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Geothermal Exploration in Nigeria

Ewa Kurowska[1], Krzysztof Schoeneich[2]

[1]University of Silesia, Faculty of Earth Sciences, Department of Fundamental Geology, Bedzinska 60, 41-200 Sosnowiec, Poland

ewa.kurowska@us.edu.pl

[2]Ahmadu Bello University, Department of Geology, Zaria, Nigeria

schoeneich2003@yahoo.com

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ABSTRACT

The geological structure of Nigeria influences geothermal exploration extent within each geological province. Sedimentary basins in Nigeria have been explored for hydrocarbons for several decades, thus the oil companies collected large subsurface temperature data basis. But not much is known about geothermal conditions within Nigerian Precambrian crystalline province.

On the basis of BHT data from oil wells it has been found that geothermal gradient in Niger Delta ranges from 1.3 to 4.7°C/100m and in Anambra Basin (directly to the north) it can reach 5.5°C/100m. Exploration for geothermal energy in northern Nigeria based on shallow water wells (down to 500 m deep) was carried out over 20 years ago. Research was concentrated mainly on geothermal conditions within Sokoto and Nigerian part of Chad sedimentary basins, where relatively high geothermal gradients were found: 7.6° and 5.9°C/100m respectively. In north-western Nigeria the geothermal anomaly of Sokoto basin extends to the Niger territory.

The other aspect of geothermal exploration in Nigeria is investigating of the thermal springs and seepages, which occur mainly within sediments of the Middle and Upper Benue Trough. The water of the warmest springs in that area: Akiri and Ruwan Zafi have the temperature about 54°C and it suggests the occurrence of some geothermal anomalies. So far, there is probably the only one (direct) geothermal energy utilisation site in Nigeria. It is a swimming pool where water from Ikogosi warm spring (37°C) is used. It is located in south-western part of the country, in Ekiti state.

1. INTRODUCTION

Nigeria is a country of insufficient production of electricity and poor energy distribution and transmission system. Electricity generation is based on thermal and hydro power plants, making up 66.7% and 33.3% of total power production respectively. Installed capacity is about 6 GB but only the small percentage out of it is in use. From among 149 million of Nigerian population (official data for 2009) only about 40% has an access to electricity (according to EIA, 2007), which is usually relatively easier within urban, developed areas than in rural peripheries. As Nigeria is one of the biggest producers of oil an gas in the world, hydrocarbons are the major source for general energy production. However, general problem within Nigerian energetic sector made the authority to search for some other solutions, including the alternative sources of energy. During the last decade, when the development in technology of renewable, clean energy use has been spreading worldwide, the awareness of energetic sector as well as federal and local authorities about renewable energy raised also in Nigeria. At present, activity is concentrated mainly on possibilities of use of solar energy what is a natural consequence of the location in sub-Saharan West Africa and tropical climatic conditions of the country. There are also some plans about use of wind energy and constructing a wind power plant.

So far, geothermal issues have not been widely known in Nigeria, although investigation of subsurface temperature of rock mass was carried out in hundreds wells due to exploration for oil and gas within sedimentary basins. There were several projects being aimed at exploration of subsurface temperature distribution, carried out with a use of data from oil and gas boreholes as well as shallow water wells. The results of those studies as well as investigation of geothermal surface manifestations give an idea about geothermal conditions of Nigeria.

2. GEOLOGICAL SETTING AND ITS IMPLICATION FOR GEOTHERMAL STUDIES IN NIGERIA

The Nigerian Precambrian basement complex is exposed on the earth surface within about 48% of total land area of the country and remained 52% of the land is covered by Cretaceous to recent sediments deposited in several basins (Fig. 1).

The basement complex of the central shield, south-western part, south-eastern and eastern margin of the country consist of three major groups of rocks: 1) migmatite and gneiss dominated (Liberian to Pan-African age), 2) schists (metasediments) with quartzites and other minor lithologies forming long, narrow, north-south trending belts, mainly in the western part of Nigeria and 3) intrusive granitic rocks – Older Granites (Late Precambrian to Early Palaeozoic age) and Jurassic Younger Granites (Ajibade et al., 1989).

The major and deepest sedimentary zone filled mainly with different kinds of clastics of marine as well as continental origin is about 1 200 km long, trending from Niger Delta in SW through Benue Trough, towards NE to Borno (Chad) Basin. That belt, consisting of several sub-basins, together with its branches is related to the crustal stretching and opening-up of the Atlantic Ocean (Gulf of Guinea) and Gondwana break-up during the lower Cretaceous time.

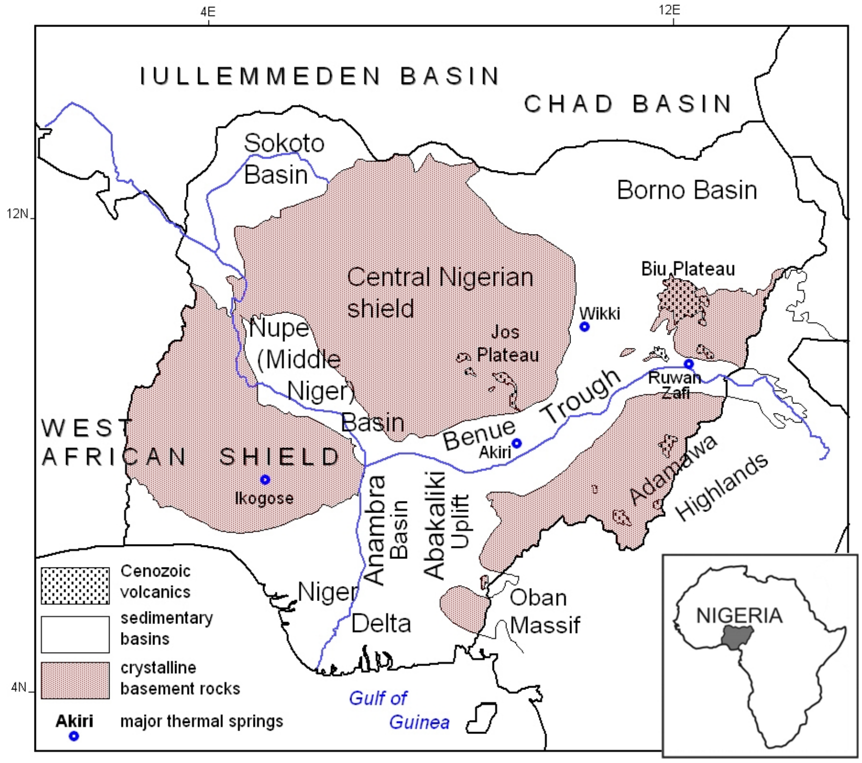

Figure 1: Geological setting and location of the major structural units in Nigeria.

The basins, interpreted partially as troughs and rifts, were subjected to synsedimentary tectonic deformations during Cretaceus to Neogene times and affected by magmatic – volcanic episodes, which resulted in present structural pattern. The Niger Delta is the deepest part of that major Nigerian sedimentary belt and the maximal thickness of sediments exceeds 9 km there (Mattick, 1982). Benue Trough is subdivided into Lower Benue Trough comprising Anambra Basin and Abakaliki Anticlinorium (Uplift), Middle and Upper Benue Trough (together with Yola Arm, Gongola and Kerri Kerri basins) and the maximal thickness of sediments reaches even 6 km in some parts of the trough (Benkhelil et. al., 1988). In the north–east the Benue Trough is overlaid by sediments of Nigerian part of Chad Basin called Borno Basin, where the deepest part consists of 4 km thick Cretaceous to Quaternary sediments (Benkhelil et al., 1989) and according to the other authors it may be much deeper (7 km deep according to Ostaficzuk, 1996).

The Middle Niger Basin (Nupe or Bida Basin), which is only about 0.5 - 1 km deep in most of the area and does not exceed 2 km in the deepest parts (Ojo et al., 1989) is a large western branch of Benue Trough.

The Sokoto Basin on the north-western outskirts of Nigeria is a part of large Iullemmeden Basin that extends far to the north. The Sokoto Basin maximal depth is about 1 km on the north-western margin of the country (Kogbe, 1979) but in the Niger and Mali territory it exceeds 2 km.

Apart from the two major Nigerian provinces: Precambrian crystalline and Cretaceous to Quaternary sedimentary, the third type of rocks is present: Cainozoic volcanics, mainly in the eastern part of the country. The products of Cainozoic magmatic and volcanic activity are numerous trachyte-phonolitic and basaltic plugs within Benue Trough and basaltic lava plateaus from among which the most prominent are: Biu Plateau with its over 80 volcanoes and extensive basaltic lava flows of Jos Plateau (Grant et al., 1972; Turner, 1978).

The geological structure of the area influences general distribution of geothermal heat in the upper earth crust and additionally, specifically for Nigeria, influences geothermal exploration extent within each geological province in the country. There is not much known about geothermal of basement rocks because those areas have no petroleum potential so they are not subject to drilling exploration and subsurface temperature measurements. Sedimentary basins in Nigeria have been explored for hydrocarbons for several decades, thus the oil companies posses large suite of subsurface temperature data. Apart from oil and gas exploration wells, a good source of information about subsurface temperatures are water boreholes. The temperature measured during pumping tests is close to the real temperature of water bearing rock formation. However, such wells are usually shallow, especially water wells drilled within crystalline areas in Nigeria usually are not deeper than 20-30 meters because the water aquifers are in most cases situated within soft overburden overlying hard crystalline rock mass. In the sedimentary areas water boreholes are usually deeper, even down to 500m and many of them can be used as the source of geothermal data.

The other source of geothermal information is a surface manifestation of geothermal activity. There are several warm and hot springs and seepages marking the areas of potential geothermal anomalies in Nigeria, most of them located within sedimentary basin of Benue Trough.

3. GEOTHERMAL INVESTIGATION OF CRYSTALLINE PROVINCE

The world average heat flow in continental Precambrian shields is about 41± 10 mW/m^2 and such value is expected for Nigerian Precambrian basement complex. However, not much has been investigated in that matter in Nigeria. The only widely known heat flow estimation by Verheijen and

Ajakaiye (1979) was carried out in the centre of Ririwai ring complex being one of the granitic ring structures of Younger Granites Province of Northern Nigeria, located within Precambrian shield. In the result of research the average heat flow of 0.92±0.04 HFU (38.5±1.7 mW/m^2) was obtained which is almost equal to the world average.

In the south-western part of Nigeria a thermal spring called Ikogosi is located within quartzite-schist formation of Nigerian basement complex. The spring water temperature is 37°C. It is used for swimming pool being a significant local tourist attraction and probably the only place of geothermal (direct) use in Nigeria.

There is another warm spring just discovered in Rafin Reewa, near Lere, to the north-west of Jos Plateau (central shield). The temperature of spring water is 42°C and it flows from migmatic and gneissic rock formation (reported by M.L. Garba, ABU). Several springs have been presently known in Jos Plateau and all of them provide cold, fresh water, commonly used by local community. The existence of Ikogosi warm spring and that recent discovery suggest that distribution of geothermal heat within Precambrian basement formations in Nigeria can be diversified due to local anomalies.

4. GEOTHERMAL INVESTIGATION OF SEDIMENTARY PROVINCES

4.1 Southern sedimentary province

Subsurface temperature distribution in the southern part of sedimentary province in Nigeria was studied by Nwachukwu (1975, 1976), Avbovbo (1978) and Onuoha and Ekine (1999). They used corrected bottom hole temperature (BHT) data measured in oil exploration wells drilled in Niger Delta and Anambra basins. According to those earlier studies by the first two authors, the lowest values of geothermal gradient were found in the centre of Niger Delta within the thick Tertiary sediments: 1,3 – 1.8°C/100m (Nwachukwu) or 2.2 – 2.6°C/100m in Warri-Port Harcourt area (Avbovbo). The northward trend of gradient increase was found resulting in maximum value of 5.5°C/100m in the area of Agwu-Enugu-Nsuka towns, within Cretaceous rocks containing coal beds in Anambra Basin. The medium values of geothermal gradient (2.9 – 4.7 °C/100m) were found along the coastal line in the South. The geothermal gradients in off-shore parts of Niger Delta calculated by Avbovbo were 3.3 – 4.7 °C/100m.

The latter research by Onuoha and Ekine shows diversity in geothermal gradient within Anambra Basin. The values calculated in 17 points (wells) range from 2.5 to 4.9 °C/100m and the heat flow estimated on the basis of these gradients was 48-76 mW/m^2. In that research, the high temperature zone within Agwu-Enugu-Nsuka and constant trend of subsurface temperature increase from south towards the north was not confirmed.

4.2 Central and northern sedimentary province

Geothermal characteristics of the Bida (Nupe, Middle Niger) Basin as well as Borno and Sokoto basins was studied on the basis of thermal data collected during pumping tests in water wells. These projects were done by Olatunji, 1989; Haruna, 1990; Askira, 1987; Kwaya, 2005 and also Moumouni, 2001 (research on part of Iullemmeden Basin in Niger), all supervised by K. Schoeneich. The water temperature data collected in northern sedimentary basins have been reviewed, corrected and used for compiling the map of geothermal gradient shown in Fig. 2 and 3.

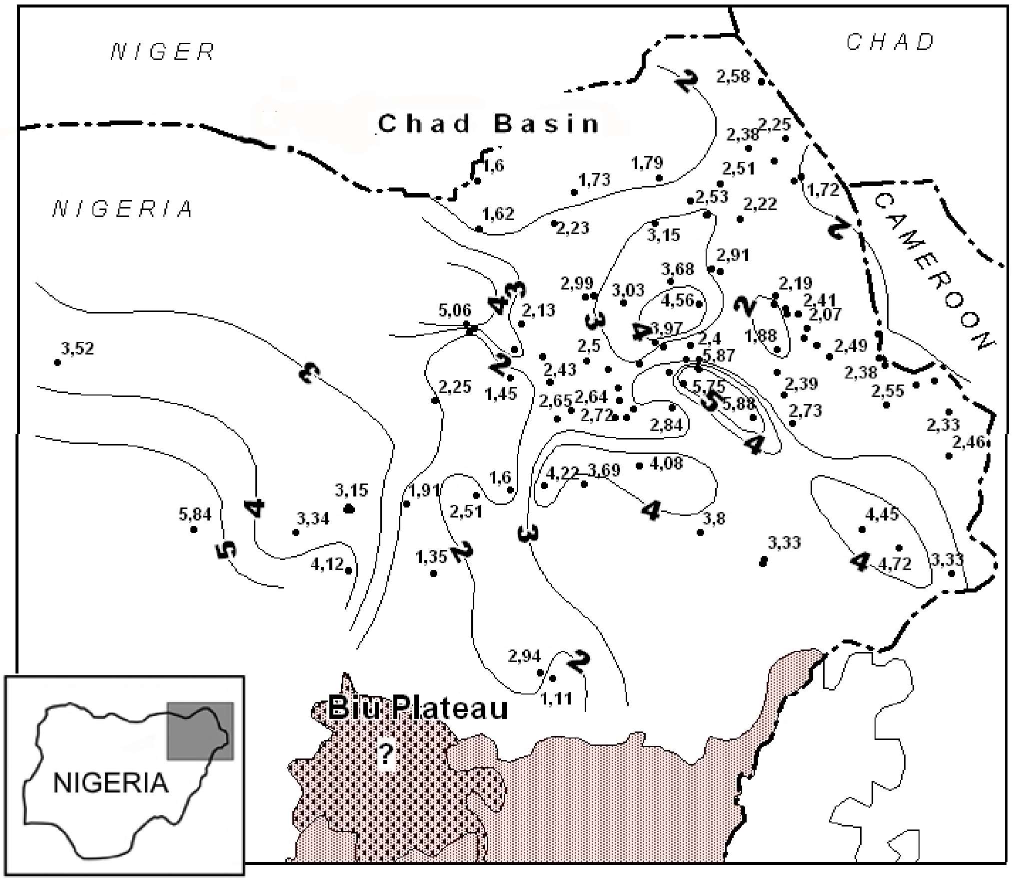

Figure 2: Map of geothermal gradients (°C/100m) within the part of Chad (Borno) Basin.

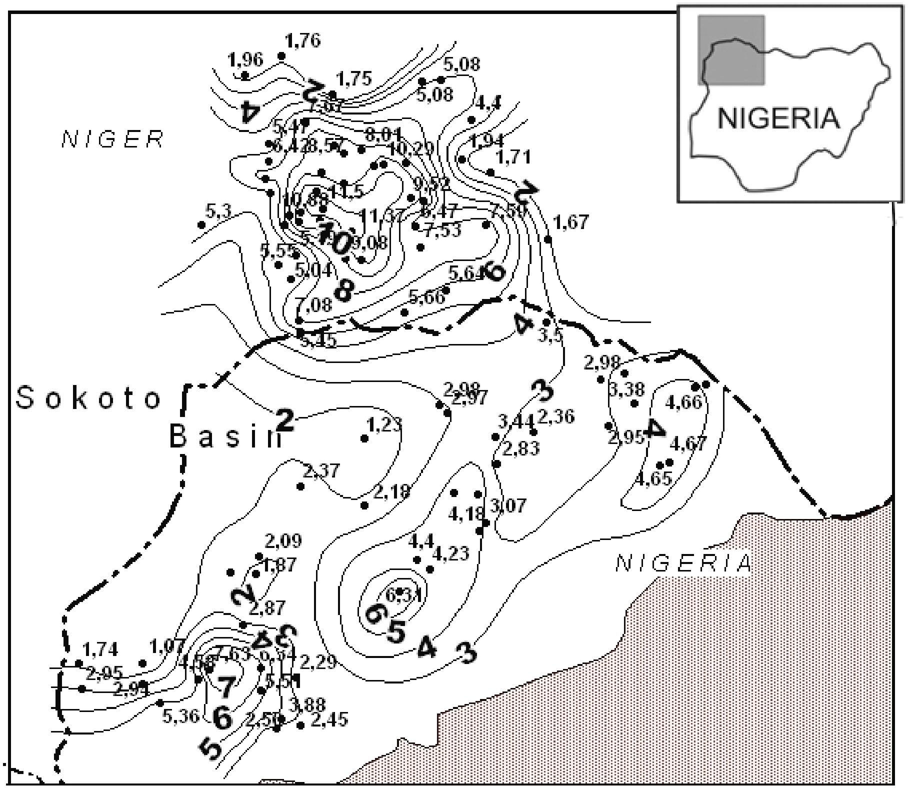

Figure 3: Map of geothermal gradients (°C/100m) within the part of Iullemmeden basin.

The temperature data from water wells 70m to 500 metres deep have been chosen, in which temperatures were measured at the pump outlet with a mercury thermometer, after eight hours of pumping. The data from Borno Basin included also information form several deep oil wells. The data base and the map shows that temperature gradient in Borno Basin ranges from 1.1 to 5.9°C/100m, in Sokoto Basin: 0.9 to 7.6 °C/100m, thus in both cases the geothermal anomalies are indicated and clearly plotted on the map. The zone of highest gradients in Sokoto basin is elongated in SW-NE direction, parallel to general strike of major sedimentary formations which are very thin in that area (about 200 m). This suggests that a significant source of geothermal heat is located below sedimentary complex, in Precambrian basement and perhaps is related to some deep tectonic active structure. The values of geothermal gradients found to the north of Nigeria, within the other part of Iullemmeden Basin in Niger, are even higher than in Sokoto Basin (Fig. 3).

There are very few temperature data from Bida Basin and many of the existing ones were taken in very shallow water wells, however the most reliable measurements taken in more than 100m deep water wells show that in SE part of the basin the geothermal gradient is about 2-2.5 °C/100m.

So far there are no any subsurface temperature data from Middle and Upper Benue Trough available for the authors, however the project of taking measurements in water wells is in process now, as a subject of an ABU student work. Nevertheless, it is very possible to find geothermal anomalies in that area because they are manifested in thermal springs and seepages at the surface (for the location of some of them see Fig. 1). The springs in Middle Benue Trough flow from the Cretaceous, porous sandstones, some of them are located within areas famous from barite mining and traditional salt production based on salty sediments. In such area one of the hottest springs (53.5°C) is located near Akiri, however the most famous Nigerian warm spring is Wikki (32°C) flowing from Gombe Sandstone in Yankari Game Reserve. Another hot one (54°C) is located in the North of Benue Trough, within a huge tectonic structure - Lamurde anticline, near by Numan and is called Ruwan Zafi. The water of the springs is heated by geothermal gradient on its way from unknown depths, in unconfined sandstone aquifer.

Within the Middle Benue Trough several minor thermal seepages were found near by Awe where the temperature of the water ranges from 34 to 38.5°C. Warm water is provided to the surface also by two artesian wells found in that area. Temperatures of the water flowing from those wells are 43.5°C and 34°C. They were drilled in the end of 1970s or beginning of 1980s and left for the local community as a source of domestic water. Today the water is still freely flowing there but the depth of the wells as well as features of the aquifer are unknown; drilling documentation obviously does not exist.

5. CONCLUSIONS

The geothermal analysis based on geothermal gradients indicated areas of higher than average gradient values and geothermal anomalies within sedimentary basins. It is possible to conduct more precise study of geothermal gradients if temperature data from oil and gas exploration wells from Benue Trough, Chad and Sokoto basins are available. Nevertheless, the areas of geothermal anomalies with gradients above 5°C/100m found in the present study might be prospective for geothermal energy utilization. In Nigeria the most needed application of geothermal energy would be production of electricity but the real possibility of that and potential assessment needs further research.

The influence of Cainozoic 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, specially Benue

Trough as well as basement complex, contributed to the development of local anomalies that can be detected presently.

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 that natural phenomena and contribute to the exploration for possibilities of use of geothermal heat from both sedimentary and Precambrian Provinces in Nigeria.

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