OPEN ACCESS

ISSN: 2835-7868

Adebowale IJ (2023): 266
DOI: 10.47378/2835-7868/2023.4.116
J Earth Envi Sci: JEES-116

Research Article

Journal of Earth & Environment Science

Investigation of Variations in Geothermal Gradient Across Parts of Eastern Niger Delta Basin, Nigeria

Iwalokun Joseph Adebowale, Ebiegberi Oborie, Davidson E. Egirani, Soukeme Ebikeme, Uzobo E. Job

Department of Geology, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

***Corresponding author:** DAVIDSON E. EGIRANI, Department of Geology, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria. Email davidsonegirani@ndu.edu.ng*

***Citation:** Adebowale IJ, Oborie E, Egirani DE, Ebikeme S, Job UE (2023) Investigation of Variations in Geothermal Gradient Across Parts of Eastern Niger Delta Basin, Nigeria. J Earth Envi Sci: JEES-116.*

***Received Date:** 16 July, 2023; **Accepted Date:** 19 July, 2023; **Published Date:** 24 July, 2023*

Abstract

Investigation of geothermal gradient from Continuous Temperature Logs was carried across the eastern part of the Niger Delta Basin. The data used for the study area were obtained from 4 (four) deep wells in the Niger Delta. Also, investigation of variation in geothermal gradient analysis showed that gradient in Eastern Niger Delta Basin was 29.65^{0}c/m in KK-01 field, 30.80^{0}c/m in KK-05, 30.82^{0}c/m in KK-06 and 30.80^{0}c/m in KK-21 field. Variation in geothermal gradient in the area are usually attributed lithological variation or rate of sedimentation. The value obtained showed agreement with those obtainable from the past research. The areas which study is carried out has low geothermal gradient which are corresponding with area of high percentage of sand because sand is good thermal conductor than shale, on the other hand, higher geothermal gradient is attributed to high shale volume. From the result gotten in this project work, from 0^{0}c-50^{0}c. It is immature source rock and all the geothermal gradient value range between 29.65^{0}c to 30.82^{0}c/m which means geothermal gradient play significant role in source rock maturation, area with low geothermal gradient are associated with immature source rock. The geothermal gradient computed in this work are comparable to the average 25^{0}c/km to those of earlier work carried out in Niger Delta.

Introduction

Geothermal gradient is the rate at which earth's temperature increase with depth, due to heat from the earth's core. It is believed that heat from the core is primarily due the decay of radioactive elements such as potassium, uranium and thorium. Variation in geothermal gradients is determined from measurement of temperature of rocks penetrated by borehole [1]. The knowledge of geothermal gradient has several applications cutting across determining the suitability of places for siting geothermal plants for the generation of electricity, siting of industries, domestic and recreational activities and establishing of hydrocarbon production zones [2]. The thermal history of a sedimentary basin is closely related to the mechanisms of basin formation and the development of suitable environments for hydrocarbon maturation [3]. The implication for petroleum exploration is that the present-day temperature field contributes to the probability of occurrence of economic hydrocarbon reserves. Knowledge of geothermal gradients are very necessary for the analysis of reservoir fluid properties as well as plate tectonics interpretation.

According to [4] geothermal gradients are very critical factors influencing the thermal structure and maturation pattern of sediments and are also useful in unravelling the past thermal regimes in a sedimentary basin or meaningful geothermal and/or maturation studies. The variability of heat flow in most basins arise from some combination of at least the following four principal influences: heat redistribution by migration of Formation fluids (hydrodynamic effect); variations in conductivity and heat generation in the sedimentary succession; variations in the heat generation of crystalline basement and variations in mantle heat flow [5].

Several appraisals, exploratory and development wells have been drilled in the Niger delta since 1956 when oil was first discovered, some of these wells have been logged for temperature data to understand the temperature plays in the subsurface. Most of the previously drilled wells for hydrocarbons in the Niger delta are of shallow depths, usually less than 3,500 m. However, hydrocarbon occurrences in the delta are also known to exist at some great depths. But drilling to these great depths requires an accurate assessment of the temperature regimes in the area.

Theoretically, higher thermal gradients are expected in deeper basins and lower thermal gradients in shallower basins [6]. However, the reverse is the case in Nigerian basins where the highest geothermal anomalies recorded were discovered by [7] in the relatively shallow Sokoto Basin, while the lowest geothermal gradients which were recorded by were observed in the deepest basin which is the Niger Delta basin.

Few researchers have investigated the variability of geothermal gradients of Nigeria's sedimentary basins. Historically, the search for geothermal energy in Nigeria dates back to a publication by two hydrogeologists prompted by reports of hot water flowing from artesian wells drilled in Chad Basin.

Description and Geology of the Study Area

The study area is located between longitudes 6º30'E – 8º00'E and latitudes 4º00'N – 5º00'N (Fig.1).

General Geology of the Study Area (Niger Delta) [8]

The study area falls within the Niger Delta Basin located between 3°N and 6°N and 5°E and 8°E. It is a clastic wedge with a 12 km thickness at the centre of the basin spanning over a 75,000 sq km area. On the Northwest it's bound by the Benin Flank, on the East by the Calabar Flank, on the southern axis it extends into the Atlantic. The formation of the basin started during the Eocene. River Niger, River Benue and Cross River transported and deposited sediments of the Niger Delta basin. The Niger-Benue river system alone has brought an average sediment load of about 0.02 km^3/yr. deposited mainly on top the delta.

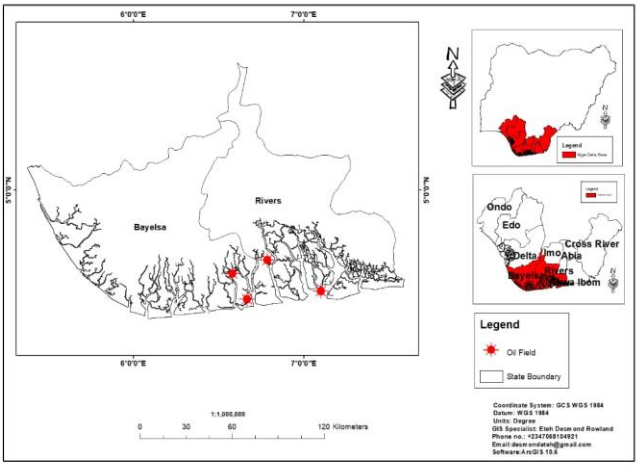

Figure 1: Location map showing wells investigated.

Materials and Methods

Data Requirement

The data used in this study were obtained from four (4) wells in the Niger Delta. They comprise of subsurface temperature data and depth in km from the four distinct wells. Analytical software used is Microsoft Excel for conversion and data analysis.

Temperature Conversion

Composite logs of four (9) wells data were used to accomplish the objectives of this research. The data set used were simple reservoir temperature log. The temperature data used was originally recorded in Fahrenheit scale but was converted to the Celsius scale.

Determination of Geothermal Gradients

Thermal Studies

Geothermal studies are useful in understanding many of the geological and geophysical phenomena that is being witnessed on the earth, such as earthquakes and volcanism as well as the earth's magnetic field and the plasticity of earth's material at depth. Heat flow studies also give us insight into the thermal history and geodynamic origin of sedimentary basins. According to [10], the thermal history of a basin depends on its tectonic origin and the circumstances of its development. The dissipation of excess heat associated with basin formation and the transfer of the continuous heat supply from the basement depend on the thermal properties of the strata and their water content. The thermal conditions of a sedimentary basin are usually influenced by the heat flow from the underlying basement and the thermal conductivity of the sedimentary cover or overprinted by other processes such as fluid flow. Present-day temperature data is most often used in studying the thermal structure of the earth. The thermal gradient and thermal conductivity values of rock types in an area have been used to obtain estimates of heat flow variations in an area. The variations in heat flow in a sedimentary basin are influenced by several factors, which include: Basement Heat flow, Radioactive Heat Production in sediments, Effect of Sedimentation, deeply buried salt structures and Fluid flow through sediment.

Basement Heat

Flow Basement heat flow is primarily controlled by the mechanics of the basin-forming rift-extension event and subsequent subsidence caused by the cooling of the lithosphere. Heat flow decreases with time as the lithosphere gradually approaches a quasi-steady state. Observed that the heat generated through the radioactive decay of unstable elements, such as uranium, thorium and potassium contained in the crustal rocks has a significant contribution to the total heat flow coming from the basement. The continental crust is also known to produce several tens of time more radiogenic heat than the oceanic crust (Table 1).

Table 1: Stages in the formation of hydrocarbon [11]

Stages of petroleum formation	Temp (^0C)	Maturity	Hydrocarbon type
	0	Premature	
		Premature	Biodegradation
Diagenesis	50	Premature	
	60	Oil window	Black heavy oil
Catagenesis		Oil window	Black oil
		Oil window	Black oil
		Oil window	Light oil
	150	Gas window	Volatile oil
		Gas window	Condensate rich
		Gas window	Dry gas rich
	200	Gas window	Dry gas
Metagenesis		Gas window	Dry gas
		Gas window	Dry gas
	240	Over mature	Dry gas
		Over mature	Dry gas
		Over mature	
		Over mature	
		Over mature	
		Over mature	
		Over mature	
		Over mature	

Results and Discussion

Presentation of results

Results from the investigation of geothermal gradient wells KK-21, KK-1, KK-5 and KK-6 are presented in Tables 1-3 and Fig. 2-3.

Table 2a: Continuous temperature Log and depth for KK-01 well.

VERSION INFORMATION	
VERS. 2.0: CWLS Log ASCII Standard - version 2.0	
WRAP. NO: One line per depth step	
WELL INFORMATION	
MNEMONIC. UNIT DESCRIPTION	VALUE:
STRT FT DEPTH	4750.0000: START
STOP FT DEPTH	9000.0000: STOP
STEP FT	0.5000: STEP
WELL	KK-01: WELL
API	KK-01: API NUMBER
UWI WELL ID	KK-01: UNIQUE
XCOORD SURFACE X	426240.900000:
YCOORD SURFACE Y	38750.100000:
LAT	4.348483: LATITUDE
LON LONGITUDE	6.261399:
ELEV FT ELEVIATION VALUE	90.000000:

Table 2b: Continuous temperature Log and depth for KK-01.

S/N	DEPTH_FT	DEPTH_M	LOGTEMP_F	LOGTEMP_C
1	4750	1447.80	129.69	54.27
2	4820	1469.13	129.69	54.27
3	4890	1490.47	129.70	54.28
4	4960	1511.80	129.71	54.28
5	5030	1533.14	129.71	54.28
6	5100	1554.48	129.72	54.29
7	5170	1575.81	129.72	54.29
8	5240	1597.15	129.73	54.29
9	5310	1618.48	129.73	54.30
10	5380	1639.82	129.74	54.30
11	5450	1661.16	129.75	54.30
12	5520	1682.49	129.75	54.31
13	5590	1703.83	129.76	54.31
14	5660	1725.16	129.76	54.31
15	5730	1746.50	129.77	54.32
16	5800	1767.84	129.77	54.32
17	5870	1789.17	129.78	54.32
18	5940	1810.51	129.78	54.32
19	6010	1831.84	129.79	54.33
20	6080	1853.18	129.80	54.33
21	6150	1874.52	129.80	54.33
22	6220	1895.85	129.81	54.34
23	6290	1917.19	129.81	54.34
24	6360	1938.52	129.82	54.34
25	6430	1959.86	129.82	54.35
26	6500	1981.20	129.83	54.35

27	6570	2002.53	129.84	54.35
28	6640	2023.87	129.84	54.36
29	6710	2045.20	129.85	54.36
30	6780	2066.54	129.85	54.36
31	9850	3002.28	129.86	54.37
32	6990	2130.55	129.86	54.37
33	7060	2151.88	129.87	54.37
34	7130	2173.22	129.88	54.38
35	7200	2194.56	129.88	54.38
36	7270	2215.89	129.89	54.38
37	7340	2237.23	129.89	54.38
38	7410	2258.56	129.90	54.39
39	7480	2279.90	129.90	54.39
40	7550	2301.24	129.91	54.39
41	7620	2322.57	129.91	54.40
42	7690	2343.91	129.92	54.40
43	7760	2365.24	129.93	54.40
44	7830	2386.58	129.93	54.41
45	7900	2407.92	129.94	54.41
46	7970	2429.25	129.94	54.41
47	8040	2450.59	129.95	54.42
48	8110	2471.92	129.95	54.42
49	8180	2493.26	129.96	54.42
50	8250	2514.60	129.97	54.43
51	8320	2535.93	129.97	54.43
52	8390	2557.27	129.98	54.43
53	8460	2578.60	129.98	54.43
54	8530	2599.94	129.99	54.44
55	8600	2621.28	129.99	54.44
56	8670	2642.61	130.00	54.44
57	8740	2663.95	130.01	54.45
58	8810	2685.28	130.01	54.45
59	8880	2706.62	130.02	54.45
60	8950	2727.96	130.02	54.46

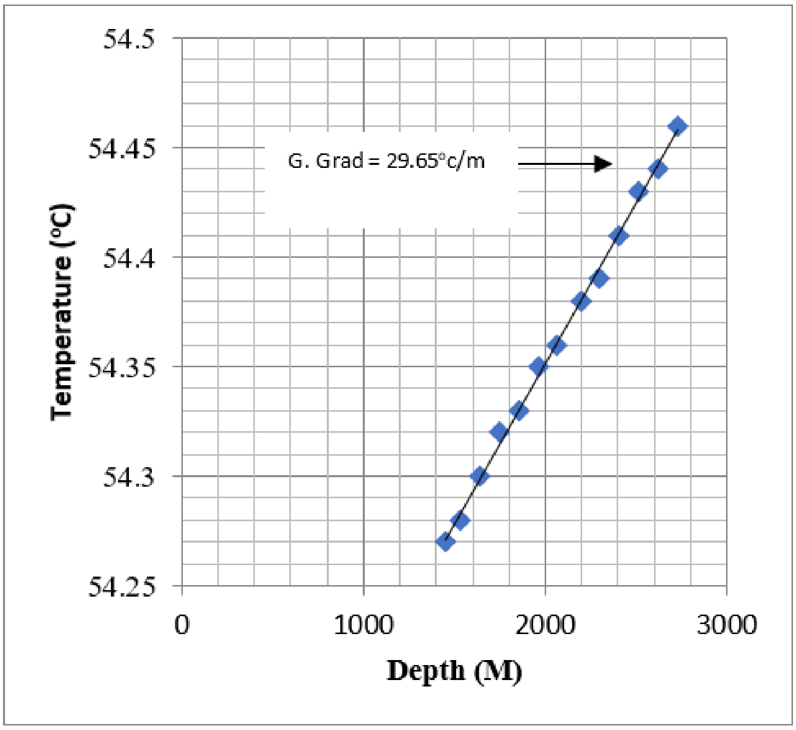

Figure 2: Temperature vs Depth plot for well kk-01.

Table 3: Calculated geothermal gradient for all five wells.

GEOTHERMAL GRADIENT	NAME OF WELL
29.65	KK-01
30.80	KK-05
30.80	KK-06
30.84	KK-21

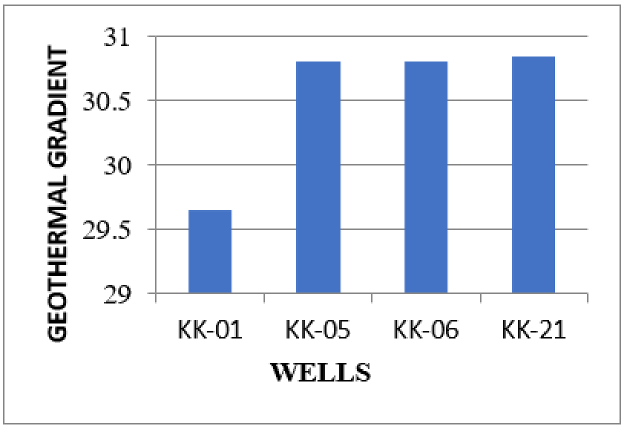

Figure 3: A Geothermal Gradient vs Depth plot for all five wells.

Discussion

Investigation of geothermal gradient analysis showed that gradient in Eastern Niger Delta Basin was 29.65^{0}c/m in KK-01 field, 30.80^{0}c/m in KK-05 field, 30.82^{0}c/m in KK-06 and 30.80^{0}C/m in KK-21 field. The value obtained showed agreement with those obtainable from the past work [12-25]. Variation in geothermal gradient in the area are usually attributed to lithological variation or rate of sedimentation. The area or the region which the study is carried out has low geothermal gradient which are attributed to high percentage of sand because sands are better thermal conductor than shale, on the other hand, higher geothermal gradient are attributed to high shale volume. Geothermal gradient plays significant role in source rock maturation, area with low geothermal gradient are associated with immature source and in some cases oil occurrence are presented.

As stated from the table 3.1 from 0^{0}c-50^0 it is immature source rock and all the geothermal gradient fall between 29.65^{0}c/m – 30.82^{0}c/m this showed that the study area has low geothermal gradient. It is hydrocarbon window) as it has been compared with [3-4].

Conclusion

Investigation of variation in geothermal gradient in Niger Delta Basin analysis is attributed to lithological variation or rate of sedimentation. The location in which this study is carried has low geothermal gradient as result of high percentage of sand because sands are good thermal conductor and associated with immature source rock and oil occurrence. The geothermal gradients computed in this work are comparable to the average 25^{0}c/km to those of earlier work carried out in Niger Delta that concluded that the value of 29.65c/m – 30.82^{0}c/m is hydrocarbon window.

Acknowledgment

My heartfelt gratitude goes to the Deans of Post Graduate School Prof. Ibaba S. Ibaba, and the Faculty of Science Professor Inengite. I am most grateful to my Head of Department Dr. Ebiegberi Oborie who doubles as my project supervisor, for his support and guidance toward making this research work a success. My so much appreciate my lecturers; Dr. Egirani, Dr. (Mrs) E. Akpofure, Dr. A. Aderogba, Dr C. Ovuru, Dr. A. Oki, Dr. A. Opukumo, Dr. T. Akana, Dr. A. Egai, Mr. A. Opigo, Mr. I. Didei, Mr. E. Debekeme, Mr. F. Akori, Mrs. L. Jonathan for the knowledge they have bestowed on me over these past years, also the technologists Mr. Fubai, Mr. Abraham, Mr. Kennedy and Mrs. Faith for their assistance through laboratory and field works, the administrative secretaries Mr. Larry and Mrs. Agada for their assistance whenever called upon.

I wish to thank my entire family for their love, support and encouragement and my thanks also goes to my Elder brother Meshach Iwalokun and his wife, Iwalokun Segun, Engr. Anyantoye and wife God bless you. I also acknowledge the effort and encouragement of the member of the deeper life campus fellowship university (UNIPORT). Finally, my thank goes to my friends and course mates; Ogede, Harry, Ebiala, Becky, Teidou, Wosley, Kennedy and Mrs. Richard Victoria who is my typist.

References

1. Adedapo, J.O., Kuro, W. E., Schoeneich, K., Ikpokone, A.E. (2013). Geothermal Gradient of the Niger Delta from Recent Studies: international journal of scientific and engineering research, vol.4(11), Pp.229-518.
2. Akpabio, I. O. (2009). Thermal Conductivity estimates in the Niger Delta using lithological data and geophysical well logs. *The Pacific Journal of Science and Technology, 10*(1), 701 – 709.
3. Akpabio, I. O., Ejedawe, J. E. & Ebeniro, J. D. (2013). Thermal state of the Niger Delta Basin. Proceedings of the 38th workshop on Geothermal Reservoir Engineering, Stanford University, Califonia. February 11 – 13.
4. Akpabio, I. O., Ejedawe, J. E., Ebeniro, J. D. & Uko, E. D. (2003). Geothermal Gradients in the Niger Delta Basin from continuous temperature logs. *Global Journal of Pure and Applied Sciences, 9*(2), 265 – 271.

5. Anomohanran, O. (2013) Evaluation of Geothermal Gradients and Heat Flow distribution in Delta State. Internal Journal Basic Applied., V2(1), pp 103-108.
6. Burke, K.C. (2003) Geological History of Benue Valley and adjacent area (Eds) African Geology Ibadan, University Press.
7. Ekine, A. S. & Onuoha, K. M. (2008). Burial history analysis and subsidence in the Anambra basin. *Nigerian Journal of Physics*, *20*(1), 145 – 154.
8. Emujakporue, G.O. and Ekine, A.S (2014). Determination of Geothermal Gradient in the Eastern Niger Delta Sedimentary Basin from Bottom Hole Temperature: Journal of Earth Science and Geotechnical Engineering, vol.4(3).
9. Emujakporue, O. G., (2009). Subsidence and geothermal history in the eastern Niger delta with implications for hydrocarbons. Unpublished PhD. Thesis U.P.H.
10. Emujakporue, (2009). Analysis of the variation of geothermal gradient and sand percentage in the eastern coastal swamp of the Niger Delta: COOU Journal of Physical Science, vol. 4(1).
11. Forster, A. (2001). Analysis of borehole temperature data in the Northeast German Basin: continuous logs versus bottom-hole temperatures. *Petroleum Geoscience, 7,* 241 – 254.
12. Frielingsdorf, J. (2009). Unpublished Petroleum Systems Event Chart in: Emujakporue, G. O. (2004). Subsidence and Geothermal history in the Eastern Niger Delta Basin with implications for hydrocarbons.
13. Kurowaska, E., Schoeneich, K (2010): Geothermal Exploration in Nigeria. Proceedings of World Geothermal Congress, 2010. Bali, Indonesia, 25-29 April 2010.
14. McKenzie, D, P. (2004). Some remarks on the development of sedimentary basins. *Earth and Planetary Science Letters*, *40*, 25 – 32.
15. Majorowicz, J., Jessop A., Alan M., Lane, L. S. (March 2005): Regional Heat Flow Pattern and Lithospheric Geotherms in Northeastern British Columbia and Adjacent Northwest Territories, Canada, Bulletin of Canadian Petroleum Geology, Vol.53(1), Pp.51-66.
16. Murat, K.C. (2005) Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In: Dessauvagie, T.F.J. and Whiteman, A.J., Eds., African Geology, University of Ibadan, 251-266.
17. Whiteman, A. (2000) Nigeria: its Petroleum Geology, Resources and Potentials. I and II. Graham and Trotman Ltd., London. http://dx.org/10.1007/978-94-009-7361-9
18. Davidson, I. Steel, I, (2018) Geology and Hydrocarbon Potential of African Continental margin. Review 57-91, 9 de November de.
19. El-Emry, Y. Shen. A.A Nyblade A. Flinder, X Bao (2018). Upper mantle Earth Structure in Africa from Full- wave Ambient Noise Tomography htttps///doi,org/10./029/2018GC007804
20. Francis, M, Otros, (2018) Petroleum System of the deeper-water mazambique basin. Energy, Technol, sustain 59-64. Time to open a new chapter, June de.
21. Kurowaska, E., Schoeneich, K (2019): Geothermal Exploration in Nigeria. Proceedings of World Geothermal Congress, 2010. Bali, Indonesia, 25-29 April 2010.
22. Macgregor, D. S. (2020) Regional Variation in geothermal gradient and heat flow across the African plate, journal of African Earth Science, 171, p. 103950.
23. Stockli and Bosworth (2019), Timing of Extensional faulting along the magma –poor central and Northern Red Sea Rift Margin- transition from Regional Extension to Necking along a hyperextend Rifted margin D0I: 10:1007/978-3-319-99408-6-5 in book – Geological setting, palaed environment and Archeology of the Red Sea (PP 81-111).
24. O.J Nhabanga Oscar J. and Nhabanga, Philip S. Ringrose (2019) Assessment of mudstone compaction in exploration in the Rovurna Basin offshore. Norwegian university of Science and Technology (NTNU) Norway.