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Determination of thermal and physical properties of sediments in the NIger delta, using wire line log data

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ABSTRACT

Wire line logs have been used in this study to determine the thermal and physical properties of sediments in the Niger Delta. Results show that thermal conductivity depends on porosity (φ) and sonic velocity (V_p). The effective thermal conductivity seems to be low at the central portion of the Niger Delta basin but increases away from the centre in all direction o the basin. Thermal conductivity and sonic velocity are practically interdependent as they increase proportionally. The physical properties such as temperature, velocity and lithology were also measure or calculated along side with thermal gradient. The values of physical and thermal parameters obtained in this research through wire line logs have been used to correlate the values of the thermal properties determined in the laboratory to establish the effective and acceptable bulk thermal conductivities of the region.

Keyword: Thermal Properties, physical properties, Niger Delta, Wire line logs and sediments

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INTRODUCTION

The thermal histories of sedimentary basins and their effect on organic maturation are topics of active study [1]. Knowledge of the present heat flow regime in a basin is important not only for understanding the thermal maturation pattern of the sediments, but also for interpreting the past thermal regime in the area. The temperature history of a sedimentary basin governs the maturation of kerogen into petroleum and the conversion of oil to natural gas. Accurate temperature and heat flow measurement are very expensive, and in Nigeria to day, little has been done in this direction [2].

To understand the thermal structure of a sedimentary basin, it is important to determine the thermal and physical properties of the sediments that constitute the basin. Of all the various thermal properties of rocks thermal conductivity is perhaps the most important in this context because it has a first order control on the configuration of isotherms and the flow of heat within the basin [3].

Knowledge of the thermal conductivity of fluid filled rocks is extremely important to petroleum geologists, geophysicists and geochemists for both theoretical and practical points of view. An accurate prediction of the thermal conductivity of reservoir rocks or aquifers on the subsurface is extremely important for a quantitative analysis of basin's thermal history and hydrocarbon maturation. This prediction of sediment thermal conductivity, physical properties and knowledge of the uncertainties of that prediction are needed otherwise even the most sophisticated and appropriate model for analysis of thermal history and maturation level many fail when applied to real basin [4]. Since sedimentary rocks are porous aggregates of rock fragments and minerals built on the silicic deposits of high energy Niger Delta, the bulk conductivity is sensitive to both matrix and fluid conductivities and also to physical properties like porosity, velocity and sand percentage shown in tables 1 – 5.

Thermal conductivity variations are generally the cause of vertical and lateral temperature variations [5, 6]. Thermal conductivity contrasts seem to be adequate to explain the change in temperature gradient across the top of the geo-pressure zone. It is important to understand the thermal conductivity of the rocks units in a sedimentary basin before attempting to understand its temperature structure [1]. Thermal conductivity has a first order control on the configuration of isotherm and the flow of heat in any basin [2].

Thermal conductivity and physical properties can be determined by wire line logs or laboratory method. Based on the fundamental importance of thermal conductivity as the controlling parameter of heat flow and the thermal state of the silicic deposit of Niger Delta, this research was conceived to determine the bulk and effective thermal conductivities of the Niger Delta through the use of wire line logs obtained from the Shell Development Company of Nigeria.

Geophysical borehole logging or wire line logging is used to derive further information about the sequence of rocks penetrated by a borehole [7]. The main logs of interest are: self potential log, Gamma ray log, sonic velocity log, density and neutron logs for identification of lithologies and other reserviour parameters like porosity and permeability.

Location and geology of the study area

The Niger Delta basin (Fig. 1) is situated on the continental margin of the Gulf of Guinea in the equatorial West Africa, between latitude 3^o and 6^o N and longitude 5^o and 8^oE (Fig 1). It is one of the most prominent basins in Africa and it covers an area of 75,000km^2 [7]. The wedge of Niger Delta sediment can be considered to consist of three lithostratigraphic units: Akata Formation, Agbada Formation and the Benin formation. The basal Akata Formation, which is predominantly marine prodelta shale, is overlain by the paralic sand / shale sequence of the Agbade Formation. The top most section is the continental upper Deltaic plain sands-the Benin Formation. The Agbade Formation that overlies the Akata Formation is the reserviour (pay zone) that produces petroleum in which the economic base of the country, Nigeria is enshrined [8, 9].

MATERIALS AND METHODS

The logs used were sonic log, formation density interval log, gamma ray log, caliper log and sand percentage of selected interval. With these logs the porosity (φ) and sonic velocity (V_p) of the sediments which are physical properties were obtained and with the use of [10] model in equation (1), the thermal conductivity of each of the wells were calculated as shown in the table 1 –5 at different depths

$$K = 0.84 - 0.040\varphi + 0.000695V_p \quad (1)$$

where φ = porosity (%)

K = bulk thermal conductivity in $Wm^{-1}k^{-1}$

V_p = Sonic velocity in m/s

The effective thermal conductivity for each location was calculated by plotting a graph of heat flow φ against the thermal gradient in which the slope gives the effective thermal conductivity in equation (2):

$$Q = K\frac{dT}{dt} \quad (2)$$

The temperature (T_B) was calculated using equation (3)

$$T_B = T_0 + \left(\frac{dT}{dt}\right)B \quad (3)$$

where T_B = Temperature at a depth B and B = the depth at which the interval was taken. In this work, the surface temperature (T_o) was taken as 25°C [2].

The thermal gradient $\left(\frac{\Delta T}{\Delta t}\right)$ was calculated using the relation between the sand percentage, depth and temperature gradient in equation (4) given below:

$$T = a - bs^2 + CD = \frac{\Delta T}{\Delta t} \quad (4)$$

where T is the temperature gradient (°F/100 feet = 18.2°C/km). S is the sand percentage of the selected interval obtained from Shell Company and D is the average depth of the selected interval. The coefficient were determined as $a = 1.811 + 0.161$; $b = (1.615 \pm 0.146) \times 10^{-4}$ and $c = (7.424 \pm 1.749) \times 10^{-5}$.

RESULTS AND DISCUSION

With wire-line logs, the lithologies and other relevant parameters shown in tables 1-5 for various locations in Fig 1 were obtained in addition to the and thermal effective conductivities. Out of the ten logs for different locations shown on the map of the study location, five of them which are representative values of the results are presented in tables 1 – 5 and three of the tables are used in plotting graphs to show the variation of their magnitude at different locations. The graphs (Fig 2-4) show that temperature, depth of sediment, porosity, thermal gradient, velocity, travel time and heat flow, each show variation in magnitude within each location of their occurrences. These variations in parameters are controlled by facies changes in lithologies. All parameters except sand percentage and travel time show increase with depth within the Niger Delta. The result of the effective value of the thermal conductivity at each location is presented on table 6. The effective thermal conductivity varies from 1.35 $Wm^{-1}K^{-1}$ at Obe – 1 to a maximum of 2.64$Wm^{-1}K^{-1}$ at Jes -1 well location.

Table 1: EHU-1 Wire Line Log Bulk Thermal Conductivity

Depth (m)	Porosity φ (%)	Temperature (^oC)	Travel time Δt (μs/ft)	Lithology	Velocity Vp (m/s)	Sand (%)	Thermal Gradient		Thermal Conductivity K($Wm^{-1}K^{-1}$)	Heat Flow Q (mWm^{-2})
							^oF/100ft	^oC/Km		
284	34.60	26.39	159.00	Sand	1926.10	100	0.27	5.00	0.80	3.90
758	31.27	45.48	151.88	Shale	2016.46	55	1.51	27.00	0.99	26.75
1348	35.21	62.75	133.88	Sand	2287.58	60	1.56	28.00	1.02	28.62
1795	24.42	95.01	152.13	Sand	2016.21	25	2.15	39.00	1.26	49.30
2063	38.63	111.63	130.13	Shale	2353.54	0	2.31	42.00	0.93	39.08
2382	23.82	129.80	131.75	Shale	2324.48	0	2.39	44.00	1.50	66.12
2428	23.33	134.01	100.88	Shale	3035.94	0	2.43	44.00	2.02	88.74
2637	14.62	143.67	91.88	Shale	3333.33	0	2.45	45.00	2.57	111.74
2724	13.09	131.23	93.56	Shale	3273.23	45	2.15	39.00	2.59	101.06

Table 2: OPM-1 Wire Line Log Bulk Thermal Conductivity

Depth (m)	Porosity φ (%)	Temperature (^oC)	Travel time Δt (μs/ft)	Lithology	Velocity Vp (m/s)	Sand (%)	Thermal Gradient		Thermal Conductivity K($Wm^{-1}K^{-1}$)	Heat Flow Q (mWm^{-2})
							^oF/100ft	^oC/Km		
1840	26.68	100.00	108.66	Shale	2818.53	0	2.26	41.00	1.73	70.93
1950	15.15	99.09	85.70	Sand	3573.72	35	2.09	38.00	2.72	103.36
2146	27.74	115.00	110.78	Shale	2764.44	10	2.32	42.00	1.65	69.30
2251	28.31	120.00	111.90	Shale	2736.74	15	2.33	48.00	1.61	67.67
2442	14.68	81.17	84.75	Sand	3613.61	85	1.24	23.00	2.76	63.48
2547	13.79	121.79	82.97	Sand	3690.96	45	2.10	38.00	2.85	108.30
2748	18.82	104.69	76.12	Shale	4023.31	75	1.57	29.00	2.88	83.52
2862	18.49	153.78	92.42	Shale	3313.60	10	2.50	45.00	2.40	108.00
3012	28.18	-	106.27	Shale	2881.89	0	2.55	46.00	1.72	79.12

Table 3: ARU -1 Wire Line Log Bulk Thermal Conductivity

Depth (m)	Porosity φ (%)	Temperature (^oC)	Travel time Δt (μs/ft)	Lithology	Velocity Vp (m/s)	Sand (%)	Thermal Gradient		Thermal Conductivity K($Wm^{-1}K^{-1}$)	Heat Flow Q (mWm^{-2})
							^oF/100ft	^oC/Km		
1311	25.19	37.32	122.00	Sand	2510.09	100	0.52	9.00	1.58	14.90
1543	24.86	83.50	120.00	Shale	2552.08	25	2.09	38.00	1.62	61.36
1685	24.12	92.39	115.00	Sand	2663.04	5	2.22	40.00	1.73	69.04
2005	20.77	105.14	100.70	Sand	3062.50	25	2.20	40.00	2.14	85.43
2156	19.10	110.81	94.00	Sand	3257.98	30	2.19	40.00	2.34	93.13
2448	16.48	130.26	86.00	Shale	3561.05	15	2.37	43.00	2.66	114.21
2621	15.08	103.63	82.00	Sand	3734.76	70	1.66	30.00	2.83	84.96
2875	21.31	154.37	102.00	Shale	3002.45	15	2.48	45.00	2.07	93.33
3080	16.75	160.53	87.00	Sand	3520.12	30	2.42	44.00	2.62	115.10

Table 4: JES -1 Wire Line Log Bulk Thermal Conductivity

Depth (m)	Porosity φ (%)	Temperature (°C)	Travel time Δt (μs/ft)	Lithology	Velocity Vp (m/s)	Sand (%)	Thermal Gradient		Thermal Conductivity K(Wm⁻¹K⁻¹)	Heat Flow Q (mWm⁻²)
							°F/100ft	°C/Km		
1175	39.30	69.53	134.00	Sand	2285.45	10	2.08	38.00	0.86	32.44
1471	43.91	72.38	143.00	Shale	2141.61	50	1.77	32.00	0.57	18.42
1936	21.98	77.28	105.00	Sand	2916.67	70	1.49	27.00	1.99	53.87
2210	16.08	57.93	85.00	Shale	3602.94	100	0.82	15.00	2.70	40.24
2538	16.42	14.60	86.00	Sand	3570.23	55	1.94	35.00	2.67	94.07
2762	15.14	111.85	83.00	Sand	3689.56	40	2.22	41.00	2.81	113.64
2981	14.87	106.97	82.00	Sand	3734.76	80	1.51	28.00	2.84	78.10

Table 5: DEL - 1 Wire Line Log Bulk Thermal Conductivity

Depth (m)	Porosity φ (%)	Temperature (°C)	Travel time Δt (μs/ft)	Lithology	Velocity Vp (m/s)	Sand (%)	Thermal Gradient		Thermal Conductivity $K(Wm^{-1}K^{-1})$	Heat Flow Q (mWm^{-2})
							°F/100ft	°C/Km		
1562	21.17	45.04	111.00	Shale	2756.75	96	0.71	12.83	1.91	24.50
1677	34.41	47.29	120.00	Shale	2549.90	96	0.73	13.37	1.24	16.52
2250	27.99	120.32	120.00	Shale	2549.90	15	2.33	42.37	1.49	63.24
2484	22.33	102.85	100.00	Sand	3060.00	66	1.72	31.30	2.07	64.91
2743	26.42	131.89	108.00	Shale	2833.25	46	2.14	38.97	1.75	68.29
2871	16.31	80.03	88.00	Sand	3477.38	95	1.05	19.17	2.60	49.92
3017	17.31	83.27	90.00	Sand	3399.79	96	1.06	19.32	2.51	48.50
3135	23.21	143.29	100.00	Shale	3060.00	56	2.07	37.73	2.04	76.90

Table 6: Effective Thermal conductivity for the various well location

Well	Thermal conductivity $K(Wm^{-1}k^{-1})$
EHU-1	I.50
OPM-1	2.20
ARU-1	2.13
JES-1	2.64
DEL-1	2.02
EgW-1	1.40
BHB-1	2.33
OBE-1	2.43
KOR-1	2.43
OGR-1	1.69

At each location, bulk thermal conductivity generally increases with depth. This is an indication that sonic velocity plays the major role in the control of thermal conductivity of sediments as temperature increases with depth just like velocity also increases [11].

The result shows that low effective thermal conductivity exists at the central portion of the Delta and increases outward in all directions. This is in agreement with [12,13]. Low thermal gradient exists at the centre of Niger Delta and increases outward in all directions. The significance of this pattern of thermal conductivity in the Niger Delta is that there exists heavy crude oil at the central part of the Delta and lighter crude oil as we move outward in all directions.

CONCLUSION

Wire line logs have been used effectively to determine the thermal properties of sediments that bear oil. It is also effective in identifying the lithologies, sonic velocity, porosity, and thermal gradient and temperature. These properties usually characterize the oil reserviour and determine its maturation. Both the bulk and effective thermal conductivities are quite correlative as they increase with depth. The magnitudes of the characterizing parameters of sediments measured in the various wire line logs are predictive and systematic in patterns. The unique variation of the parameters mostly the thermal conductivities and velocities at the depth of sediment may be attributable to the approximate uniqueness of formation at deeper depth such as depth of hydrocarbon sediments that act as traps. The present study has provided the base line data that control thermal conductivities of the hydrocarbon sediments usually formed at deeper depth of the Agbada Formation in the Niger Delta. It is also significant to note that the results obtained in this research can be used to correlate and establish unique or effective values of thermal conductivities between laboratory and wire line logs.

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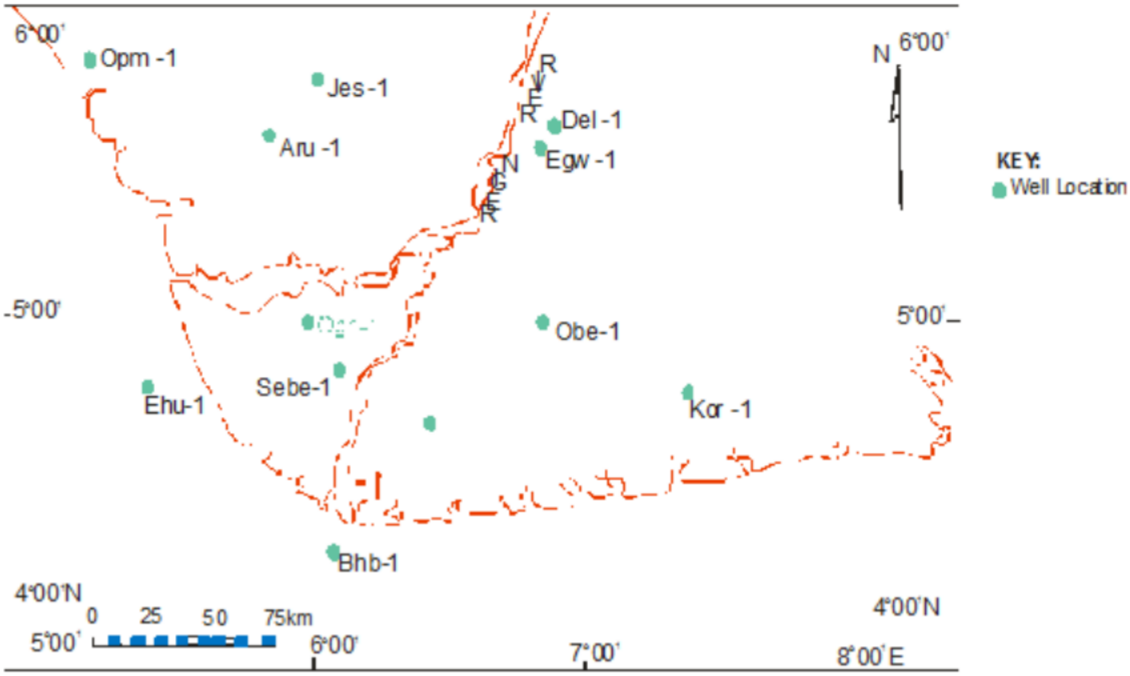

Fig 1 (After 6)

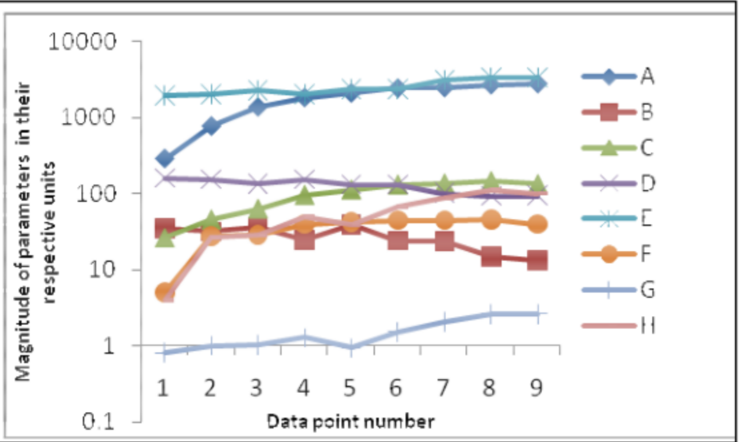

Fig 2: Variation of parameters and their magnitudes in EHU-1 log

KEY:
A – Depth (m)
B – Porosity (%)
C – Temperature (°C)
D – Travel Time (Δt (μs/ft))
E – Velocity Vp (m/s)
F – Thermal Gradient (°C/km)
G – Thermal Conductivity k ($Wm^{-1}k^{-1}$)
H – Heat Flow Q (mWm^{-2})

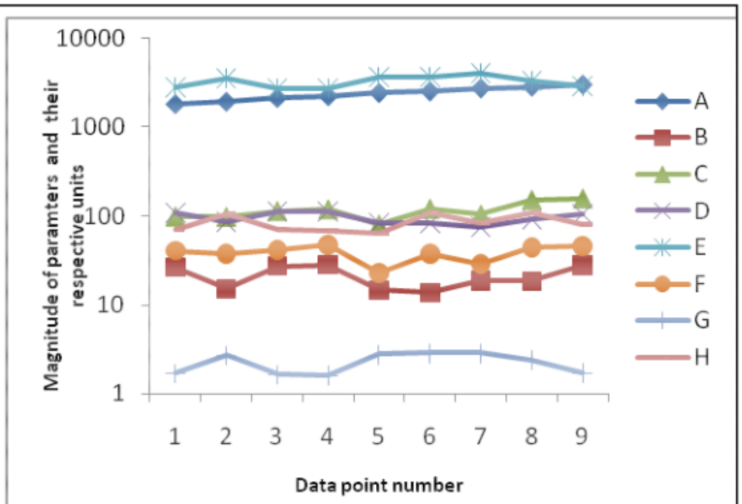

Fig 3: Variation of parameters and their magnitudes in OPM-1 log

KEY:
A – Depth (m)
B – Porosity (%)
C – Temperature (°C)
D – Travel Time (Δt (μs/ft))
E – Velocity Vp (m/s)
F – Thermal Gradient (°C/km)
G – Thermal Conductivity k ($Wm^{-1}k^{-1}$)
H – Heat Flow Q (mWm^{-2})

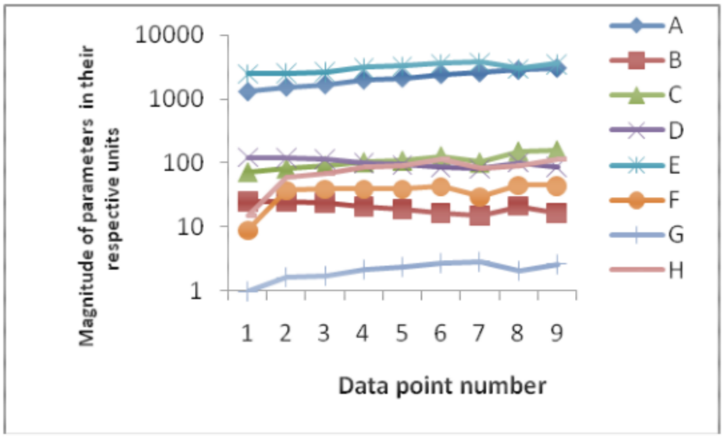

Fig 4: Variation of parameters and their magnitudes in ARU-1 log

KEY:
A – Depth (m)
B – Porosity (%)
C – Temperature (^oC)
D – Travel Time (Δt (μs/ft))
E – Velocity Vp (m/s)
F – Thermal Gradient (^oC/km)
G – Thermal Conductivity k ($Wm^{-1}k^{-1}$)
H – Heat Flow Q (mWm^{-2})