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TEMPERATURE VARIATIONS IN THE NIGER DELTA SUBSURFACE FROM CONTINUOUS TEMPERATURE LOGS

IDARA O. AKPABIO and J. E. EJEDAW

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ABSTRACT

Continuous temperature data from 126 wells allowed to attain a state of thermal equilibrium for several months and 134 wells (stabilisation within thirty days) were used to determine the variations in temperature in the Niger Delta.

At about 8,000ftss, high temperatures of 80 - 122°C exist in the Northern and Ughelli depobelts, low temperatures of 46 - 88°C are recorded in the Central and Coastal depobelts, moderate temperatures of 80 - 100°C are seen in the Offshore depobelt. At 6,000 and 4,000ftss, similar trends are also evident.

Regional geothermal gradients range from 1.5 - 2.5°C/100m in the Coastal depobelt and Offshore regions and increases northward to 4.5°C/100m. Vertical geothermal gradients show a continuous but non linear function with depth and increases with diminishing sand percentage from less than 1.0°C/100m in the continental sands through 2.5°C/100m in the paralic section to 5.0°C/100m in the continuous shaly section. Higher gradients are associated with shaly formations primarily because of low thermal conductivity.

Keywords: Temperature variations, subsurface, temperature logs, sand percentage, depobelts.

INTRODUCTION

The need for the understanding of the thermal history, hydrocarbon generation, migration and maturation is very glaring. One of the important requirements in this regard is the accurate formation temperature data.

With the ongoing exploration of the deep play prospects in the Niger Delta, accurate formation temperatures are also required for establishing geothermal gradient that can be used in predicting temperature at the deep zones and hence in designing deep well mud and cementing programmes. The geothermal gradient map in the Niger Delta could also be used in tracing or studying the liquid window concepts for oil exploration.

STRUCTURAL DEVELOPMENT AND TECTONICS

The structural deformations observed in the Niger Delta are predominantly extensional and expressed by growth faulting. There is a combination of four basement tectonic processes associated with these deformations. These are

i. Slope failure,
ii. Differential isostatic subsidence,
iii. Lateral extension of a ductile substratum by differential loading, and
iv. Folding and piercement due to density inversion.

These processes depend on a number of complex but interrelated factors. These are documented in standard articles (Weber and Daukoro 1975, Reijers et al. 1997).

DATA COLLECTION

Three classes of temperature data were used i this study. Location sites are in Fig. 1

i. Continuous temperature logs
ii. Bottom Hole Temperature
iii. Reservoir temperature and sand percentage data obtained from Gamma Ray log.

The temperature data used in this study had duration of well stabilisation of thirty days and above, a period from well completion to logging in which the well has attained equilibrium or near equilibrium.

DATA ANALYSIS AND INTERPRETATION

During subsurface temperature measurements, the process of gaining access to the subsurface destroys the thermal equilibrium and the rocks surrounding such openings are at least temporarily in a state of thermal dis - equilibrium. Generally, the method of subsurface access results in a cooling of the rock face through the mud circulation.

In order to obtain meaningful temperature values, there are two alternatives.

i. Let the well stand idle for a period of time in order to regain thermal equilibrium.
ii. Use mathematical techniques to extrapolate to the equilibrium temperature.

IDARA O. AKPABIO, Department of Physics, University of Uyo, Uyo, Nigeria
J. E. EJEDAWE, Shell Petroleum Development Company, Port Harcourt, Nigeria

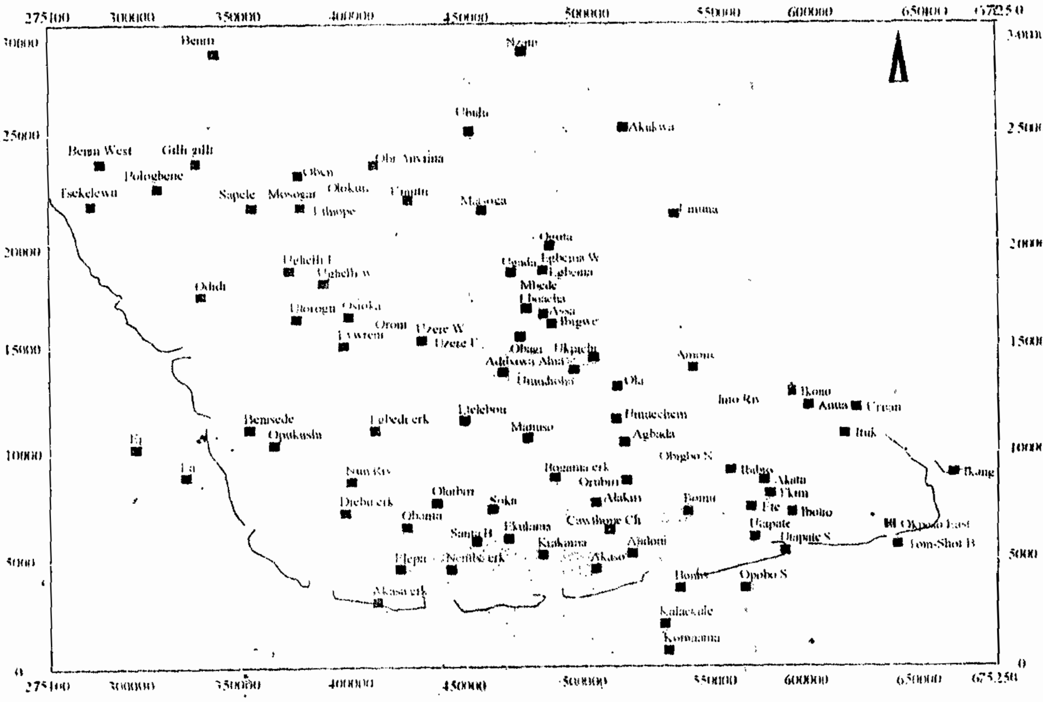

Fig. 1: Location map of study area

Option (i) was adopted in this study primarily because (ii) lacks the proper input parameters such as the circulation time and time since circulation for each well.

A surface ambient temperature of 80°F (27°C) has been assumed.

The continuous temperature depth log is a reliable device that gives a good, detailed and continuous information provided the well is in thermal equilibrium and thermally stable. In most temperatur logging, the wells have been closed for several month or years.

The most abundant temperature information is collected during normal logging operations of oil wells. Since these logs are taken only few hours after drilling had stopped, the measured Bottom Hole Temperatures (BHT) are too low, besides, they provide only two or three data points in a bore hole. This may not be quite useful in generating well temperature profiles, especially with the variable lithology in the Niger Delta, and the difference in heat transfer conditions between the continental and paralic/marine successions.

To ascertain the degree of difference between the continuous temperature (for wells that had stabilized for several months) and BHT data (corresponding to such wells), comparisons were made between these two sets of data. The well logs show generally lower temperatures of an average of 10°C from the surface to 5000ft and 15°C from 5000ft to 14000ft. A temperature correction factor that will adjust the BHT by 10 degrees in the Benin Formation and 15 degrees from base continental to continuous shale region respectively is here recommended.

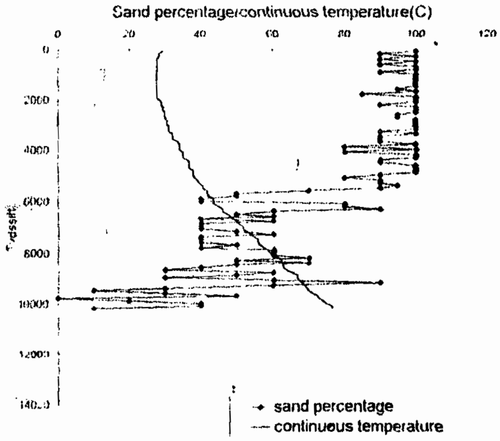

Fig. 2 Sand Percentage/continuous temperature vs depth

Maximum reservoir/production temperatures have also been plotted. It gives a good fit with the continuous temperature data.

DISCUSSION

Analysis of temperature data in the Niger Delta from well logs indicates that regional scale processes influence subsurface temperature. The most prominent pattern is lithologically controlled. Temperature increases with diminishing sand percentage (Fig. 2). Minimum temperatures coincide with zones of maximum thickness of sandy Agbada and Benin Formations. These suggest a cooling effect of the continental sands ascribed to convection currents set up in the freely moving groundwater, augmenting the overall cooling by conduction. Geothermal hotbelt coincides with shale formation.

Further discussions have been detailed and broken down into structural provinces of the Niger Delta.

The variation shown in depobelts is summarised on Tables 1 and 2 while the Temperature depth curve is on Fig. 3. Regional temperature variations at depths of 4000ftss. 6000ftss and 8000ftss are shown on Fig. 4.

TABLE 1: Temperature variations shown in Depobelts.

Depobelts	Temperature at 4000ftss (°C)	Temperature at 6000ftss (°C)	Temperature at 8000ftss (°C)
Offshore	52-72	68-88	78-90
Coastal	36-58	34-78	50-86
Central	32-64	42-72	50-122
Ughelli	32-75	38-102	50-122
Northern	32-78	38-88	50-100

TABLE 2

Temperature variations shown in Depobelts. (Well stabilization within 30 d

Depobelts	Temperature at 4000ftss (°C)	Temperature at 6000ftss (°C)	Temperature at 8000ftss (°C)
Coastal	-38-71	40-76	53-95
Central	30-68	36-91	48-102
Ughelli	32-76	44-92	57-110
Northern	38-71	44-90	62-110

Delta edge

At the extremes of the Delta, well Benin West (OML1) has a temperature of 212°F(100°C) at 7700ft. Wells Pologbene. (OML96). Gilli Gilli, in the West. (OML14) and Tom Shot Bank (in the East). have very high temperatures: 189°F(87°C) and . 195°F(91°C). and 170°F (77°C) respectively all at 5000ft depth.

The paralic section starts at about 4000ft - 6000ft. It is most probable that the high temperatures at the delta edges are due to nearness to the basement. Temperature anomalies could be associated with basement uplift.

Wells in OML12 record the highest temperatures. for instance Umuna-1, 190°F(88°C) at 6000ft. Anua-1 and Uruan-1 have 236°F(113°C) and 251°F(122°C) all at 8000ft. These however are not producing wells.

Inner belt

This belt has OML5 and OPL51 in the north. part of OML4. 1 and 40 in the west and narrows to OML48 in the southeast and OML14 in the east. Temperatures increase from the central inner belt towards east and west. e.g. in OML5. Obi Anyima has 129°F(54°C). Matsogo 129°F(54°C). Amojie (OML48) 130°F(54°C) all at depth 6000ft. The value increases eastward to 170°F(77°C) at a lower depth of 5000ft in Tom Shot Bank (OML14). Westward. the temperatures increase to 189°F(87°C) in Pologbene (OML1). 222°F(106°C) in Tsekelewu and Benin West. Generally. temperatures here are relatively lower than in the delta edge averaging 40 - 75°C at 8000ft. The structural features are steep faults compared to the low angle faults observed in the delta edge.

Central belt

The central belt is further subdivided into four sections

i North central

This belt is bounded to the north by OML38. to the west by OML41. east by OML21. 26. part of 39 and to the south by OML34 and part of 35. The structural features are characterised by large shifts of culmination. crestal blocks and numerous flank structures.

The thickness of the shallow continental facies varies between 1500ft and 2400ft (E.g. in Oben). The deeper continental facies is found at about 4100ft and wedges progressively towards the south (Sapale). The top of the marine shale is found at about 12400ft. Oben has preponderance of shale at a shallow depth range of

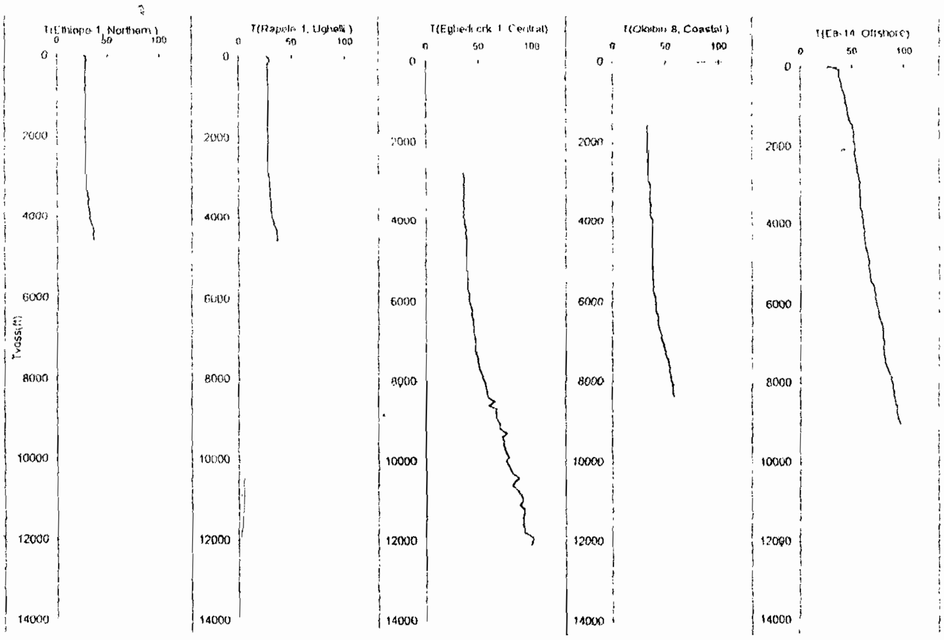

Fig 3: Temperature depth curve shown in depobelt

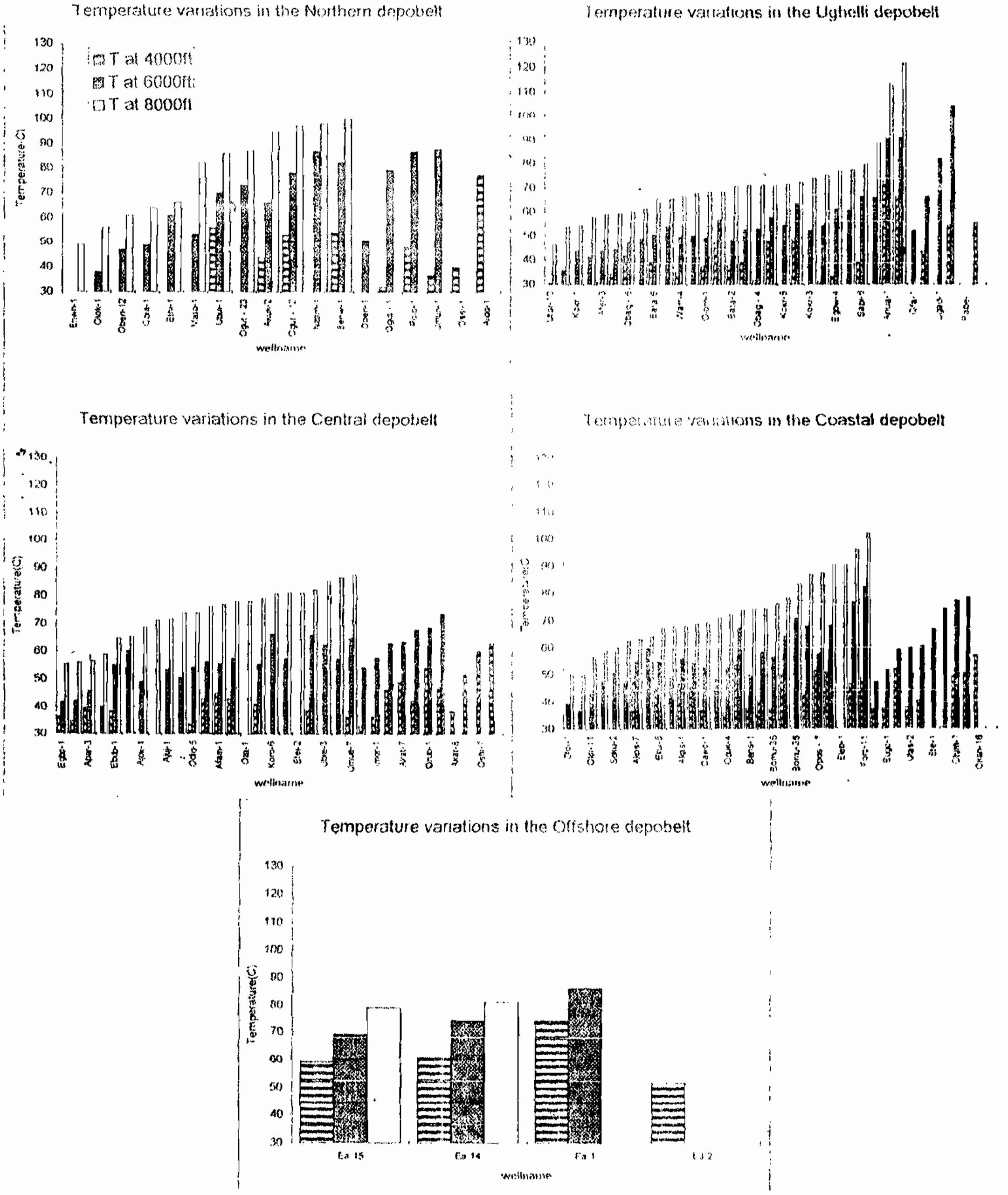

Fig. 4 Temperature variations shown in different depobelts

2500 - 4100ft where surprisingly, temperatures are not as high as one would expect.

In the Aboh - Isoko area, OML26, the temperature at 8000ft is 88°C.

ii West Central

The western central belt has OMLs 42 and 43. In the Otumara - Escravous Beach region, OML43, a higher temperature of about 77 - 91 °C is observed at 8000ft.

iii Central

This region essentially is the central depobelt, i.e. OML27, 28, 31, 35, 58 and 61. It also includes part of OMLs44, 22 and 21. Temperatures at 8000ft range between 56 - 86 °C with the highest in Ubie. The continental facies is generally thick at about 5800ft (i Adibawa, OML27) to 6300ft (in Etelebou, OML28). The marine shales are deeper.

In the Egbedi Creek and Kolo Creek areas, large stee regional flanks bounded by major counter regiona faults are present.

iv East Central

The temperature in the east central belt is relativel higher (between 54 - 80°C) at about 6000ft radiatin from the central portion (Bomu 176°F), Afam (174 °F outward to Isimiri (130 °F) in the north, Soku (135 °F to the west, Akata (146 °F) in the east and Utapate South (140°F) in the south-east.

Generally, low temperatures of 50 - 91 °C are observed in the central belt at about 8000ft.

Southern belt

This is the largest structural province. It extends from the Forcados Yokri (OML45) in the west, OML46 through Diebu Creek OML32, Oloibiri OML29 at the central portion

To the south of this belt has Elepa (OML33) and Nembe Creek (OML29). Kalaekule is found at the south-east region.

From the central portion Oloibiri and Diebu Creek, the temperature of 144°F(62°C) and 147°F(64°C) respectively increase outward at 8000ft.

The southern parts of Nembe Creek and Elepa fields record an increase up to 166°F(74°C) and 195°F(91°C) respectively. Farther in the north-western direction of Ramos River and Forcados Yokri 165°F(74°C) and 216°F(102°C) are recorded.

The north-western and eastern areas are characterized by more mobile shales at depth. In the north-western Forcados Yokri estuary for instance, the base continental is between 3260 - 4600ft. The continental facies is seen to decrease further in the Offshore region to about 2360ft in Ea-14 (OML79). The high mobility of the ductile substratum that leads to shale ridges becomes shallower in this area. Generally, high temperatures of 90 - 102°C are observed

Distal belt

The distal part of the Niger Delta is characterized by topographic irregularities that are highlighted by folding and piercement due to density inversion. The tops of asymmetrical shale diapirs are within 2000ft of the sea - floor, the shale plugs can be seen on seismic, rising to less than 5000ft. No temperature data were available in the distal part, but the high shale plugs suggest of high temperatures.

Generally, the thermal conductivity of the rocks decreases with increase in depth, temperature and heat flow, Akpabio, (1997). In the Benin Formation conductivity is as high as 10±4W/m/k but reduces to an average of 5±2W/m/k in the marine/paralic section.

However, in some wells thermal conductivity of the shallow section is lower than in the deeper section or conversely, the temperature and heat flow are greater in the shallow portions of the well. Examples are dominant in the Offshore depobelt.

There is a corresponding decrease in travel time in such areas, this may be associated with loss or absence of porosity within the interval. According to Brigaud et al. (1990) and Uko (1996), the actual porosity depth function (i.e. porosity decreasing exponentially with depth) at each site depends strongly on the local lithology of the formation which in turn is dependent on the burial history of the formation (e.g. compaction and dewatering process). Porosity decreases as a result of compacton, thermal conductivity decreases as a result of low conductivity pore water in rocks of a given formation. Berge et al. (1995) also showed that porosity decreases with increase in velocity and conversely the interval transit time

A possible explanation for these anomalies is that the EA sequence shows an upward change from sand-dominated lowstand deposits intercalated with transgressive and highstand shales towards thicker and more sand-prone highstand and transgressive deposits interrupted by thinner lowstand deposits (reflecting overall progradation across the depobelt). .

Conclusions

Results from the study show that temperature variation is lithologically controlled, its minimum coincides with the zones of maximum thickness of the sandy Agbada and Benin Formations while high temperatures coincide with the marginal zones of the tertiary depocentres.

ACKNOWLEDGEMENT

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