SALEM JOURNAL OF HEALTH & ENVIRONMENTAL SCIENCES, ENTREPRENEURSHIP, ENGINEERING & AGRICULTURE
VOL 4 NO. 1 MARCH 2025

GEOTHERMAL PROPERTIES OF HYDROCARBON RESERVOIRS IN OML-63 FIELD IN THE NIGER DELTA BASIN, NIGERIA

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.

ABSTRACT

This research investigates the geothermal properties of hydrocarbon reservoirs in Tebidaba Field, OML 63 in the Niger Delta basin, Nigeria, using continuous temperature, gamma ray, neutron, density and resistivity log data. Techlog and Excel softwares were employed for data loading, analysis, and visualization of reservoir tops, and bases. The results showed that the reservoir thickness ranges between 18.24m and 45.06m with an average of net thickness of 37.74m. The temperature of the reservoirs ranges between 83.11 and 83.59^{o}C with average reservoir temperature of 83.14^{o}C. The geothermal gradient ranges between 12.62^{o}C/km to 17.57^{o}C/km with an average of 16.70^{o}C/km. The thermal conductivity varies from 2.06Wm^{-1}k^{-1} to 2.58Wm^{-1}k^{-1} with an average of 2.43Wm^{-1}k^{-1}. Heatflow ranges from 32.56mWm^{-2} to 45.38mWm^{-2} with an average of 40.54mWm^{-2}. The porosity of the reservoirs ranges between 28.54% and 38.90% with an average of 33.55%. Shale volume ranges from 0.50 to 0.63 with an average of 0.56 in the reservoir. The sand volume ranges between 0.37 and 0.50 with an average of 0.44. The results suggest that the hydrocarbon bearing sand reservoir has a favourable geothermal condition and highlights the influence of depth, porosity and lithology on the thermal characteristics of the reservoirs. The crossplots of temperature against depth and lithology validates the fact that temperature increases with depth as sand volume decreases, while shale volume increases with increasing depth. This study provides a new insight of the geothermal properties of hydrocarbon reservoirs in Tebidaba Field (OML 63), which is crucial for evaluating reservoir productivity and exploitability.

Key Words: *Temperature, thermal conductivity, heatflow, lithology, reservoir, Niger Delta* basin.

Introduction

The Niger Delta basin, located in southern Nigeria is one of the prolific hydrocarbon provinces in the world. Its complex stratigraphy and abundant hydrocarbon resources have made it a focus for extensive geological and geophysical studies. The geothermal properties evaluation of hydrocarbon reservoirs is essential for understanding the generation, maturation, migration and accumulation of oil and gas. An understanding of thermal history can help improve models for use in exploration of oil and gas [12]. Knowledge of the earth's heat flow and its variations is required for an understanding of deep-seated earth's processes e.g faulting, volcanism, earthquake and continental drift [7]. Thermal analysis are also useful in hydrocarbon recovery and for assessing potentials for geothermal energy exploitation. Geothermal heat flow is a natural mechanism by which heat is transferred from the hotter part to the cooler surface of the earth [14]. Heat flow transport can be by radiative, conductive and convective in sediments [20]. Thermal conduction is the major form of heat transport through sedimentary basin [16]. The heat flow in any medium is due to temperature difference between two points within the material [2]. For heat flow from the Earth's interior to its surface, two phenomena are responsible: Earth cooling and Radiogenic heat production with a ratio of 17% to 83% respectively [6,23].

Previous studies in the Niger Delta examined the broad regional assessment of geothermal gradient, heat flow, and thermal conductivity [1] and neglecting the detailed characterization of geothermal properties of individual hydrocarbon reservoirs at the scale level. Limited literatures exist on the geothermal properties evaluation of Tebidaba (OML 63) Field.

This research seeks to address the gap, by conducting a detailed analysis of the geothermal properties of hydrocarbon reservoirs in the Tebidaba field, through the integration of well log data to analyse the combined effect of lithology, porosity, and depth on the thermal behavoir of reservoirs within the field. This study provides a comprehensive understanding of how reservoir characteristics influence thermal properties and its importance on hydrocarbon production and geothermal energy development of the basin.

Study Area and Its Geology

Tebidaba field is located in the west Niger Delta. The Niger Delta Basin occupies part of the Gulf of Guinea continental margin in the equatorial West Africa between latitude 3° and 6°N and longitude 5° and 8°E (Figure 1). The basin is comprised of a very thick sediment assemblage formed by a failed arm of a triple junction " RRR" fault system when South America and the African plates where pulled apart by tectonic forces during the Late Jurassic, opening up the Atlantic Ocean[8].Sediments of the Niger Delta basin span over an area of 70,000 sq. km with a depth of over 12 km to the basement complex at the middle of the basin [18,25].The basin is bond on the Northwest by the Benin flank, to the East by the Calabar flank and to the South by the Atlantic Ocean which drains the basin [19].Three stratigraphic units exist in the Niger Delta basin namely from the oldest; the Akata Formation, the Agbada Formation, and the Benin Formation.[5]. The Akata Formation is characterized by a marine depositional environment comprising of dark grey shales. The Agbada Formation comprises of a sequence of sandstones and shales characteristic of transitional or deltaic depositional environment. The Benin Formation which is the youngest lithostratigraphic unit is composed mainly of sandstones with some intercalations of shales which is a characteristic of a continental depositional environment [4,11,5]. (Figure 2).

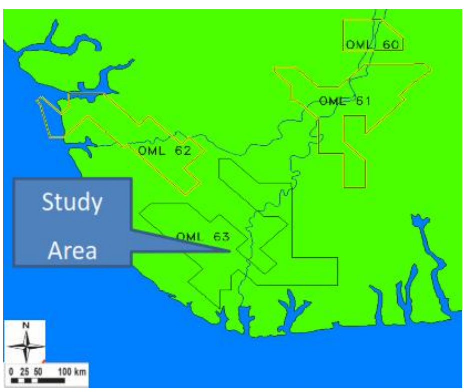


Figure 1: Map of Niger Delta showing the study Area (Doust and Omatols (1990)

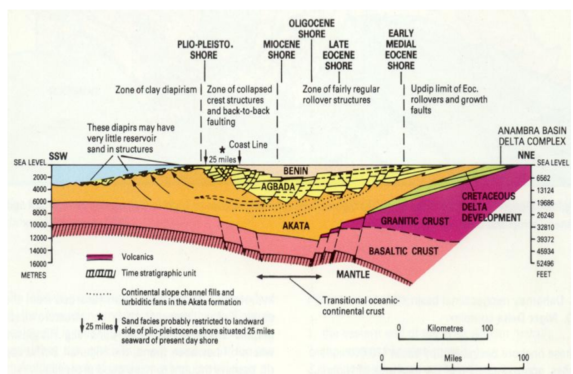


Figure 2: Map of Niger Delta showing Benin, Agbada and Akata Formations (Short and Stauble, 1

Materials and Methods

Delineation and Identification of Lithologies

The gamma ray log was estimated by counting the interval of a particular lithofacies and then assigned a fraction of this to the total interval within the sand-shale lines which then was expressed as a percentage. In mathematical equations [3], the gamma ray index (GR_{index}) was first calculated in order to calculate the shale volume based on [22] empirical equation as follows:

$$GR_{index} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \quad (1)$$

where GR_{log} = GR log reading of formation; GR_{min} = GR log sand baseline; GR_{max} = GR log shale baseline. The [17] equation for tertiary reservoirs was utilized for calculating the shale volume:

$$V_{sh} = 0.083\, x \left(2^{(3.7\, x\, GR_{index})} - 1\right) \quad (2)$$

Determination of Thermal Conductivity

[15] derived a relationship between porosity ϕ in % sonic velocity (vp) in mls and thermal conductivity (k) in w/mk.

$$K=0.84-0.4\,\phi + 0.00695Vp \quad (3)$$

As such, K was computed from porosity and sonic velocity log

Determination of Geothermal Gradient and Vertical Heat Flow

Geothermal gradient (m) was determined using the linear rela

$$T=mZ+C \quad (4)$$

Where;

T =Temperature at a given depth Zkm,

m =Geothermal gradient at that depth

C =Mean surface temperature in the Niger delta taken as 27°C

HEAT FLOW DETERMINATION

The basic relation for vertical conductive heat transport is Fourier's law: The heat flux, Q, or the flow of heat per unit area and per unit time, at a point in a medium is directly proportional to the temperature gradient at the point. In one-dimension (1D), Fourier's law takes the form:

$$Q=-K\frac{dT}{dZ} \quad (5)$$

where K = coefficient of thermal conductivity of the medium; Z = coordinate in the direction of the temperature variation. The negative sign indicates that heat flows in the direction of decreasing temperature.

Results and Discussion

Reservoir Geothermal Properties

The geothermal properties computed for this study are temperature, geothermal gradients, thermal conductivities, and surface heatflow and values presented in Figures 3 - 5, and Table 2. Temperature ranges between 82.463°C and 83.590°C with average of 83.138°C, geothermal gradients range between 12.62°Ckm^{-1} and 17.57°Ckm^{-1} with average of 16.70°Ckm^{-1}, thermal conductivities ranges between 2.0578Wm^{-1}K^{-1} and 2.5829Wm^{-1}K^{-1} with average of 2.43Wm^{-1}K^{-1}, and surface heatflow ranges between 32.5622mWm^{-2} and 45.3821mWm^{-2} with average of 40.54mWm^{-2}.

The temperature-depth profiles of the six wells as presented in Fig. 4.1 shows that temperature increases with increase in depth. The formation temperature is relatively stable, with values ranging from 82.46°C (Tebidaba-09) to 83.59°C (Tebidaba-06), with an average of 83.13°C. This narrow range suggests a relatively uniform subsurface thermal regime across the field.

Geothermal gradient for most wells are around 17.57°C/Km, which is typical for sedimentary basins and conducive to hydrocarbon maturation. However, Tebidaba-11ST stands out with a significantly lower geothermal gradient of 12.62°C/Km, probably due to localized structural or lithological variations affecting thermal conductivity or fluid movement. Thermal conductivity, ranges from 2.06 to 2.58W/m.K, and vertical heatflow (32.56-45.38 mWm^{-2}) vary in response to underlying rock properties. Tebidaba-06, with the highest heatflow 45.38mWm^{-2}, and Tebidaba-01 (44.04 mWm^{-2}) 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 supports 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.

We observed that 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 [24]. 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 occur at delta fronts where the deeper Akata Formation exerts a stronger influence. In this research, the reservoir under study is located within the depth range of 3162.96 - 3265.31m in the Agbada Formation.

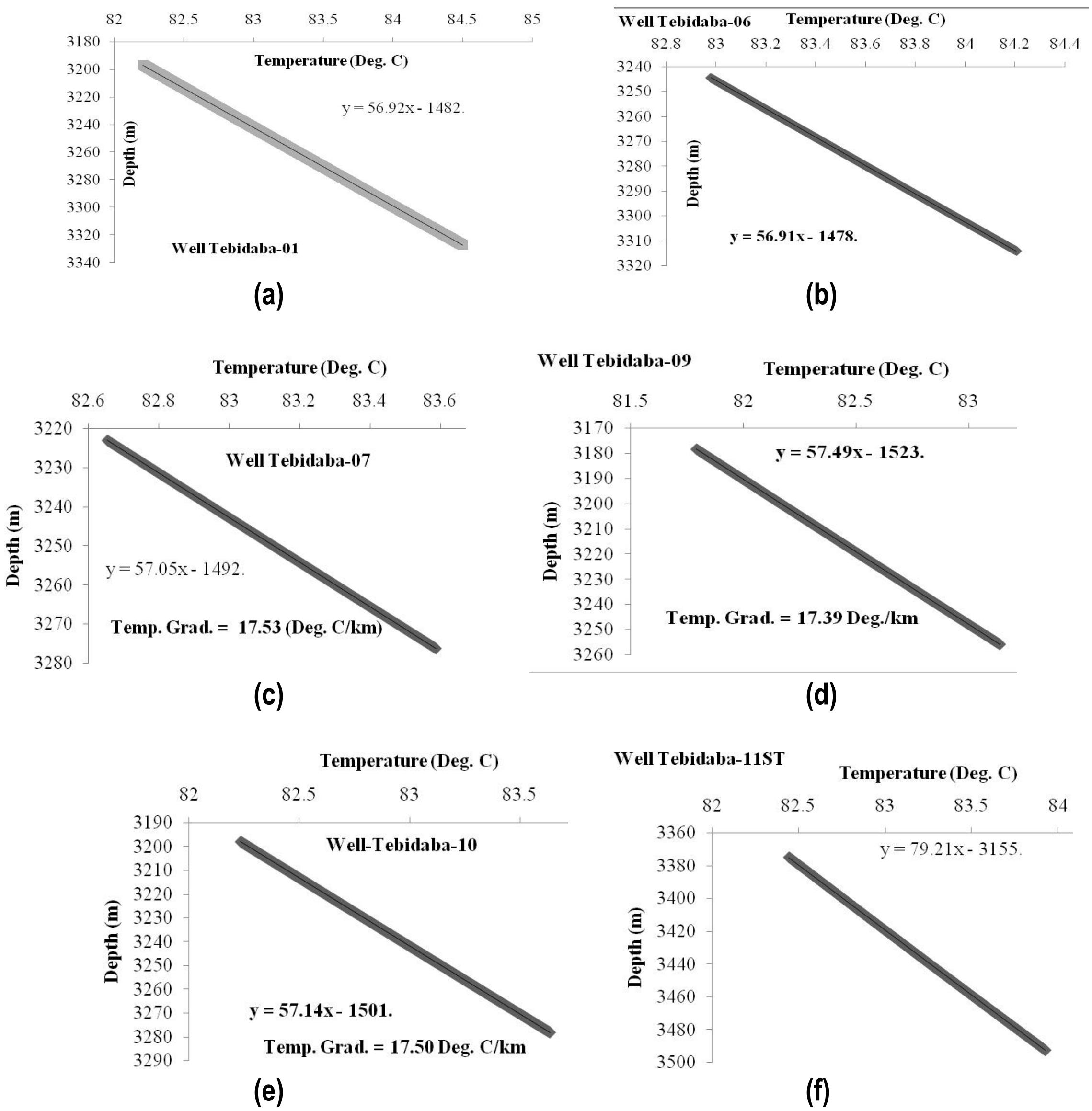


Figure 3: Temperature against Depth for Wells (a) Tebidaba 01, (b) Tebidaba 06, (c) Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST

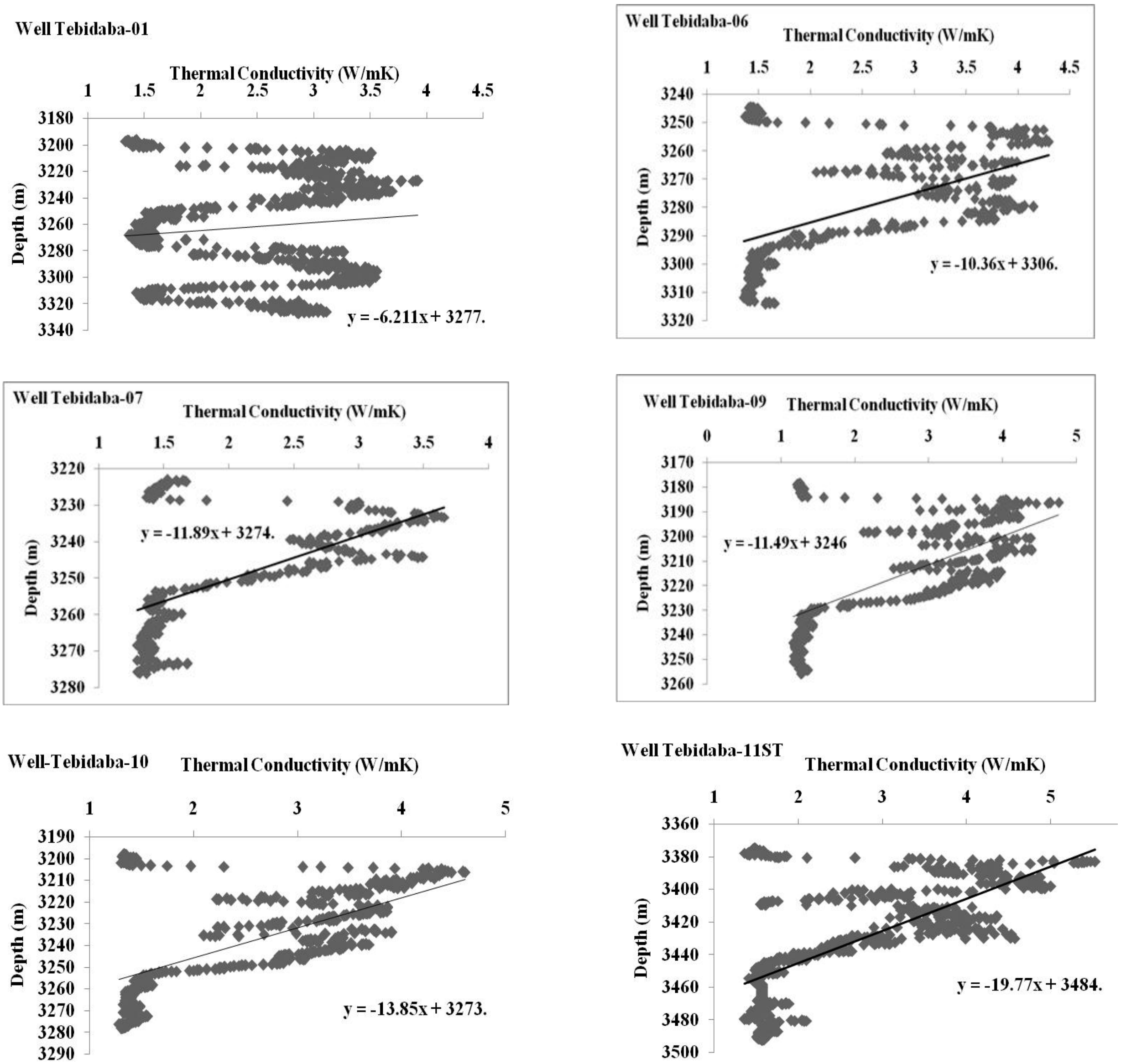
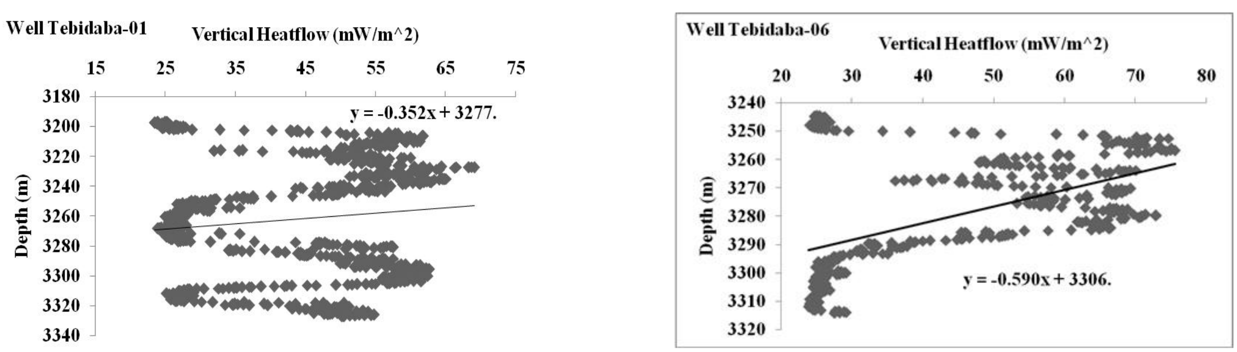


Figure 4: Thermal Conductivity against for Depth for (a) Tebidaba 01, (b) Tebidaba 06, (c) Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST



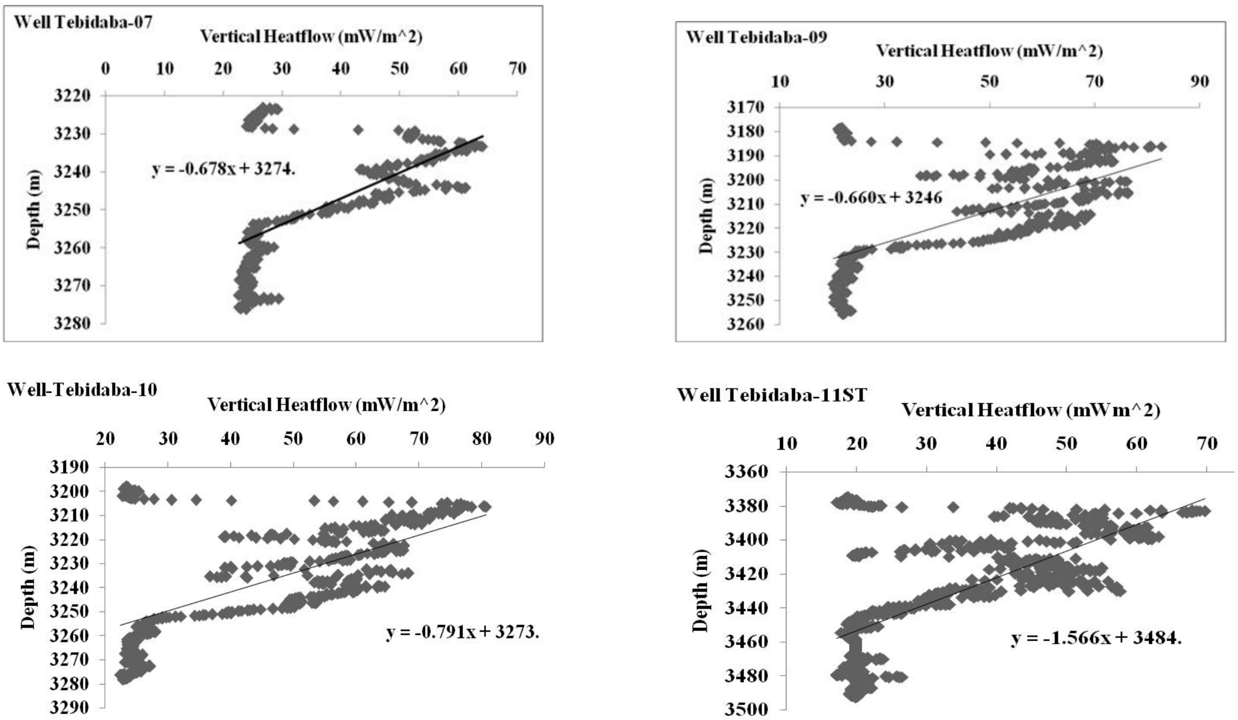
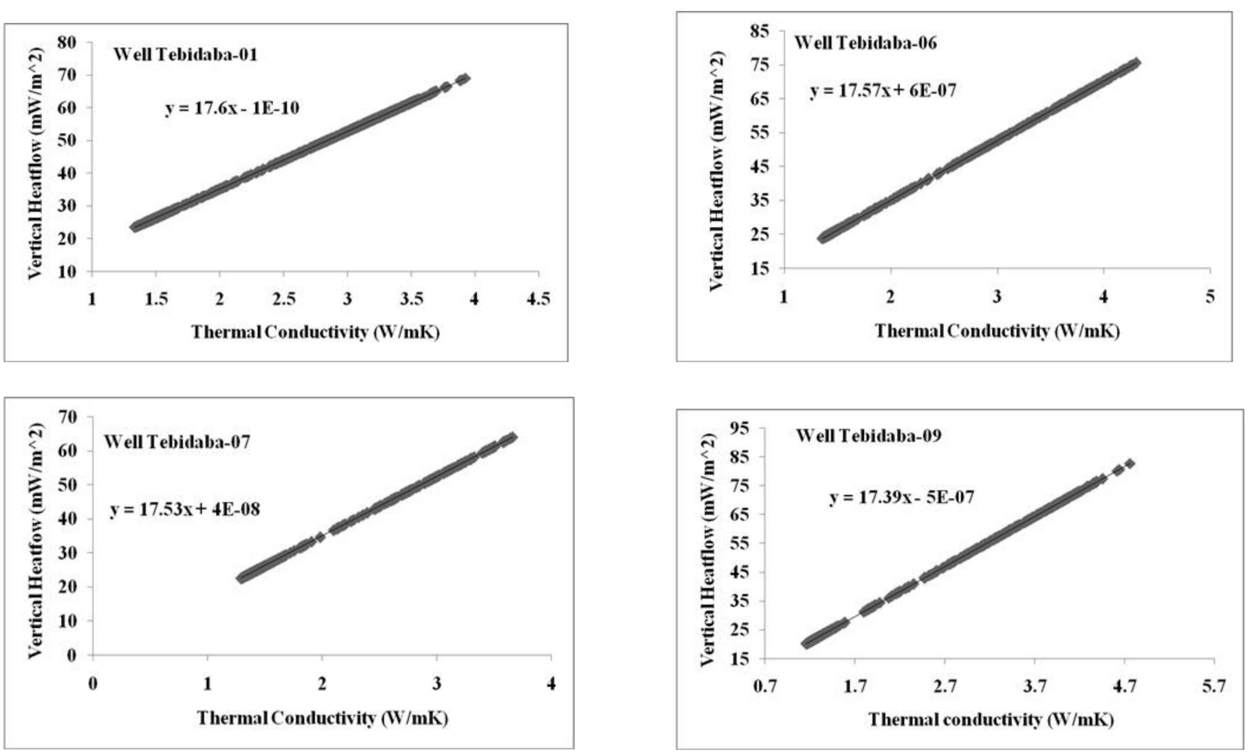


Figure 5: Vertical Heatflow against Depth for (a)Tebidaba 01, (b) Tebidaba 06, (c)Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST



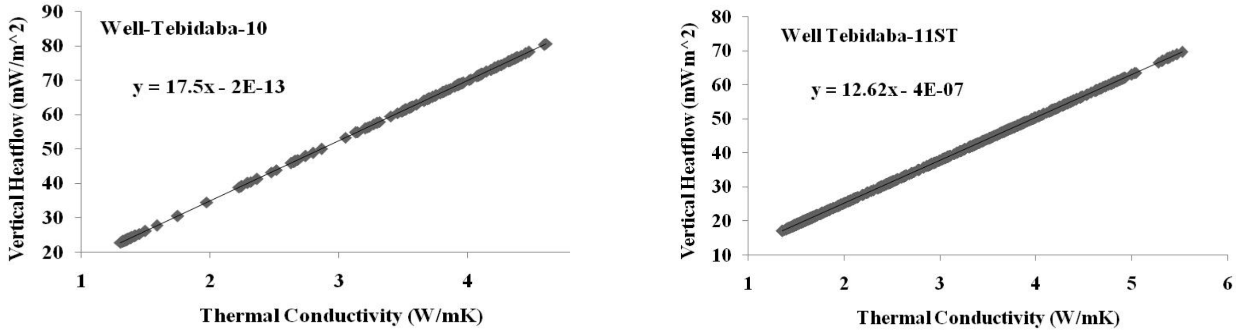


Figure 6: Vertical Heatflow against Thermal Conductivity for (a)Tebidaba 01, (b)Tebidaba 06, (c) Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST

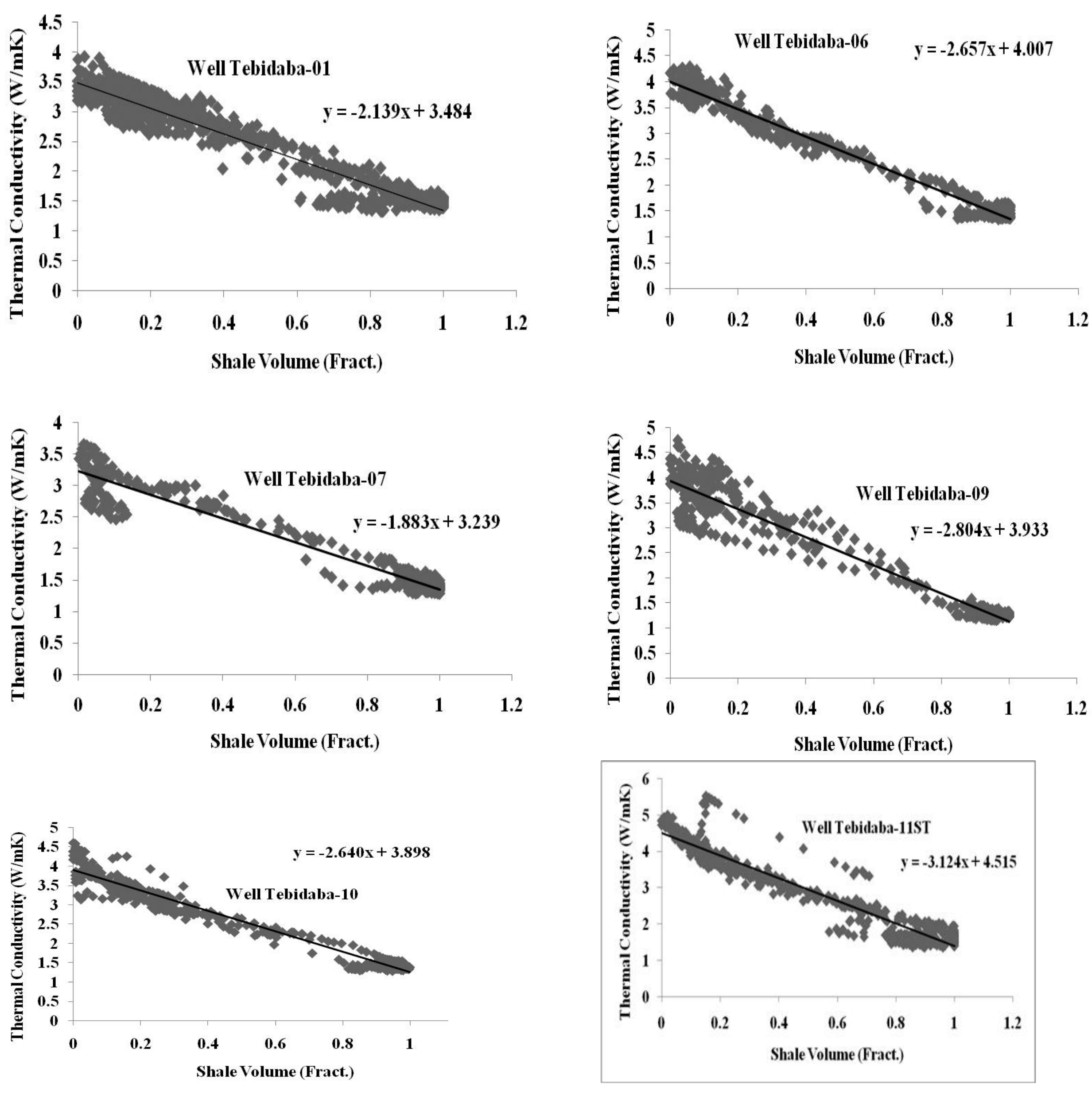


Figure 7: Thermal Conductivity against Shale Volume for (a) Tebidaba 01, (b) Tebidaba 06, (c) Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST

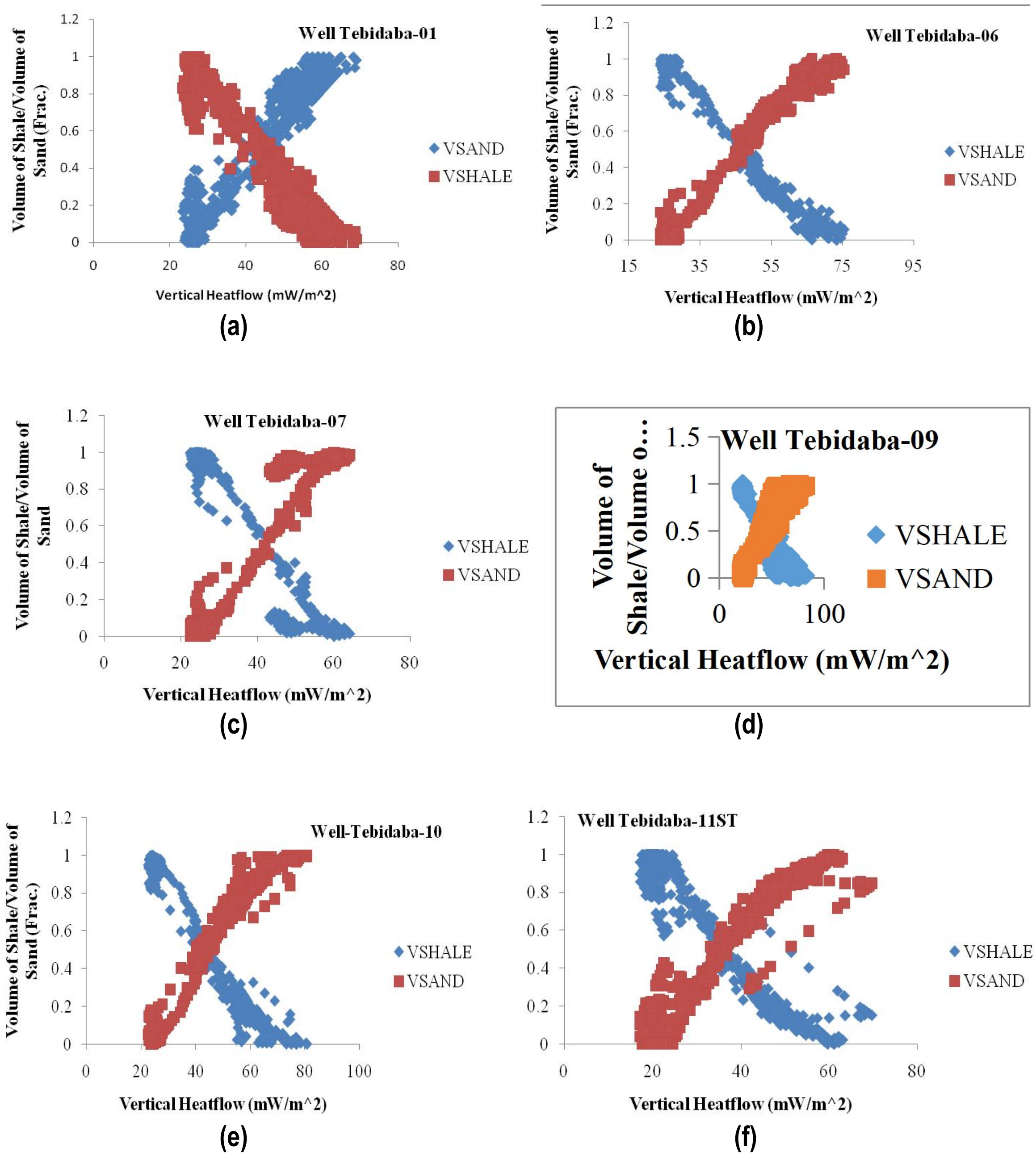


Fig. 8: Vertical Heatflow against Lithology for (a)Tebidaba 01, (b) Tebidaba 06, (c) Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST

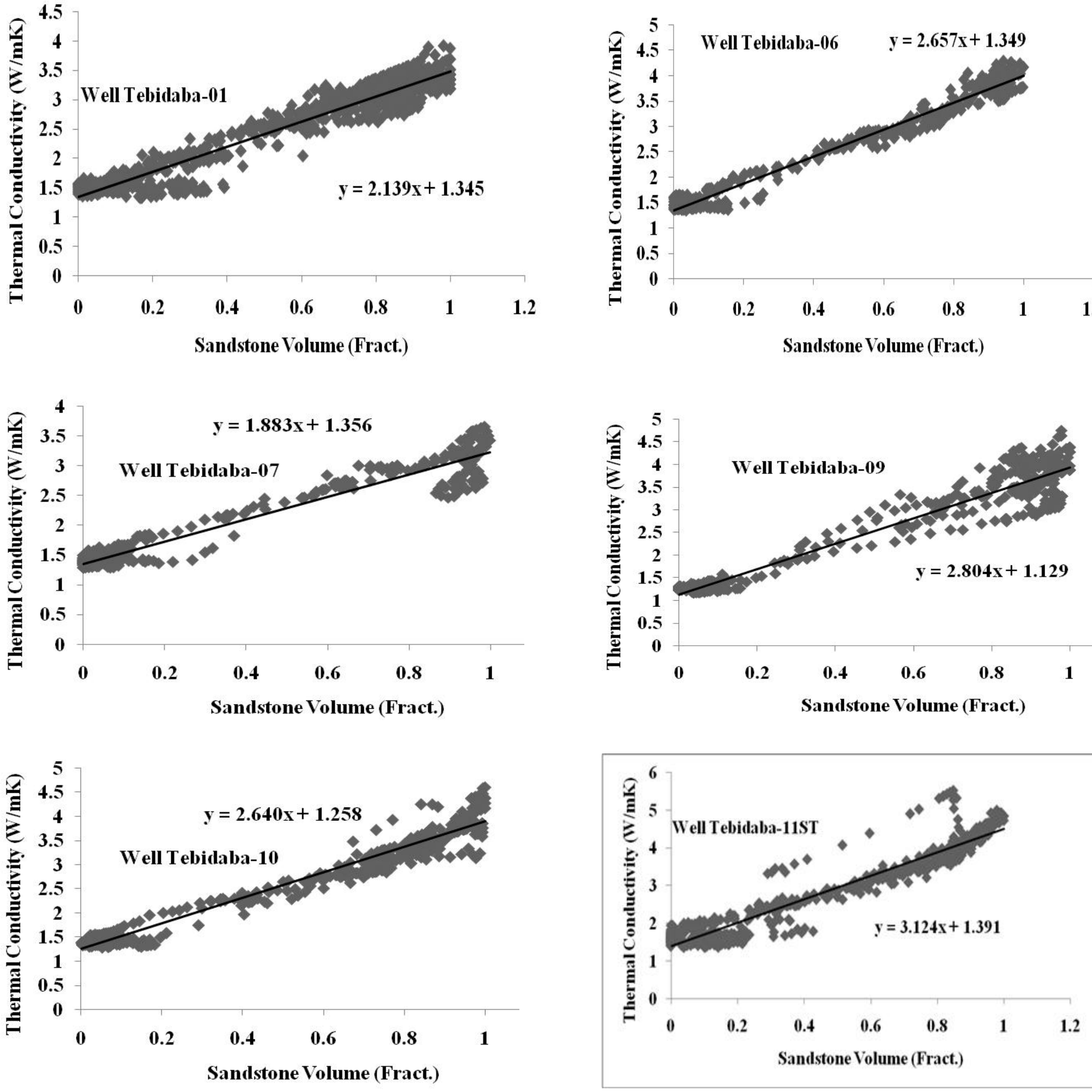
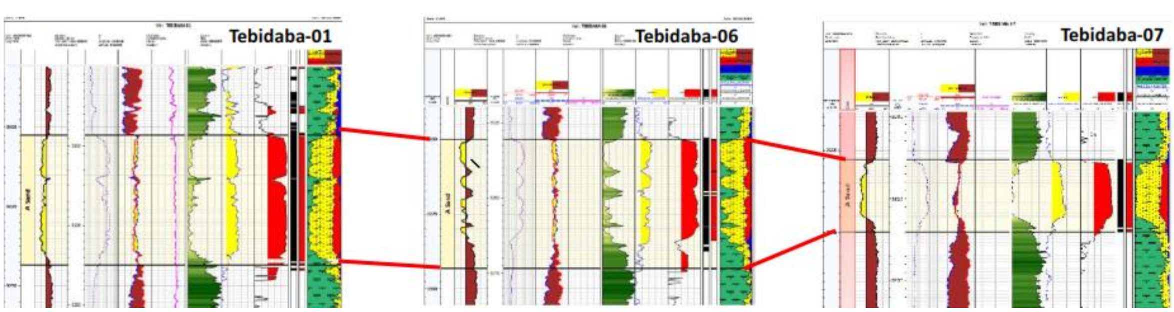


Figure 9: Thermal Conductivity against Sandstone Volume for (a)Tebidaba 01, (b) Tebidaba 06, (c) Tebidaba 07, (d) Tebidaba 09, (e) Tebidaba 10, (f) Tebidaba 11ST



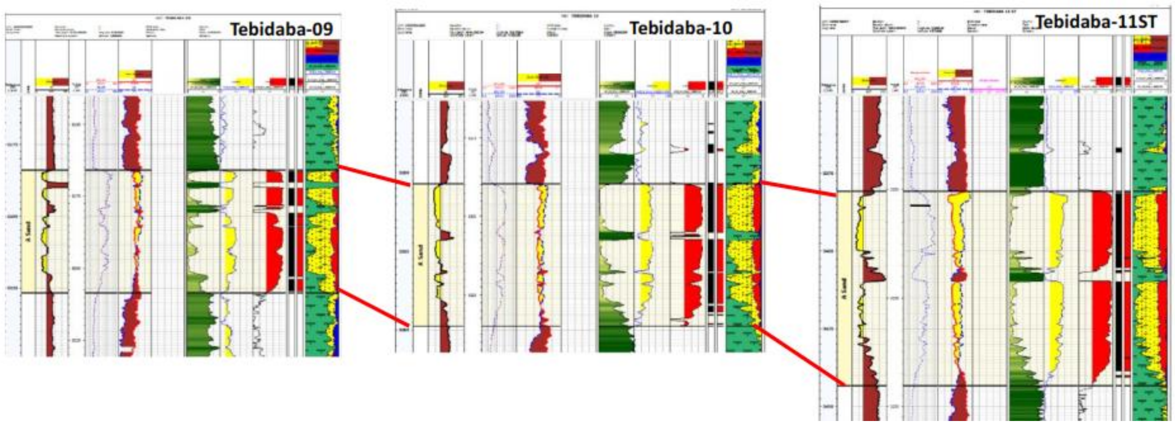


Figure 10: Well Section showing Reservoir Identification across Tabidaba Field

Table 2: Summary of Geothermal and Petrophysical Properties for Sand A Reservoirs

Well Name	Top (m)	Base (m)	Net-to-Gross (m)	Average Porosity (Frac.)	Average Vertical Thermal Conductivity ($Wm^{-1}K^{-1}$)	Average Vertical Geothermal Gradient (°C/Km)	Average Vertical Heatflow (mWm^{-2})	Average Shale Volume (Frac.)	Average Sandstone Volume (Frac.)	Average Density (gcm^{-3})	Average Temp (Deg. C)	Water Saturation (Fract.)
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	2.40	83.590	0.138
Tebidaba-07	3213.62	3231.86	18.24	0.3890	2.0578	17.53	36.0739	0.6276	0.3724	2.39	83.119	0.137
Tebidaba-09	3162.96	3205.34	42.38	0.3597	2.5183	17.39	43.7936	0.5046	0.4954	2.24	82.463	0.168
Tebidaba-10	3189.25	3234.31	45.06	0.3427	2.3654	17.50	41.3938	0.5050	0.4950	2.27	83.127	0.138
Tebidaba-11ST	3200.26	3245.26	45.00	0.2854	2.5802	12.62	32.5622	0.6195	0.3805	2.34	83.183	0.082
Average			**37.74**	**0.3355**	**2.4300**	**16.70**	**40.54**	**0.5555**	**0.4444**	**2.33**	**83.138**	**0.122**

Reservoir Identification and Delineation

The results for lithology and reservoir identification are presented in (Figures 7 and 8). One hydrocarbon-bearing reservoir of interest, A, runs across the six Wells Tebidaba-01, 06, 07, 09, 10 and 11ST. The tops and bases of the identified reservoir are shown in Table 1. The wells display a shale/sand arrangement which is illustrative of the Niger Delta formation. Low gamma ray and high resistivities are sand lithologies. Shale lithologies were defined by the high gamma ray value. Gamma ray logs measures the degree of radioactivity of formations in the well which connected to clay mineral, oil source rock, organic matter and shale in reservoir rock [21]. This analysis shows that each of the sand units extends through the field, varies in thickness and some units occurring at greater depth than their adjacent unit which is probably an indication of faulting. The shale layers were observed to increase with depth along with a corresponding decrease in sand layers.

The volume of shale ranges from 50.46% to 62.76% with average of 55.55%. This means the reservoir has 44.45% of sand deposit for hydrocarbon to be saturated in. The reservoirs effective porosity ranges from 28.54 to 38.90 with average of 33.55 indicating a very good reservoir quality. These results imply that the reservoir is highly porous. It also contains high hydrocarbons that is very viable for production.

Influence of Lithology on Thermal Conductivity and Heatflow

Figure 4 shows a trend of increase in thermal conductivity as depth increases. This relationship is not linear. At shallow depth, thermal conductivity decrease relatively due to the presence of hydrocarbon, lithology, compaction and fluid content. Figure 5 shows the relationship between heat flow and depth; that heatflow increases with depth due to the combined effects of a rising temperature gradient and compaction of the rocks, which enhances thermal conductivity. However, the presence of hydrocarbons and variations in lithology modify the relationship, leading to localized changes in heatflow at certain depths. Thermal conductivity and vertical heatflow are highly variable in the reservoir due to intercalations of sandstone and shale mineralogy with depth (Figures 6 and 7).

The control of the thermal conductivity and vertical heatflow variation of the Niger Delta basin is due to the influence of lithology. Thermal and vertical heatflow increases as sandstone volume increase and decreases as shale content increases (Figures 8 and 9). Thermal conductivity and heatflow shows a wide variation from well to well, and within this reservoir in the Agbada formation, conductivity varies between $2.0578Wm^{-1}K^{-1}$ and $2.5829Wm^{-1}K^{-1}$, while heatflow varies between $32.5622mWm^{-2}$ and $45.3821mWm^{-2}$. There is a correlative increase of vertical heatflow with increase in thermal conductivity (Figure 6). These values compare closely with that of other workers in the Niger Delta basin [10]. Other variabilities in the data point plots may be due to fluid content, mineral composition and local geological complexities.

Conclusion

The geothermal properties evaluation of hydrocarbon reservoirs in OML-63 (Tebidaba Field) was successfully carried out.

The results showed that one hydrocarbon bearing reservoir of interest, A, runs across the six wells; Tebidaba 01, 06,07, 09, 10 and 11ST. The wells display a shale/sand arrangement which is illustrative of the Niger Delta formation. The result revealed that the reservoir under study is within the Agbada Formation, with depth range of 3162.96m-3265.31m. The reservoir temperature varies within 82.46^0C and 83.59^0C with an average of 83.13^0C. The temperature-depth profile of the six wells in Fig. 4.1 shows that temperature increases with increase in depth.

Average computed geothermal gradient across the six wells showed values of $17.57^oC/km$, $17.57^oC/km$, 17.53 $^oC/km$, 17.39 $^oC/km$, 17.50 $^oC/km$ and 12.62 $^oC/km$ respectively. The variations in geothermal gradients in the reservoir may be probably due to lithological variations or differential rates of sedimentation during basin evolution. Wells with low geothermal gradients corresponds with areas of high percentage of sands because sands are better thermal conductors than shales; while areas with higher thermal gradients corresponds with high shale percentage volume [24].

The thermal conductivity within the reservoir varies from 2.0578 $wm^{-1}k^{-1}$ to $2.5829wm^{-1}k^{-1}$ with an average of $2.43wm^{-1}k^{-1}$. The heat flow ranges from $32.562mWm^{-2}$ to $45.3821mWm^{-2}$ with an average of $40.54mWm^{-2}$. The control of the thermal conductivity and heat flow variations across the reservoir may probably be due to the influence of lithology, fluid content, hydrocarbon presence and geological complexities.

Funding Information.
The project was self sponsors.

Competing Interests.

The authors hereby declared that there is no competing interest.

References

[1] J. O. Adedapo, et al., “Geothermal gradient of the Niger Delta from recent studies”. International Journal of Science and Engineering Research (IJSER), vol.4, no.11, pp.39-45, 2013. [CrossReff] [Google Scholar] [Publisher Link]

[2] P.A. Allen, and J.R. Allen, *Basin Analysis*, Blackwell Publishing, second edition, 2005. [Publisher Link]

[3] Asquith, G. and Krygowski, D. “Basic Well Log Analysis,” (Second Edition). AAPG. Methods in exploration series 16, The American Association of Petroleum Geologists Tulsa, Oklahoma. 2004.[CrossReff] [Google Scholar] [Publisher Link]

[4] A.A. Avbovbo, “Tertiary lithostratigraphy of Niger Delta” AAPG Bulletin vol. 62, no. 2, pp. 295-300, 1978. [CrossReff] [Google Scholar] [Publisher Link]

[5] K.C. Short, and A.J. Stauble, “Outline of Geology of Niger Delta” AAPG Bulletin, vol. 51, pp. 761-779, 1967. [CrossRef] [Google Scholar] [Publisher Link]

[6] Beardsmore, G. R. and Cull, J. P. “*Crustal Heat Flow,”* Cambridge University Press, 2001. [Google Publisher]

[7] T.N Blaike, et al., “Interpreting subsurface- volcanic structures using geologically constrained 3-D gravity-inversion,” Examples of Maar-diatremes, Newer volcanics- province, South eastern Australia. Journal of Geophysical Research: Solid Earth, pp.119, 2014. [Google Scholar]

[8] Kelvin Burke, “Longshore Drift, Submarine Canyons and Submarine Fans in the Development of the Niger Delta,” AAPG Bulletin, vol. 56, no. 10,

pp. 1975-1983, 1972. [CrossReff] [Google Scholar] [Publisher Link]

[9] D.S. Chapman, et al., “Heat flow in the Uinta Basin determined from bottom hole temperature (BHT) data,” *Geophysics*, vol.49 no.4, pp.453-466, 1984. [CrossReff] [Google Scholar] [Publisher Link]

[10] Chukwueke, C., Thomas, G. and Delfaud, J. “Sedimentary processes, eustatism, subsidence and heat flow in the distal part of the Niger Delta,” Bulletin Centres Rech. Exploration, Prod. *Elf-Aquitaine,* vol.16, pp.137 – 186, 1992. [CrossReff] [Google Scholar] [Publisher Link]

[11] C.A. Kogbe, Geology of Nigeria, Elizabethan Publishing Company, pp. 1-436, 1976. [Publisher Link]

[12] D. Deming, et al.“Some problems in thermal history studies, in Nuccio, V.F., and Barker, C.E., eds., Applications of thermal maturity studies to energy exploration,” Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, pp.61-80. 1989. [CrossReff] [Google Scholar] [Publisher Link]

[13] Doust, H. and Omatsola, E. M. “The Niger Delta in Divergent/passing Margin Basins ed., J.O. Edwards and P.A. Santugross”. *American Association of Petroleum Geologists Memoris* vol.45, pp.201-238, 1990. [Google Scholar]

[14] Goff, F. and Janik, C. J. “Geothermal Systems, *in* Sigurdsson, H., Houghton, B., McNutt, S., Rymer, H., and Stix, J., eds., Encyclopedia of Volcanoes,” Academic Press, San Diego, CA, pp. 817–834, 2000. [CrossReff] [Google Scholar] [Publisher Link]

[15] R.D. Goss, and Combs J. Terrestrial heat flow determination in the North Central United States. Journal of Geophysics Research, vol. 78, pp. 441-461, 1976 .[Google Scholar]

[16] H. K. Gupta, and Roy, S. “Geothermal Energy: An Alternative Resources for the 21st century”. Amsterdam; Elsevier. 2007. [Google Scholar]

[17] Larionov, V. V. “Radiometry of boreholes (in Russian) NEDRA”, Moscow. 1969. [Google Scholar]

[18] M.L. Tuttle et al., “The Niger Delta Petroleum System; Niger Delta Province Nigeria, Cameroon and Equitorial Guinea, Africa”. US Department of the Interior, US. Geological Survey, Open-File Report 99-50-H, pp. 1-65, 1999. [CrossReff] [Google Scholar] [Publisher Link]

[19] R.C. Murat, “Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. African Geology,” University of Ibadan Press, Nigeria, pp. 251-266, 1972. [Google Scholar]

[20] W.A. Naje, and Z.M. Hasan,. “A Review Paper: Study Effect Heat Transfer Convection Natural In Vertical Channel”, *International Journal of Mechanical Engineering, Kalahari Journals*, vol. 7, no.8, pp.131-139. 2022. [Google Scholar]

[21] Schlumberger, Log interpretation; Principles” New York, Schlumberger Limited, vol, 1, p.113. 1972. [CrossReff] [Google Scholar] [Publisher Link]

[22] Schlumberger, Log Interpretation Charts, Schlumberger Education Services”, New York Press, Pp83. 1974. [Publisher Link]

[23] D.L. Turcotte, “On the thermal evolution of the earth,” *Earth and Planetary Science Letters*, no.48, pp.53–58. 1980. [Google Scholar]

[23] E. D. Uko, et al., “Stratigraphic control of Temperature in the North-west Niger Delta Basin, Nigeria,” *Journal of Scientific and Engineering Research,* no.2, pp.1–10. 2018. [Google Scholar]

[25] A.J. Whiteman, Nigeria; Its Petroleum Geology, Resources and Potential Volume 1, Springer Netherlands, pp. 1-394, 1982. [Google Scholar] [Publisher Link]