PRELIMINARY ESTIMATION OF THERMAL CONDUCTIVITY IN BORNU-CHAD BASIN, NIGERIA

Tamunosiki Dieokuma, M.Sc
China University of Geosciences (Wuhan), P.R. China.
Gu Han Ming, Prof.
Department of Geophysics, China University of Geosciences (Wuhan), P.R. China.
Etim D. Uko, Dr.
Department of Physics, Rivers State University of Science and Technology, Port-Harcourt, Nigeria.

Abstract

Thermal conductivity estimates are computed from four randomly selected and spaced petroleum wells in the Bornu-Chad basin, Nigeria, using a geometric mean model. Sonic and gamma-ray logs were digitized and used in the estimation of *in situ* conductivity. The area under study is composed of 4 major diachronous lithostratigraphic units of Chad, Fika, Gongila and Bima formations, which form the bulk of the basin's sediments. Porosity, lithology, and depth of burial exert the most important control on the matrix thermal conductivity in the basin. There is a decrease of thermal conductivity with increasing shale fraction. The bulk conductivity also shows an increase with increasing sandstone fraction. Increase in porosity results in a decrease in bulk conductivity. Thermal conductivity values and variations for a given lithologic unit are reduced at increased porosity, such that thermal conductivity of the topmost continental Chad sandstone Formation vary between 2.055W/m°C and 2.854W/m°C with an average of 2.397W/m°C. Thermal conductivity for the underlying, marine shaly-sandstone Fika formation varies between 1.895W/m°C and 2.860W/m°C with an average of 2.432W/m°C. Furthermore, the thermal conductivity for the Gongila formation varies between 2.382W/m°C and 2.557W/m°C with an average of 2.470W/m°C, while Bima formation has thermal conductivity of 2.080 W/m°C and 3.580 W/m°C with an average of 2.879 W/m°C.

Keywords: Thermal conductivity, porosity, sand-shale ratio, Bornu-Chad basin

1. Introduction

Thermal conductivity is a key parameter for modelling the present and palaeothermal structure in sedimentary basins. Heat flow data are important parameters in investigations of hydrocarbon maturation (Ungerer, 1984; Uko *et al*., 2002). Representations of heat flow data in contour maps offer suggestions for the interpretations of crustal tectonics and large-scale hydrodynamics, and formation of basins (Uko et al., 2009).

The bulk conductivity of a multi-component sedimentary rock may be expressed as a function of the conductivity of each component constituting the rock, and of its relative proportions (Kaichi, 1984; Bjorkum and Nadeau, 1998). Various expressions have been proposed for modelling multi-component conductivity as a function of individual contribution, and the most commonly used being the geometric mean model, and has been found successful in the absence of rock core samples (Brigaud and Vasseur, 1989).

In this paper, we applied the geometric mean model to the set of well-log data to estimate the conductivity of the lithostratigraphic units of the Borno-Chad Basin, Nigeria.

2. Geology Of Bornu-Chad Basin

The Bornu Basin represents the Chad Basin in Nigeria. The Chad Basin extends to the Republic of Niger, Chad and Cameroun within latitudes 10^oN to 14^oN and longitudes 12^oE to 15^oE (Fig.1). It is a part of the Western Central African Rift System [WCAS] (Genic, 1992). This Bornu-Chad basin is a broad sediment-filled depression spanning northeastern Nigeria and adjoining parts of the Republic of Chad. The stratigraphy of Bornu-Chad basin has been reported by several workers (Avbovbo *et al.*, 1986; Obaje, 2009; Nwachukwu and Ekine, 2009)

Chad formation is the uppermost formation consisting of mudstone with traces of sandstone, muddy sandstone, sandstone, and claystone. The Chad Formation, a sequence consisting of mostly massive and gritty clays, loosely to uncemented sands and silts. Fika formation underlies Chad formation and consists of shale, mudstone and limestone. A wholly marine sequence, the Fika Formation, consisting of a sequence of blue-black shales containing one or two thin non-persistent limestone horizons, conformably overlies the Gongila. The Gongila Formation is a transitional sequence between the underlying Bima sandstone. The Gongila Formation is regarded as transitional deposits that accompanied marine incursions into the basin. The formation consists of a sequence of sandstones, clays, shales and limestone layers. The Bima Formation is the oldest stratigraphic unit consisting of thin to thick beds of fine to coarse-grained sandstone of variable colour from white, brown, and reddish brown to grey. The coarse-grained textures are more common with depth of burial. Thin bands of clay and siltstone vary in colour from red to grey or brown and occur as intercalations with the sandstone. The Bima Formation is the basal unit. The deposition of this sequence of sandstones, mudstones and occasional shales of variable lithology, texture, colour and structure.

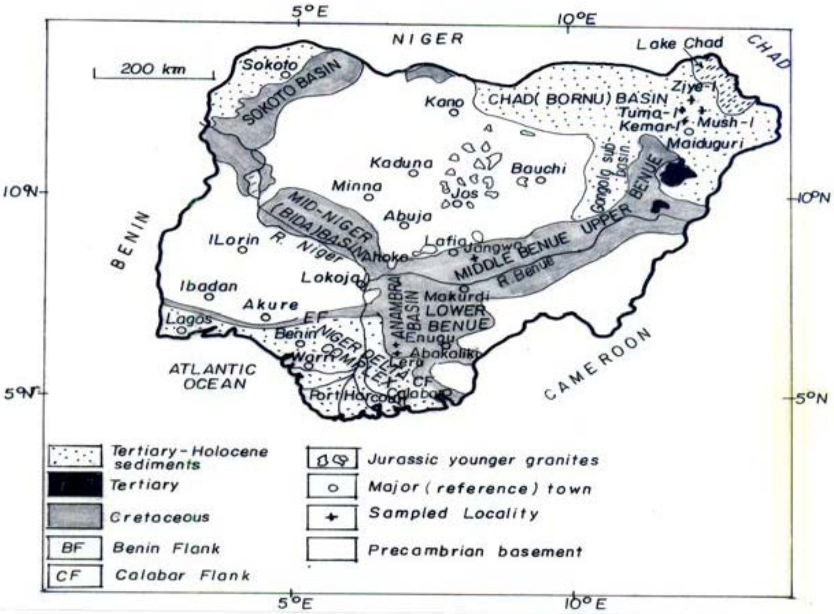

Fig.1: Map of Nigeria showing Bornu-Chad basin (After Obaje et al., 2004)

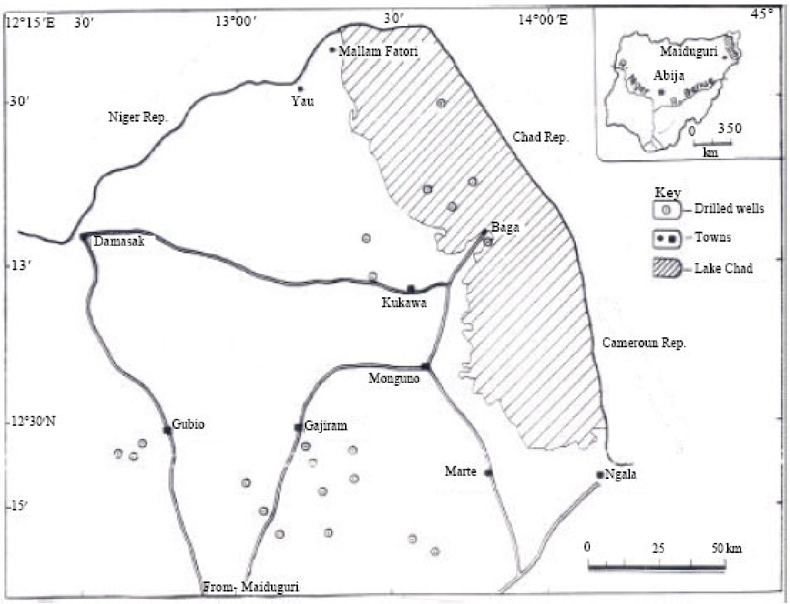

Fig. 2: Location map of the study area (Ali and Orazulike, 2009)

3. MATERIALS AND METHODS

3.1 Data collection

We used borehole sonic and gamma-ray logs from 4 randomly selected closely spaced oil wells (Fig. 2), from which sonic interval transit times and shale-sandstone lithology ratios are computed respectively. The sand-shale ratios were used to place markers on the stratigraphic units (Table 2) where Chad, Fika, Gongila and Bima formations are at 0-840m, 840-1520m, 1520-2190m and 2190-2850m respectively.

3.2 Thermal conductivity estimation

In sedimentary basins, thermal conductivity of a rock mainly depends on the mineral composition, porosity and the nature of the saturating fluid in the pore space. It also depends on rock structure (Kaichi, 1984). The bulk thermal conductivity of the porous rock, k_s, can be expressed by a function of the *in situ* conductivity of the solid rock (k_m), the *in situ* conductivity of saturating fluid in the pore space, k_f, and the *in situ* porosity, ϕ, (Kaichi, 1984).

For the Bornu-Chad Basin as in any other sedimentary basins, thermal conductivity mainly depends on the conductivity of each constituent of the rock and of the fluid which fills the pores. The thermal conductivity of the rock (matrix), K_S, can be expressed by a function of the conductivity of the solid phase (K_m), the conductivity of pore-fluid, K_f, and the porosity, ϕ, of the rock (Kaichi, 1984; Brigaud, 1989):

$$K_s = K_f^{\phi} K_m^{1-\phi} \quad (1)$$

If the solid phase contains several elements, the bulk thermal conductivity is calculated from geometrical model applied to matrix conductivity

$$K_m = K_1^{\varphi 1} K_2^{\varphi 2} K_3^{\varphi 3} \ldots K_n^{\varphi n} \quad (2)$$

where k_n represents the thermal conductivity of the principal constituents and φ_n their volumetric proportion. Sonic and Density logs were used to determine porosity change with depth. Porosity,ϕ, was computed using the Wyllie time-average equation (Wyllie *et al.*,1956):

$$\phi = \frac{\Delta t_{\log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \quad \textbf{(3)}$$

where Δt_{log} is the transit time on the sonic log (μs/ft), Δt_{ma} is the transit time of the matrix material (μs/ft), Δt_f is the transit time of the pore fluid (μs/ft). Porosity is treated as a function of lithology and depth.

The thermal conductivity of the rocks in the wells could not be measured as there were no core and drilling cutting samples at the time of this study. The results from the studies of thermal conductivity in sedimentary basins predicted from lithologic data and geophysical well logs by Brigaud (1989) were used to estimate the bulk conductivity. Table 1 lists the thermal conductivities of the main mineral constituents used in this work. Each formation was assumed to have a constant value of matrix conductivity throughout the study area. The thermal conductivities shown in Table 2 are for the sedimentary columns lying between the surface and the total depth (TD) of each well.

In our study, the thermal conductivity of the rocks in the wells could not be measured as there were no core and drilling cutting samples. However, the geophysical well logs were used to estimate the required sandstone-shale ratio and porosity. The conductivity for sandstone, shale and water was obtained from the results of Brigaud (1989): 7.0W/m^{o}C for sandstone, 2.7W/m°C for shale and 0.6W/m°C for water. We deduced sandstone-shale ratios from the gamma-ray (lithologic) log from which we placed markers for Chad, Fika, Gongila and Bima formations.

Table 1: Thermal conductivity of sedimentary minerals and fluid **(Brigaud, 1989**)

Minerals	Thermal conductivity (W/m^{o}C)
Sandstone	7
Shale	2.7
Water	0.6

4. Results

The depths, lithologies, stratigraphies and thermal conductivities and their correlations with each other are presented in Table 2 and Figs. 3-7.

Table 2: Depth range, lithology, stratigraphic units, and thermal conductivity, for each well

Well name	Depth range (m)	Lithology	Lithostratigraphic Units	Thermal conductivity (W/m^{o}C)	
					Average
Kasade-1	0 – 840 840 – 1190 1190 – 1420	Sandstone Sandstone/shale Shale	Chad formation Fika formation Gongila formation	2.055 1.895 2.382	2.111
Herwa-1	0 – 510 510 – 1520 1520 – 2190	sandstone Sandstone/Shale Sandstone/Shale	Chad formation Fika formation Gongila formation	2.854 2.860 2.557	2.757
Kermar-1	0 – 560 560 – 680	sandstone Sandstone/Shale	Chad formation Fika formation	2.283 2.542	2.413
Albarka-1	2850 – 3450	Sandstone/Shale	Bima formation	2.830	2.895

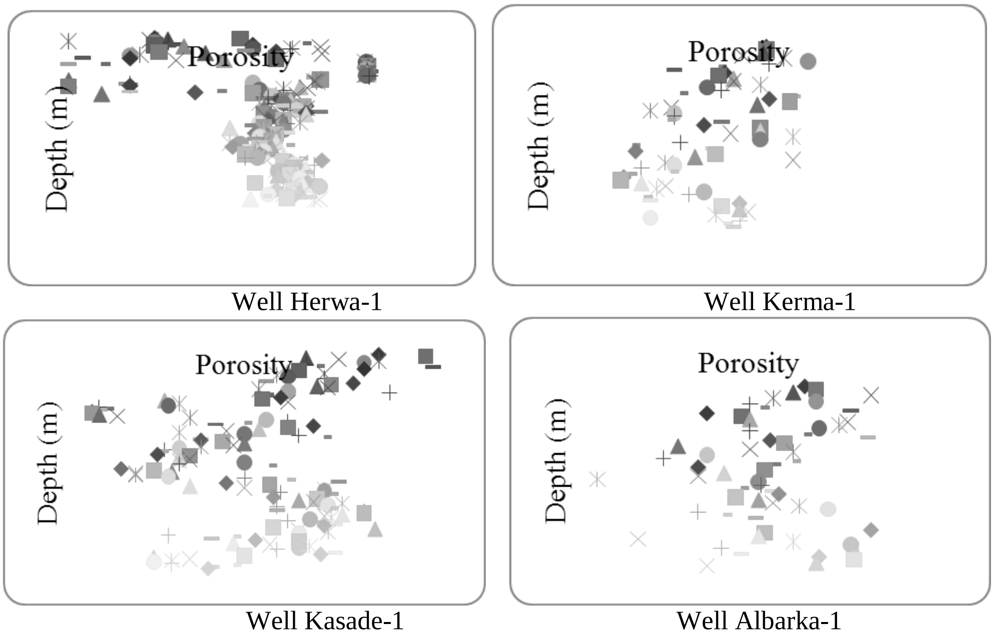

Fig. 3: Depth-porosity profiles for Wells Herwa-1, Kerma-1, Kasade-1, and Albarka-1

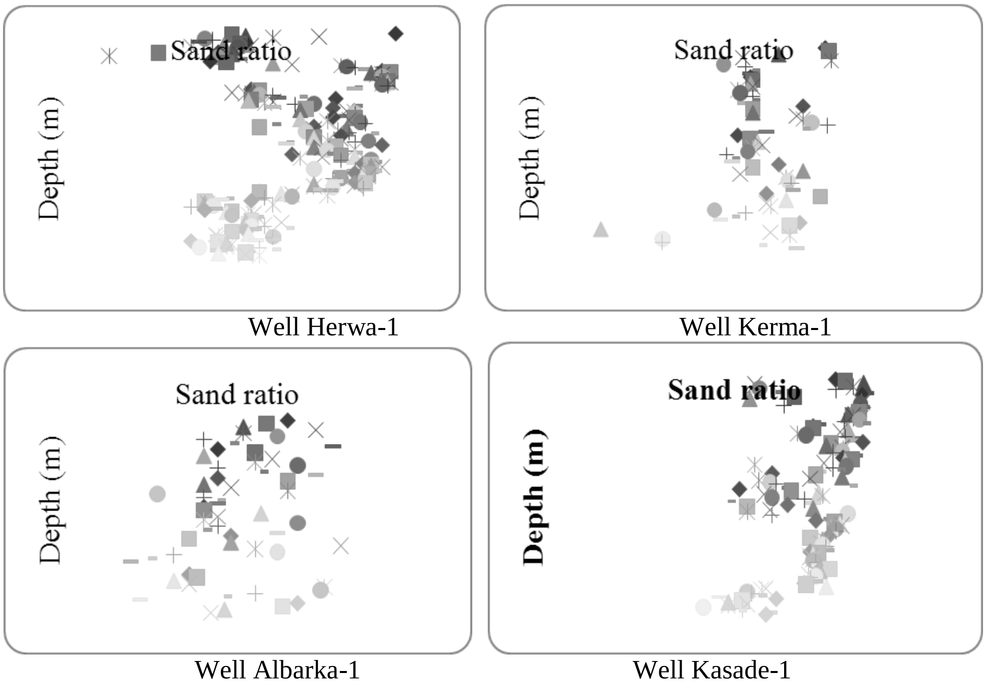

Fig. 4: Depth-sand ratio profiles for Wells Herwa-1, Kerma-1, Kasade-1, and Albarka-1

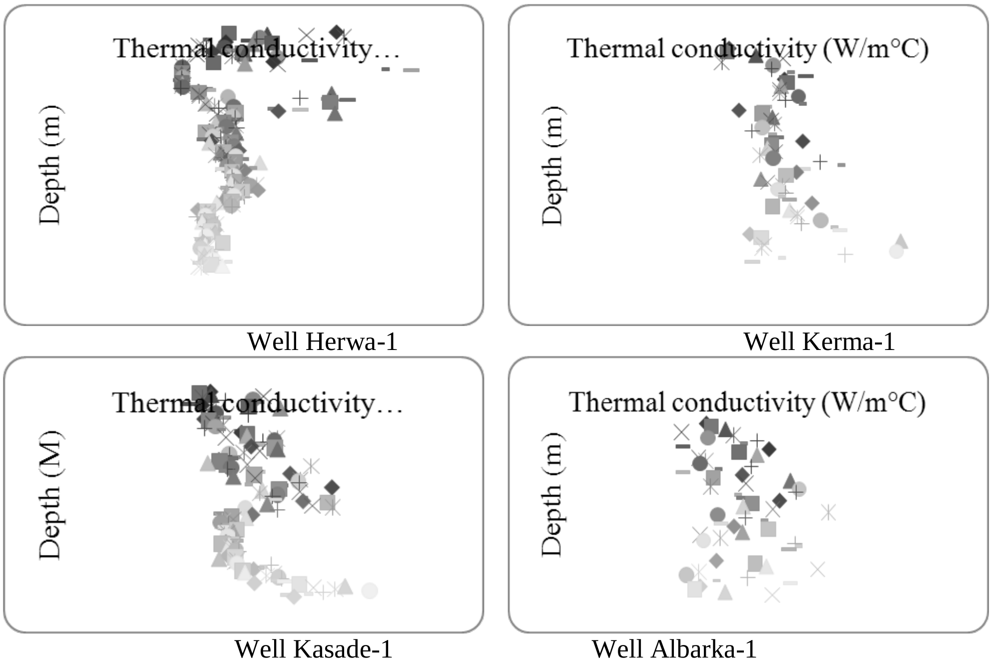

Fig. 5: Depth-thermal conductivity profiles for Wells Herwa-1, Kerma-1, Kasade-1, and Albarka-1

Discussion

The procedure stated in this paper provides a practical application of geophysical well logs to predict *in situ* thermal conductivity of sedimentary formations in the absence of well core samples. The control of the thermal conductivity variation of the Niger Delta basin may be due to the influence of porosity and lithology.

Influence of porosity

The influence of porosity is demonstrated with conductivity computations. Fig. 3 presents plots of bulk conductivity as a function of porosity. An increasing porosity implies a decrease in bulk conductivity. The decrease is more rapid for small porosities than for larger ones. This indicates a non-linear effect of porosity on bulk conductivity. However, Well Herwa-1 exhibits near-surface lower porosity/sand ratios than other Wells is suggestive of Gongila shale outcropping (Figs. 3 and 4).

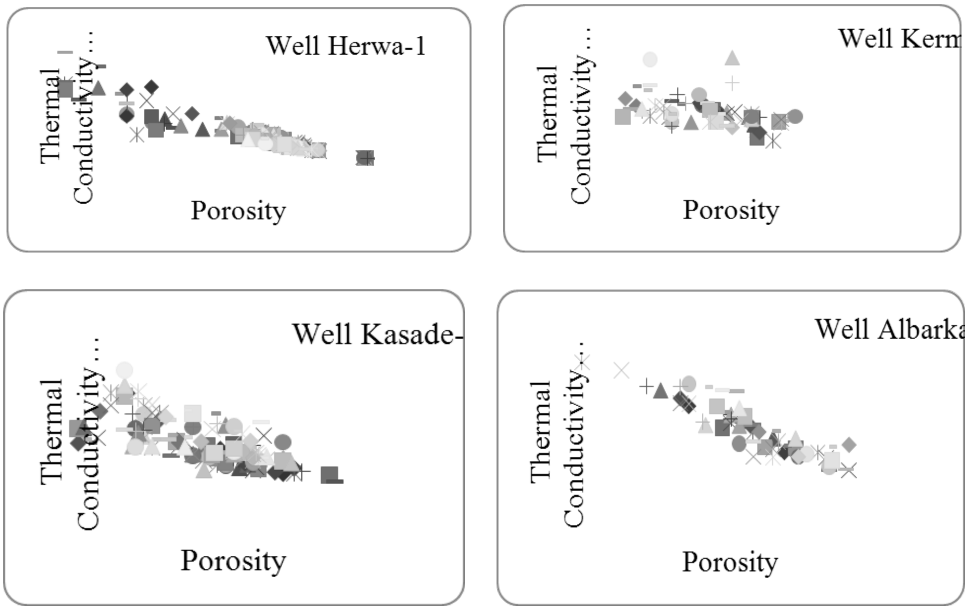

Fig. 6: Thermal conductivity-porosity profiles for Wells Herwa-1, Kerma-1, Kasade-1, and Albarka-1

Influence of Lithology

Lithologic changes have dominant influence on thermal conductivity variations. Large fluctuations in the sandstone/shale ratio produce variations from 1.895 to 2.860 W/m^{o}C. More gradual changes, such as the steadily increasing shale content within the Bornu-Chad (Fig. 4) produce corresponding gradual changes in conductivity. Porosity generally decreases with depth from 51 - 39 per cent near the surface (Chad Formation), in the Bornu-Chad basin, to values less than 10 per cent for the deeper Fika Formation. Therefore, for a given type of sedimentary rock, an increase in porosity results in a decrease in bulk conductivity (Fig. 3).

Thermal conductivity for Chad, Fika, Gongila and Bima formations shows a wide variation from Well to Well. Thermal conductivity of the topmost continental Chad Formation vary between 2.055W/m°C and 2.854W/m°C with an average of 2.397W/m°C. Thermal conductivity for the underlying Fika formation varies between 1.895W/m°C and 2.860W/m°C with an average of 2.432W/m°C. Furthermore, the thermal conductivity for the Gongila formation varies between 2.382W/m°C and 2.557W/m°C with an average of 2.470W/m°C, while Bima formation has thermal conductivity of 2.080 W/m°C and 3.580 W/m°C with an average of 2.879 W/m°C.

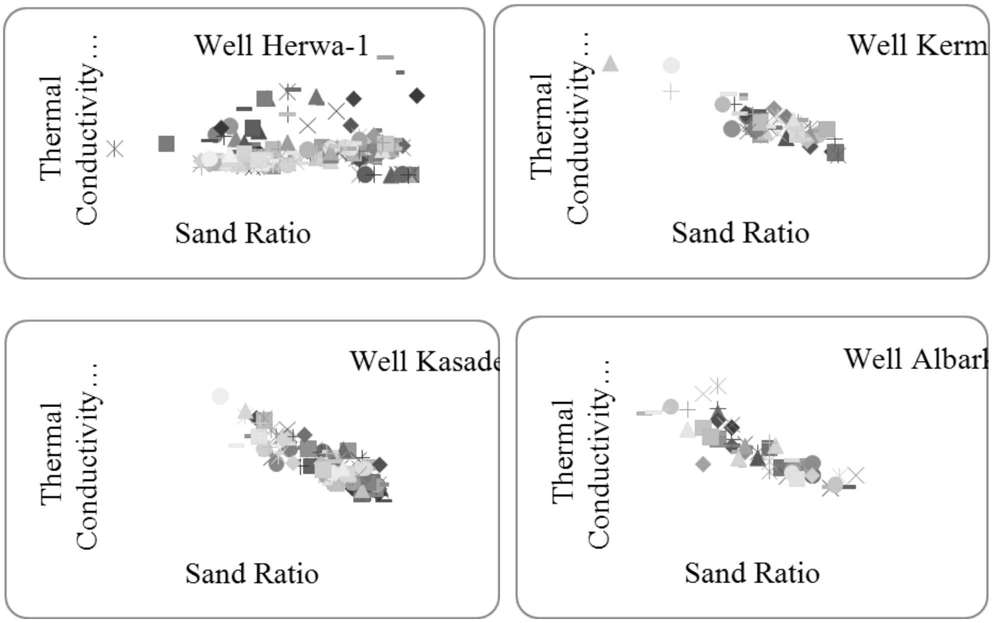

Fig. 7: Thermal conductivity-sand ratio profiles for Wells Herwa-1, Kerma-1, Kasade-1, and Albarka-1

Conclusion

Thermal conductivity was estimated in the Bornu-Chad Basin sedimentary basin using geophysical well logs. Porosity and lithology exert the most important control on the matrix thermal conductivity of a sedimentary rock. In Chad Formation it varies between 2.055W/m°C and 2.854W/m°C with an average of 2.397W/m°C. Thermal conductivity for the underlying, marine shaly-sandstone Fika formation varies between 1.895W/m°C and 2.860W/m°C with an average of 2.432W/m°C. Furthermore, the thermal conductivity for the Gongila formation varies between 2.382W/m°C and 2.557W/m°C with an average of 2.470W/m°C, while Bima formation has thermal conductivity of 2.080 W/m°C and 3.580 W/m°C with an average of 2.879 W/m°C.

Acknowledgements

The authors are grateful to China University of Geosciences (Wuhan), Nigerian National Petroleum Corporation (NNPC) for provision of the necessary data. We are also grateful to Dr. Cyril Nwankwo, University of Port Harcourt, Nigeria for useful comments.

References:

Avbovbo, A. A., E.O. Ayoola and G.A. Osahon, 1986. Depositional and structural styles in Chad Basin of northeastern Nigeria. AAPG Bull., 80: 1787-1798.

Bjorkum, P. A., P. H. Nadeau, 1998, Temperature controlled porosity/ permeability reduction, fluid migration and petroleum exploration in sedimentary basins: *Australian Petroleum Production Exploration Association Journal*, Vol. 38, p. 453 – 465.

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, p. 414.

Carter, J.D., W. Barber, E.A. Tait and G.P. Jones, 1963. The geology of parts of Adamawa, Bauchi and Borno provinces in North-eastern Nigeria. Bull. Geol. Surv. Nig., 30: 109-109.

Genik, G.J., 1992. Regional framework, structural and petroleum aspects of rift basins in niger, chad and central African republic (C.A.R.). Tectonophysics, 213: 169-188.

Kaichi, S., 1984, A method of determining terrestrial heat flow in oil basinal areas: *Tectonophysics*, Vol. 103, p. 67 - 79.

Obaje, N. G. 2009. Geology and resources of Nigeria, lecture notes in Earth Sciences, 120, DOI.1007/978-3-540-92685-6_6, Springler-Verlag, Berlin Heidelberg.

Uko, E. D., P. O. Ekanem, A. G. Warmate, C. L. Eze and I. O. Akpabio, 2009. Estimation of thermal conductivity in the north-western Niger Delta basin, using geophysical well logs. *Discovery and Innovation*, Vol. 21 (Nos. 1 & 2), p. 50 – 55.

Ungerer, P., 1984. Models of petroleum: how to take into account geology and chemical kinetics. Insitut Francais du petrole, report 32327, 12 p.

Wyllie, M. R. J., A. R. Gregory, and L. W. Gardner, 1956, Elastic wave velocities in heterogeneous and porous media: *Geophysics*, vol. 21, p. 41 – 70.