Journal of the Nigerian Association of Mathematical Physics, Volume 9 (November 2005)

In-situ thermal conductivity estimates in the Western Niger Delta sediments derived from geophysical logs.

D. O. Ogagarue
Department of Integrated Science, College of Education, Agbor, Nigeria.
and
***Vincent E. Asor**
Subsurface Information Technology Portfolio, Shell International, Port Harcourt, Nigeria
e-mial:VincentAsor@shell.com

Abstract

An estimate of thermal conductivity was carried out in 21 well-spaced petroleum wells in the western Niger Delta using sonic and continuous temperature logs. The temperature logs were measured after the wells had attained thermal equilibrium as a result of drilling activities. Regional thermal conductivity varies from 1.1$Wm^{-1}\ {}^{0}C^{-1}$ to 6.2 $Wm^{-1}\ {}^{0}C^{-1}$, with an average of 3.1$Wm^{-1}\ {}^{0}C^{-1}$. The North-Central part of the studied area is characterized by high thermal conductivity and this decreases towards the North-East and seawards. The values are lowest around the sea with an average of 1.43$Wm^{-1}\ {}^{0}C^{-1}$. Our method of direct computation is in agreement with previous works and are also comparable to those of other passive continental margins in the world.

pp 425 - 430

Keywords: Thermal conductivity, Niger Delta, temperature, logs, petroleum wells.

1.0 Introduction

Thermal Conductivity, λ_l, is defined as the quantity of heat which will traverse a medium of unit thickness and cross-sectional area per unit time, under the influence of an applied temperature gradient. Furthermore, it is only weakly a function of temperature, usually decreasing as temperature increases. At ambient conditions, any temperature correction to it would likely be less than other uncertainties in the calculation. Data acquired therefrom can be used in understanding the thermal structure of sedimentary basins. The data have first order dependence on the configuration of isotherms and the heat flow within the basin [3].

Direct, on-the-site measurement of thermal conductivity of sediments in in-situ conditions in petroleum wells are both difficult and time consuming. Instead, laboratory measurements are preferred and these are usually made on cores and drill cuttings collected from the wells. In order to apply to in-situ conditions, however, the measured data will have to be modified [3] and this is a major setback to laboratory measurements of thermal conductivity estimation in sedimentary basins.

[5] used the results of [2] to make estimates of the bulk thermal conductivity from lithostratigraphic and BHT data in the northern Niger Delta. They obtained thermal conductivity varying from 2.47+/-0.04 $Wm^{-1}\ {}^{0}C^{-1}$ for the Benin Formation to 2.24+/-0.03 $Wm^{-1}\ {}^{0}C^{-1}$ in the Agbada Formation.

---

*Corresponding author.

In the present study, we have directly computed thermal conductivities at different depths within each of 21 well spaced petroleum wells in the western Niger Delta from continuous temperature and sonic log data.

2.0 Basic data

The data used for this work comprised a set of continuous temperature and sonic log data obtained from 21 well spaced petroleum wells in the western Niger Delta. Continuous temperature data have been used instead of BHT data because enough time usually elapses so that the borehole could attain thermal equilibrium before continuous temperature logs are recorded. In this way, they provide very accurate in-situ temperature conditions in the wells.

The geophysical logs available for the wells vary in completeness from one well to the other. As a result, the study could not be limited to a particular depth range for all the wells.

3.0 Data treatment

3.1 Temperature data

The temperature at a depth for each well was read from the log and recorded against the depth. The temperatures were read at every 100ft from the temperature logs. The value read at each depth was converted from ^0F to ^0C by using the relation:

$$^0\mathrm{C} = (5/9)(^0\mathrm{F}-32) \tag{3.1}$$

The temperature gradient, TG, in ^{0}C/100m, at depth Z was then calculated from the relation:

$$TG = \{(100/\mathrm{Z}_{\mathrm{ft}}*0.305)(^0\mathrm{C}-\mathrm{S})\} \tag{3.2}$$

where S is the surface temperature.

Following [1], [5], [6] and [8], we have used an average atmospheric temperature of 27^{0}C for the Niger Delta. The continuous temperature data used for this work were not corrected for drilling disturbances, [4], since thermal equilibrium is assumed to have been attained before the measurements are made.

3.2 Sonic log data

This comprised the interval transit time, i.e. the time necessary for elastic waves to travel 1ft of formation, recorded in µsec/ft. The interval transit times were picked to correspond to the depth for which temperature had been previously picked.

The one-way sound travel time, t_{sec}, at a particular depth, Z_{m}, was thereafter obtained from the relation:

$$t_{\mathrm{sec}} = Z_{\mathrm{m}}/V_{\mathrm{ms\text{-}1}} \tag{3.3}$$

where $V_{\mathrm{ms\text{-}1}}$ is velocity of sound waves at depth Z_{ft}, given by

$$\mathrm{V}_{\mathrm{ms\text{-}1}} = \{(10^6/\Delta t)\}*0.305 \tag{3.4}$$

Δt is the sonic log reading in µsec/ft.

If the interval transit time at 6,000ft depth is 125µsec/ft, then, the sound velocity at this depth will be:

$$V_{\mathrm{ms\text{-}1}} = \{(10^6/125)\}*0.305$$

$$= 2440\mathrm{ms}^{-1}.$$

From equation (3.3), the one-way sound travel time at this depth will thus be:

$$= (6000*0.305)/2440$$

$$= 0.75 \text{ sec.}$$

4.0 Thermal conductivity estimation

The Fourier's one-dimensional heat flow law, neglecting the direction of flow, was used in estimating the rock's thermal conductivity in the wells studied. Thermal conductivity was calculated directly from the observed heat flow and geothermal gradient according to the Fourier's one-dimensional heat flow equation:

$$K = Q/TG \qquad (4.1)$$

where Q = heat flow in Wm^{-2}

TG = temperature gradient in $Wm^{-1}\,{}^{0}C^{-1}$

The heat flow for the wells was calculated using the method of [7]. This method, however, is constrained by the difficulty in choosing the best intervals for heat flow, hence thermal conductivity estimation. As a quick way of determining the best intervals, we made a travel time versus depth plot (Figure 1) for each of the wells and imagined a best fit line through the points. Points well separated, and which fell on the lines were chosen, and their axes read to give the depths and corresponding travel times, respectively.

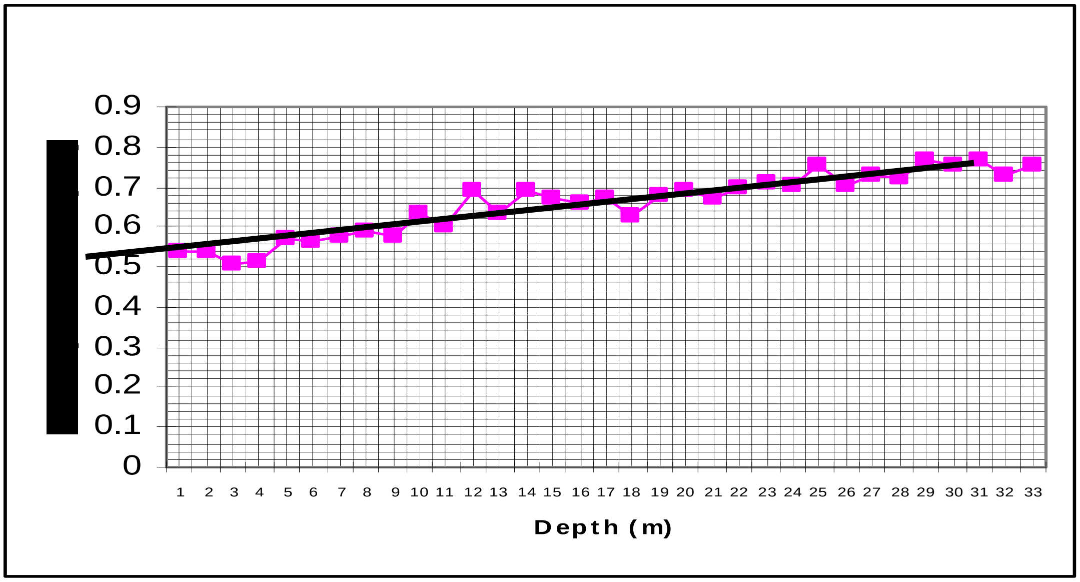

Figure 1: Travel time versus depth plot for one of the wells studied. Depth points range from 1220m to 2196m with an increment of 30.5m (100ft).

The suitable depth intervals and their corresponding temperatures and travel times for the above well is shown in Table 1.

Table 1: Suitable intervals for thermal conductivity estimation for well Ovr-1.

Depth (m)	Temperature (^{0}C)	One-way travel time (sec)
1250.5	43.33	0.5371
1433.5	44.33	0.5922
1677.5	45.50	0.6600
1891.0	50.28	0.7130
2135.0	54.44	0.7700
2348.5	56.11	0.8085

The heat flow at the respective intervals was then calculated using the relation:

$$Q = \{(In(\beta + T_U)/(\beta + T_L))*(\gamma(t_L - t_U))\}*77 \text{ (m Wm}^{-2}) \qquad (4.2)$$

where β , γ are constants equal to 80.031 and 1.039 respectively;
T_L, t_L = temperature and one-way travel time respectively, at the deeper level between any two chosen intervals along the well;
T_U, t_U = temperature and one-way travel time respectively, at the upper depth level of the interval.

The calculated heat flow and average temperature gradient values at the various intervals were finally used in the Fourier's one-dimensional heat flow equation (Equation 4.1) to compute the thermal conductivity at the various intervals. The average thermal conductivity at the intervals gives the average thermal conductivity for the respective wells. Computation result for one of the wells studied is given in Table 2.

Table 2: Computed Result For One Well.

Depth (m)	Temp. (0C)	One-way tt (sec)	Heat Flow (m W/m2)	Av. GG (0C/Km)	Thermal Conductivity (W/m^{0}C)
1250.5	43.33	0.5371			
			10.86	12.43	0.87
1433.5	44.33	0.5922			
			10.24	11.51	0.89
1677.5	45.5	0.66			
			52.26	11.61	4.5
1891	50.28	0.713			
			40.86	13.05	3.13
2135	54.44	0.77			
			23.76	12.37	1.92
2348.5	56.11	0.8085			
Average			27.596	12.194	2.262

5.0 Discussion

Thermal conductivity map of the western Niger Delta constructed from 21 well spaced petroleum wells is shown in Figure 2. Thermal conductivity varies from 1.1 $Wm^{-1}\,{}^0C^{-1}$ to 6.2 $Wm^{-1}\,{}^0C^{-}$

^{1} with an average of about 3.1 Wm^{-1} ^{0}C^{-1}. The north-central part of the western Niger Delta is characterized by high thermal conductivity, and this decreases towards the north-east and south. The results agree well with the results of [5] and are also comparable to those of other passive continental margins in the world. Reliable values of thermal conductivity are essential to models of basin evolution and thermal maturation.

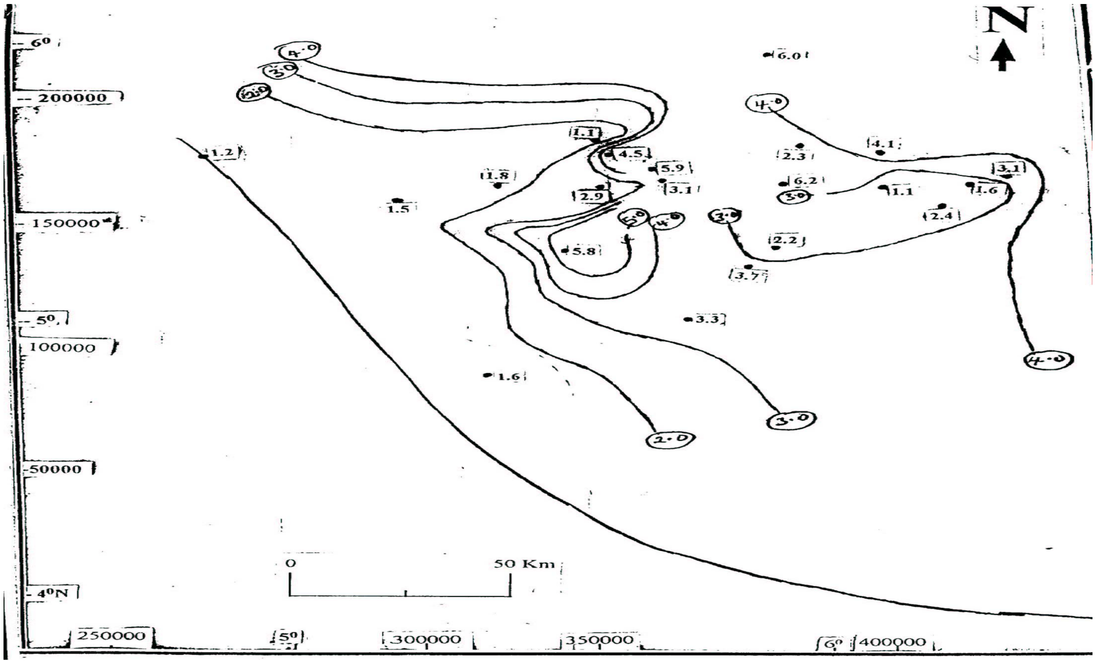

Figure 2: Thermal conductivity map of the western Niger Delta determined from sonic and continuous temperature log data..

6.0 Conclusion

In-situ thermal conductivity measured from sonic and continuous temperature log data in the western Niger Delta presents a simple average of 3.1 Wm^{-1} ^{0}C^{-1}. The method described is adequate for making regional thermal conductivity studies in sedimentary basins. It is preferred to laboratory measurements because it may not be possible to obtain core samples representative of the in-situ condition within every region of interest in the wells. The results of the method presented are comparable with the results obtained for other continental margins of the world.

References

[1] Avbovbo, A.A. (1978): Tertiary lithostratigraphy of the Niger Delta, AAPG Bull., Vol. 62, p. 295 – 306.

[2] Brigaud, E. (1989): Conductivite thermique et champ de temperature dans les basins sedimentaires a partir de donnes de puits. These de Doctorat, Univ. de Sciences et Tech. Du Languedoc, Montpellier, 414p.

[3] Brigaud, F., Chapman D.S. and Sylie D. (1990): Estimating Thermal Conductivity in Sedimentary Basins using Lithology Data and Geophysical Well Logs, AAPG Bull., Vol. 74, no.p, p. 1459 – 1477.

[4] Cronoble, J.M. (1980): Geothermal gradients and their application in petroleum geology, The Mountain Geologist, Vol. 6, p. 27 – 39.

[5] Etim, D.U., Ofoegbu C.O., Ebeniro J.O. and Chukwueke C.C. (1996): Present day heat flow in the northern Niger Delta, Nigeria, NAPE Bull, 1996, 4p.

[6] Evamy, D.D., Haremboure J., Kammerling P., Knaap W.A., Molloy F.A. and Rowland P.H. (1978): Hydrocarbon habitat of the Tertiary Niger Delta, AAPG Bull., Vol. 62, no.1, p. 1 – 39.

[7] Houbolt, J.J.H.C. and Wells P.R.A. (1980): Estimating heat flow in oil wells based on a relation between heat conductivity and sound velocity, Geologie en Mijnbouw, Vol. 59, no.3, p. 215 – 224.

[8] Nwachukwu, S.O. (1976): Approximate geothermal gradients in the Niger Delta sedimentary basin, AAPG Bull., Vol. 60, p. 1073 – 1077.