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GEOTHERMAL GRADIENTS IN THE NIGER DELTA BASIN FROM CONTINUOUS TEMPERATURE LOGS

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ABSTRACT

Subsurface temperatures obtained from continuous temperature logs in 260 wells allowed to stabilize for several months were used in determining the geothermal gradients in the Niger Delta. Regional gradients are lowest (0.82°C/100m) at the central part of the Delta and increases both seaward and northward up to 2.62°C/100m and 2.95°C/100m respectively in the continental sands of the Benin formation. In the marine paralic deposition, geothermal gradients range from 1.83°C/100m to 3.0°C/100m at the central portions. The highest values of 3.5°C/100m to 4.6°C/100m are seen northwards while intermediate values of 2.0°C/100m to 2.5°C/100m are recorded seaward. The thermal gradients are clearly influenced by the lithology or rate of sedimentation in the area. Regions of low thermal gradients correspond with areas of high sand percentage, primarily because sands are better conductors than shale and therefore show as low thermal gradients. There is a continuous but non-linear relationship between geothermal gradients and depth, from less than 1.0°C/100m in the continental sands through 2.5°C/100m in the marine paralic section to 5.0°C/100m in the continuous shaly section.

Key words: Geothermal gradient, temperature, sand percentage, heat flow

INTRODUCTION

The most abundant temperature information collected during normal logging operations of oil wells are Bottom Hole Temperatures (BHT). Since these logs are taken only few hours after drilling have stopped, the measured data are too low, besides, they provide only two or three data points in a bore hole. Consequently, in generating well temperature profiles, you are left with the option of either inter or extrapolating temperature data which in most cases gives doubtful results especially with the lack of input information for correcting the BHT data. The Continuous Temperature depth log is a reliable device that gives a good, detailed and continuous information provided the well is in thermal equilibrium.

The thermal gradients presented here were calculated at 100ft intervals from Continuous temperature logs for two hundred and sixty wells. In most temperature loggings, the wells have been closed for several months or sometimes years to ensure their stability.

The results are useful in predicting temperatures at any depth and for any exploration activity that requires the use of temperature information, notably in designing deep well mud and cementing programmes, determining reservoir fluid properties, in studying the evolution of the oil and gas kitchen, regional distribution of oil and most importantly, in studying the hydrocarbon generation, migration and organic maturity.

It is here noted that several authors have highlighted the geothermal pattern in the Niger Delta based on BHT data. For instance, Nwachukwu (1976) showed that values are lowest in the center of the Delta approximately 0.7 to 1.0°F/100ft and increases outward to about 3°F/100ft in the Cretaceous rocks in the North. Avbovbo (1978) documented a map of the geothermal gradient that shows a North-eastern increase in the gradient. Low gradients of 1.20 to 1.40°F/100ft occur in the Warri – Port Harcourt area of the Niger Delta. In the Offshore areas, the maximum temperature gradient is 1.80°F/100ft. The geothermal gradient at the distal part of the Niger Delta have been calculated by Chukwueke et. al., (1992). The observations showed a variation between 19.0 and 32.0°C/km. Finally, Uko (1996) calculated and gave an average of 21.27 ± 1.5°C/km for thermal gradient in the Northern Niger Delta.

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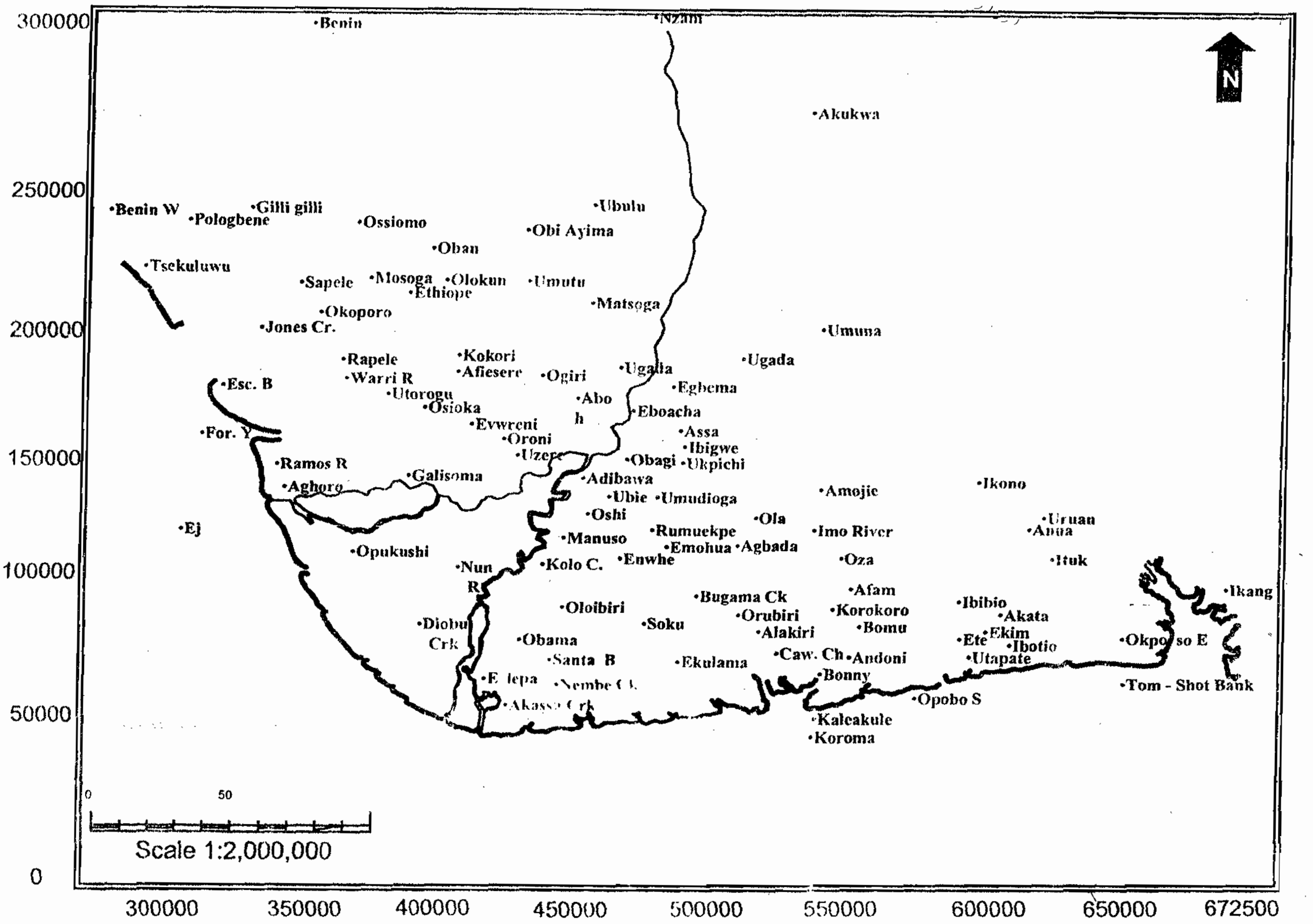

Fig. 1: Location Map of the Niger Delta showing wells used in the study

GEOLOGICAL SETTING OF THE NIGER DELTA

The Niger Delta Basin occupies the Gulf of Guinea continental margin in the equatorial West Africa between latitudes 3° and 6°N and longitudes 5° and 8°E. It ranks among the world's most prolific petroleum producing tertiary deltas occupying an aerial extent of approximately 75,000km^2. it comprises an overall regressive clastic sequence with a maximum thickness of approximately 30,000 to 40,000ft (9,000m to 12,000m), (Reijers et. al., 1997). Evamy et. al., (1978) chronicles that the development of the Delta has been dependent on the balance between rate of sedimentation and subsidence, hence the balance and the resulting sedimentary patterns have been affected by the structural configuration and the basement. The ocean floor steepens into the continental slope zone beyond the margins of the shelf and then plunges into the Guinea basin to a depth approximately 6,240m.

The Delta shelf itself extends in length to about 720km and in width to about 56km.

Three main lithostratigraphic units have been recognized in the Niger Delta and were laid down under Marine, Transitional and Continental environments corresponding to Akata, Agbada and Benin formations. The formations transgress time boundaries ranging from Eocene to recent age.

Akata formation

This is the basal sedimentary unit. The formation is mainly composed of marine shales. The shales are under compacted and may contain abnormally high pressured silt stone or fine grained sandstone. It is believed to be the main source rock for the Delta and the basic unit of the Cenozoic complex. It ranges in thickness from approximately 600m to 6,000m. The formation is generally gray in colour.

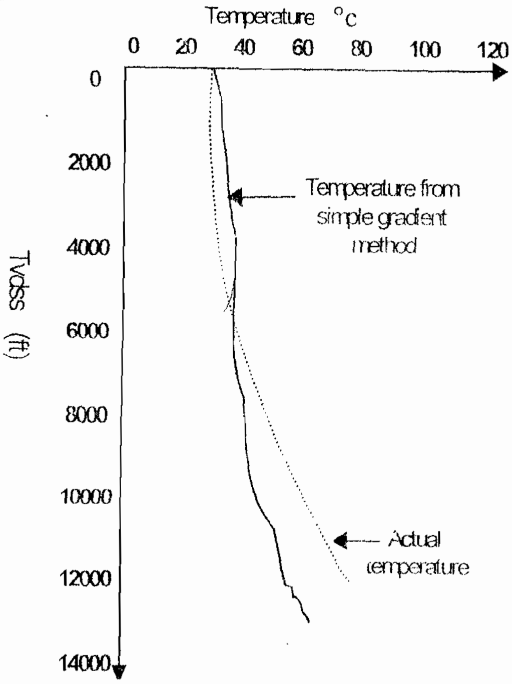

Fig. 2: Simple thermal gradient method

Agbada formation

It consists of alternations of sands, sandstones and siltstones. Due to differential subsidence variations in the sediment, Agbada sandstone is poorly sorted with various grain sizes ranging from fine to coarse while its sands contribute the main hydrocarbon reservoir of the Delta. The consolidated sands have a calcareous matrix, shale fragments and Glauconite occur while Lignite streaks and Limonite are common.

The shales that consist the cap rocks are often hard and silty and are mineralogically mainly of Kaolinite. They are denser in the base than in the upper section due to normal pressure of compaction. The thickness ranges approximately from 2,880m – 4,200m while the age ranges from mid – Miocene to late Miocene.

Benin formation

This is the uppermost limit of the Delta as thick as 3,000m and extends to about 9,730m out of the Bonny beach The sands and sandstones range from coarse to fine and are poorly sorted showing a little lateral continuity. The interval consists mainly of fresh water fluviatile sands and gravels occasionally interspersed with shale beds towards the base of the rock unit. In the sub – surface, the Benin formation is Oligocene in the south but becomes younger progressively south wards.

DATA COLLECTION

The data used in this study were obtained from 260 wells in the Niger Delta (Fig. 1). The wells had duration of stabilization of thirty days and above, a period from well completion to logging in which the well has attained equilibrium or near equilibrium. A surface average ambient temperature of 80°F (27°C) has been assumed.

The data were in three categories:

i. Temperature data interpreted at 100ft interval from continuous temperature logs.

ii. Sand Percentage data for the different formations were interpreted from Gamma Ray and Resistivity logs.

Reservoir temperature obtained from reservoir fields.

The Reservoir/Production temperatures were obtained, plotted with the Continuous Temperatures to ensure it gave a good fit.

It is here noted that as a result of the variations in lithology within the upward regressive deltaic offlap sequence and heat transfer conditions between the continental and paralic/marine sequence, the subsurface temperature gradient increases with depth. In generating well thermal gradients profiles, data were collected in two sections, the shallow (continental- Benin sequence) and deeper (paralic/marine sequence) sections.

DETERMINATION OF GEOTHERMAL GRADIENT

There are two methods that are commonly used in calculating thermal gradients. These are the thermal resistance method and the simple gradient method. Thermal resistance is the quotient of a thickness ΔZ of a characteristic thermal conductivity K given by

$$T_B = T_O + q_o \sum_{z=o}^{B} \left({}^{\Delta z}/_{k} \right) \tag{1}$$

The steps in using this method comprises

i. A set of bottom hole temperatures (T_B) are compiled and corrected if possible.

ii. Thermal conductivity values must be measured or determined.

iii. Summing the thermal resistance at each well from surface to depth of bottom hole temperature. Chapman et. al, (1984).

The simple gradient method is an alternative approach to analyzing temperature data. Thermal gradients are calculated either as two point differences using a single temperature data and an estimate of the mean annual gradient temperature. The relation is

$$T_B = T_O + ({}^{dt}/_{dz}).\ B \tag{2}$$

Where T_B is the temperature at depth B, T_O is the surface temperature at, q_o is the surface heat flow and the thermal resistance (${}^{\Delta Z}/_{K}$) is summed for all rock units between the surface and depth B. The simple gradient method (Fig. 2) was employed in this work. The depth intervals used for obtaining data correspond to the surface to end of continental sands and 2,000ft below continental sands. may be affected to equally great depths.

The lower limits of interval were determined from gamma ray and resistivity logs.

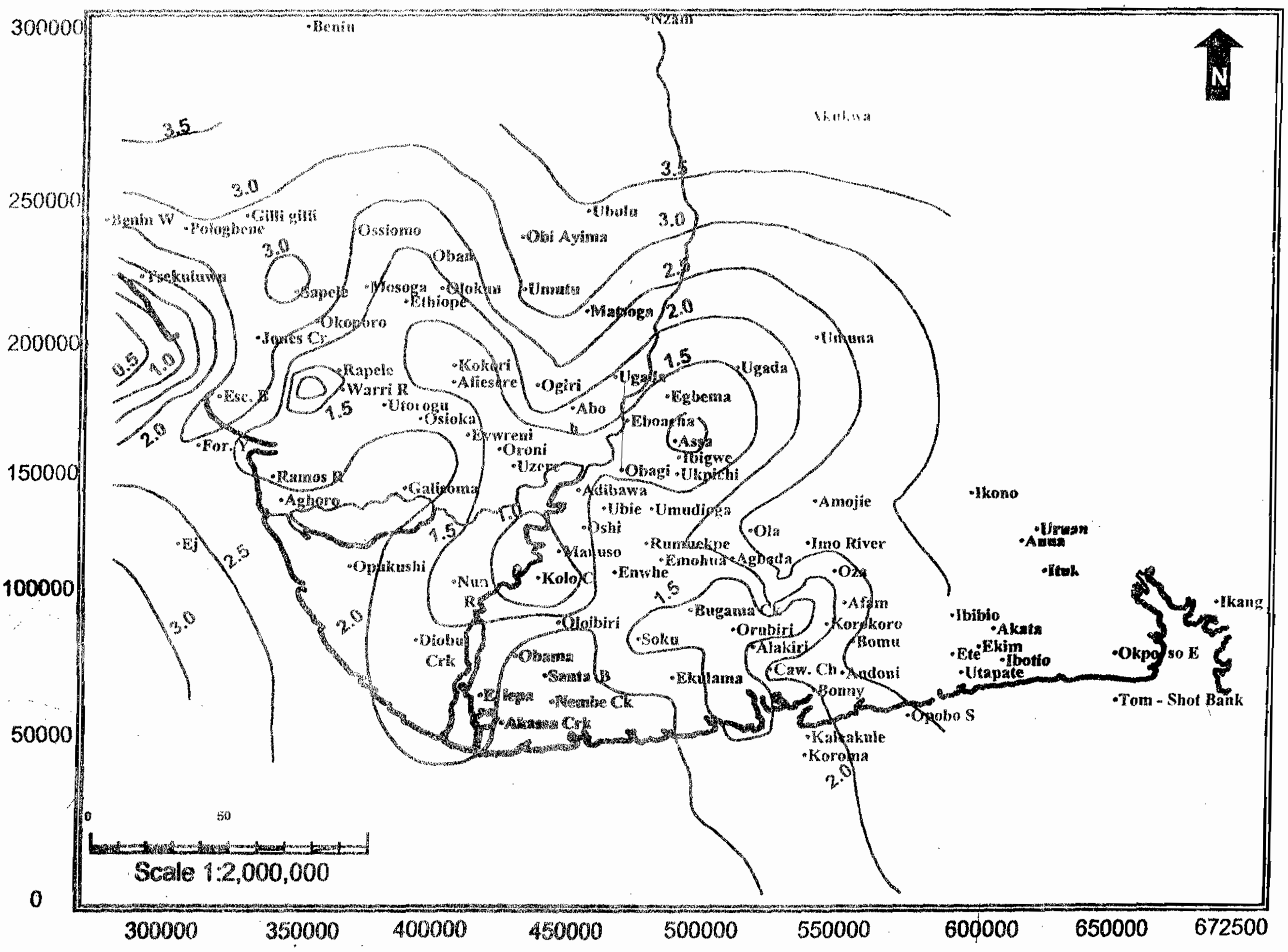

Fig. 3: Thermal Gradient of the shallow section (Benin formation) of the Niger Delta

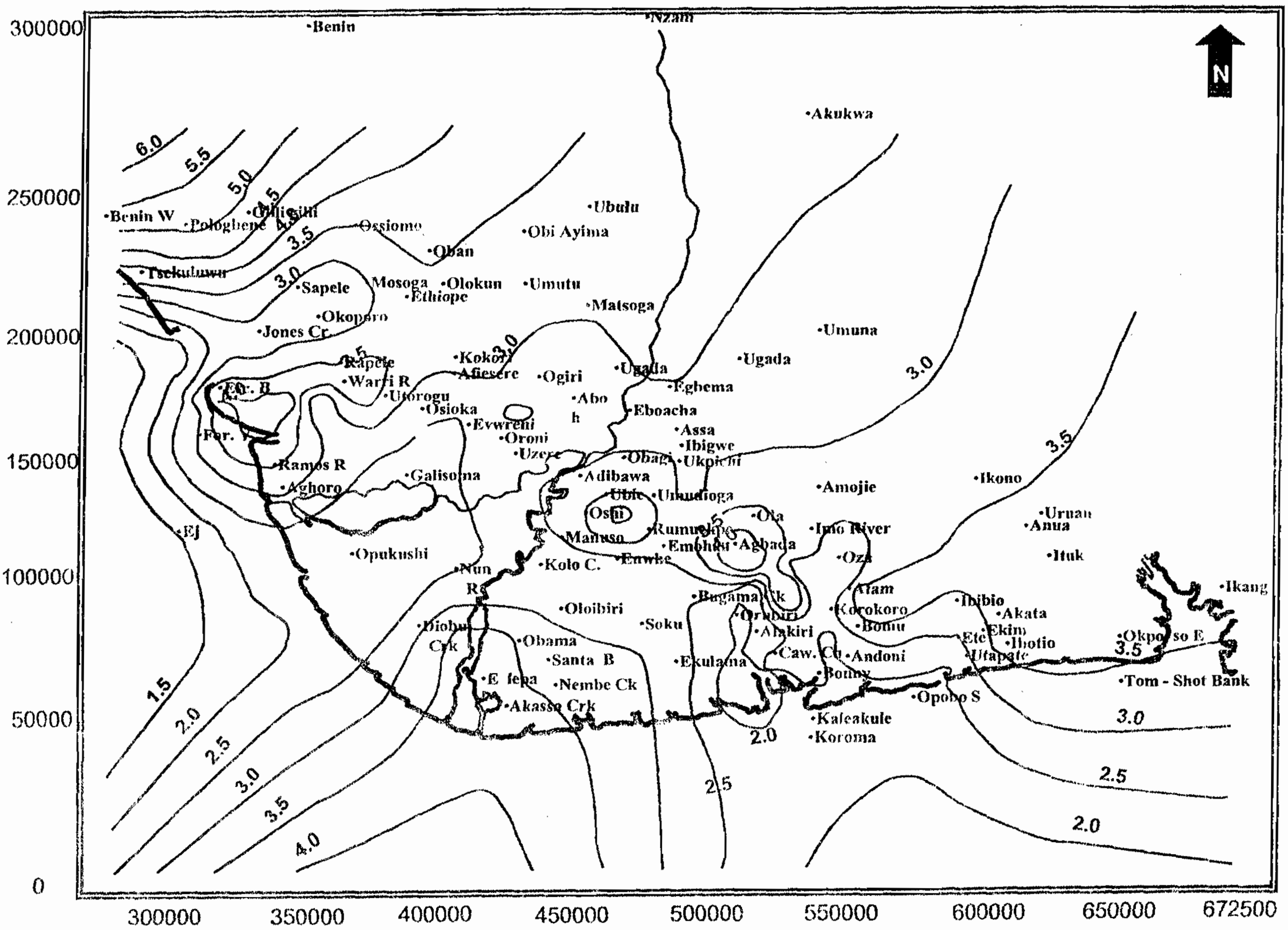

Fig. 4: Thermal Gradient of the deeper section (Marine formation) of the Niger Delta

RESULTS AND DISCUSSION

The geothermal gradients are lowest (0.82°C/100m) at the central part of the Delta and increases both seaward and northward up to 2.62°/C100m and 2.95°C/100m respectively in the continental sands of the Benin Formation. The mappings of these values are in Figure 3.

In the marine paralic deposition, geothermal gradients range from 1.83 to 3.0°C/100m at the central portions of the Delta. Highest values of 3.5°C/100m to 4.6°C/100m are seen northwards while intermediate values of 2.0°C/100m to 2.5°C/100m are recorded seaward, (Fig. 4).

Pockets of high gradients are however recorded in different parts of the Delta, notably, in the southern part of Elepa, where 4.0°C/100m conspicuously stands out. In Agbada and Umuechem areas, 4.0°C/100m is also recorded. It is possible that high geothermal gradients could be associated with overpressured zones, which could be caused by loss of sands and not necessarily abnormal conductivity (Gretener, 1989). It is also the view of Gretener that since shale and water are almost equally poor conductors, the thermal conductivity of high and low porosity shale ought not be significantly different (Gretener, 1989).

The thermal gradients are influenced by the lithology in the area. Regions of low thermal gradients correspond with areas of high sand percentage.

These therefore show as low thermal gradients. The vertical view also shows that geothermal gradient increases as sand percentage decreases (Fig. 5a & b.). Fig. 5 also indicates that there is a continuous but non – linear relationship between geothermal gradients and depth from less than 1.0°C/100m in the continental sands through 2.5°C/100m in the marine paralic section to 5.0°C/100m in the continuous shaly section. Generally, the geothermal gradients are highly variable reflecting where there is a drastic change in gross lithology. Regions of high thermal conductivity correspond to low geothermal gradient.

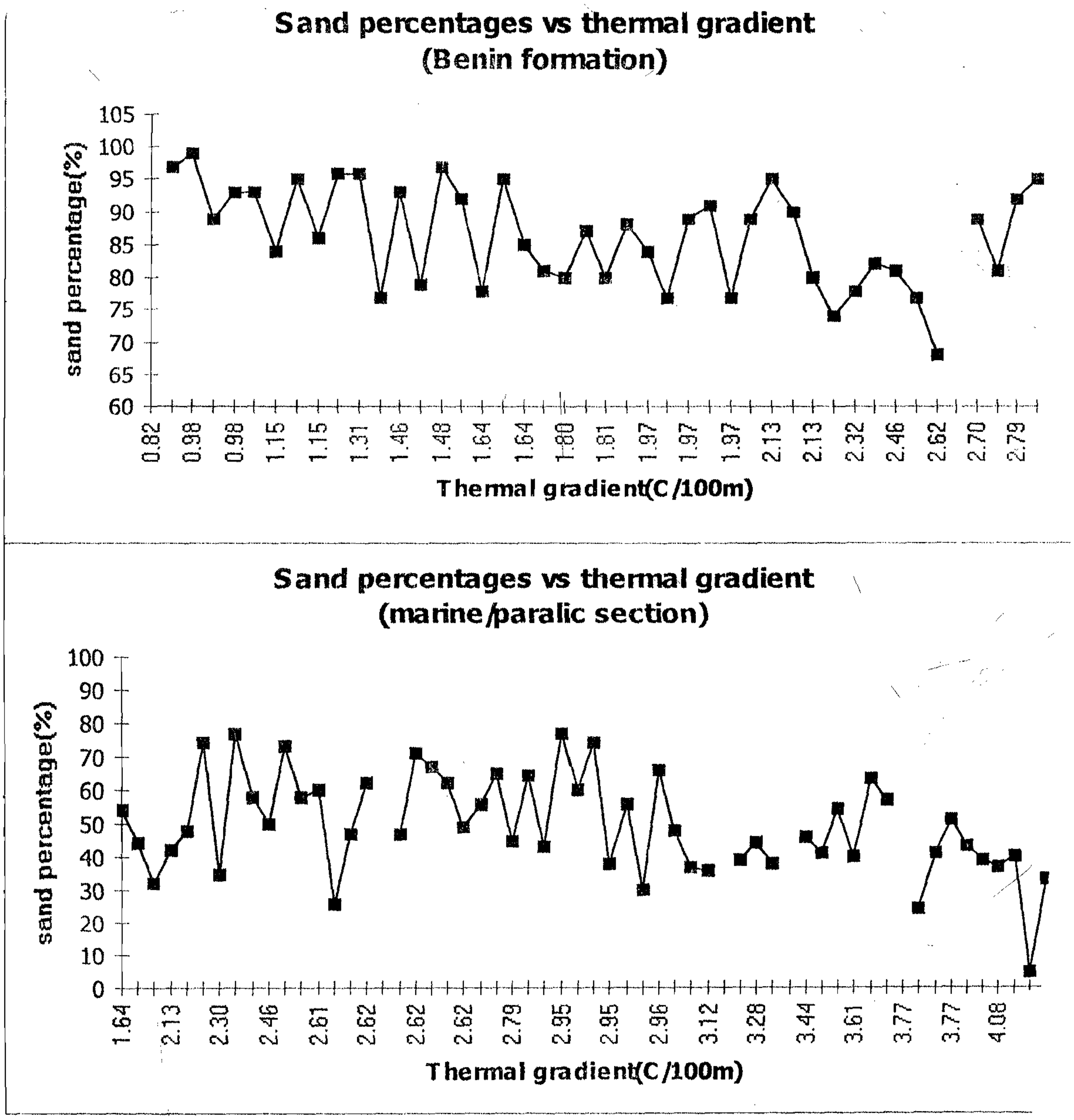

Fig. 5: Sand percentage vs thermal gradient (areal view)

These differences clearly reflect changes in thermal conductivity of the intervening rocks, sand and shale, that seems to vary from well to well in a given formation.

Thermal conductivity decreases with depth from 10±4W/m/k in the continental sands to 5±2W/m/k in the marine paralic sections (Akpabio, 1997).

Groundwater movements may also affect or influence geothermal gradient. The process of compaction demands the migration of fluids, since water is such an excellent heat exchanger, the conclusion is inevitable that flow regimes with an increase or decrease component of the movement, must give rise to thermal anomalies. That such fluid motions can occur at great depths, indicates that geothermal gradients.

CONCLUSIONS

i. We can conclude from this study that geothermal pattern is lithologically controlled, the geothermal minimum coincides with the zone of maximum thickness of the sandy Agbada and Benin formations of the Niger Delta.

ii. Geothermal gradients could be extrapolated the geothermal if the gradient. lithology o th deeper section is known.

iii. Geothermal variations clearly reflect changes in thermal conductivity of the intervening rocks, san and shale that vary from will to well in a given formation.

iv. There is a continuous but non-linear relationship between geothermal gradients and depth from les than 1.0°C/100m in the continental sands through 2.5°C/100m in the marine paralic section t 5.0°C/100m in the continuous shaly section.

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