Proceedings, 7th African Rift Geothermal Conference
Kigali, Rwanda 31st October – 2nd November 2018

Geothermal Exploration in Nigeria – Country Update

[1]Mohammed YerimaKwaya and [2]Ewa Kurowska

[1]Department of Geology, Faculty of Earth and Environmental Sciences, Bayero University, Kano-Nigeria

[2]Polish Geothermal Society, Poland

mkyerima.geo@buk.edu.ng,yerimamohammad@yahoo.com

Keywords: Nigeria, geothermal, warm spring, Chad Basin

ABSTRACT

The geology of Nigeria comprises both the crystalline basement complex and the sedimentary basins of different ages. Research studies from many angles indicate potentials for geothermal energy in the country. Temperature data obtained from oil drilling activities in some deep basins give a geothermal gradient of up to 5°C/100m. Temperatures of 100°C to 175°C were obtained at 1200 to 2600 m below ground level in some part of the Nigerian sector of the Chad Basin. The Chad basin is reported as a rift-related basin, with recognized faults system. Interpreted gravity data from the Nigeria's Chad Basin shows that large geothermal anomalies in a fault-bounded graben-horst system are caused by uplifted mantle (thinned crust) to the depth range of 23 to 26 km in the Basin. There also exist some known and unknown thermal springs within Nigerian crystalline province. Water of warm springs in Akiri and Ruwan Zafi in Nigeria has the temperature of about 54°C, suggesting occurrence of some geothermal anomalies. This paper presents the status of knowledge of geothermal energy exploration in Nigeria. Major challenge hindering geothermal investigation in Nigeria is an absence of awareness in both the public and private sector. There is little technical knowledge, expertise and exposure on geothermal energy in the country in general. Public outreach and acceptance is a key factor for geothermal energy exploration. Government should put in place a project with a time frame that will come out with a Strategic Geothermal Resource Assessment in Nigeria and encourage the private sector to participate in geothermal energy development projects.

1. Introduction

Nigeria, with atotal area coverage of 923,768 km^2, is the most populous in Africa with more than 170 million people. With this large number of population in a wide geographical and regional distribution the energy demand is increasing and the energy available is grossly inadequate. Geothermal energy which is an renewable source that may contribute to the country energy sourcehas not been given due consideration so far. However some preliminary studies indicate an existence of potential for geothermal energy in Nigeria (Babalola, 1984; Kwaya, 2013; Olumide, 2014; Otobong and Onovugve, 2016). The geological distribution in the country, which comprises both the crystalline basement complex and the deep sedimentary basins of different ages indicated geothermal energy manifestations in some areas. This paper presents the status of knowledge of geothermal energy exploration in Nigeria and some major challenges hindering geothermal investigation and exploitation in the country. Suggestion and recommendations were then offered for possible exploration and exploitation of this clean and environmentally friendly energy source.

2. Geological Settings

Lying within the Pan African mobile belt in between the West African and Congo cratons, geologically, Nigeria is dominated and made up of two main rock types: Precambrian and Mesozoic to Tertiary Basement complex, volcanic rocks and the Mesozoic to Tertiary sedimentary basins, which are equally dispersed (Figure 1). Other minor formations are younger granites which comprise several Jurassic magmatic ring complexes centered around Jos and other parts of north-central Nigeria. These rocks are structurally and petrologically distinct from the Older Granites (Obaje, 2009).Along the river channels there are Quaternary to Recent alluvial deposits. In the basement complex terrain rock types are predominantly of migmatitic and granitic gneisses, quartzites, slightly migmatised to unmigmatised metasedimentary schists and dioritic rocks (Rahaman,1989). The sedimentary rocks overlying the basement complex consist of arkosic, gravely, poorly sorted and cross bedded sandstones (Cretaceous and Tertiary).The sedimentary basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida-Nupe) Basin and the Dahomey Basin.

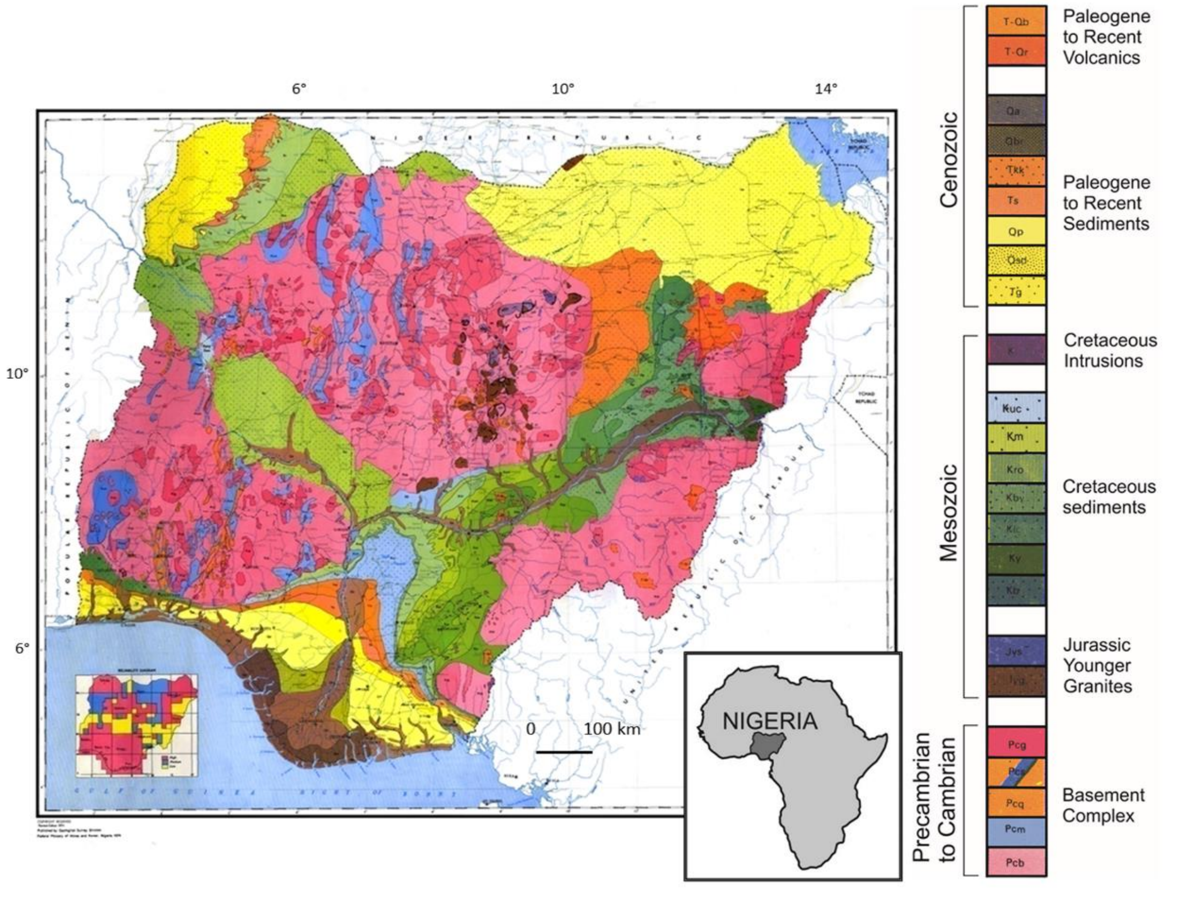

Figure1: Geology of Nigeria (after Nigeria Geological Survey, 1974; slightly modified).

3. Geothermal Exploration in Nigeria

Geothermal studies in Nigeria can be discussed under the following:

i. geothermal features of sedimentary province (subsurface temperatures and geothermal gradients),
ii. thermal springs asgeothermal surface manifestations.

3.1 Sedimentary Geothermal Energy Potential

Researchers over the last couple of decades have reported moderate to high geothermal gradients in some of the sedimentary basins in Nigeria. The sedimentary basins investigated for geothermal occurrence include: the Chad Basin, the Sokoto Basin, the Niger Delta Basin, the Anambra Basin and Middle Benue Trough

3.1.1The Chad Basin, Nigerian Sector

The Chad Basin is a large structured depression which spans five countries: Cameroon, Central African Republic, Niger, Nigeria and Chad. The Chad Basin belongs to a series of Cretaceous and later rift basin in Central and West Africa (Figure 2). The origin is generally attributed to the rift system that develops in the early Cretaceous when the African and South American lithospheric plates separated and the Atlantic opened. The Chad Basin with an area of about 2,335,000km^2 (Oteze and Fayose, 1988;Okosun, 1992) occupies a vast area at an altitude of between 200m and 500m above sea level in Central Africa (Cratchleyet al, 1984). The Bornu Basin (Nigerian sector of the Chad Basin) makes up approximately 10 percent of the basin and lies between latitude 11˚Nand 13˚45'38''N and longitudes 8˚21'49"and 14°40'22"E in north-eastern Nigeria. Thickness of the sediments in the Chad Basin inNigeria, reaches up to 10 km according to Avbovbo (1986), eight kilometres according toNur (2001) and up to 6.5 km was inferred by Kwaya et al (2013).

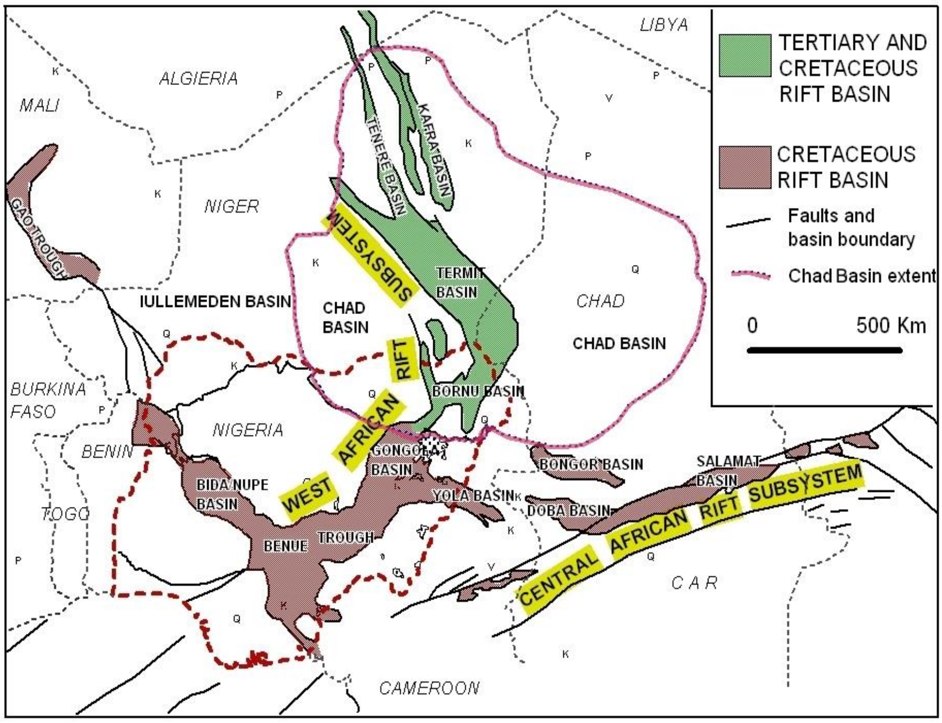

Figure 2: Location of Nigeria and Chad/Bornu Basin within regional geological map with rifts of West and Central African Rift System (afterGenik, 1992; modified).

The Nigerian sector of the Chad Basin is the most studied basin in terms of geothermal investigation, more than ten authors working in the Chad Basin over the last three decades had reported an established regional average geothermal gradient of 3°C/100m and above. Some of the reported geothermal gradient in the Chad Basin are shown in Table 1 below:

Table.1: Some reported geothermal gradients in the Chad Basin

Authors	**Geothermal gradient**
Askira and Schoeneich,1987	3°C/100m to 6.44°C/100m
Kwaya*et al*, 2005; 2016	2.81˚C/100 m to 5.88˚C/100m
Nwazeapu, 1990	2.16˚C/100m to 5.26˚C/100m
Nwankwo *et al*, 2009	3.0˚C/100m to 4.4˚C/100m
Olugbemiro and Ligous,1999	3.1˚C/100m to 4.2˚C/100m
Nwankwo and Ekine, 2010	3.4˚C/100m (mean)
Umar, 1999	3.31˚C/100m (mean)

Kwaya et al 2016 reported thermal conductivity values from the different representative samples range from 0.58 W/mK to 4.207 W/mK with an average of 1.626 W/mK. Their work also presented a heat flow value ranging from 45 mW/m^2 to about 90 mW/m^2 in the Nigerian sector of the Chad Basin.

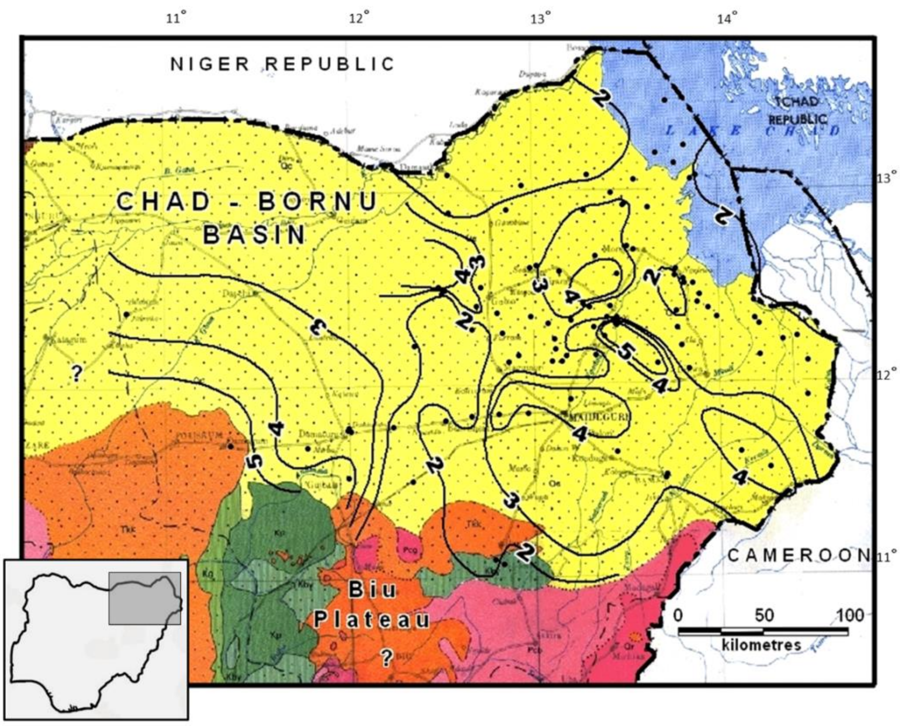

Figure 3: Geothermal gradient in Nigerian sector of Chad Basin on a background of Geological Map of Nigeria by Geological Survey Division, Federal Ministry of Mines and Power, Nigeria, 1974. Based on temperature data from water wells and oil exploration wells collected by Askira&Schoeneich, 1987; Kwaya et al, 2005.

Ikpokonte (2009) interpreted gravity data from the Chad Basin and concluded that large geothermal anomalies in a fault-bounded graben-horst system are caused by uplifted mantle (thinned crust) to the depth range of 23 to 26 km in the basin. The basin is confirmed to be a tectonic basin, the sediments are lying on a rifted basin, and there is possibility of thermal uplift in a rifted system, consequently large amount of heat must have originated from the upper mantle. The basement deep seated faults there may cause easy dispersion of heat to the upper level. These are probably the major source of heat and the thermal energy in the Chad basin, Nigeria.

3.1.2 The IllummedenBasin -Nigerian Sector (Sokoto Basin)

An evaluation of Curie-point depths, geothermal gradients and near-surface heat flow has been carried out fromthe spectral analysis of the recently acquired high resolution aeromagnetic (HRAM) data of the entire Sokoto Basin in northwestern Nigeria. The geothermal gradient varies between 20.84 and 52.11 °C/km with an average of 33.99 °C/km, and the resulting heat flow varies between 52.11 and 130.28 mW/m^2 with an average of 84.97mW/m^2(Nwankwo and Shehu, 2015). Map of geothermal gradient in the Nigerian part of the Illummedin based on temperature data from 76 water wells collected by Olatunji & Schoeneich (1989) is presented in Figure 4.Olatunji (1989) reported that "peak of the geothermal gradient is marked by the geothermal gradient of 13 °C/100m compared to a general value of about 4 °C/100m outside the anomalous zone". Moumoni (2001) analyzed temperature data from 59 boreholes with depth ranging from 50m to 300m in the Niger sector of the Illummedin Basin and reported geothermal gradient values varying from 3.24 °C/100m to 16 °C/100m.

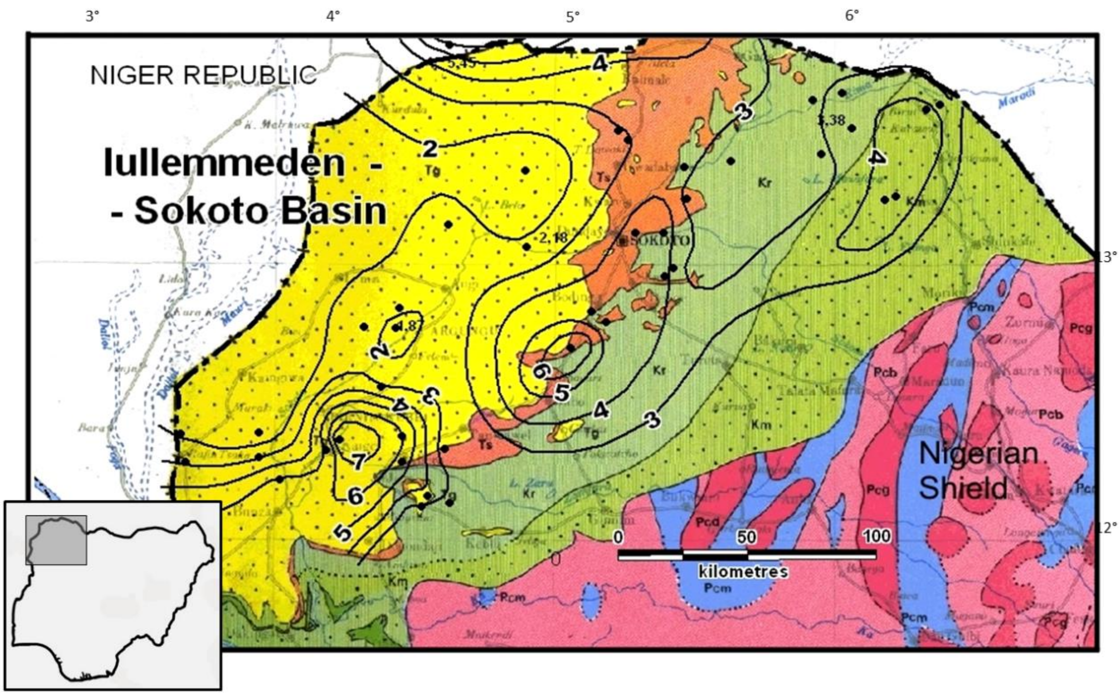

Figure 4: Geothermal gradient in Nigerian part of Iullemmeden Basin (Sokoto) based on temperature data from water wells collected by Olatunji 1989.Geological background by Nigeria Geological Survey, 1974.

3.1.3 The Niger Delta and Anambra Basin

The Niger Delta geothermics was investigated by Nwachukwu (1976),Avbovbo (1978), and Onuoha and Ekine (1999), (Figure 5). Latter, Idara (2009)used two hundred and sixty wells

in the Niger Delta to determine thermal rock properties and heat flow. According to his findings thermal conductivity varies with depth due to variable lithology and water content, from
8W/mK in the Benin formation to 5 W/mKin the marine shale formation. Thermal conductivity calculations were based on assumed matrix conductivity of sand 6.1W/mK and shale 2.1W/mK, predominant lithologies in the Niger Delta. Heat flow derived from thermal conductivity estimates at the central part of the Delta is (20 – 30 mW/m^2), it increases both seaward and northward to (40 - 55 mW/m^2). Olumide (2013) also analysed temperature data from boreholes of the Niger Delta and created series of geothermal maps – the map of geothermal gradient is presented in Figure 6. The values range from 1.2°C/100m to 7.56°C/100m. His preliminary estimates of geothermal energy resources in depth interval 0-4000 m in the Niger Delta indicated a range of resource value between 400 GJ/m^2 to 1250 GJ/m^2.On the basis of sub-surface temperature that is bottom hole temperature from oil wells Otobong and Onovugve (2016)came out with geothermal gradient of 1.3°C to 5.5°C/100m in the Niger Delta. A geothermal gradient value of about 5.5^{o}C/100m was obtained in the Anambra Basin by Onuoha and Ekine (1999) (Figure 5).

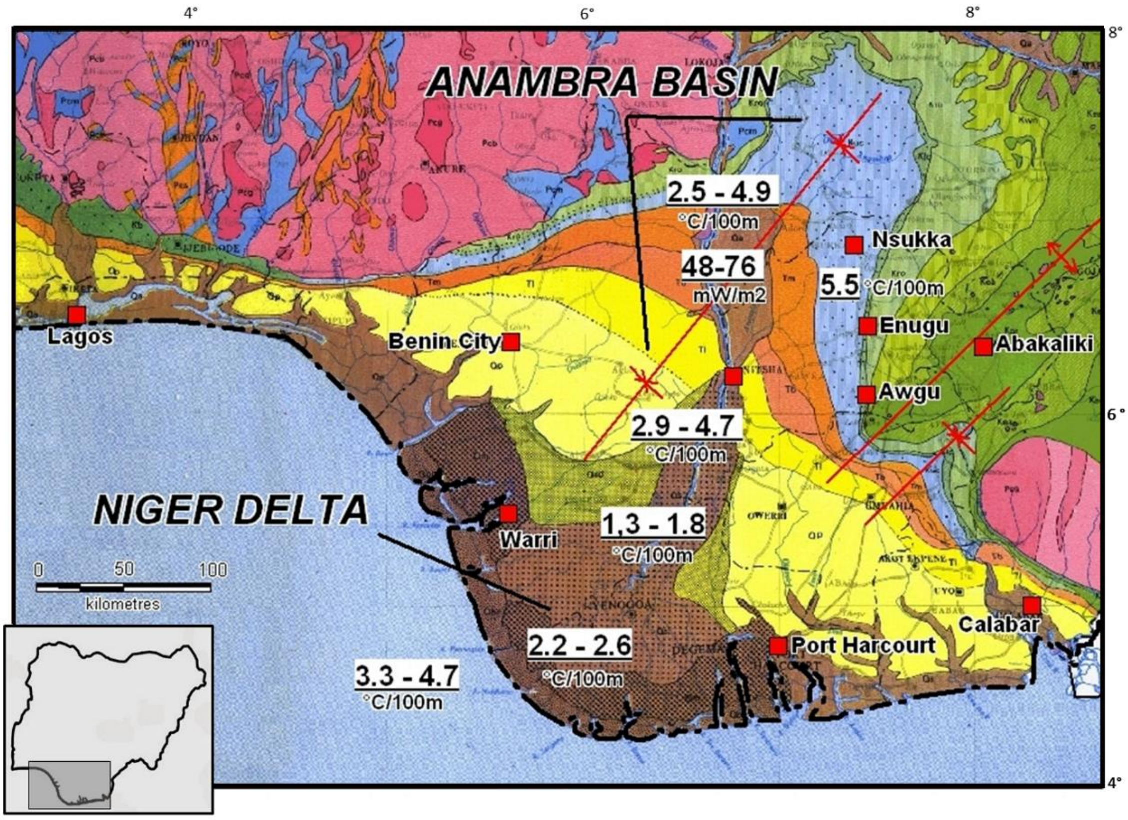

Figure 5:Geothermal gradients in southern Nigeria. Gradient calculations by Nwachukwu (1976) , Avbovbo (1978), Onuoha and Ekine(1999)on the background of geological map by Nigerian Geological Survey, 1974.

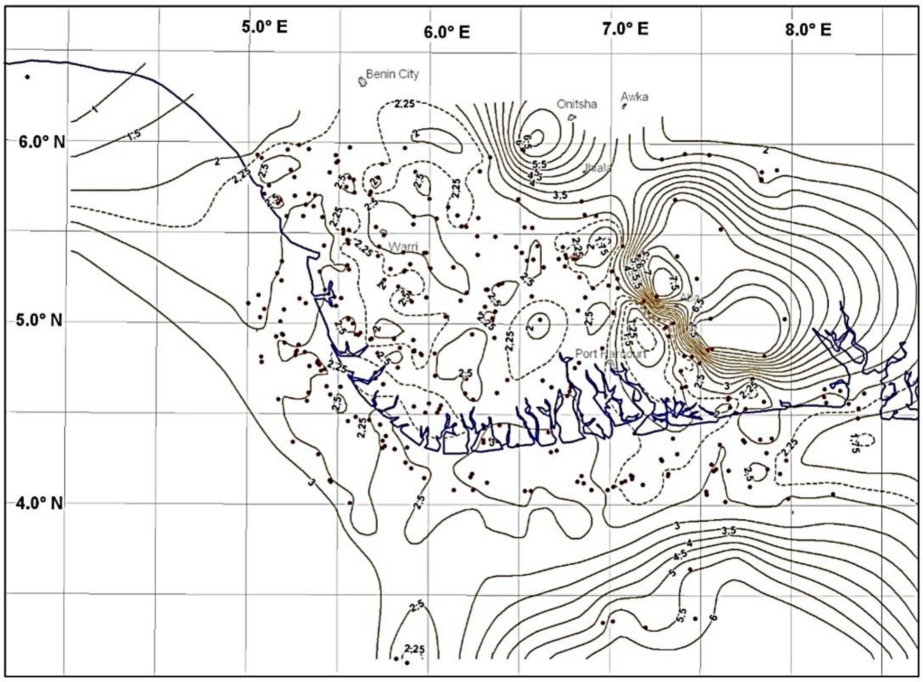

Figure 6: Geothermal gradient map of Niger Delta Basin (in °C/100m) and location of boreholes with temperature data used for the construction of this map (Olumide, 2013).

3.2 Thermal springs

There are several known and unknown thermal springs in Nigeria, few were reported within the crystalline province and some within the Middle Benue Through(Bako, 2010; Kurowska and Schoeneich, 2010; Nghargbu et al, 2011; Garba et al, 2012;).Ikogosi Warm spring in Ondo State and the Wikki warm spring in Bauchi State (Yankari) are the best known springs in Nigeria. The first known is the Ikogosi spring (Precambrian basement and schist belt), where the recreation resort have been developed. Figure 7 presents the location of thermal springs in Nigeria on the background of topography with elevation above mean sea level.

Rafin Rewa warm Spring is an ascending perennial spring that yields up to 0.1 l/s, flows from an unconfined aquifer, made up of saprolite, mostly gritty clays and clayey sands derived from the weathering of migmatite on the Precambrian crystalline rocks of Northern Nigeria. The water and gas are of endogenic origin, flowing from depth not less than 700 m below ground level, thus making the spring the only known occurrence of juvenile water in Nigeria. Temperature is 42.2 °C (Garba et al, 2012***)***. Rafin Rewa warm spring may have originated from the Tertiary to Recent magmatic activity that affected the Jos Plateau area of Nigeria.

Bako (2010) intensively documented the surface geothermal manifestations in the Middle Benue Trough in Nasarawa State; 150 boreholes and seven thermal springs were studied. Thermal springs investigated and reported includes; Akiri, Awe, Keana, Ribi, Kanje and Azara, and thermal free flowing boreholes in Assakio and Giza. Akiri thermal spring has the highest temperature 53.5^{o}C. Water from the thermal springs was sampled and analyzed, apart from Azara and Kanje thermal springs that are of meteoric origin, the remaining (5) are of connate origin with mineralization as high as 6644-50736 mg/l. Water of warm spring in Akiri and Ruwan Zafi in Nigeria has the temperature of about 54^{o}C suggesting occurrence of some geothermal anomalies. Bako further plotted the results in form of geothermal gradient map, several positive geothermal anomalies were discovered with the highest (9.3 °C/100m) around

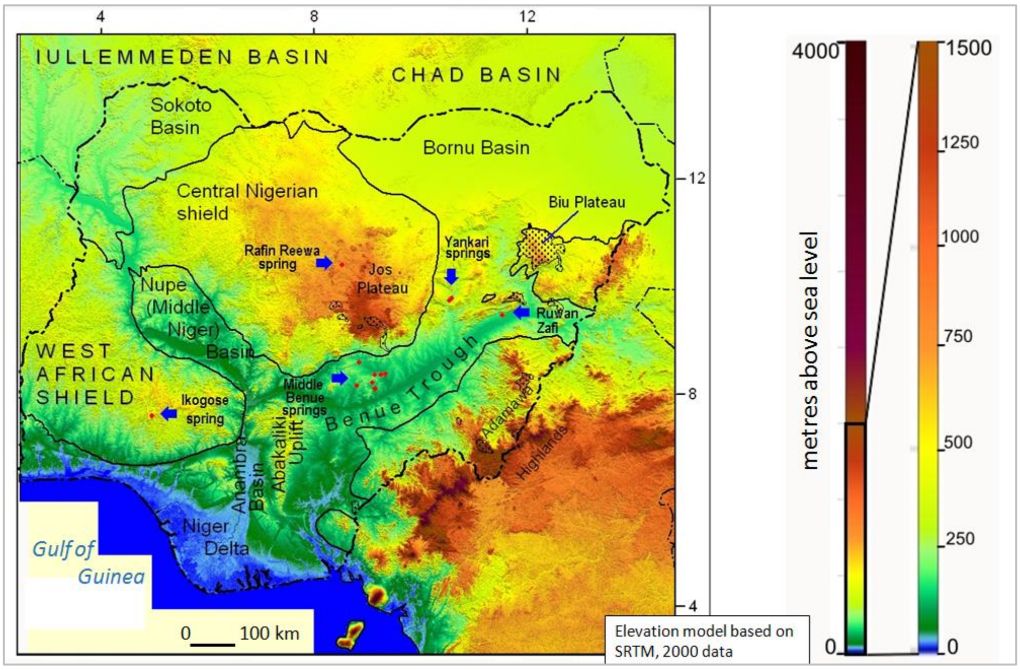

Figure 7: Nigerian thermal springs – geothermal surface manifestations on the background of topography (data source: SRTM 90m Digital Elevation Data).

the Awe anticline. These springs are indicators of probable high geothermal potential within the sedimentary hydrogeological province of the Middle Benue Trough of Nigeria. It is worth mentioning that the warm springs of the Middle Benue Trough were also investigated in terms of suitability for curative purposes by Nghargbu et al (2011, 2017). The recreational use of the geothermal waters is known worldwide, also in Nigeria (in Ikogosi and Wikki areas).

4. Challenges

The major problems and barriers to geothermal development in Nigeria may be specified in the following points:

- There is little technical knowledge, expertise and exposure on geothermal energy in Nigeria in general, this results in limitations in local technological and human resource capacity;
- Full understanding of the hydrogeology beneath deep sedimentary basins as well as in some areas in the crystalline province that includes porosity, permeability and occurrence of water within deep formations or fault/fracture zones;
- Identification of the nature of geothermal heat concentrations and prospective resources prior to drill; more direct and indirect (geophysical) research are needed;
- Security situation in the regions hindered continuous research;

- Generally it is difficult, time consuming and expensive acquiring data for geothermal exploration in the deep sedimentary basin.

5. Conclusion and Recommendation

The geothermal analysis based on geothermal gradients indicated geothermal anomalies within sedimentary basins. The areas of geothermal anomalies with gradients above 5°C/100m might be prospective for geothermal energy utilization. The influence of Cenozoic volcanic episodes on geothermal regime in the area has not been investigated yet. It is likely that heating effect of volcanic and intrusive activity on Cretaceous sedimentary basins, especially Benue Trough, Chad Basin as well as basement complex, contributed to the development of local anomalies that can be detected presently. In Nigeria the most needed application of geothermal energy would be production of electricity but the real possibility of that and potential assessment need further research. The possibility of electricity production isnot obvious, as there is no active volcanic zones in Nigeria. The technology known as geothermal binary power generation system" might be feasible, if the area with proper geothermal and hydrogeological conditions is found.

The more detail investigation on thermal springs should explain the origin of heat carried by the water to the surface and the depth of water circulation. It will give an idea about those natural phenomena and contribute to the exploration for possibilities of use of geothermal heat from both sedimentary and Precambrian Provinces in Nigeria. The elements that are absolutely necessary to be able to assess the real possibilities for geothermal utilization are:

- existence of subsurface deep reservoirs containing water,
- knowledge about hydrogeological and geothermal properties of rocks,
- knowledge about amount and properties of geothermal fluids,
- knowledge about the features and processes in the hydrogeothermal system of interest.

As geothermal energy is not widely known in Nigeria, public outreach and acceptance associated with this energy is a key factor for its exploration and exploitation. Government should put in place a project with a time frame that will come out with a strategic geothermal resource assessment in Nigeria. Geothermal energy resources to be integrated in the national energy development plan. Encourage the private sector to participate in geothermal energy development projects. Establish a geothermal energy research centre in few and capable universities with the vision for the centre to provide urgent, forward looking research, development and support for establishment of geothermal energy as a clean energy option through a program of research.

Formation of professional association, for example 'Nigerian Geothermal Association' (NGA) would help in development of geothermal in the country.

Further activities that may lead to a practical use of geothermal energy should comprise drilling or recovery of old boreholesaimed at recognition of the geological, hydrogeological and thermal parameters necessary for geothermal modelling and design.

REFERENCES

Askira, M.T., and Schoeneich K.“Preliminary Geothermal Outline of the Nigerian Part of the Lake Chad Basin.”*Paper presented at the International Seminar on Water Resources of the Lake Chad Basin Management and Conservation,* N’jamena, Chad Republic, (1987).

Avbovbo, A.A. “Geothermal Gradients in the Southern Nigerian Basins.”*Bulletin of Canada Petroleum Geology,*26 (2), (1978), 268-274.

Avbovbo, A.A., Ayoola, E.O., and Osahon G.A. “Depositional and Structural Styles of the Chad Basin of Northeastern Nigeria.”*Bulletin American Association of Petroleum Geologist 70,* (1986), 1787- 1798.

Bako A.S.J. “Geothermal Energy Potential in the Part of Middle Benue Trough Located in Nasarawa State.”*Unpublished Master of Science thesis,* Department of Geology, Ahmadu Bello University, Zaria (2010).

Babalola, O.O. “High-Potential Geothermal Energy Resource Areas of Nigeria and Their Geologic and Geophysical Assessment.” *AAPG Bulletin,* 68 (4), (1984), 450.

Cratchley, C.R., Louis P., and Ajakaiye, D.E. “Geophysical and Geological Evidence for the Benue - Chad Basin Cretaceous Rift System and its Tectonic Implications.”*Journal African Earth Sciences 2,* (1984), 141-150.

Garba, M.L., Kurowska, E., Schoeneich, K., and Abdullahi, I. “Rafin Rewa Warm Spring, a New Geothermal Discovery.” *American International Journal of Contemporary Research,* 2 (9), (2012).

Genik, G.J.“Regional Framework, Structural and Petroleum Aspects of Rift Basins in Niger, Chad and Central African Republic, C.A.R.”*Technophysics, 213(1992), 169-185.*

Idara O.A. “Thermal Conductivity Estimates in the Niger Delta Using Lithological Data and Geophysical Well Logs.”*Pacific Journal of Science and Technology,*10 (1), (2009).

Ikpokonte, A.E. “Gravity and Geothermal Anomalies in Borno Basin, Nigeria.”*Nigerian Journal of Physics,*21 (1), (2009), 43-52.

Kurowska E., and Schoeneich K. “Geothermal Exploration in Nigeria.”*Proceedings World Geothermal Congress*, Bali, Indonesia (2010).

Kwaya, M.Y. “Geothermal Energy Potential of Nigerian Sector of Chad Basin.” *Unpublished PhD dissertation,* Department of Geology, Ahmadu Bello University, Zaria (2013).

Kwaya, M.Y., Schoeneich, K., and Ikpokonte, A.E. “Thermal Water in Borno Basin.”*Borno Journal of Geology,* 3 (4 and 5), (2005).

Kwaya, M.Y., Kurowska, E., and Arabi, A.S. “Geothermal Gradient and Heat Flow in the Nigeria Sector of the Chad Basin, Nigeria.”*Computational Water, Energy, and Environmental Engineering*, 5, (2016), 70-78.

Nghargbu K., Ponikowska I., and Kurowska E.“Prospects for Balneotherapy in Nigeria.”*ActaBalneologica*, LIII (3), (125), (2011), 164-168.

Nghargbu K., Ponikowska I., Latour T., Kurowska E., Schoeneich K., and Alagbe S.A.“Geo-medical Resource Inventory of Nigeria.”In:Ibaraki M., andMori H. (ed.)*“*Progress in Medical Geology.”*Cambridge Scholars Publishing*, UK (2017) 146-165.

Nur, A. “Spectral Analysis and Hilbert Transformation of Gravity Data over the Southwest of the Chad Basin, Nigeria.”*Journal of Mining Geology,* 37 (2), (2001), 153-161.

Nwachukwu, S.O. “Approximate Geothermal Gradients in the Niger Delta Sedimentary Basins.”*The American Association of Petroleum Geology*, 60 (7), (1976), 1073-1077.

Nwankwo, C.N., Ekine, A.S., and Nwosu, L.I. “Estimation of the Heat Flow in the Chad Basin Nigeria.”*Journal Applied Sci. Environ. Management,*13 (1),(2009), 73-80.

Nwankwo, C.N., and Ekine, A.S. “Geothermal Gradient in the Chad Basin, Nigeria from Bottom Hole Temperature Logs.”*Scientia Africana, 9 (1), (2010), 37-45.*

Nwankwo, L. I., and Shehu, A.T. “Evaluation of Curie-point Depths, Geothermal Gradients and Near-surface Heat Flow from High-resolution Aeromagnetic (HRAM) Data of the Entire Sokoto Basin.” *Journal of Volcanology and Geothermal Research*, 305 (2015), 45–55.

Nwazeapu, A.U. “Hydrocarbon Exploration in Frontier Basin the Nigerian Chad Basin Experience.”*28th Annual Conference of the Nigeria Mining and Geosciences Society*, Port Harcourt(1990), 14.

Olatunji S.A. “Geothermal Gradients and Temperatures of Ground Water in Sokoto Basin, Sokoto State, Nigeria.”*Unpublished Master of Science thesis*, Department of Geology, Ahmadu Bello University, Zaria, Nigeria (1989).

Olugbemiro, O.R., and Ligouis, B. “Thermal Maturity and Hydrocarbon Potential of the Cretaceous (Cenomanian – Santonian) Sediments in the Bornu (Chad) Basin, NE Nigeria”*Bull. Soc. Geol. France* 1, 170 (5), (1990), 759-772.

Olumide, A.J. “Geothermics of Niger Delta, Nigeria.” *Unpublished PhD dissertation,* Department of Geology, Ahmadu Bello University, Zaria (2014).

Olumide, A.J., Kurowska E., Schoeneich K., and Ikpokonte A.E. “Geothermal Gradient of the Niger Delta from Recent Studies.” *International Journal of Scientific & Engineering Research,* 4 (11), (2013).

Okosun, E.A. “Review of the Geology of Borno Basin.”*Journal Mining and Geology,* 21, (1995), 113-122.

Onuaha, K.M., and Ekine, A.S. “Subsurface Temperature Variations and Heat Flow in the Anambra Basin, Nigeria.” *Journal of African Earth Sciences*, 28 (3), (1999), 641-652.

Oteze, G.E., and Fayose, S.A. “Regional Development in the Hydrogeology of Chad Basin.”*Water Resources Journal,* 1 (1), (1988), 9-29.

Otobong, T., and Onovugve, E. “Geothermal Energy Power Potential of Hot Water From Oil Wells in Niger Delta, Nigeria.”*Journal of Multidisciplinary Science Studies (JMESS),*2 (8), (2016), 804-809.

Rahaman, M.A. “Recent Advances in the Study of the Basement Complex of Nigeria.” In: Geological Survey of Nigeria (ed.) “Precambrian Geol. Nigeria” (1988), 11–43.

Umar, T. “GeologiePetroliere du Secteur Nigeria du Lac Tchad.”*Unpublished PhD dissertation.* Universite du pau et des pays de l’adour. Centre Universitaire de Recherche Scientifique Laboratoire de Geodynamique et Modelisation des Bassins Sedimentaires (1999).

U.S. Geological Survey: SRTM data Collection, http://srtm.usgs.gov/