole Temperature logs. International Journal of Physical Sciences. 2009; 4(12):777-783.
5. Emujakporue GO, Ekine AS. Determination of Geothermal Gradients in the Eastern Niger Delta sedimentary basin from Bottom Hole Temperature logs. Journal of Earth Sciences and Geotechnical Engineering. 2013; 4(3):109-114.
6. Uko ED, Amakiri ARC, Alagoa KD. Effects of lithology on Geothermal Gradients in the South East Niger Delta, Nigeria. Global Journal of Pure and Applied Sciences. 2002; 8(3):325-337.
7. Akpabio IO, Ejevwe KE, Ebeniro JO, Uko ED. Geothermal Gradients in the Niger Delta Basin from Continuous Temperature Logs. Global Journal of Pure and Applied Sciences. 2003; 9(2): 265-271.
8. Uko ED, Tamunoberon-arii I, Omubo-Peppe VB, Loveday PJ. Stratigraphic control of Temperature in the North-west Niger Delta Basin, Nigeria. Journal of Scientific and Engineering Research. 2018; 5(2):1-10.
9. Nwachukwu JI. Approximate geothermal gradient in the Niger Delta sedimentary Basin. AAPG Bulletin. 1976; 60:1073-1077.
10. Chukwueke C, Thomas G, Delfrau J. Sedimentary processes, eustatism, subsidence and heat flow in the distal parts of the Niger Delta. Bull. Centre Rech. Exploration – Production, Elf – Aquitaine. 1992; 16(1):137–186.
11. Akpabio IO, Ejevwe KE. Temperature variations in the Niger Delta subsurface from Continuous Temperature Logs. Global Journal of Pure and Applied Science. 2001; 7(1):137-142.
12. Oghuokwe A. Determination of geothermal gradient and heat flow distribution in Delta State. Nigeria International Journal of the Physical Sciences. 2011; 6(31):7106–7111.
13. Odumodu CFR, Mode AW. Present Day Geothermal Regime in Parts of The Eastern Niger Delta, Nigeria. PTDF Journal. 2014; 1(7):26.
14. Short KC, Stauble AJ. Outline of geology of Niger Delta: AAPG Bulletin. 1967; 51:761–779.
15. Kagbe CA. Geology of Nigeria. Rock View (2nd Edition). 1989; 311–324.
16. Tuttle ML, Charpentier RR, Brownfield ME. The Niger Delta petroleum Tissot BP, Pelet R, Ungerer P. 1987. Thermal history of sedimentary basins, maturation indices, and kinetics of oil and gas generation. AAPG Bull. 1999; 71:1445–1466.
17. Hussler L, Henry P, Le Pichon X. Thermal regime of the NW shelf of the Gulf of Mexico, Part A: Thermal and pressure fields. Bull. Soc. Geol. Fr. 2008a; 179(2):129–137.
18. Akebvo BA. Tertiary lithostratigraphy of Niger Delta: AAPG Bulletin. 1978; 62:295 – 300.
19. Evamy BD, Haremboire J, Kamerling P, Knaap WA, Molloy FA, Rowlands PH. Hydrocarbon habitat of Tertiary Niger Delta: AAPG Bulletin. 1978; 62:277–298.
20. Emujakporue OG. Subsidence and Geothermal history in the Eastern Niger Delta with implications for hydrocarbons. Unpublished PhD Thesis. University of Port Harcourt, Rivers State, Nigeria; 2009.
21. Adedapo JO, Kurowsta E, Schoeneich K, Ikpokonte AE. Geothermal Gradient of the Niger Delta from recent studies. International Journal of Scientific and Engineering Research. 2013; 4(11):39 – 45.
Akpabio IO, Ejedawe JE, Ebeniro JD. Geothermal Reservoir Engineering, Thermal state of the Niger Delta Basin. Stanford University, California. 2013; 11–13.

Peer-review history:
The peer review history for this paper can be accessed here: https://www.sdiarticle4.com/review-history/68803