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

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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.

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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 17.3^{0}C/Km, 22.6^{0}C/Km and 23.1^{0}C/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.

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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 6^0 15'' E and 7^0 15'' E and longitudes 4^0 15'' N and 4^0 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);

$$T = mZ + C \tag{1}$$

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

$$m = \frac{T-C}{Z} \tag{2}$$

Where m is the slope or geothermal gradient, T is the temperature at depth in ^{0}C or ^{0}F, C is the surface temperature in ^{0}C or ^{0}F, Z is depth in m or ft. The average surface temperature obtained in Niger Delta from literature is 27^{0}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);

$$C = (F - 32) \times \frac{5}{9} \tag{3}$$

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

Fahrenheit scale has an interval of 180^{o}F. It starts from 32^{o}F ending at 212 ^{o}F, while the Celsius scale starts from 0 and ends at 100^{o}C having an interval of 100^{o}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 27^0C, the Temperature (T^0C) - 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 17.3^0C/Km, 22.6^0C/Km and 23.1^0C/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.

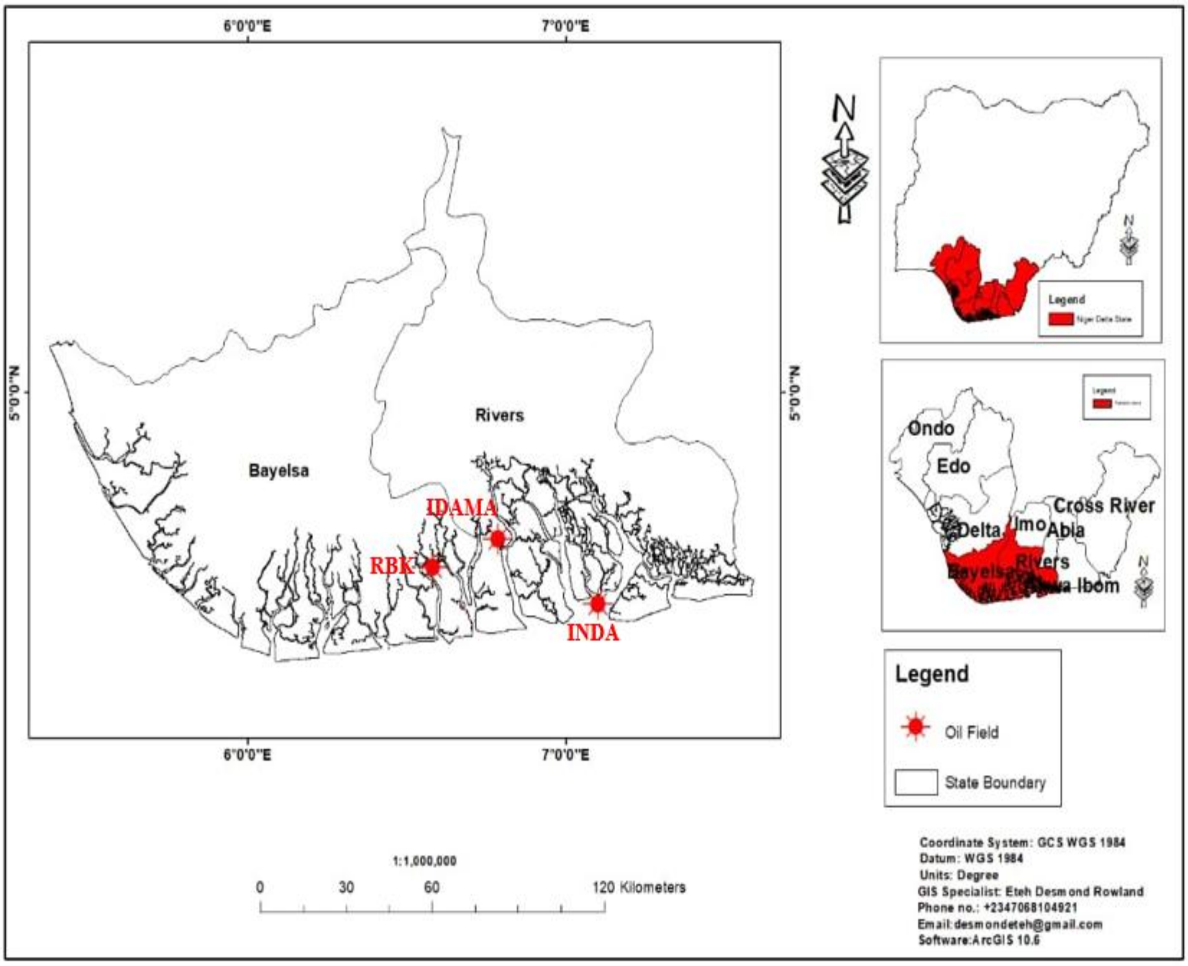

Fig. 1. Map of the Niger Delta showing study area

Table 1. Geothermal gradient computed from corrected BHT data

S/No	Well name	Test date	Depth (ft)	Depth (Km)	BHT (ºF)	BHT (ºC)	BHT * 110%	Geothermal Grad. (C/Km)	Ave. Geothermal Grad. (ºC/Km)
1	Idama-04	30-Jan-94	11162	3.382424242	169	76.1111111	83.72222222	16.7696948	17.294107
2	Idama-04	31-Jan-94	9583	2.903939394	160	71.1111111	78.22222222	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	82.7777778	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	134.444444	147.8888889	30.80566281	
16	Rbk-04	10-Aug-86	12950	3.924242424	224	106.666667	117.3333333	23.01930502	
17	Rbk-04	17-Aug-86	12950	3.924242424	225	107.222222	117.9444444	23.17503218	
18	Rbk-04	06-Apr-87	12950	3.924242424	230	110	121	23.95366795	
19	Rbk-04	12-Apr-87	12950	3.924242424	220	104.444444	114.8888889	22.3963964	
20	Rbk-05	30-Oct-85	9850	2.984848485	240	115.555556	127.1111111	33.53976311	25.84747386
21	Rbk-05	08-Aug-86	9850	2.984848485	175	79.4444444	87.38888889	20.23181049	
22	Rbk-05	22-Jul-87	9850	2.984848485	218	103.333333	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	87.7777778	96.55555556	23.30287648	
25	Rbk-05	16-Oct-92	9850	2.984848485	214	101.111111	111.2222222	28.21658206	
26	Rbk-05	23-May-93	9850	2.984848485	240	115.555556	127.1111111	33.53976311	
27	Rbk-08	17-Apr-85	12800	3.878787879	226	107.777778	118.5555556	23.60416667	23.13151067
28	Rbk-08	14-Jun-86	12800	3.878787879	208	97.7777778	107.5555556	20.76822917	
29	Rbk-08	08-Apr-87	12800	3.878787879	226	107.777778	118.5555556	23.60416667	
30	Rbk-08	16-Mar-88	12800	3.878787879	226	107.777778	118.5555556	23.60416667	
31	Rbk-08	05-Aug-90	12800	3.878787879	225	107.222222	117.9444444	23.44661458	

S/No	Well name	Test date	Depth (ft)	Depth (Km)	BHT (ºF)	BHT (ºC)	BHT * 110%	Geothermal Grad. (C/Km)	Ave. Geothermal Grad. (ºC/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	21.650521
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	23.44661458	
37	Rbk-10	01-May-93	12800	3.878787879	190	87.7777778	96.55555556	17.93229167	
38	Rbk-12	08-Aug-95	12800	3.878787879	224	106.666667	117.3333333	23.2890625	21.45206801
39	Rbk-12	02-Nov-85	10060	3.048484848	190	87.7777778	96.55555556	22.81643472	
40	Rbk-12	19-Aug-86	10060	3.048484848	184	84.4444444	92.88888889	21.61365142	
41	Rbk-12	21-Jul-87	10060	3.048484848	118	47.7777778	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	81.1111111	89.22222222	20.41086812	
44	Rbk-12	16-Aug-95	10060	3.048484848	202	94.4444444	103.8888889	25.22200133	
45	Rbk-13	19-Jul-87	9825	2.977272727	200	93.3333333	102.6666667	25.41475827	17.7517668
46	Rbk-13	18-Aug-88	9825	2.977272727	118	47.7777778	52.55555556	8.583545377	
47	Rbk-13	23-Jan-93	9825	2.977272727	170	76.6666667	84.33333333	19.25699746	
48	Rbk-14	30-Sep-92	14668	4.444848485	250	121.111111	133.2222222	23.89782747	23.897827

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 (^{0}C)	at 2km (^{0}C)	at 3km (^{0}C)	at 4km (^{0}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

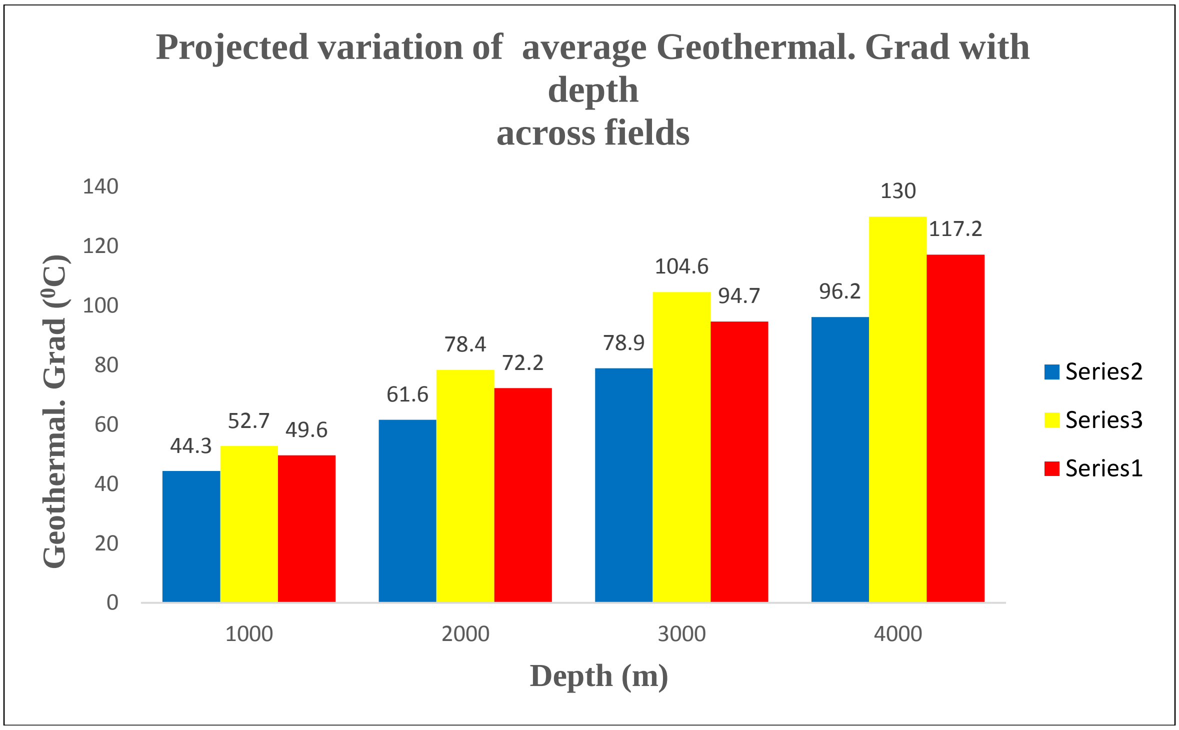

Fig. 2. Graph showing projected variation of Geothermal Gradient with depth

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^{0}C/Km, 22.6^{0}C/Km and 23.1^{0}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.

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