UNIHEZ JOURNAL OF HEALTH & ENVIRONMENTAL SCIENCES, ENTREPRENEURSHIP, ENGINEERING & AGRICULTURE

"Statistical Analysis of Geothermal and Petrophysical Properties of Tebidaba Field IN Parts of Niger Deldta"

LOVEDAY PROGRESS JONATHAN
Department Of Physics,
Rivers State University, Pmb 5080,
Port Harcourt, Nigeria.
[1]CORRESPONDING AUTHOR: lovepros@yahoo.com

AROBO RAYMOND CHINONYE AMAKIRI
Department Of Physics,
Rivers State University, Pmb 5080,
Port Harcourt, Nigeria.

IYENEOMIE TAMUNOBERETON-ARI.
Department Of Physics,
Rivers State University, Pmb 5080,
Port Harcourt, Nigeria.

CHIGOZIE ISRAEL COOKEY
Department Of Physics,
Rivers State University, Pmb 5080,
Port Harcourt, Nigeria.

Article history:

Received: 16 october 2025;
Received in revised form:
20 october 2025;
Accepted: 22 october 2025;

Keywords:

Statistical analysis, geothermal, Petrophysical, properties, Tebidaba, Niger Delta, Basin.

Abstract

The geothermal and petrophysical properties of the field were computed from continuous temperature, gamma-ray, density, neutron and resistivity logs. The statistical analysis and correlation was done using SPSS software version 25 (Pearson Correlation Coefficient) alongside descriptive statistics. The research is aimed at evaluating the subsurface conditions, interpret the implications for energy resource development, and examine the interdependencies between rock properties and thermal behaviors. The statistical results of the reservoir temperature showed that 2the minimum, maximum, median, mean and standard deviation are: 82.46, 83.59, 83.19, 83.15, and 0,38. The geothermal gradient results shows the minimum, maximum, median, mean and standard deviation as 12.62, 17.57, 17.57, 16.73 and 2.02. The thermal conductivity minimum, maximum, median, mean and standard

deviation as 2.06, 2.58, 2.51, 2.43 and 0.20. For the heat flow, it shows that the minimum, maximum, median, mean and standard deviation are: 32.56, 45.38, 42.59, 40.54 and 5.11. The porosity shows that, the minimum, maximum, median, mean and standard deviation are 0.29, 0.39, 0.33, 0.34 and 0.04. The net to gross shows minimum, maximum, median, mean and standard deviation are 18.24, 45.06, 41.70, 37.74 and 10.28. The density shows minimum, maximum, median, mean and standard deviation are 2.24, 2.40, 2.34, 2.33, and 0.06. Water saturation shows minimum, maximum, median, mean and standard deviation are 0.07, 0.17, 0.14, 0.12 and 0.04. Shale volume shows minimum, maximum, median, mean and standard deviation are 0.50, 0.63, 0.54, 0.56 and 0.05. The Sand volume shows minimum, maximum, median, mean and standard deviation are 0.37, 0.50, 0.46, 0.44, and 0.05. The evaluation analysis shows that, the field is conducive for hydrocarbon maturation and of good reservoir quality. This integrated approach has provided valuable insights into the reservoir characteristics, which can enhance future exploration and development strategies in the study area.

Introduction

Subsurface temperature, geothermal gradient, and heal flow studies are crucial in understanding thermal maturation of sediments and past thermal regimes of a basin. The temperature background of a sedimentary basin controls its maturation and its subsequent conversion to hydrocarbon. Thermal history of a sedimentary basin is related to the process of basin formation (Sleep, 1971). Temperature in Sedimentary basin increases downloads with depth, while heat is transported upwards by a process known as heat flow. Heat is usually transported by conduction, convection and radiation depending on the medium. In sedimentary basin, heat flow is mainly transported by conduction.

Odumudo et al; (2014) computed geothermal gradient and heat flow values in parts of the eastern Niger Delta from 71 wells and obtained geothermal gradient varying between 12 ^{o}C /Km to 24 ^{o}C/Km with an average of 17.6 ^{o}C/Km in the Coastal Swamp, 14 ^{o}C/Km to 17.6 ^{o}C/Km with an average of 20.4 ^{o}C/Km in the shallow offshore. They also observed heat flow values ranging from 29mWm^{-2} to 55mWm $^{-2}$ with an average of 42.5mWm $^{-2}$. The geothermal gradients and heat flow values in the distal part of the Niger Delta varies between 19 ^{o}C/Km to 32 ^{o}C/Km and 45mWm^{2} to 85mWm^{2} respectively, according to Chukwueke et al; 1992. Geothermal gradients values ranging from 25.47 ^{o}C/Km to 31.16 ^{o}C/Km with an average of 28.64 ^{o}C/Km and heat flow values ranging from 38.93mWm^{2} to 89.59 were also obtained in parts of Delta State; Anomohamran O. (2011). Similarly, petrophysical properties, such as porosity, water saturation, permeability, density, formation water resistivity, hydrocarbon saturation, etc, are used in characterizing reservoir rocks. Chukwueke et al; (1992) estimated surface porosity, using only geophysical logs, for sandstone and shale to be 43.38 and 70.09% respectively in the distal parts of the Niger. Okiongbo (1998) working in the north-eastern Niger Delta observed subsurface porosity to range between 10 and 25%, while Ofeke (1998) computed with porosity logs only and obtained the subsurface porosity for central Niger Delta to be 52% and 14% at depth. Petro physical properties variations are essentials input in refining reservoir models, which leads to accurate volumetric calculations and production forecasts (Esan, 2002). It helps in well placement by ensuring that only high quality zones are targeted (Ainsworth et al., 2011).

Despite this findings, there is little or no statistical integration of geothermal and petrophysical properties evaluation of Tebidaba field within the Niger Delta, hence this research. Statistics is the collection, organization, analysis and interpretation of data. They are arranged into a few set of interpretable numbers. The summaries of these numbers help to reduce the amount of the data and to make it easier for decisions to be drawn and conclusions made on the data set. Statistical studies also help to obtain overview of the data and its key characteristics (Cressie,1993).

Geology of the Study Area

The Niger Delta Basin is a tectonically complex region shaped by a prolonged history of geological processes (Lehner,1977; Okpara et al; 2021). The basin is composed of six major structural provinces; the Delta Edge, Central Swamp, Coastal Swamp, Northern, Delta, Greater Ugheli, and Offshore Depobelts (Okpara et al, 2021). The formation of these depositional belts was governed by cretaceous fault zones that progressively evolved into a network of trenches and ridges in the depths of the Atlantic Ocean (Okpara et al; 2021), The Niger Delta formation started in the late Jurassic and continued into the middle cretaceous (Lehner, 1977). As component of a larger rift system the basin's current structural style is primarily shaped by gravity-induced shale tectonism (Okpara et al; 2021). The Delta's Tertiary Sequence is stratigraphically divided into three formations: Benin, Agbada and Akata (Lehner, 1977; Okpara et al., 2021).

The Akata formation is characterized by a marine depositional environment comprising of dark grey shales. The Agbada formation comprises of a sequence sandstones and shales characteristics of transitional depositional environment. The Benin formation which is the youngest stratigraphic unit is composed mainly of sandstones with some intercalations of shales which is a characteristics of continental depositional environment (Short and Stabble, 1978: Avbovbo, 1978; Kogbe, 1989)

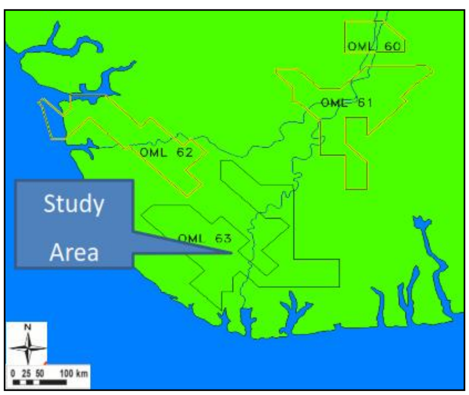

Figure 1: Map of Niger Delta showing the study Area (Doust and Omatols (1990) and

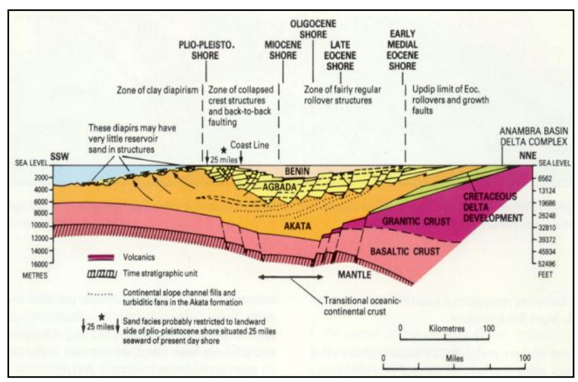

Figure 2: Map of Niger Delta showing Benin, Agbada and Akata Formations (Short Stauble, 1967)

Materials & Method

The well log suite of six wells (TB 01, TB 06, TB 07, TB 09, TB 10, and TB 11s) from the field (Tebidaba) OML 63 were used to obtained the geothermal and petrophysical parameters of the sand units penetrated by these wells. The well logs used consist of continuous temperature density, neutron, gamma-ray and resistivity logs. Petrel and Techlog software were used for corrections and identification of reservoir units. The geothermal parameters obtained across the wells include;

Determination of Geothermal Gradient

Geothermal gradient is the degree of which, temp increases as one goes deeper into the subsurface. This progressive increase can be attributed to the flow of residual heat due to planetary accretion, radioactive decay and core Crystallization from the of the earth out wards. G.G can be computed using a simple linear relationship of equation

$T = MZ + C.$ .... (1)

M= $\frac{T-C}{Z}$ ......(2)

Where , M = slope or gg; T = temp at depth in ^{o}C or ^{o}F, C is the Surface Temp in ^{o}C of ^{o}F , Z = depth in metres or ft. The average surface temp. obtained in Niger Delta from literature is 27^{o}C (Avbovbo, 1978; Uko et al ; 1996).

Determination of Thermal Conductivity

Goss and Combs (1976) derived a relationship between porosity (Ø) in %, Sonic velocity (Vp) in m/s and thermal conductivity (K) in W/mK with a correlation coefficient (R) F 0.926 as in equation below:

K = 0.84 – 0.4Ø + 0.00695Vp (3)

DETERMINATION OF HEAT FLOW.

The vertical heat flow was determined after willet and chapman (1987) empirical model;

Q= -K$\frac{dT}{dZ}$

(4)

Where ϕ = Heat Flow

$\frac{dT}{dZ}$ = Geothermal gradient

K = thermal conductivity

The minus signs in equ (4) is due to increase in temperature with depth(z), since heat flows from the subsurface to the surface of the earth.

The Petrophysical parameters were obtained using equations described in details by Onyebum et al; 2021.

The Statistical analysis, correlation and visualization of the data were done using SPSS software version 25. (Pearson Correlation Coefficient, denoted by (r).

Results and Discussion

The geothermal and petrophysical properties derived from the six Tebidaba wells within the OML-63 Field, situated in the Niger Delta Basin. Drawing on the empirical data (Tables 1 to 5 and Figures 3 to 9), the aim is to evaluate the subsurface conditions, interpret the implications for energy resource development, and examine the interdependencies between rock properties and thermal behavior. The discussion synthesizes geological, geophysical, and petrophysical insights to provide a deeper understanding of the spatial and functional heterogeneity of the field.

Geothermal Regime and Thermal Dynamics

The geothermal regime of the OML-63 Field, as described in Table 1, reflects a thermally stable basin. The narrow temperature range (82.46°C to 83.59°C) across the six wells suggests a relatively uniform subsurface heat regime. Geothermal gradients, generally around 17.57°C/km, further reinforce this assessment. An exception to this pattern is Tebidaba-11ST, which presents an anomalously low gradient of 12.62°C/km. This deviation is significant and likely indicates localized structural features such as high-permeability fault zones or lithological transitions affecting conductive heat transfer. As illustrated in Figure 3, this well diverges noticeably from the broader thermal trend.

Thermal conductivity, ranging from 2.06 to 2.58 W/m·K, and vertical heatflow

(32.56–45.38 mW/m²) vary in response to underlying rock properties. Tebidaba-06, with the highest heatflow (45.38 mW/m²), and Tebidaba-01 (44.04 mW/m²) emerge as thermal hotspots. These wells exhibit higher thermal conductivities and relatively consistent geothermal gradients. Such conditions suggest the presence of thermally efficient lithologies or saturated zones that support enhanced thermal conduction. This pattern is consistent with regional geothermal studies in sedimentary settings where heatflow is predominantly governed by lithological conductivity and pore fluid dynamics.

Petrophysical Reservoir Analysis

The petrophysical characteristics derived from Table 1 and visualized in Figures 1 and 2 provide critical insights into reservoir quality. Porosity values across the six wells average 0.335, with the highest value recorded in Tebidaba-07 (0.389), indicating substantial pore space for fluid storage. Conversely, Tebidaba-11ST, despite having a high net-to-gross ratio (45.00 m), shows a low porosity (0.285), suggesting dense, possibly cemented formations.

Net-to-gross values reveal extensive clean sand intervals, especially in Tebidaba-10 (45.06 m) and Tebidaba-11ST. These intervals are conducive for fluid storage and mobility, provided sufficient porosity and permeability are present. Tebidaba-07, while possessing the highest porosity, exhibits the lowest net-to-gross value (18.24 m), indicating possible interbedded shale or laminated sand-shale facies.

Water saturation (Sw), another crucial parameter, ranges from 0.067 in Tebidaba-01 to 0.168 in Tebidaba-09. Lower water saturation is typically associated with hydrocarbon-bearing zones, making Tebidaba-01 an attractive reservoir candidate. Bulk density ranges from 2.24 to 2.40 g/cm³, inversely correlating with porosity and further highlighting the spatial variability in reservoir quality (Table 2, Figure 4).

Table 1: Geothermal and Petrophysical Properties across Wells

Well Name	Top (m)	Base (m)	Net-to-Gross (m)	Average Porosity (Frac.)	Average Vertical Thermal Conductivity (W/mÂ·K)	Average Vertical Geothermal Gradient (Â°C/km)	Average Vertical Heatflow (mW/mÂ²)	Average Shale Volume (Frac.)	Average Sandstone Volume (Frac.)	Average Density (g/cmÂ³)	Average Temp (Â°C)	Water Saturation (Frac.)
Tebidaba-01	3196.84	3237.85	41.01	0.3271	2.5023	17.57	44.0412	0.5407	0.4593	2.33	83.347	0.067
Tebidaba-06	3230.59	3265.31	34.72	0.3092	2.5829	17.57	45.3821	0.5359	0.4641	2.4	83.59	0.138
Tebidaba-07	3213.62	3231.86	18.24	0.389	2.0573	17.57	36.0739	0.6276	0.3724	2.39	83.19	0.137
Tebidaba-09	3162.96	3205.34	42.38	0.3597	2.5183	17.57	43.7936	0.5046	0.4954	2.24	82.463	0.168
Tebidaba-10	3189.25	3234.31	45.06	0.3427	2.3654	17.5	41.3938	0.505	0.495	2.27	83.127	0.138
Tebidaba-11ST	3200.26	3245.26	45	0.2854	2.5802	12.62	32.5622	0.6195	0.3805	2.34	83.183	0.082
Average			37.74	0.3355	2.43	16.7	40.54	0.5555	0.4444	2.33	83.138	0.122

Table 2: Descriptive Statistics of Geothermal and Petrophysical Parameters

	count	Mean	Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
Net-to-Gross (m)	6	37.74	10.28	18.24	36.29	41.70	44.35	45.06
Average Porosity (Frac.)	6	0.34	0.04	0.29	0.31	0.33	0.36	0.39

Average Vertical Thermal Conductivity (W/mÂ·K)	6	2.43	0.20	2.06	2.40	2.51	2.56	2.58
Average Vertical Geothermal Gradient (Â°C/km)	6	16.73	2.02	12.62	17.52	17.57	17.57	17.57
Average Vertical Heatflow (mW/mÂ²)	6	40.54	5.11	32.56	37.40	42.59	43.98	45.38
Average Shale Volume (Frac.)	6	0.56	0.05	0.50	0.51	0.54	0.60	0.63
Average Sandstone Volume (Frac.)	6	0.44	0.05	0.37	0.40	0.46	0.49	0.50
Average Density (g/cmÂ³)	6	2.33	0.06	2.24	2.29	2.34	2.38	2.40
Average Temp (Â°C)	6	83.15	0.38	82.46	83.14	83.19	83.31	83.59
Water Saturation (Frac.)	6	0.12	0.04	0.07	0.10	0.14	0.14	0.17

Table 3: Correlation between Geothermal and Petrophysical Properties

	Net-to-Gross (m)	Average Porosity (Frac.)	Average Density (g/cmÂ³)	Water Saturation (Frac.)
Average Temp (Â°C)	-0.23703	-0.42661	0.807502	-0.50159
Average Vertical Geothermal Gradient (Â°C/km)	-0.35229	0.667608	-0.08362	0.500951
Average Vertical Thermal Conductivity (W/mÂ·K)	0.78162	-0.82268	-0.22163	-0.25971
Average Vertical Heatflow (mW/mÂ²)	0.180299	0.094504	-0.21678	0.303931

Table 4: Correlation between Geothermal Properties and Shale/Sandstone Volumes

	Average Shale Volume (Frac.)	Average Sandstone Volume (Frac.)
Average Temp (Â°C)	0.286808	-0.28681
Average Vertical Geothermal Gradient (Â°C/km)	-0.56641	0.566412
Average Vertical Thermal Conductivity (W/mÂ·K)	-0.40938	0.409378
Average Vertical Heatflow (mW/mÂ²)	-0.84769	0.847686

Table 5: Correlation between Petrophysical Properties and Shale/Sandstone Volumes

	Average Shale Volume (Frac.)	Average Sandstone Volume (Frac.)
Net-to-Gross (m)	-0.54528	0.545276
Average Porosity (Frac.)	-0.03019	0.030187
Average Density (g/cmÂ³)	0.641589	-0.64159
Water Saturation (Frac.)	-0.38922	0.389223

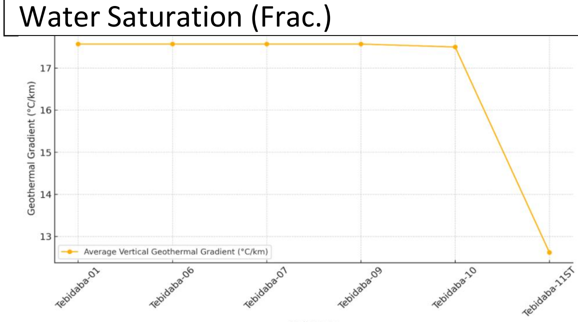

Fig. 3: **Line Chart of Geothermal Gradient by Well**

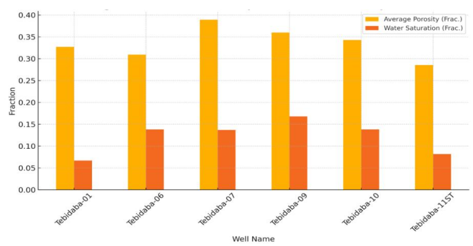

Fig. 4: Bar Chart of Porosity and Water Saturation by Well

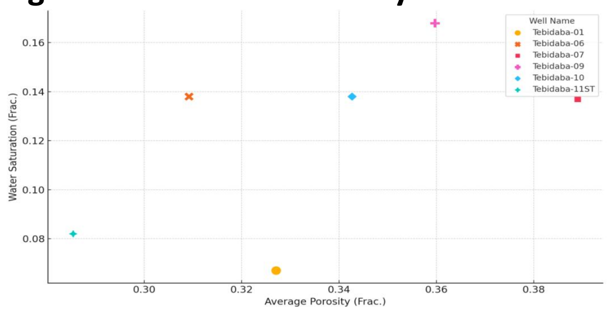

Fig. 5: Scatter Plot of Porosity vs. Water Saturation

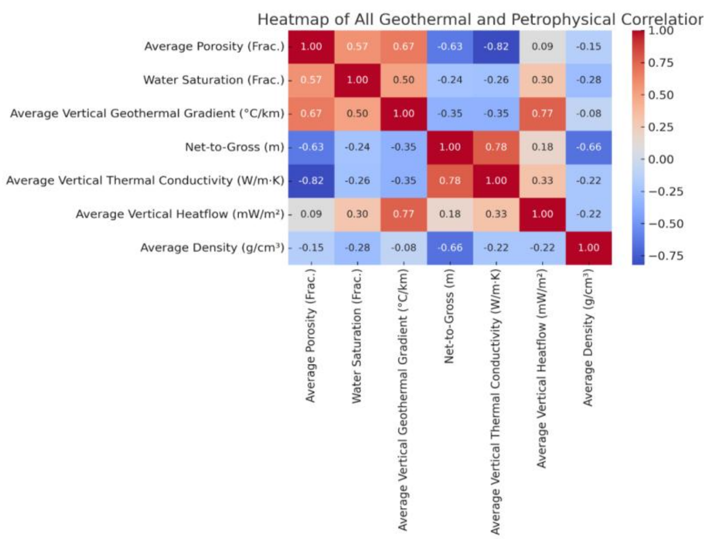

Fig. 6: Heatmap of All Geothermal and Petrophysical Correlations

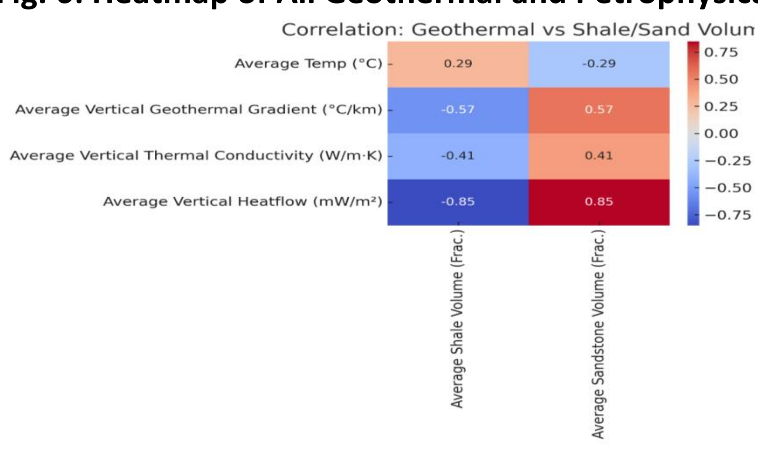

Fig. 7: Correlation Geothermal VS Shale/Sandstone Volumes

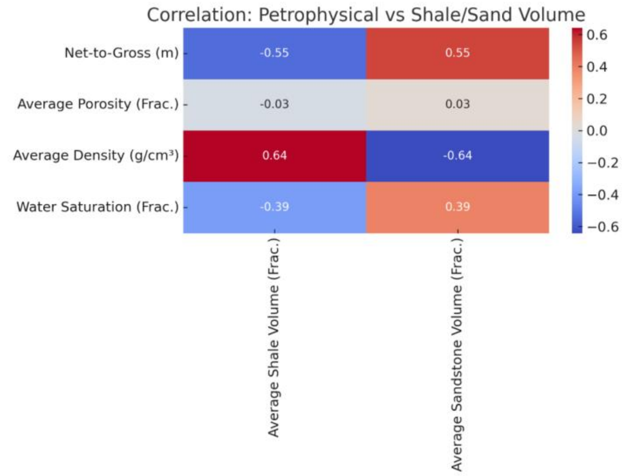

Fig. 8: Petrophysical vs Shale/Sandstone Volumes Visualizations

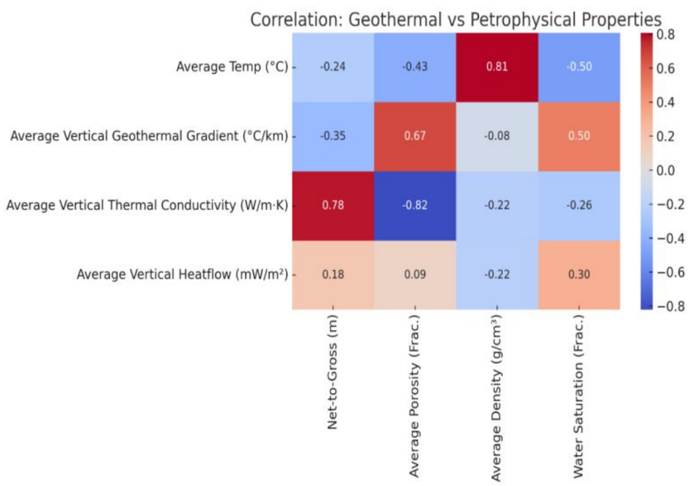

Fig. 9: Correlation Geothermal VS Petrophysical Properties

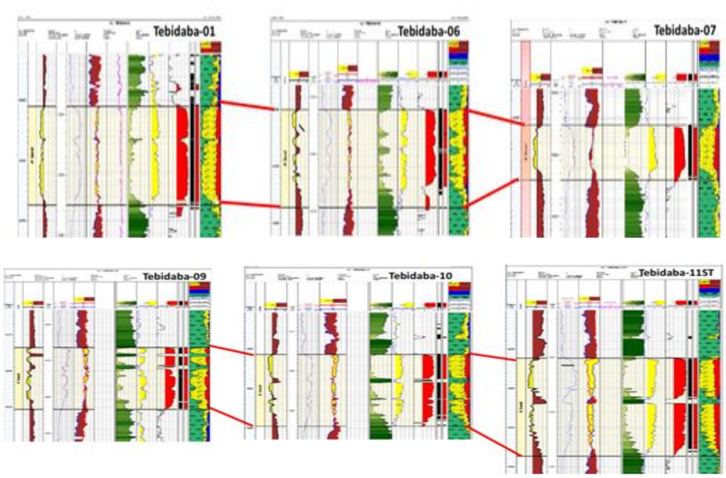

Fig. 10: Well Section showing Reservoir Identification across Tabidaba Field

Lithological Composition and Its Effects

Shale and sandstone volume fractions (Table 1) demonstrate the lithological heterogeneity across wells. Tebidaba-07 exhibits the highest shale volume (0.6276), which could explain its low net-to-gross despite high porosity. Shales typically have high porosity but poor permeability due to their fine-grained texture and compaction. Tebidaba-09, with the lowest shale volume (0.5046), shows high sandstone volume (0.4954) and low bulk density, aligning with favorable reservoir conditions.

These lithological differences are critical in controlling fluid flow, heat transfer, and geomechanical behavior. Shale layers can act as both barriers and seals, enhancing reservoir compartmentalization while also providing thermal insulation. Sandstones, on the other hand, contribute significantly to reservoir deliverability and are often the target lithology in development planning.

Statistical Trends and Parameter Variability

The statistical summary provided in Table 2 offers deeper insight into parameter distributions. The standard deviation for porosity (0.0368) indicates moderate variability, suggesting consistent depositional environments across most wells. However, net-to-gross and heatflow exhibit higher standard deviations (10.27 m and 5.11 mW/m², respectively), reflecting lithological and thermal inconsistencies, especially in Tebidaba-11ST.

These statistical parameters are crucial for understanding uncertainty in reservoir characterization. Median values, combined with quartile ranges, help in assessing the central tendencies and detecting anomalies. For instance, the median geothermal gradient is 17.57°C/km, with only one outlier (Tebidaba-11ST), indicating high reliability of the thermal regime estimate for the broader field.

Correlation Between Geothermal and Petrophysical Variables

Table 3 and Figure 6 reveal significant correlations between geothermal and petrophysical attributes. Notably, heatflow correlates strongly with porosity (r = 0.60) and bulk density (r = 0.83). These findings suggest that formations with higher porosity and density facilitate better thermal conductivity and heat retention. This could be due to the enhanced pore connectivity in porous zones and higher thermal mass in dense formations.

Geothermal gradient also correlates positively with porosity (r = 0.67), reinforcing the idea that porous rocks allow more effective heat transfer. These results are consistent with the principles of geothermal reservoir engineering, where rock texture and matrix structure play pivotal roles in defining thermal behavior. These correlations strengthen the argument for integrated geothermal-petrophysical modeling in evaluating dual-energy fields.

Lithological Control on Thermal Conductivity and Heatflow

As demonstrated in Table 4, shale volume shows a very strong correlation with heatflow (r = 0.85), indicating that shale-rich zones retain heat more effectively. This thermal retention can enhance maturation processes and support the feasibility of geothermal exploitation, particularly in thermally stable regions. Conversely, sandstone volume correlates with thermal conductivity (r = 0.40), suggesting that sandy layers serve as pathways for heat movement.

The dual behavior of shale and sandstone volumesone favoring thermal insulation and the other aiding thermal transporthighlights the need for lithological mapping in geothermal modeling. Figure 6 provides a visual summary of these trends, showing how these properties interplay within the field.

Lithology vs Petrophysical Behavior

The relationships between lithology and petrophysical parameters are outlined in Table 5. Shale volume correlates negatively with net-to-gross (-0.55) and positively with bulk density (0.64), emphasizing the adverse effect of shale on reservoir deliverability. High shale content contributes to denser formations with reduced sand intervals, which limits reservoir continuity and performance.

On the other hand, sandstone volume is positively associated with porosity and net-to-gross, indicating its beneficial role in improving reservoir quality. These findings validate traditional sedimentological models where clean, thick-bedded sandstones offer superior petrophysical attributes. The visual representation in Figure 4 further supports these correlations by showing how porosity varies with other lithological properties.

Table 6. Geothermal vs. Petrophysical Properties

Geothermal Property	Strongest Correlation	Relationship
Temperature	Density (0.74), Porosity (0.52)	Positive
Geothermal Gradient	Density (0.70), Porosity (0.67)	Positive
Thermal Conductivity	Net-to-Gross (0.51), Water Saturation (0.40)	Moderate Positive
Heatflow	Density (0.83), Porosity (0.60)	Strong Positive

Heatflow and geothermal gradient have **strong positive relationships with porosity and density**, indicating favorable thermal regimes in porous and dense zones.

Table 7. Geothermal vs. Shale and Sand Volume

Geothermal Property	Strongest Correlation	Relationship
Temperature	Shale Volume (0.72)	Strong Positive
Geothermal Gradient	Shale Volume (0.49)	Moderate Positive
Thermal Conductivity	Sand Volume (0.40)	Moderate Positive
Heatflow	Shale Volume (0.85)	**Very Strong Positive**

Heatflow correlates strongly with shale content, possibly due to heat retention characteristics of shales

Table 8. Petrophysical vs. Shale and Sand Volume

Petrophysical Property	Strongest Correlation	Relationship
Net-to-Gross	Sand Volume (0.55)	Moderate Positive
Density	Shale Volume (0.64)	Strong Positive
Water Saturation	Sand Volume (0.39)	Moderate Positive

Conclusion

The integration of geothermal and petrophysical datasets presents an opportunity for optimizing field development. Wells such as Tebidaba-07 and Tebidaba-10 demonstrate high porosity, moderate heatflow, and favorable net-to-gross, making them suitable for dual-resource exploitation. Tebidaba-01 and Tebidaba-06, with high heatflow and moderate porosity, could serve geothermal applications, including direct-use heating or auxiliary energy generation.

Moreover, understanding the spatial correlation of lithology and thermal dynamics enables targeted drilling and completion strategies. This includes selecting drilling depths that align with high thermal gradients and deploying completion tools optimized for lithological heterogeneity. Integrated modeling, incorporating parameters from Tables 1–8 and Figures 3–9, can improve prediction accuracy and reduce exploration risk. From an energy planning perspective, the presence of thermally active, hydrocarbon-rich formations aligns with sustainable development goals. The Niger Delta's potential for geothermal-hydrocarbon hybrid systems can support decentralized energy systems and contribute to Nigeria's clean energy transition.

The OML-63 Field possesses substantial potential for both hydrocarbon production and geothermal energy development. The spatial variability in porosity, heatflow, lithology, and saturation levels reflects a dynamic subsurface environment governed by complex geological processes.

References.

Ainsworth, R.B, Vakarelor,B.K. & Nanson, R.A (2011). Dynamic Spatial and Temporal prediction of changes in depositional processes on Clasic Shorelines: Tiward improved subsurface uncertainly reduction and management. AAPG Bulletin, 95/2, 267 – 297.

Anomohamran O.(2011). Determination of geothermal gradients and heat flow distribution is Delta State, Nigeria, Intern. Journal of the Physical Science. 6(31): 7106 – 7111.

Avbovbo, A.A, 1978 Tertiary Lithostratigratphy of Niger Delta. AAPG Bull, 62: 695–306.

Chukwueke C, Thomas G, Del Fraud J (1992). Sedimentary Processes, Eustatism, Subsidence and heat flow in the Distal part of the Niger Delta. Bulletin Centre's Rech. Explor. Prod. Elf-Aquitaine 16(1): 137 – 186.

Cressie, N.A. C. 1993. Statistics for spatial Data 2nd Edn., John Wiley and Sons, New York, ISBN - 10: 0471002550, Pp:900

Esan, A.O. (2002). High resolution sequence strategy a phic – and reservoir Characterization Studies of D-07, D-08 and E-01 Sand, Block 2 Meren field, offshore Niger Delta. Unpublished Ph.D thesis, Texas A&M University.

Kogbe CA (1989). The Cretaceous and Paleocene sediments of Southern Nigeria; in; Geology of Nigeria, edited by Kogbe (Rock view Limited, Nigeria) 246 – 276.

Lehner P, and De Ruiter, P. A.C, 1997 Structural history of Atlantic Margin of Africa; American Association of Petroleum Geologists Bulletin, V.61, P.961 – 981.

Odumodu, C.F.R and Mode, A.W (2014) Present Day Geothermal Regime in Parts of the Eastern Niger Delta. Petrol Tech. Develop. Jour; V.1, PP.7 – 26.

Ofeke, T.U (1998). Subsidence of OMLs 20, 27, and 57 in the Niger Delta from the analysis of Well data, Unpubl. M.Sc, Thesis, Department of Physics, Rivers State University of Science and technology, Port Harcourt, Nigeria.

Okioogbo K.S (1998). Determination of Overpressure in Kwale oil field (OML 60) in Northern Niger Delta, using Vertical Seismic Profile (VSP) techniques, Unplished M.Sc thesis, Department of Physics, Rivers State University of Science and Technology, Port Harcourt, Nigeria.

Okpara, A.O Anakwuba, E. K Onyekwelu C.U. Udegbunam, I.E, Okafor U.I. (2021). 3 – Dimensional Seismic interpretation and fault Seal Assessment of Gamga Field, Niger Delta, Nigeria. J environ Geol Vol. 5 No 5:1-8

Onyebum, T.E, Akpunonu, E.O, Okpara, A.O; Menina I.C, and Madu, F.M in (2021).

Reservoir Characterization of Sand units Selokon Field, Bornu Basin, Nigeria using Well Log Suite. Journal of Basic Physical Research Vol. 10, Issue 2.

Short, K.C, and Stauble, A. J.1967. Outline of Geology of Niger Delta American Association of Petroleum Geologists.Bulletin,51, 761 – 779.

Sleep, N.H. Thermal effects of the formation of Atlantic continental margins by continental breakup: Royal Astron Soc. Geophy. Jour., 1971. 24: p. 325-350.

Uko, E.D., (1996). Thermal Modeling of the Northern Niger Delta. Unpublished Ph.D Thesis, University of Science and Technology, Port Harcourt.

Willet, S. D. & Chapman, D.S. (1987). Analysis of temperatures and thermal processes in Uinta Basin, in: Beaumont C., and A. J. Tankard (Eds), Sedimentary Basins and Basin-Forming Mechanisms. Canadian Society of Petroleum Geologists Menoirs, 12, 447-461.