Heat Flow Estimates in the Western Niger Delta Basin, Nigeria

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ABSTRACT

Present day heat flow values are calculated for twenty-one well-spaced petroleum wells in the western Niger Delta Basin, Nigeria using geophysical log data. Heat flow estimates vary between 27.6 mWm^{-2} and 68.3 mWm^{-2}, with a simple average of 43.92 mWm^{-2}. The north-central part of the study area is characterized by high heat flow which decreases towards the Niger Delta coast. The values obtained are comparable with those of other passive continental margins of the world.

(Keywords: geophysical data, petroleum exploration, hydrodynamics, tectonics, hydrocarbon reserves)

INTRODUCTION

The Niger Delta sedimentary basin is widely recognized as holding significant hydrocarbon reserves and continues to attract exploration interests. Successful exploration for these resources demand multi-disciplinary efforts to integrate all available data and utilize advanced technologies to mitigate the exploration and drilling risks. Heat flow data are important in investigating the geothermal resource potential in an area. Representations of heat flow data on contour maps offer suggestions for the interpretation of crustal tectonics and large-scale hydrodynamics, and formation of basins (Lachenbruch and Sass , 1977). For a sedimentary basin, the data provide an additional measure of investigating hydrocarbon maturation, migration and accumulation.

Heat flow data have been estimated by Etim et al, 1996. They utilized the Thermal Resistance method of Bullard (1939) and Chapman *et al*., (1984) to estimate heat flow values for the northern Niger Delta sedimentary basin and obtained heat flow values varying between 38.70 mWm^{-2} and 64.28 mWm^{-2} with an average of 51.49 ± mWm^{-2}. In the present study, heat flow estimates are calculated for twenty-one petroleum wells in the western Niger Delta basin, following the Relative Heat Flow model of Houbolt and Wells (1980). The method calculates heat flow values in terms of subsurface temperature and one-way sound travel times.

GEOLOGY OF THE NIGER DELTA BASIN

Works by several authors (Hospers, 1965; Short and Stuable, 1967; Weber, 1971; Merki, 1972) show that the Niger delta is a sedimentary basin formed by the built out and up of sediments over a transitional crustal tract. This tract was developed by rift faulting during the Precambrian with outlines controlled by deep seated faults associated with the rifting (Weber,1971). The delta is situated on the Gulf of Guinea on the west coast of central Africa, and extends from longitude 3^0E to 9^0E and from latitude $4^030'$N to $5^020'$N. It started as separate depocenters in the Bende–Ameki area, east of the delta and in the Anambra shelf, west of the delta in the mid–late Eocene (Hospers, 1965).

The two depocenters coalesced to form a single united Niger delta sedimentary basin in the late Miocene to date. The delta has a tripartite lithostrrgraphic succession in which a regressive sequence is properly defined. The delta sequence is mainly a sequence of over pressurized marine clays (Akata Formation) overlain by a paralic sediment sequence (Agbada Formation), that is predominantly sandy and shaly at the top and bottom, respectively. These two formations were finally capped by continental gravels and sands (Benin Formation). Of these three formations, the Agbada Formation constitutes the main reservoir for hydrocarbon in the Niger delta (Short and Stauble, 1967).

The maximum thickness of the sediments may be of the order of 40,000ft to the basement. The known thickness of the continental sands is variable but generally exceeds 6,000ft, while that of the paralic sequence is 10,000ft to 15,000ft at the center of the delta. The Akata Formation exceeds 4,000ft (Merki, 1972).

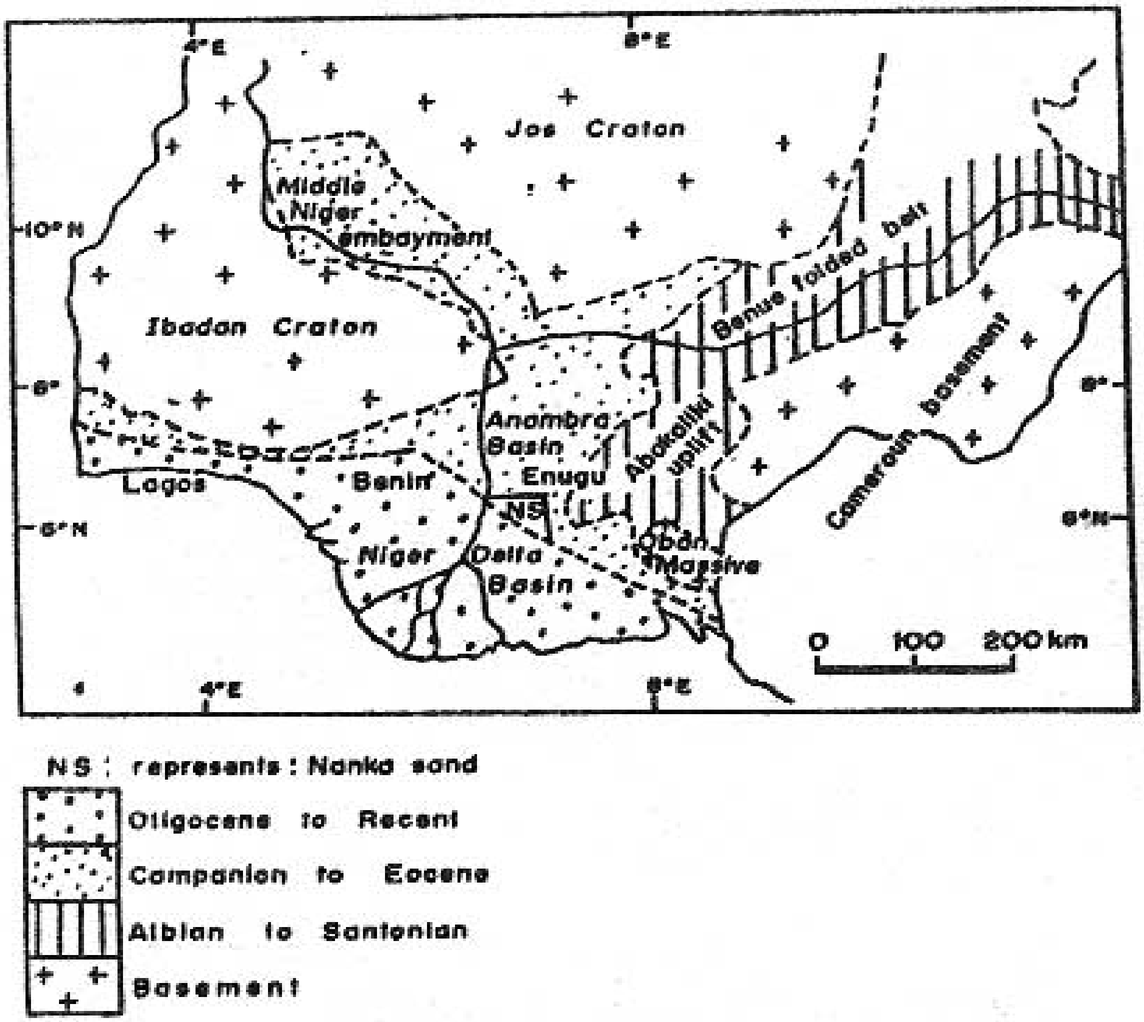

Table 1: Generalized Geology and Tectonic features of Southeastern Nigeria (adapted from Murat, 1970)

These sediments thicken progressively towards the continental shelf and accumulated rather fast resulting in faulting contemporaneous with deposition. The delta is characterized by synsedimentary faulting (growth faults) within the delta pile and lateral flowage of pro–delta sediments (clay diapirs). There is evidence that only the Akata and Agbada Formations are so deformed by these structures, the Benin Formation being tilted slightly regionally down (Weber, 1971)

BASIC DATA

The data used for this work comprised a set of continuous temperature and sonic log data obtained from twenty one well spaced petroleum wells in the western Niger Delta. Continuous temperature data have been used for this study instead of BHT data.

The preference in continuous temperature data to BHT data is not unconnected to the fact that enough time usually elapses after the wells have been drilled before continuous measurements are made. This allows the wells to attain thermal equilibrium and the temperatures recorded will be representative of the in-situ condition of the wells, and as a result, the measurements are not usually corrected for drilling disturbances (Cronoble, 1980).

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 the wells.

HEAT FLOW ESTIMATION

Temperature Data

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

$$ {}^0C = \frac{5}{9}\left({}^0F - 32\right) \qquad \textbf{(1)} $$

Sonic Log Data

The sonic log data comprised interval transit time, which is defined as the time necessary for an elastic wave to travel one foot of formation. The sonic logs were recorded in µsec/ft. The interval transit times were selected to correspond to the depth for which temperature had been previously recorded.

The velocity, in ms^{-1}, of sound waves in a formation was estimated from a sonic log using the relation,

$$ V_{(m/s)} = \left(\frac{1000000}{\Delta t}\right) * 0.305 \qquad \textbf{(2)} $$

where Δt was interval transit time, in $\mu \sec ft^{-1}$ read from the sonic log.

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

$$ t(\sec) = \frac{Z(m)}{V(m/s)} \qquad \textbf{(3)} $$

For example, imagine that the interval transit time at 7,000ft depth is $140\,\mu \sec ft^{-1}$, the sound velocity at this depth will be:

$$ V(m/s) = \left(\frac{1000000}{140}\right) * 0.305 = 2{,}178.57\ m/s. $$

The one-way sound travel time at this depth will thus be:

$$ t(\sec) = \frac{7{,}000 * 0.305\,m}{2{,}178.57\,m/s} = 0.98 \sec. $$

Houbolt and Wells (1980), through analysis of some wells in selected sedimentary environments around world, developed a method to calculate heat flow by assuming an empirical relationship between subsurface temperature and one-way sound travel time. The method has also been used by Leadholm *et al*. (1985) to predict thermal conductivity of rocks to model organic maturation on the Norwegian continental shelf. The relation is:

$$ Q = \left\{ a\left(t_L - t_U\right)^{-1} * In\left(\frac{c + T_L}{c + T_U}\right)\right\} \qquad \textbf{(4)} $$

where,

Q = relative heat flow in Boderij unit (BU), which is equal to 77 mWm^{-2} in S.I. unit.

a, c are constants having values 1.039 and 80.031 respectively,

T_L, t_L are temperature and one-way travel time, respectively, at a deeper depth level of any chosen interval within the well,

T_U, t_U are temperature and one-way travel time at the shallower depth level of the chosen interval.

The application of the above relation is constrained by the difficulty in choosing the best intervals for heat flow estimation.

As a quick way of determining the best intervals, travel time versus depth plot (Figure 2) was made for each of the wells and a best fit line drawn through the points. Points well separated, and which fell on the lines then were chosen, and their axes read to give the depths and corresponding travel times, respectively.

The suitable depth intervals and their corresponding temperatures and travel times for the above well is shown in Table 2. Using intervals 1372.5m and 1586.0m (Figure 3), heat flow is estimated as shown.

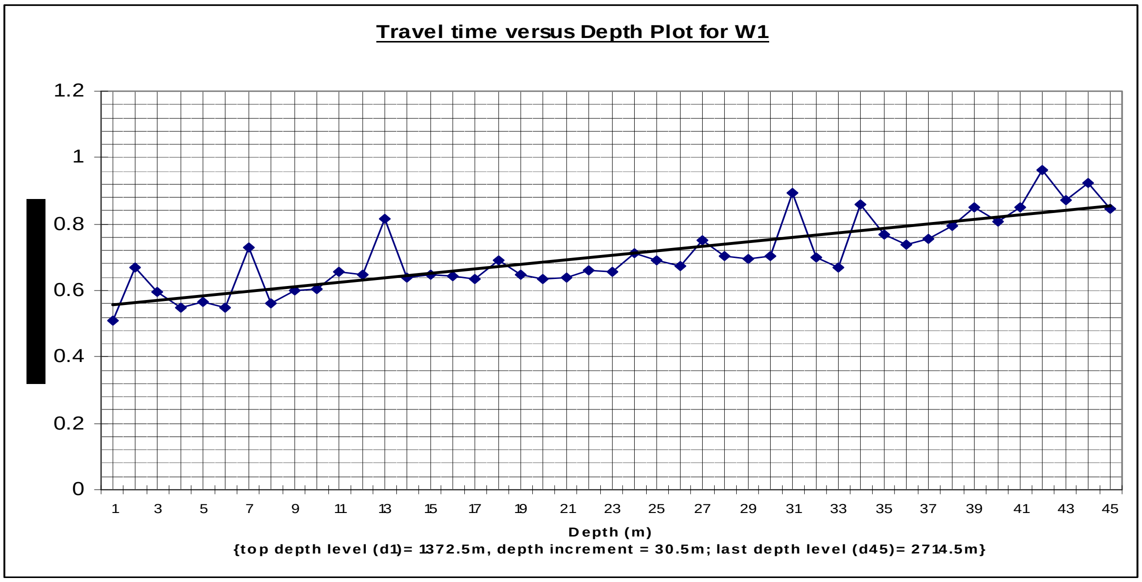

Figure 2: Travel Time versus Depth Plot for one of the Wells Studied.

Table 2: Suitable Intervals for Heat Flow Estimation for Well -1.

Depth (m)	Temperature (^{0}C)	One-way travel time (sec)
1372.5	80.56	0.5085
1586.0	86.39	0.5616
1860.5	93.33	0.6344
2104.5	99.67	0.6900
2409.5	106.65	0.7703
2714.5	113.72	0.8455

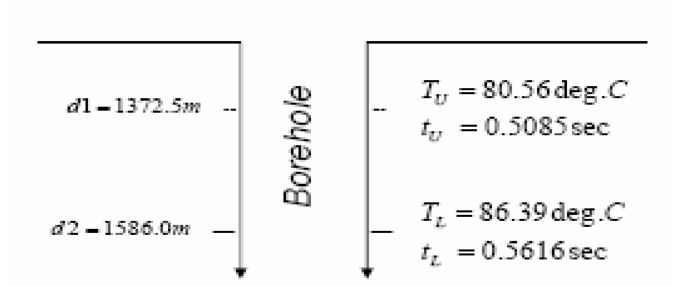

Figure 3: Heat Flow Estimation for Intervals d1 and d2 for W1.

Using the relation, the following is obtained:

$$Q\,(mWm^{-2}) = \left\{1.039\,(0.5616 - 0.5085)^{-1} * In\left(\frac{80.031 + 86.39}{80.031 + 80.56}\right)\right\} * 77$$

$$= 49.77\ mWm^{-2}.$$

For the second interval, d2 and d3 (Figure 4), heat flow value of $41.59\ mWm^{-2}$ is obtained:

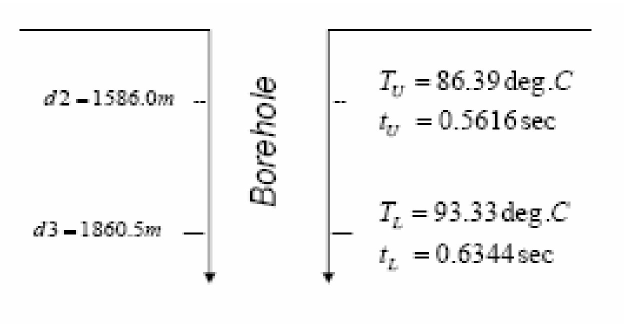

Figure 4: Heat Flow Estimation for Intervals d2 and d3 for W1.

The procedure was followed until estimates were made for the entire well depth. The heat flow calculated for each well was the average heat flow computed for the respective wells. Table 3 shows heat flow computed for W1.

Table 3: Computed Result For W1.

Depth (m)	Temp. (0C)	One-way tt (sec)	Heat Flow (m W/m2)
1372.5	80.56	0.5085	
			49.77
1586.0	86.39	0.5616	
			41.59
1860.5	93.33	0.6344	
			47.88
2104.5	99.67	0.6900	
			34.72
2409.5	106.56	0.7703	
			37.11
2714.5	113.72	0.8455	
Average			**42.214**

DISCUSSION

A heat flow of the western Niger Delta was constructed from twenty-one fairly dispersed wells. The isoflux varies from 27.6 mWm^{-2} to a maximum value of 68.3 mWm^{-2} , which is comparable to the average world heat flow value of 64 mWm^{-2} (Chapman and Pollack, 1975), continental margin basins of 62 mWm^{-2} (Sclater *et al.*, 11980), and Nigerian continental margin of 65 mWm^{-2} (Chukweke *et al.*, 1992).

The values obtained in this study present a regional average heat flow of 43.92 mWm^{-2} which compares with the average value of 51.49 ± mWm^{-2} calculated for the northern Niger Delta basin (Etim *et al.*, 1996). The regional surface heat flow shows a gentle increase of heat flow from the onshore of the delta to the offshore.

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} 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.

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