GEOTHERMAL ENERGY POTENTIAL IN THE PART OF MIDDLE BENUE TROUGH LOCATED IN NASARAWA STATE

By

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JUNE, 2010

DECLARATION

I hereby declare that the research work presented in this thesis for the award of Master of Science in Geology (Hydrogeology) has been written and compiled by me, **Mr. BAKO ARUWA SARKINPADA JAMES** in the Department of Geology, Ahmadu Bello University, under the supervision of Dr Ewa Kurowska and Dr Solomon Ayo Alagbe. The research is exclusively the report of the investigation conducted by me. I also declare that this thesis has not been written or submitted in any form whether partly or wholly for any other degree in any university or higher institution. All sources of publications and other related reports cited in this research have duly been identified in the reference section.

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--BAKO ARUWA SARKINPADA JAMES DATE

CERTIFICATION

This thesis entitled

"GEOTHERMAL ENERGY POTENTIAL IN THE PART OF MIDDLE BENUE TROUGH LOCATED IN NASARAWA STATE"

BY

BAKO ARUWA SARKINPADA JAMES

Meets the regulations governing the award of Master of Science (Geology) in Ahmadu Bello University, Zaria, Nigeria,

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(Chairman, Supervisory Committee)

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(Head of Department)

…… ……...
Dean, Postgraduate School Date

DEDICATION

This work is dedicated to the sweet memory of my Late Parents who could not live to witness my achievement, but had to submit to God's unquestionable action. Dad and Mum- I miss you all; especially Mum (Gomna Agaguwa) that had to leave me orphan to join Dad on the 16 day of June 2007.

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ABSTRACT

In Nasarawa State, little known thermal springs exist. These springs are indicators of probable high geothermal potential in the Middle Benue Trough of Nigeria, within the State. However, nobody so far has studied their geothermal potential. Therefore this study is aimed at identifying and delineating the areas of positive geothermal anomalies as prospective locations of geothermal energy deposits. This study has documented these surface geothermal manifestations and added documentation of sub-surface manifestations, in boreholes drilled for water supply. The springs and boreholes were located with satellite navigator and temperature of water has been measured, Akiri thermal spring has the highest temperature (53.2 ^{o} C). Water from the thermal springs was sampled and analyzed, apart from Azara and kanje thermal Springs that are of meteoric origin, the rest(5) are of connate origin with mineralization as high as 6644-50736 mg/l . Altogether 150 boreholes and seven thermal springs were studied. Then the results were plotted in form of geothermal gradient map, the first geothermal map in the Benue Trough of Nigeria. Several positive geothermal anomalies were discovered with the highest (9.3 ^{o} C/100m) around the Awe anticline. High geothermal gradients are a prerequisite for any type of geothermal system. Therefore the exploration which will follow the effort presented in this research should concentrate on more detailed studies of the geothermal exploration techniques/methods for proper utilization of these potentials.

Chapter 1 INTRODUCTION

1.1 Statement of the Problem

A search for a renewable source of energy is inevitable as the life of a contemporary person is impossible without energy. Traditional sources of energy are unfortunately exhaustible, but there are alternative sources of energy; one of these is geothermal energy. It is sustainable heat energy from deep inside the earth (Dickson and Fanelli, 2004). Geothermal energy in many countries of the world is used either for electricity generation or direct use for heating residential houses. In Nigeria, little of this alternative source is known, even though according to Babalola (2004), there are two best known potential areas namely the Ikogosi Warm spring in Ondo State and the Wikki Warm spring in Bauchi State. According to the same source high geothermal anomalies were identified in the Lagos sub basin, the Okiti Pupa Ridge, the Auchi-Agbede, the Benin flank/hinge line, and the Abakaliki Anticlinorium.

Babalola (2004), continues that the deeper Cretaceous and Tertiary sequence of the Niger Delta contain geopressured geothermal horizons. Probable geothermal anomalies exist in the Benue fold belt, extending from the Abakaliki Anticlinorium to the Keana Anticlinorium and the Zambuk Ridge where several magmatic intrusions were emplaced during the Late Cretaceous. Also on the Jos Plateau, Bauchi Plateau and the Adamawa highlands and in all areas which experienced Cenozoic volcanism and magmatism, probability of existence of positive geothermal anomalies is very high.

1.2 Justification of the Study

In Nasarawa State, surface geothermal manifestations exist, there are thermal springs in Akiri, Awe, Keana, Ribi, Kanje and Azara, and thermal free flowing boreholes in Assakio and Giza. These springs and boreholes are indicators of probable high geothermal potential within the sedimentary hydrogeological province of the State in the Middle Benue Trough of Nigeria. However a systematic geothermal study of this promising area of Nasarawa State has not yet been conducted. This study investigated geothermic of this part of Benue Trough within Nassarawa State as a research topic for master's thesis.

1.3 Theoretical Frame Work

Working hypothesis presented in the section 1.5 below is that since there are surface geothermal manifestations in the Sedimentary Hydrogeological Province of Nasarawa State there must be sub-surface geothermal anomalies, some of them perhaps of economic significance. To prove or disprove their existence, this research embarked at systematic documentation of geothermal manifestations – surface manifestations in form of thermal springs and thermal flowing boreholes, and sub-surface manifestations, which was documented by measuring temperature at the bottom of boreholes drilled for drinking water supply. Doing this, the researcher expected that the documented geothermal phenomena, when plotted in form of map, will help to delineate geothermal anomalies on which further geothermal exploration will concentrate.

1.4 Objective of the Research

The research is aimed at measuring temperatures of water in thermal springs, thermal freely flowing boreholes, and in pumped boreholes; with the aim of producing a map of geothermal gradient within the research area that will be used in identifying and delineating the areas with favourable geothermal conditions.

1.5 Statement of Research Hypotheses

The research hypothesis, adopted in this present work, is that the geothermal surface manifestations observed in parts of Benue Trough located in Nasarawa State are indicators of deposits of geothermal energy, which is needed to be identified and delineated.

1.6 Location, Extent and Accessibility

The study area is bounded by latitudes 8^{o} 00'N to 9^{o} 30'N and longitudes 7^{o} 00′E to 9^{o} 10'E (Fig1). Politically, Nasarawa State is centrally located in Nigeria, in the region called the Middle Belt. It shares borders with Federal Capital Territory (FCT) Abuja in the west, in the south west with Kogi State, Benue State in the south east, Taraba State to the east, Plateau and Kaduna States to the north. Nasarawa State is approximately 27,119 km^2 in area according to the Nasarawa State Ministry of Information (2005). The area is accessible with a good network of roads and rural feeder roads.

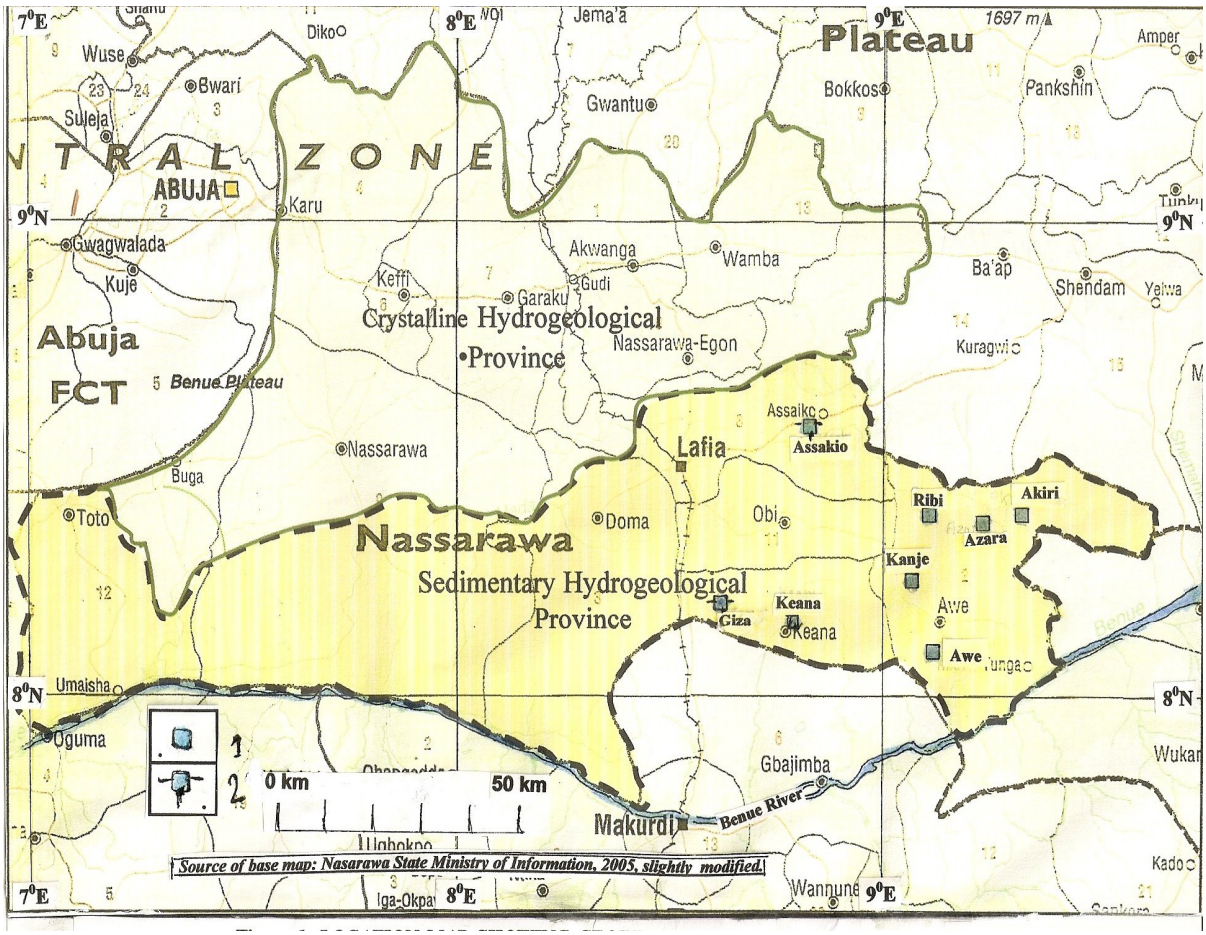


Figure1. LOCATION MAP SHOWING GEOTHERMAL MANIFESTATION IN THE STUDY AREA. Source of base map: Nassarawa State Ministry of Information, 2005, Slightly modified. Note geothermal manifestation: 1-thermal springs; 2-thermal flowing boreholes.

Note that Northern part of the state is located within Crystalline Hydrogeological Province of Nigeria, while the southern part is located within the Sedimentary Hydrogeological Province and especially within the Benue Trough. The study area is limited to the Sedimentary Hydrogeological Province.

1.7 Relief and Drainage

The relief is undulating highlands to average height of about 427m (1,400ft) above sea level on the Crystalline Hydrogeological Province but has fairly plain terrains on average 100 m (300 ft) on the sedimentary hydrogeological province. All rivers flow through the Study

Area from the north to the south, to empty their water into River Benue. All of them are perennial rivers.

1.8 Climate, Vegetation and Landuse

Nasarawa State is characterized by two distinct seasons; dry and wet. The dry season spans from November to February, while the wet seasons is from March to October. Wet season starts normally from early April till ending of October, on average of about 210 days. The relative humidity of air varies. The cumulus and cumulonimbus clouds produce rains, heavy and thundery, at the beginning of every wet season. It is more pronounced, steady and prolonged towards the end of the raining season. The dry season on the other hand last from early November to ending March, on average of about 150 days. The first half of the dry season is called harmattan period. It is normally dominated by dusty wind, while the second half is a purely hot period (without wind but instead very sunny).

The vegetation of the study area falls within the southern Guinea Savanna zone. The vegetation type is an open forest mostly predominated by the species *Khaya senegalensis*. The vegetation is affected in some areas because of human activities. Human activities have intensely reduced the vegetation to tree savanna (mostly economic trees) where clusters of trees stands amongst grass and shrubs. Other common natural tree species found scattered in the area are *Daniella oliveri, Prosopis africana*, *Parkia clappertoniana, Cutyropermum paradoxina*.

Broadly speaking, the vegetation can be divided into two types made up of: a) The flood plain complexes of savannah, which is a mixture of several vegetation types, found on river flood plain; b) Mixed leguminous, wooded savannah characterized by mixed formation of trees, shrubs and grasses. It is also wooded with *Daniella oliveri* and oil palms. Economic

trees, mostly citrus, mango, bananas, cashew,and oil palm trees have replaced most of the natural tree vegetation in the area of study.

On land use, sugar cane and other garden crops, mostly vegetable, are intensively cultivated especially along stream courses. The perennial flow streams in the area sustain such cultivation in the dry season via traditional shad of irrigation system. Dominant food crops found in the area include the root crops, e.g- yam and cassava. Other crops include sorghum, maize, rice and beans. Along the ridges, the grassland is interrupted by bare grounds mostly of ironstones and iron pans which hardly have soil to sustain any vegetation of significance. Such areas are also uncultivated and have invariably attracted the erecting of buildins and hamlets.

Chapter 2 PREVIOUS WORKS

2.1 General Geological Setting

Nasarawa State of Nigeria has the two geological terrains namely the Basement Complex terrain and the sedimentary terrain. The northern part of Nasarawa State is covered by the Basement Complex rocks while the southern part is sedimentary (Fig. 1). Nasarawa state is underlain by Precambrian migmatite-gneiss complex, metasediments/metavolcanics (mostly quartzite and banded iron formations). These various rock units have been affected by many periods of orogenic movements, resulting in extensive deformation and migmatisation. Eduvie (2003) reported that the oldest rocks of the area are the gneisses and older metasediments believed to be Birrimian in age (about 2,500 my).

The southern part which is covered by the sedimentary rocks is believed to be part of a long narrow stretch of sedimentary basin extending from the Gulf of Guinea to the northeast. The basin comprises essentially the Abakaliki trough, slightly displaced to the southeast, and the central Benue Trough. The two troughs are structurally controlled and their origin is controversial.

The Benue valley is loosely subdivided geographically into an upper, middle and lower Benue valley. The Lafia-Keana-Awe area falls within the middle Benue area and is the link between the south Atlantic and the Tithes. The geology of the region, according to Offodile (1976), is determined mainly by six sedimentary Formations. The oldest, the Asu Formation, occupies the crest of a major structure, the Keana anticline, is flanked on either side by the Awe and Ezeaku Formation. The youngest Formations, the Awgu and Lafia

Formations are only on the eastern flank. Remnants of the younger Formations are, however, found on some of the volcanic hills on the axis of the Keana Anticline. The superficial deposits consist essentially of the soil cover, arising mainly from the weathering of the underlying lithological units. The soil texture and colour vary from place to place, depending on the underlying strata.

The project area is located within the Cretaceous sedimentary rocks of the Middle Benue Valley. The area was first mapped geologically in 1957 by Shell-BP on a small scale of 1,250,000. The map was based on photo- geological interpretation with few ground traverses. Similar mapping was undertaken in 1967 by ESSO West Africa. Both maps were unpublished (*fide*: Aku, 1983). The current geological map in use that covers major part of the area of this project was by Offodile (Offodile, 1976) as a doctoral thesis on the scale of 1:100,000. Additionally, some investigations have been carried out around the Middle Benue Trough aimed at determining the general geology and stratigraphy and possible enrichment of radioactive minerals in the sediments. Other works include Hydrogeological investigations aimed at determining the hydraulic properties of the aquifers as well as assessing the general water resources and the physico-chemical properties of both springs and groundwater of the area. Nevertheless studies from geothermal point of view have not been conducted as evidence of such studies does not exist.

Offodile (1976) considered the geology of Keana-Awe area to have comprised essentially, six geological Formations;- Asu River, Awe,Keana, Ezeaku, Awgu and Lafia Formations. The Asu River Formation consists of shale and siltstones of marine origin, representing the first Albian transgression into the Benue valley and marked by species of the ammonites' genus *Oxvtropidoceras*. The Awe Formation marks the beginning of the regressive phase of the Albian sea, with transition beds of continental fluviatile sands of the Keana Formation

followed by the marine strata of the Ezeaku and Awgu Formations, indicative of the Late Cenomanian-Turonian and Coniacian transgressions respectively. Continental conditions prevailed after probably, the intensive Santonian tectonic activity. Continental beds of the Lafia Formation were thinly deposited and appeared to have thickened southwestwards.

The structural framework of the area according to Offodile (1976) coincides with the setup in the Benue Valley as a whole. The dominance of the Keana Anticline and its possible relationship to the moderate positive gravity anomaly of the Benue Valley suggests some regional fracture systems. The economic importance of the region is studied with particular reference to the occurrence of brines which are thought to be of economic interest. Other rocks of economic interest include: limestone, barites and coal.

The hydrogeology of the area was briefly considered by Aku (1983). He studied the groundwater resources of the Lafia catchment area; the study shows that the predominant rock is sediment of mostly interbedded sandstones, clays and mudstones. Logs of boreholes drilled within the study area placed the thickness of the continental sediments bearing water at over 150m. The Lafia groundwater are generally potable except for Fe^{2+} and Mn^{2+} concentrations which exceed acceptable limits in certain areas. According to a report on the geology and geochemistry of salt springs in Keana, Azara, Kanje, and Awe by David and Raymond of the U.S Geological Survey submitted to the Ministry of Mines and Power, Republic of Nigeria (GSN,1966), it reveals that the salt springs arise from marine sediments of Cretaceous age. These sediments occupy an easterly trending structural trough which parallels the River Gongola, Benue and Niger. Westwards from the springs in Lafia area and towards the delta of the River Niger correlative rocks are of marine origin; eastward in the

basin of the River Gongola, they are dominantly continental. These would imply that a transitional zone from marine to continental conditions of deposition, perhaps favorable to the deposition of evaporites, occurs in region of the salt springs. Structural details in this part of the Benue basin have not been mapped. However, it might also be significant that three of the springs arise in areas of structurally deformed black fissile shale, siltstones and fine-grained sandstones. In some places, the rocks have been intruded by basalt of Tertiary age and they also occur in an area known to be mineralized by small deposits of barites and galena.

Gravity surveys of Benue Basin by Cratchley and Jones, (1965) indicate the presence of elongated anomalous features in the subsurface which in general parallel the axis of the basin. Pronounced anomalies are also near and parallel to the northern edge of the basin. The interpretation of these features is upon assumptions which appear reasonably valid. The most plausible model suggests that axial parts of the Basin are underlain by crystalline rocks at relatively shallow depth. However, results are not sufficiently conclusive to eliminate a comparable influence by rocks of sedimentary origin. In the area of the salt springs, it is reasonable to postulate a sedimentary succession of at least 4,000 metres thick.

At present, the evidence for the large deposits of saline minerals in the subsurface near Lafia is not sufficiently encouraging, warranting a special purpose borehole to test these possibilities. Secondly, the most promising area in which to attempt improvements or alterations in the industry appears to be at Awe. Two possibilities exist here: boreholes drilled to depths of less than three hundred and five metres encountered permeable sediments saturated with brine and under sufficient pressure flow at the land surface. More than likely

however, if the discharge from the boreholes is large the concentration of total dissolved solid will be low, the Ministry of Mines and Powers (GSN, 1966) continues. The hydrochemical water sample analyses of the springs show that the sodium chloride types characterized by relatively low concentrations of other associated anions and cations. Total dissolved solids range between 7.550 and 20,000 parts per million (p p m): more than 90% combined sodium chloride is present in each sample. The source for the sodium chloride is of economic importance. The meager discharge from these and other small quantities produced by the evaporation of water from Lake Chad represent the sole internal supply in Nigeria and meet considerable requirements in salt. The compositions of these waters suggest a discrete source for sodium chloride in these waters.

2.2 Lithological Characteristics

The lithology of the project area is of great interest as it relates to defining the extent and thicknesses of the various Formations. Lithological logs obtained from boreholes drilled between 1979 and 1982 in and around Lafia-Awe-Keana areas indicate that the Lafia Formation is far thicker and extensive than has been established. Based on the simple lithological description of boreholes, the thickness of Lafia Formation is placed at about 150 m around the town but attenuates fairly rapidly in the northwestern and western directions. The Ezeaku Formation has series of silt argillites, cavernous limestones and dolomites, with marls and sandy horizons. Asu River Group (Arufu, Uomba and Gboko Formations) consist of shales, Limestones and sandstones. Awe and Keana Formations consist of sandstones, siltstones and claystones while Awgu Formation consist of shale, coals, limestone, siltstones (Figs.2, 3 and 4).

2.3 Stratigraphy and Structures

The study conducted by Offodile (1976) distinguishes six sedimentary Formations. The oldest, Asu River Formation being Middle to Albian and the youngest, Lafia Formation is of the Maestrichtian age. The stratigraphy of the area and its correlation to the adjoining region of the Benue Trough show that they have the same source of origin. The Awgu Formation is believed to have been deposited during the Coniacian transgression.

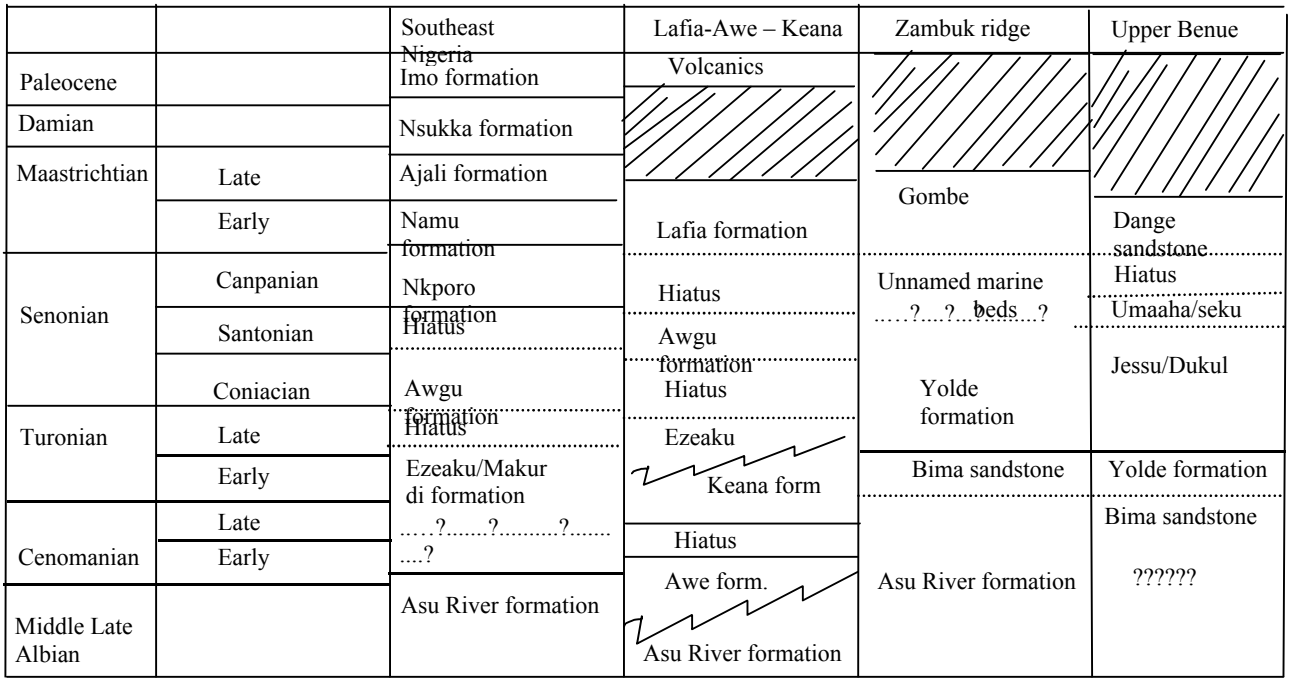


Figure 2. STRATIGRAPHY OF THE MIDDLE BENUE VALLEY IN CORRELATION WITH OTHER PART OF THE BENUE VALLEY (after Offiodile, 1976).

The environment type of deposition was shallow marine conditions and this warrant the formation of coal seams interbedded with shale, limestone and occasional sandstones. The Awgu Formation is overlaid by the Lafia Formation. It is made up of predominantly fluviatile sandstones considered to be of Maestrichtian age. The ferrugination associated with sandstones of the Lafia Formation is of probable syndepositional origin arising from strong oxidizing tendency that existed during the prevailing continental conditions (Offodile, 1976).

Structurally, Lafia-Awe-Keana conveniently falls in the belts of Cretaceous sediments deposited in the Benue Trough.

Post-cretaceous		**Volcanics**
Late cretaceous	Maastrichtian	Lafia formation?
	Santonian-campanian	Volcanics
	Coniacian	Awgu formation
	Late Turonian	Hiatus
	Early Turonian	Ezeaku formation
	Late Cenomanian	Keana formation
		Hiatus
	Early Cenomanian	Awe formation
Early cretaceous	Middle – late Albian	Asu river formation

Figure 3. SUMMARY OF THE STRATIGRAPHY OF THE KEANA – AWE AREA (after Offiodile, 1976).

From the results of regional geologic studies of north eastern Nigeria (Cratchley and Jones, 1965) of South- eastern Nigeria and of nearby deposits of lead-zinc mineral deposits by Farrington, 1952, in Offodile (1976) concluded, that deformation along this trough in Cretaceous time was sufficient to allow several depositional activities of both marine and non-marine sediments to take place.

It is believed from the interpretations of geology and gravity anomalies of the Benue valley (Cratchley and Jones, 1965) that the Benue valley originated as a rift valley under tension which continued while these sediments were being laid down. The salt springs in Lafia division arise from sediments of Cretaceous age that crop out about midway between these two areas of known stratigraphy, according to Offodile (1976).

The major folds trend in the Lafia-Keana -Awe areas run northeast-southwest at the azimuth

CHRONO-STRATIGRAPHY	FORMATION (approx. thickness)	LITHOLOGY	PALAEO-ENVIRONMENT
Tertiary-Quaternary	Alluvium Volcanics	Sand Volcanics	Alluvial Volcanics
Maastrichtian	**Lafia Fm** (800m)	Sandstones, Siltstones, Claystones.	Fluvial
Campanian			
Santonian	**Awgu Fm** (1000m)	Shales, Coals, Limestones, Siltstones	Shallow marine, Deltaic
Coniacian	**Ezeaku Fm** (500m)	Shales, Limestones	Shallow marine
Turonian	**Keena Fm** (500m) / **Awe Fm** (400m)	Sandstones, Siltstones, Claystones	Fluviodeltaic
Cenomanian			
Albian	**Arufu, Uomba, Gboko Fms** **(Asu River Group)** (1800m)	Shales, limestones, Sandstones	Marine
Pre-Albian	Basement Complex	Granites, Gneisses, Schist, Migmatites	Igneous, Metamorphic



Figure 4. STRATIGRAPHIC SUCCESSION IN THE MIDDLE BENUE TROUGH (after Obaje and Hamza, 2000).

210^0, while the strike tends to reflect the sinuosity of the fold axes. There are also minor flexures runs approximately north west-southeast almost at right angles to the former. The sinusoidal feature of the main fold axes is thought to be due to the Lafia Formation because of the Cretaceous sediments. This effect is very obvious on the Awe Formations at Awe.

The Keana anticline is the major structural feature and dominates the geology of the area, it is marked by a long ridge southwest-northeast to the east of Keana town and scattered by few volcanic plugs. The structure is over 100 km long and extends towards the south to Makurdi area. The dips are variable. In the Asu River Formation, they vary from 1^0 on the crest of the Keana Anticline to 27^o on the flanks. The older formations are characteristically intensely folded, and in the Asu River Formation, drag fold features are common. These features according to Offodile (1976) are thought to have resulted form repeated compressive forces that have acted on the Formation. Faults and fractures are not well exposed, evidence of numerous fractures occurs and some of them reflect the existence of major faults.

Chapter 3 MATERIAL AND METHODS

3.1. The Study Design

The geothermal energy potential field investigation of the Sedimentary Hydrogeological Province of Nasarawa State was carried in three stages; a) field temperature data collections of thermal springs; b) data collection from free flowing boreholes and c) data collection from pumped boreholes. The evaluation of field data was prepared in form of the geothermal map.

3.2 Sources of Data

This is the illustration of the procedure employed in the conduct of this research. Basically three methods were employed in this research work. These are: obtaining primary sources of information, archival or secondary sources of information, and laboratory sources of information.

The primary sources of information include readings of temperature of thermal springs and boreholes water at depths. This work was done through the help of some assistants. Air temperatures at borehole sites and temperature of water at the bottom of borehole, were measured in situ with mercury maximum-minimum thermometer graduated $0.1^{o}C$. topographic maps, geologic compass and satellite navigator, were used as guide in locating thermal springs points, borehole sites and their features while buckets were used for measurements of yields,.

Archival sources included books, journals, bulletins, and unpublished reports for literature on temperature of thermal water on the surface and on the subsurface of the earth.

The third source of data is the laboratory source. Water samples were collected from the thermal springs and analyzed at the laboratory of Silesian University in Katowice, Poland in order to obtain information about the chemical composition of these waters. The water samples from boreholes were not taken because the main objective of this project is to determine the geothermal energy potential through the rate of changes in temperature with depth (that is geothermal gradient).

3.3 Field Temperature Data Collection

It took seven days to collect temperature data from seven thermal springs (22-29 May, 2008) and 45 days to collect temperature data from 150 boreholes (25 October-10th December 2008). The temperature data collected on the study area are of two types; ground surface temperature (air temperature) at every thermal spring and borehole site, and groundwater temperatures measured at the bottom (depth) of each borehole and thermal spring location.

The temperatures were measured with the mercury –in- glass type minimum and maximum thermometer. It was usually submerged into the thermal springs and bottom of boreholes. In case of boreholes, the thermometer was inserted into a PVC tube of 1¼ inch diameter and tied to a string (marine rope) of about 250 meters length. The string/marine rope was then lowered down the bottom of the borehole and allowed to remain there for at least 15 - 20 minutes to stabilize the temperature. In boreholes the temperatures were read after removing the thermometer from the PVC tube this was made possible because the thermometer has the ability to retain the last (highest) temperature reading until the mercury in the thermometer is drag down with the use of a magnet or thorough shaking. In thermal springs, the thermometer was not inserted into PVC tube but submerged directly into the spring and left

there for 15 to 20 minutes after which the reading was taken. After the reading, the thermometer was normalized either by dragging down the mercury using a magnet or by thorough shaking before using it at the next site.

The temperatures measured in springs and boreholes are shown in tables 1 and 2. Almost all boreholes were shallow, between 32 and 40 metres, but it is still enough to determine geothermal gradient. Two boreholes are flowing freely (artesian wells) as it is the case of boreholes No. 6 and No. 94 in table 2, and the temperature of water, measured at their bottom was high (42.0 ^{o}C).

Chapter 4 THE RESULTS

4.1 Temperatures of thermal springs

4.1.1. General introduction to the springs

The thermal springs were located using geographical coordinates (see Table 1 and Figs 5 to 12), which were measured with Garmin satellite navigator during the field work. To the best knowledge of this writer, it is the first measurement of coordinates and the first accurate locations of these springs on detailed topographical maps. From the field work results, presented in table 1, it is observed that all the warm springs are located at the culmination of the Awe Anticline within the outcrops of the Eze Aku Shale Group and Asu River Group (see Figs.14 and 15). The warm springs and pools occur in the low-lying, undulating country of the study area on the Awe Anticline. The warm springs are saline, indicating presence of salt dome within the environs. Detailed investigation of these saline springs was undertaken by the Colonial Mineral Surveys of Nigeria, during the years from 1904 to 1905 and at Awe shallow boreholes were drilled, the deepest being 17 meters. The effort was to increase the yield of brine. . On a general note, sizeable village are in the near vicinity of each spring and one of the main occupations of the inhabitants is the production of salt by evaporation of water from the springs. Water from each spring is relatively diluted brine.

The warm, saline springs distributed throughout the Benue River valley flow from the Cretaceous sedimentary rocks. No beds of rock salt are exposed at the surface within this belt, and from a consideration of the Lower Cretaceous lithology seems unlikely that such beds are preserved at deeper levels. It is improbable, therefore, that the saline springs originate from such a source. Comparably the brine which in many oilfields throughout the

world collects in anticlines below the oils is of connate origin, and is considered to have been derived from sea water imprisoned in the pore space, of marine mud which were later converted to shale. As a result of fracturing of the overlying cap rock the oil may have been dissipated though much of the underlying brine may still be preserved to occur at the surface in the form of springs. Such an origin is feasible for the saline springs of Nigeria, and it was observed by Falconer and reported by Offodile (1976), that the latter commonly occur near the foot of anticlines or domes. On the other hand it has been suggested by Dr. R.B. McConnell (fide: Offodile 1976), that the brines are not connate in origin, and that the springs represent a late hydrothermal phase of an expiring period of recent volcanic activity. In support of this theory it is significant; that recent volcanic rocks of comparatively recent igneous infusion occur near all the brine springs e.g. Awe, Keana, Akiri. Also relatively high percentage of bicarbonates and carbonates further suggests their volcanic origin. If the theory put forward by Dr. McConnell is correct, there is little hope of finding commercial concentrations of brine at depths.

4.1.2. Description of the Thermal Springs

Akiri Thermal Spring

The thermal spring is located 4 kilometers north of Azara and two and half kilometers west of River Ankwe. The area is 2 kilometers after Wuse village (Fig.5) and is covered by alluvial deposits of sand and silt. The spring discharges from theses sediments (Plate 1).

The spring's pool serves as a source of water for bathing and livestock besides uses as a local source of salt (Plate 2). The temperature of the spring at the time of measurement was

53.2^{0}C. The water is rich in sodium chloride and has total dissolved solid concentration of 6644 mg/l (T*able 2)*



Plate1. AKIRI THERMAL SPRING, THE VIEW. The spring flows from the alluvial sediments covering shales and limestones of Asu River Group, Albian To Cenomanian. The Author, sampling water, is surrounded by children from Akiri Village.

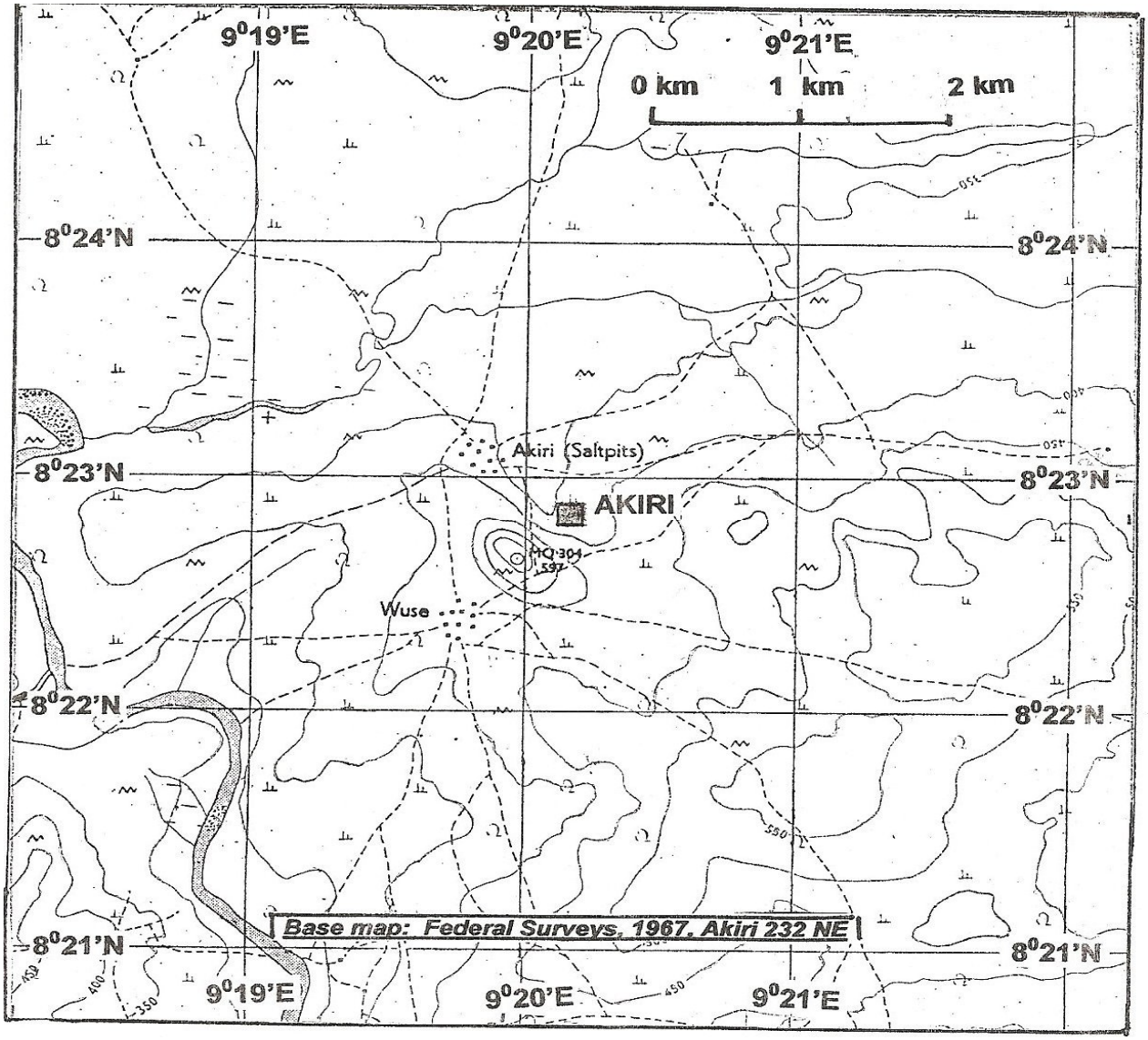


Figure 5 . LOCATION OF AKIRI THERMAL SPRING. The spring yields 1.0 l/s of connate water, its mineralization 6.6 g/l and temperature 53.2^{0}C;



Plate 2. AKIRI THERMAL SPRING AND BRINE FLOWING FROM IT. With its mineralization 6.6 g/l, it is still used for production of salt and for bathing. The reader may note that it is women and children who are producing the salt.

Awe Thermal Springs

In Awe there are three thermal springs (Fig. 6 and Table 1). The spring Awe 1 is the most conspicuous among the three. Awe town is almost 65 km away from Lafia town.

The area of the spring Awe 1 is a low circular depression of about of half a kilometer in diameter. This depression is surrounded on all sides by marshy land created by seeps and warm springs. The village rests on a thin layer of sandy silt, probably largely formed from the constant process of weathering (Plates 3 and 4).

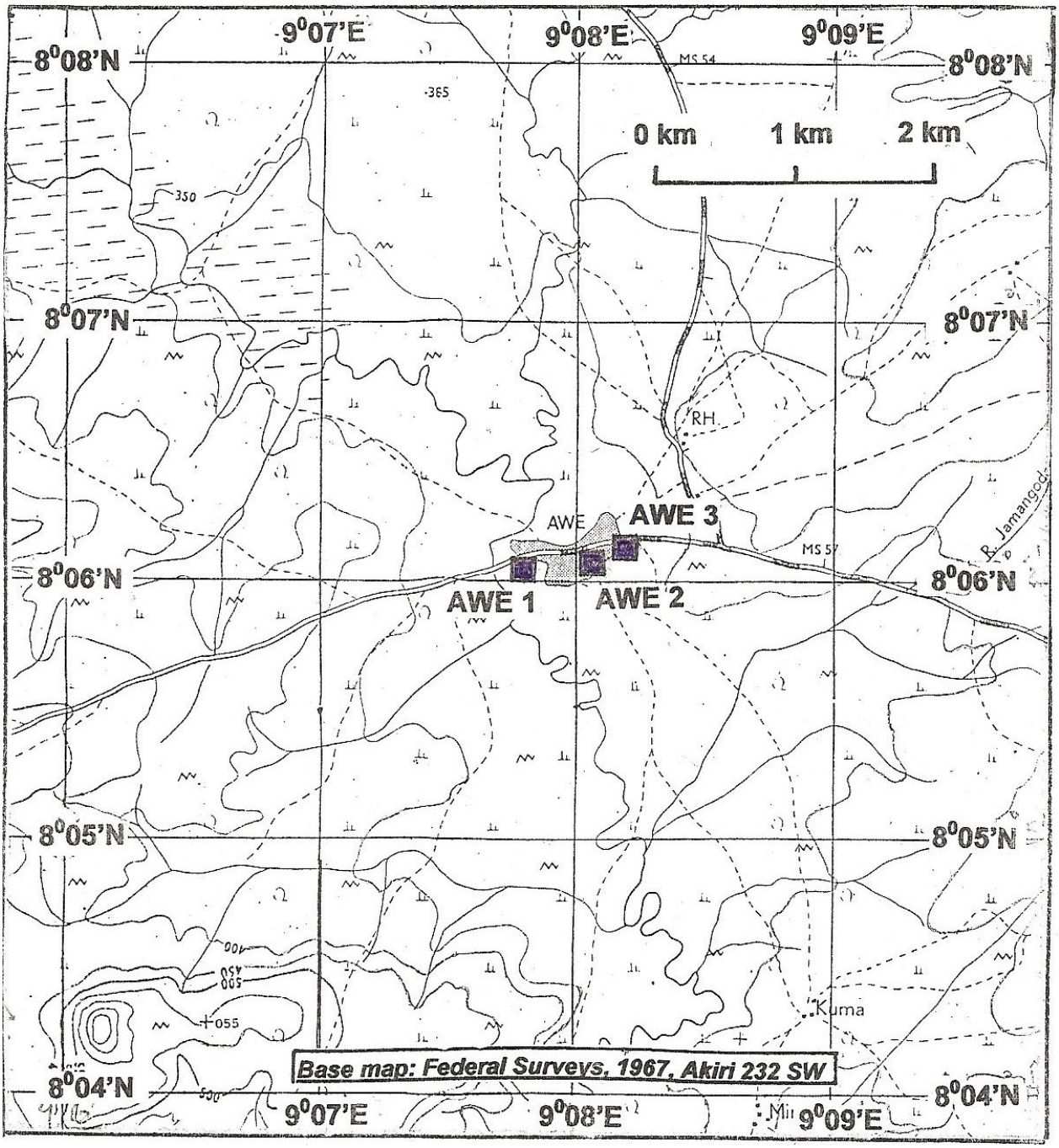


Figure 6. LOCATION OF AWE THERMAL SPRINGS.

Awe 1 Thermal Spring yields 1.5 l/s of connate water, its mineralization 10.2 g/l and temperature 43.4^{0}C; Awe 2 Thermal Spring yields 0.5 l/s of connate water, its mineralization 10.8 g/l and temperature 38.6^{0}C; Awe 3 Thermal Spring yields 0.2 l/s of connate water, its mineralization not known, temperature 34.8^{0}C.



Plate 3. DEPRESSION AROUND AWE 1 THERMAL SPRING. The reader may note, that salty water is carried away to the thatched houses (outside of this picture) for evaporation.

Underlying this thin layer of detritus and exposed throughout the surrounding marsh lands, are alternating beds of coarse grained sandstones, thin beds of pebble, conglomerate, siltstones, limy siltstone and beds of pyritiferous black shale. This sediment is gently folded seemingly in a small anticline structure with an axial trend which is generally eastward. Three of the most productive warm spring was visited and samples were taken. All the three originate from beds of jointed sandstone which crops out in the marsh land about 100 meters north of the village (Plate 5).

A shallow borehole, of about 17 meter deep, was drilled within the Awe 1 Thermal Spring site, with the aim of mining salt, by the Colonial Mineral Surveys in 1904 and 1905. Discharge from the first spring is about 1.5 l/s, while temperature of water was 43.4^{0}C at the time of measurement.



Plate 4. AWE 1 THERMAL SPRING, MEASUREMENT OF TEMPERATURE. The reader may note the thatched hut, for evaporation of salt, in the background and the settlement resting on the thin layer of loamy clay.

The second spring, Awe 2, about 500 meters east of the first one, has a discharge of about 0.5 litres per second from the small pool lying between gently dipping beds of resistant sandstone (Plate 5). The three thermal springs, Awe 1, Awe 2, and Awe 3, were also used for bathing purposes and the water was carried to the village, where, until the present day, it is evaporated for salt production. Temperature of the Awe 2 Thermal Spring at the time of measurement was 38.6 ^{0}C and the temperature of Awe 3 was 34.8 ^{0}C. Awe 3 Warm Spring has yield 0.2 l/s. Awe 1 and Awe 2 springs yield water rich in sodium chloride, with total

dissolved solids 10196 and 10765 mg/l respectively (see analyses in Table 2). Awe 3 Thermal Spring was not sampled.



Plate 5. AWE2 THERMAL SPRING, THE VIEW. The water flows from gently dipping beds of sandstone.

Keana Thermal Spring

The thermal spring at Keana is located south slope of a broad open valley about two kilometers east of the town (Fig.7). The valley and the slope bordering it are underlain by alluvial deposits of sand and clayey silt. For many years the inhabitants of Keana have

excavated a large circular depression at the spring. The alluvium is exposed in the sides and floor (bottom) of the depression which is about two metres deep (Plate 6)

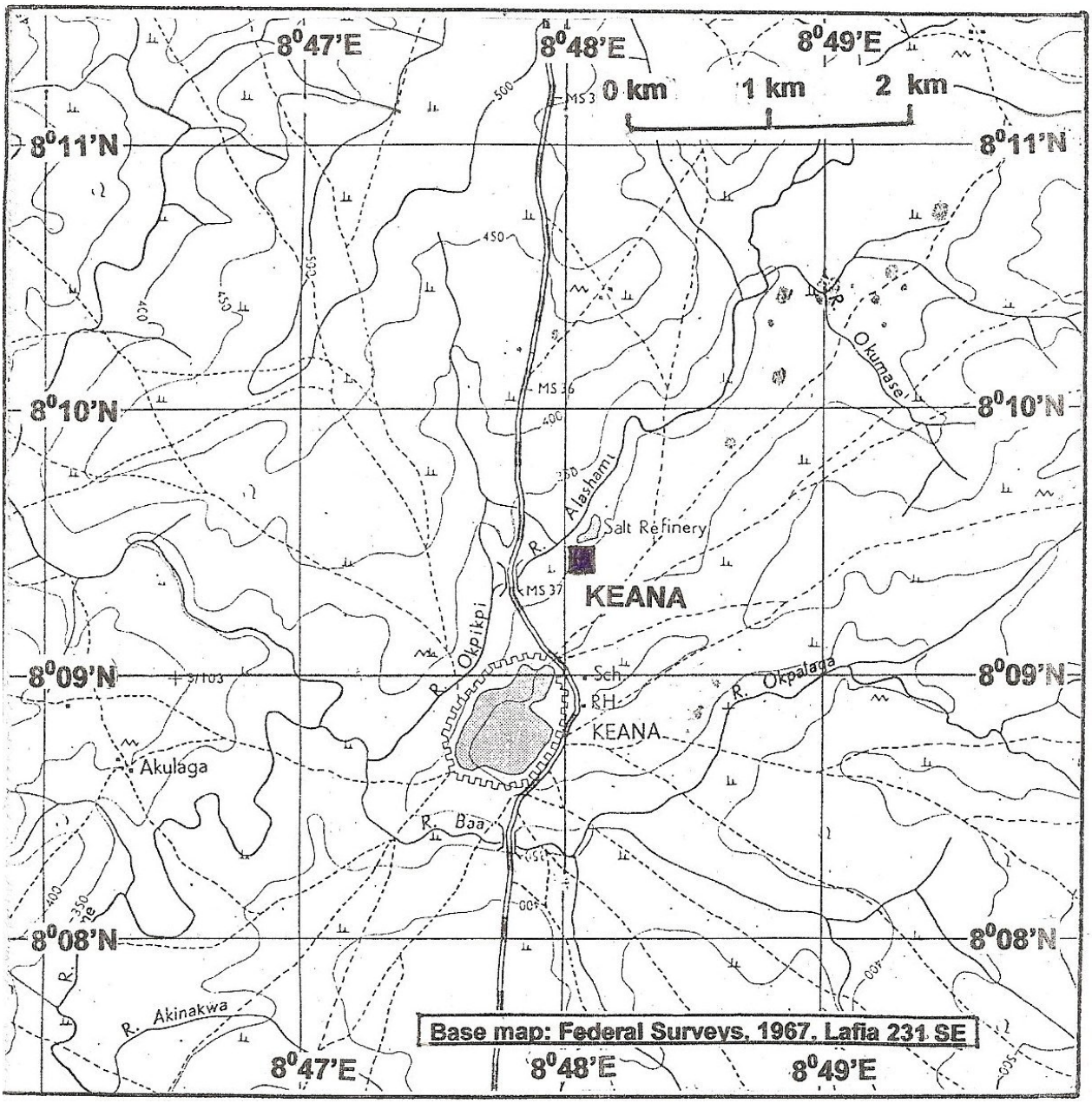


Figure 7. LOCATION OF KEANA THERMAL SPRING. The spring yields 0.6 l/s of connate water, its mineralization 13.5 g/l and temperature 36.4^{0}C;

The evaporation surface, used for concentration of salt, covers a semi circular area on the slopes with depression several metres south of the spring.



Plate 6. KEANA SALT RAFINERY. See, please, depression in Neogene to Recent sediments covered by green, fresh vegetation surrounding the pool of water in the background. There is the place of Keana spring, now covered by pond.

During the rainy season the evaporation process is abandoned and rain runoff fills the spring depression with fresh water. The artesian pressure and discharge at the spring is insufficient to replace this fresh water and hence the pool is periodically pumped out. The alluvium exposed at the spring obscures the underlying geology in most places surrounding Keana. However, in less than one kilometer south of Keana contorted black fissile shale outcrops locally along side of the dirt old road leading to Makurdi. These rocks are believed to be of marine origin. Few kilometers east of the warm spring, is a conspicuous but small conical hill believed to be a small cone of basaltic lava similar to several such occurrences in the Benue Basin.

The water collected from the Keana Thermal Spring during dry season, has high in concentration of sodium and chloride, and mineralization about 13 g/l (Tables 1 and 2). However, according to information from the villagers, during the wet season it is highly diluted. The water sampled during the dry season, as Table 2 shows contains similar constituents as other saline waters in the area.

The temperature of water from the spring at Keana was measured at several places in the spring pool. The highest temperature measured in the centre of the spring pool, where water is discharged when the pool is drained was 36.4 ^{0}C (Table 1).

Azara Thermal Spring

Azara thermal spring is located to the north from the axis of Awe anticline, about one kilometer west from the centre of Azara town (Figure 8).

Inhabitants of this area used this spring over a long period of time and excavated around it a large circular depression about 8 meters deep.

In this process they have removed the thin blanket of alluvial deposit, which formerly covered consolidated thinly bedded limy sandstones. The exposed beds are dipping at about 68^{0} eastward and strike north-south at 0^{0}. They are cracked and distorted by faulting (Plate 7).

The inhabitants say that formerly the spring yielded salty water, but now the water is becoming fresh. They added, that formerly early in the morning thin encrustation of salty mineral coating exposures of the shale and sandstone in the exposed parts of the pit could be

seen. But now it can not be seen. And the villager are no more producing salt in Azara, instead they engaged themselves in mining of barite (plate 8).

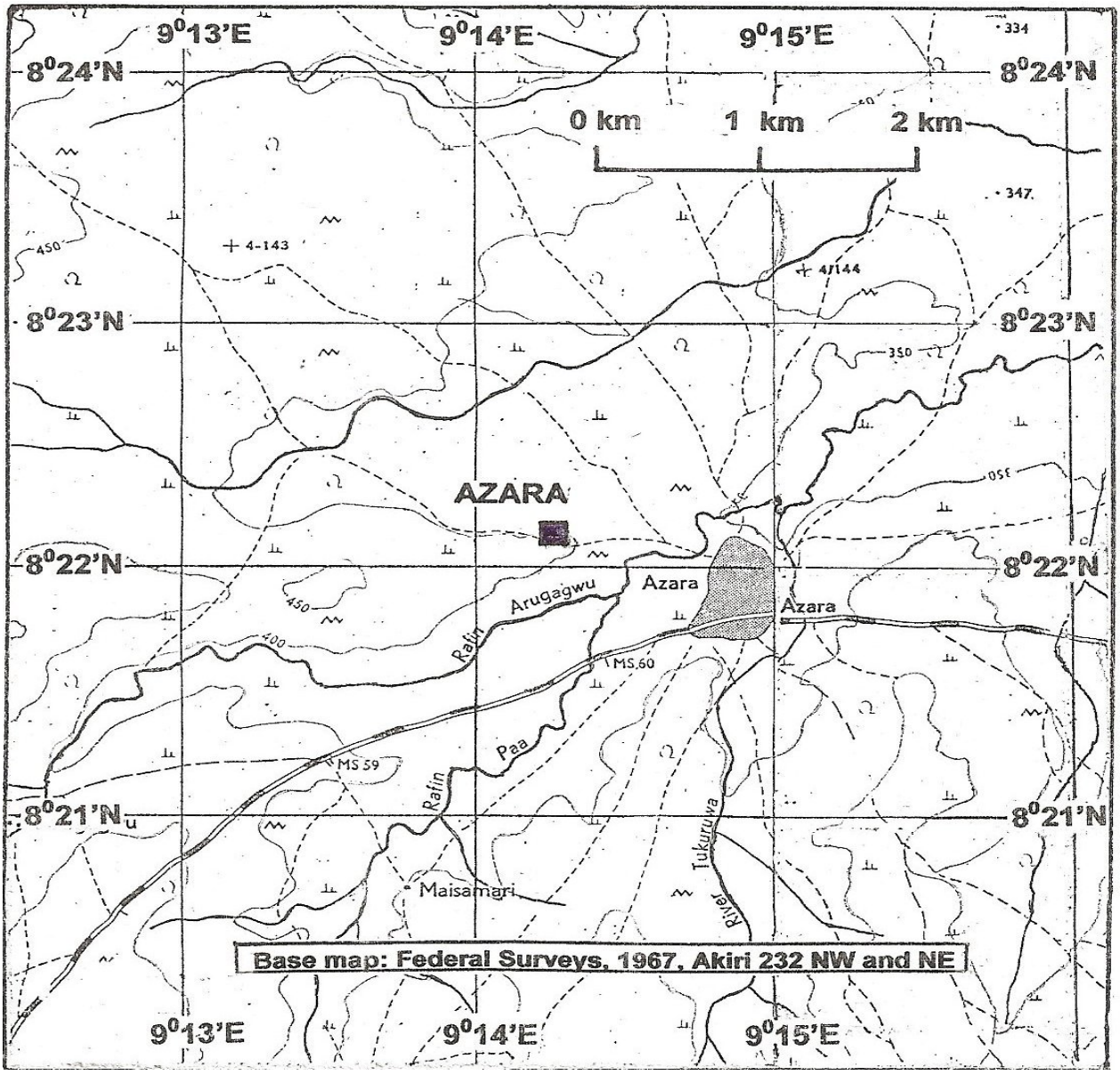


Figure 8. LOCATION OF AZARA THERMAL SPRING. The spring yields 0.4 l/s of meteoric water, its mineralization 0.8 g/l and temperature 33.4^{0}C.



Plate 7. AZARA THERMAL SPRING. The spring is covered by pond now.

However they say that since production of salt is part of their inheritance, there are still two or three women in the town who still evaporate this highly diluted water to produce a little salt. Water from the spring, as laboratory analysis presented in Tables 2 and 3 shows, 0.8 g/l in dry season, is now so diluted that the villagers use it for drinking despite its slightly saline taste.

Calcite and barite vein lodes occur abundantly throughout the broken rock. Small scale mining of barite for needs of oil industry and copper ore – malachite sold to intermediaries coming from Lagos, probably for export, is still active.



Plate 8. MINING OF BARITE AND CALCITE AT AZARA. The lode is north-west from the Azara Thermal Spring.

The discharge or flow rate of the spring at the time of the measurement was 0.4 l/s (Table 1) a small pool of water was seen in the bottom of the pit. The water seeps originate from fractured and jointed rocks on the walls of the pits. In old days, when the salt in Azara was actively mined, during the dry season the entire discharge of the springs was collected in calabash containers and carried to the nearby mud pans where it was evaporated and further refined to make marketable salt product. The temperature of water, 33.4 ^{0}C at the time of measurement, is presented in Table 1.

At all of these localities, the exposed rocks are sandstones, limy sandstone and black shale and they are structurally, complicated by faulting and folding. The relationship of these

rocks and the structure can be believed to also comprise of rocks of Cretaceous age which occupy other parts of the Benue Through in the Lafia area.

Kanje Thermal Spring

Kanje Thermal Spring is located in the centre of the group of all the warm springs discussed in this study, at the axis of the Awe Anticline. The area is covered by alluvial deposits of sand and

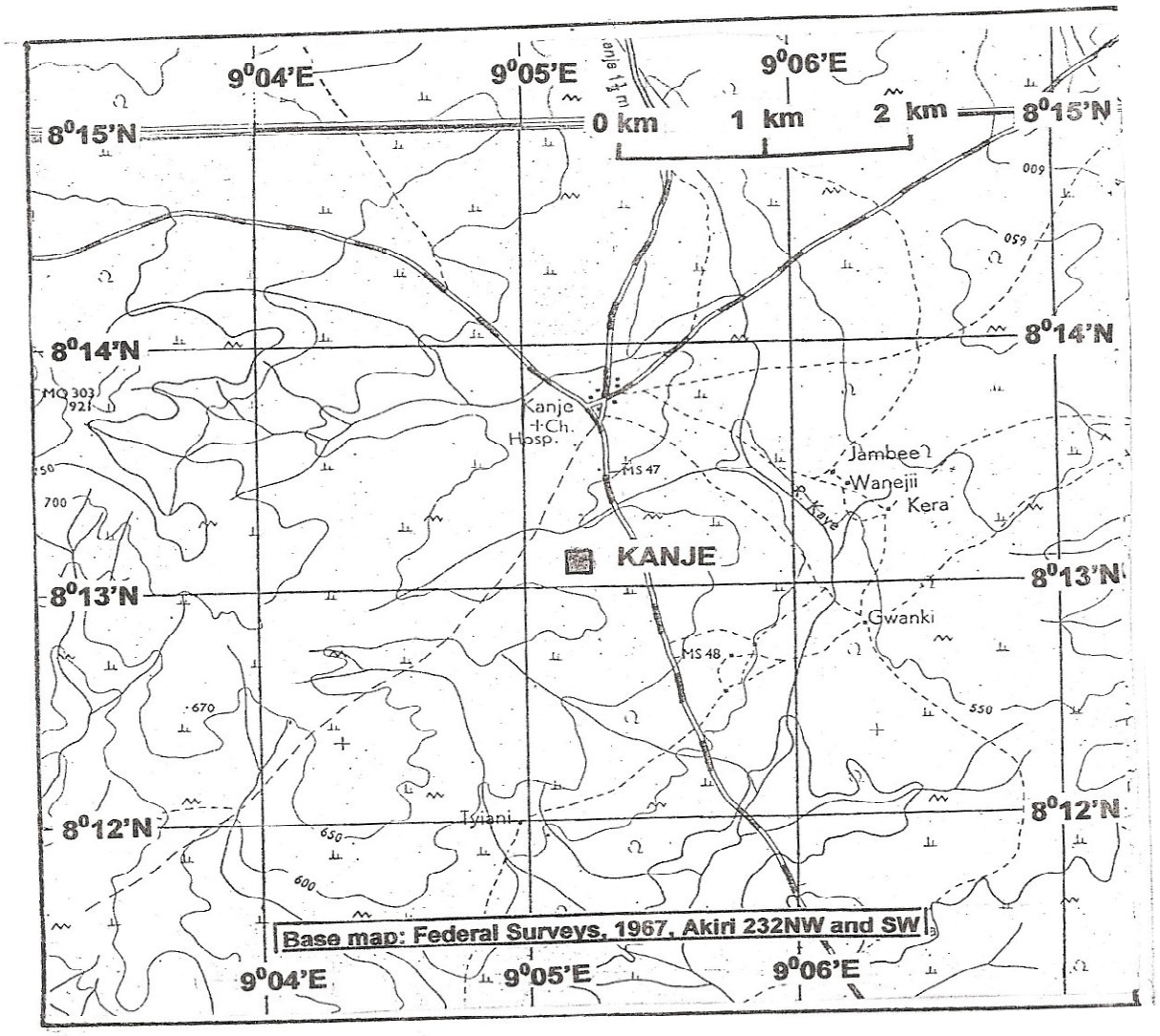


Figure 9. LOCATION OF KANJE THERMAL SPRING. Kanje Thermal Spring yields 0.4 l/s of meteoric water, its mineralization 0.1 g/l and temperature 33.4^{0}C.

Silt and seemingly the spring discharges from theses sediments, near the head of a shallow streambed. The spring pool serves as a source of water for livestock and other village uses. The temperature of the spring at the time of investigation was 33.4 ^{0}C (Table 1).

Unlike Keana, Awe, and Akiri, activity connected with the production of salt at Kanje, appears to be no more there or carried on intermittently by only a few women. Perhaps it is caused by low mineralization of the spring water, some 105 mg/l as Tables 1 and 2 show, but also possibly due to lack of financial motivation in the salt production.

Ribi Thermal Spring

Ribi village is located 20 kilometer north-north-east from the Kanje Town. In Ribi village the thermal spring is located in a broad open valley about 150 meters west of the town (Figure 9).

The bottom of the valley and its slopes are covered by alluvial deposits of sand and clayey silt. In the old days, in process of salt production, a pit few metres deep, has been excavated around the spring (Plate 9). In the sides and the floor of this pit underlying geology has been exposed.

The temperature of water from the spring, 34.2 ^{0}C, was measured at the centre of the pool where water is discharged when the pool is drained during dry season. The temperature reading is presented in table 1 above. The water is highly saline. Results of analysis in Table 2, show 51 g/l. The salt is normally produced b the old women, who can abandon that profession for any other more profitable work. The old women are assisted by small children (Plate 9) who are attending primary school, because salt is produced only in the afternoon.



Plate 9. RIBI THERMAL SPRING OR RATHER POND, VIEW OF THE VALLEY. The reader may note broad open valley covered by alluvial deposits of sand, clay and silt, also some half buried pots used for collection of brine water.

4.1.3. Chemical Analyses of Thermal Springs

Water samples from the springs were collected during the height of the dry season to avoid the diluting influence of surface streams. These water samples were subsequently analyzed in the Laboratory of Faculty of Earth Science, University of Silesia, Poland in the Solaar AA with results presented in Table 2: From the chemical properties of the springs, it is possible to speculate that the springs might owe origin to connate due to high concentration of TDS (6644-50736 mg/l); And has contact with natural deposits of salt somewhere in the subsurface, evidence by the encrustation of salt at the surface.

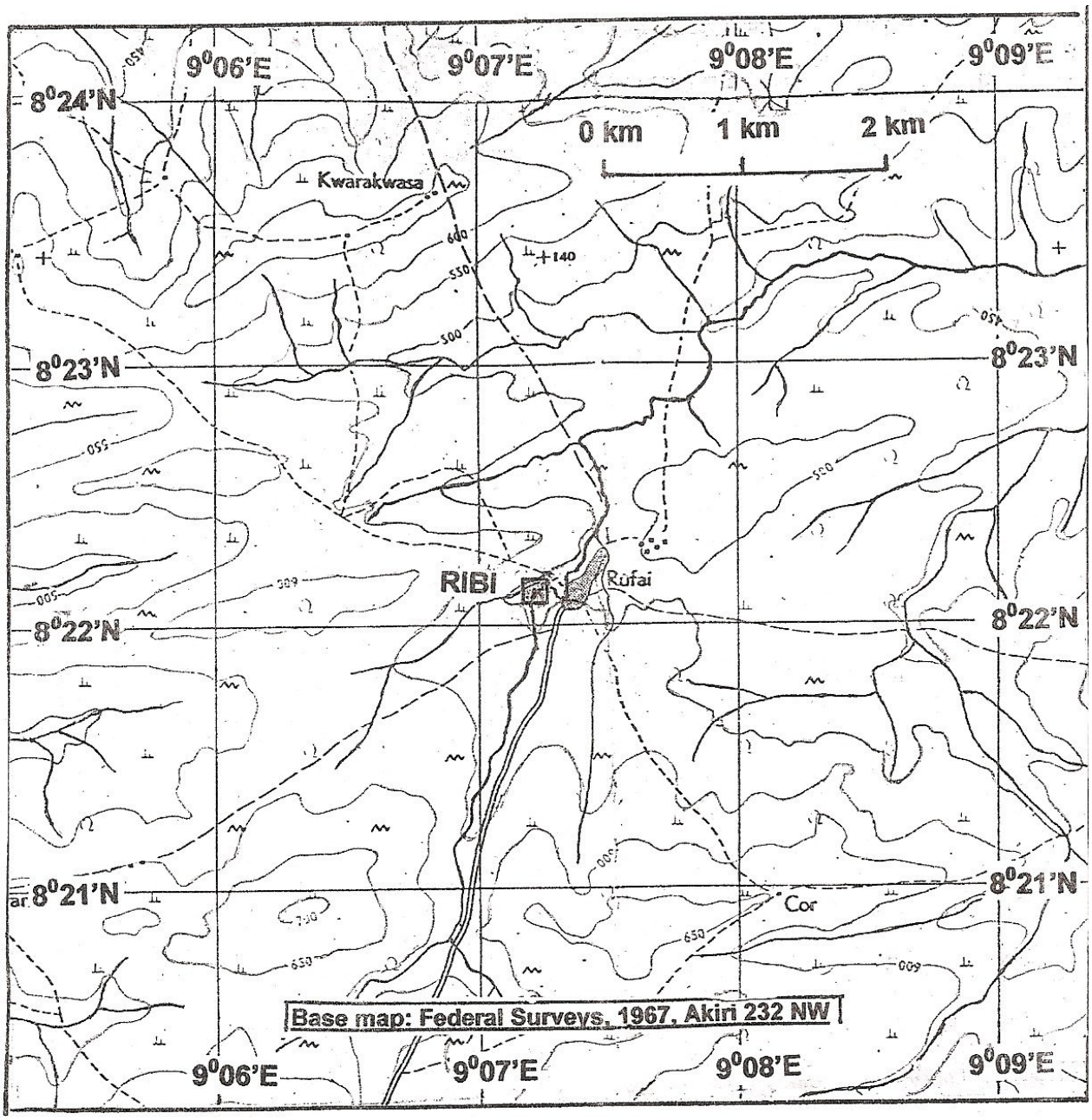


Figure 10. LOCATION OF RIBI THERMAL SPRING. The spring yields 0.4 l/s of connate water. Its mineralization is 50.7 g/l and temperature 34.2^{0}C.



Plate 10. RIBI - SALT PROCESSING AND THERMAL SPRING IN THE BACKGROUND. The reader may see the women processing salt and their equipment.

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4.2. Measurements in Boreholes

4.2.1. The free flowing boreholes

There are two free flowing boreholes in the study area: Assakio and Giza Police Stations, their identification numbers are in Table 4 and Borehole Location Map in Figure 13.

The two boreholes can be considered as "artificial springs", because they also provide thermal water like springs discussed above. However, they differ from the thermal springs in the following: a) they are not located together with the thermal springs on Awe anticline and Asu River Group sediments. Both of them, Assakio and Giza are located in Obi syncline on

Cretaceous sediments belonging to Awgu Shale Group (Figure 14). b) They are fresh water. This fres water is used for domestic purposes.

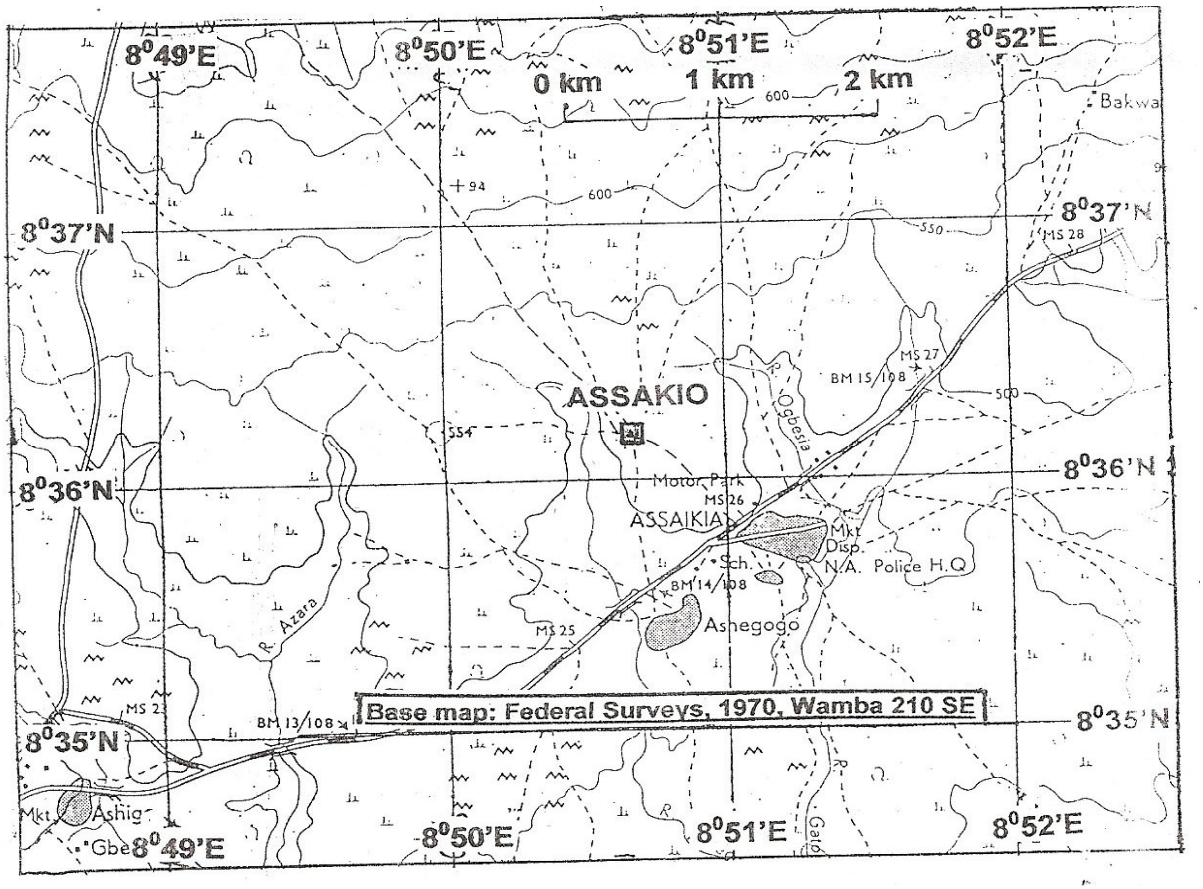


Figure 11. LOCATION OF ASSAKIO THERMAL, FREE FLOWING BOREHOLE. Assakio thermal free flowing borehole_yields 1.5 l/s of fresh water, its temperature 34.1^{0}C.

All parameters of the two flowing boreholes, measured during field work, are presented in Table 3.

4.2.2. The pumped boreholes

Altogether 150 numbers of boreholes were measured in the study area. Few of them are outside of the study area, on the Crystalline Hydrogeological Province but most of them are located in the Middle Benue Trough, within Nasarawa State (Fig 13). All the boreholes have shallow depth, on the average of 30 to 40 metres deep. Only few of them have depth above

50 metres. All of them yield fresh water. The parameters measured during the field work are shown in Table 4. In the boreholes with hand pumps mounted on them, the pumps were



Plate 11. ASSAKIO THERMAL FREE FLOWING BOREHOLE. See children fetching water for drinking and domestic use. The bus, on the background is also used to carry water from this borehole for commercial purposes.

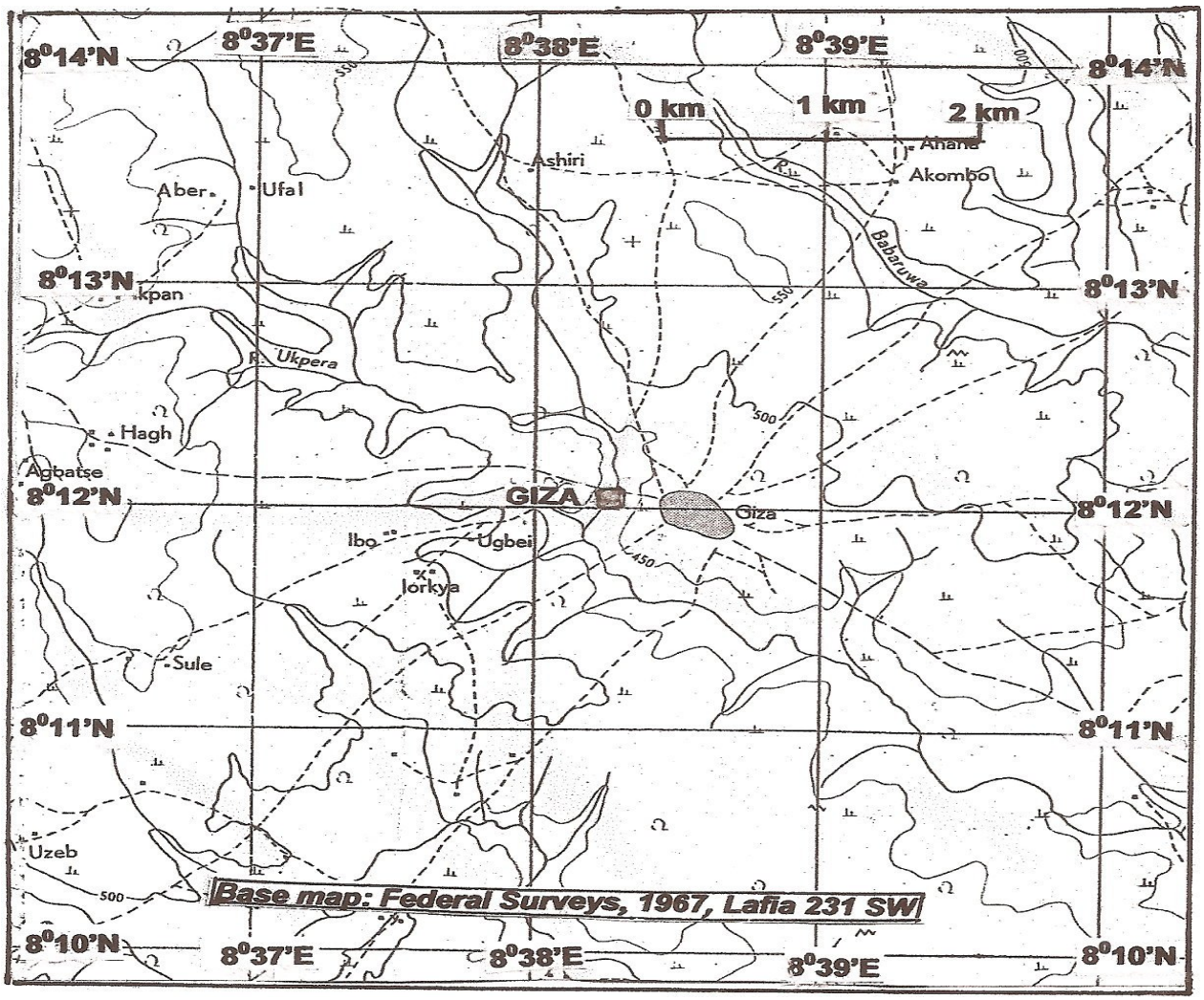


Figure 12. LOCATION OF GIZA THERMAL FREE FLOWING BOREHOLE. Giza Thermal free flowing borehole yields 0.3 l/s of fresh water, its temperature 42.0^{0}C.

temporarily disconnected from the suction pipe and dismantled, then the suction pipes were pulled out using pipe ranges, and thereafter measurements of depth to water table and to the bottom of the borehole were made with marine rope, to the end of it an iron rod was attached to add weight. A mercury maximum-minimum thermometer was inserted within a narrow, perforated, two inches diameter, PVC pipe, which was slightly longer than the thermometer and its bottom cover was tied close to the iron rod., at the end of the rope. The mercury

maximum-minimum thermometer was kept at the bottom of the borehole, for temperature stabilization. After pulling the rope with the attached thermometer out of the borehole, temperature of water at the maximum thermometer was read, and thereafter the length of the rope submerged into the borehole was measured with a metric tape, one hundred metres long. After that, the suction pipe and the hand pump were installed back onto the borehole. The same procedure was applied to boreholes with submersible pumps installed in them.

Geothermal gradients calculated for the 150 boreholes used in this study (Table 4), were then plotted into a geothermal gradient map for the sedimentary Hydrogeological province of Nasarawa state in the part of Middle Benue Trough (Fig. 16) and contoured interval of 1^0 C/100m.

The geothermal gradient map shows the areas with the highest geothermal gradient, so called geothermal anomalies, and these were identified towards the southeastern part of the state. That is, both on the Awe Anticline and on Obi Syncline (compare Figures 16,15 and 14) as in the case of the free flowing boreholes in Giza (42^0 C) and Assakio (34.1^0C) respectively (boreholes 6 and 94 in Table 4).

Those elements (surface and subsurface temperatures and, the gradient) of geothermal field indicates areas of more or less favourable geothermal conditions for geothermal energy use, in other words, interpretation of subsurface and surface temperatures and gradients plotted in tables, maps and cross-sections interprets geothermal anomalies in the research area where relatively high amount of geothermal energy is stored.

4.3. Evaluation of Temperatures Measurements

The interpretation of subsurface and surface temperatures and gradients plotted in tables, maps and cross-sections interprets geothermal anomalies in the research area where relatively high amount of geothermal energy is stored around the Awe and Keana anticlines. To know the real values - real amount of the energy underground further advanced calculations must be done. It is possible to evaluate the amount of geothermal energy and show the results as figures but it would need much more time and effort where Terrestrial heat flow and geothermal reservoirs will be determined

At the site, ground surface temperatures were measured, but not used for calculation of geothermal gradient. Instead, the mean annual ground surface (Stevenson screen) temperature was read from the map of ground surface temperatures in Nigeria (Schoeneich 1997). Isotherms from this map are shown in Fig.13. Then three centigrade were added as compensation for earth thermometer temperature and this value, accepted as most probable mean annual earth thermometers. Ground surface temperature was used for calculation of geothermal gradient using the formula bellow:-

$$[Td^0C - (Tss^0C + 3^0C)] : Dm = G^0C/m \qquad [1]$$

Where Td^0C = temperature at bottom of the borehole in ^0C; Tss0C = Mean annual Stevenson screen temperature in ^0C, read from map in Fig. 5; 3^0C = allowance for earth thermometers temperature in ^0C; Dm = Depth of the borehole, in hundred of metres; G^0C/m = Geothermal gradient in $^oC/100$ m.

The results of measurement of ground water temperature at the bottom of each borehole, was used for calculation of geothermal gradients which are shown in Table 4.

Then the gradients from table 4 were used for plotting map of geothermal gradients shown in Figure 16. Boreholes with close locations, forming cluster, were grouped and their average

gradient was calculated (Table 4) and used for the geothermal gradient map construction as shown in Figure 16. In some boreholes temperature gradient reads either zero (0) or a negative value (see boreholes Nos. 91 and 116 in Table 4). Zero values and negative values are obviously erroneous, perhaps due to shallow depth of some boreholes, and were not used for construction of the map of geothermal gradient in Fig 16.

4.4. Essentials Facts and Results of Field Data Processing

The field results such as location, depth, and temperatures were plotted in form of tables and maps. In Table 1, are presented field data on location, yield, and temperatures of thermal springs.

Table 1. THERMAL SPRINGS AND THEIR PARAMETERS.

Location	Coordinates	Elevation m asl	Air tempe-ature, ^{0}C at site	Water tempe-rature, ^{o}C at site	Water Minerali-Zation,mg/l	Yield (1/s)
Akiri Warm Saline Spring	N 08^{o}22.866' E 009° 20. 156'	96	28.5	53.2	6644	1.0
Awe 1 Flowing Saline Spring	N 08°06.035' E 009° 07.766'	104	27.0	43.4	10196	1.5
Awe 2 Warm Saline Spring	N 08° 06.075' E009°08.132'	108.2	29.5	38.6	10765	0.5
Awe 3 Warm Saline Spring	N 08° 06.167' E 009°08.211'	107.2	29.0	34.8	Not Analyzed	0.2
Keana Warm Saline Spring	N 08°09.469' E008^{o}48.052'	100	28.5	36.4	13517	0.6
Azara Warm Fresh W. Spring	N08^{o}22.149' E009°14.312'	102	28.0	33.4	802	0.4

Kanje Warm Fresh W. Spring	N 08°13.214' E009°05.108'	163	28.0	33.4	105	0.4
Ribi Warm Saline Spring	N 08°22.152' E009°07.223'	160	28.0	34.2	50736	0.4

All the parameters were measured in year 2008 during the visit of each spring. Column "air temperature" shows temperature of air, one metre above ground surface, measured with mercury thermometer at the time of visit. Column "water temperature" shows temperature of water in the neck of the spring, measured with the same maximum/minimum mercury thermometer. Yield of spring was assessed at the site. Water mineralization measured by Solaar AA Laboratory in Katowice.

Table 2 shows laboratory analysis of samples of water collected from the thermal springs during the period of field work.

Table 2: ANALYSES OF WATER FROM THERMAL SPRINGS.(Analyzed by Solaar AA in Sosnowiec, Poland, on 12.02.2008, and 24.10.2008)

	Akiri	Awe 1	Awe 2	Keana	Azara	Kanje	Ribi
Ph		7.52	8.03	6.85	7.81	5.40	6.65
Min., mg/l	6644	10196	10765	13517	802	106	50736
Ca	116	176	172	304	72	8	1800
Mg	34	26	22	41	19	4	792
Na	2490	4220	4280	5020	43	2	3840
K	84	98	98	302	5	1	1690
HCO_3	470	647	653	281	281	31	311
$S0_4$	5	17	15	16	1	2	153
Cl	3000	5000	5000	6600	120	24	34000
NO_3	15	12	7	23	0	0	1240
$Si0_2$	55	44	44	27	-	-	-
Origin:	connate	Connate	connate	Connate	Meteoric	Meteoric	Connate

Table 3 contains field data – geographical coordinates, elevation, and depth - on the thermal free flowing boreholes.

Table 3. THERMAL FREE FLOWING BOREHOLES AND THEIR PARAMETERS.

Location	Coordinates	Elevation m asl	Air tempe-ature, "C at site	Water Tempetature ^{0}C		Water Minerali-zation, mg/l	Depth of b-hole, m	Yield l/s
				At the Bottom	At the Mouth			
Assakio Fresh W. B-hole	N08^U 36.184' E008°50.707'	170.2	29.0	34.2	34.1	Fresh Water	58	1.5
Giza-Police: Fresh W. B-hole.	N8^{0}12.072' E8^{0}38.328'	138	30.0	42.0	29.3	Fresh Water	68	0.3

All the parameters were measured in year 2008 during the visit of each spring. Column "air temperature" shows temperature of air, one metre above ground surface, measured with mercury thermometer at the time of visit. Column "water temperature" shows temperature of water for Assakio measured at the mouth of the free flowing borehole, while temperature of water at Giza was measured at the bottom of the borehole. Temperature was measured with the maximum/minimum mercury thermometer. Yield of the borehole was measured using bucket and watch. Table 4 shows results of 150 pumped boreholes.

Table4. RESULTS OF MEASUREMENT OF TEMPERATURES IN BOREHOLES

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother-mal gra-dient, ^{0}C/100m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annua l					
1	Kadarko	8^{0}13.794’ 8^{0}34.335’	179	30.0	27.2	34.0	4.0	32.0	10.93	6.6
2	Kadarko	8^{0}13.469’ 8^{0}34.150’	176	34.0	27.2	32.1	4.2	35.0	4.57	
3	Kadarko PHC	8^{0}13.391’ 8^{0}34.456’	187	34.0	27.2	32.0	4.4	37.3	4.02	
4	Kadarko 3	8^{0}13.476’ 8^{0}34.265’	189	32.3	27.2	32.5	5.0	29.0	6.90	
5	Giza Market	8^{0}11.865’ 8^{0}38.628’	136	34.0	27.2	32.0	4.0	38.0	3.95	7.0
6	Giza Police Station	8^{0}12.072’ 8^{0}38.323’	138	30.0	27.2	42.0	Free flow	68.0	16.91	
7	Giza Sec-retariat Junction	8^{0}12.024’ 8^{0}38.590’	151	27.0	27.2	31.0	5.2	22.0	2.27	
8	Giza PHC	8^{0}11.726’ 8^{0}38.797’	139	29.0	27.0	32.0	7.3	32.0	4.69	
9	Giza	8^{0}11.574’ 8^{0}31.314’	152	30.4	27.2	32.6	4.8	39.0	5.64	Longitude Suspicious
10	Balura	8^{0}10.205’ 8^{0}40.528’	166	31.0	27.2	32.5	4.4	42.6	4.93	-
11	Ihwabo	8^{0}13.361’ 8^{0}10.472’	179	32.0	27.3	32.8	4.6	48.0	5.0	Longitude Suspicious
12	Kwara	8^{0}20.195’ 8^{0}29.097’	196	32.0	27.1	34.0	5.2	38.0	10.26	
13	Keana PHC	8^{0}08.741’ 8^{0}47.605’	124	36.0	27.4	32.0	5.3	24.0	6.67	
14	Keana Behind PHC	8^{0}08.706’ 8^{0}47.594’	123	43.0	27.4	32.0	5.0	28.0	5.71	
15	Keana General Hospital	8^{0}09.117’ 8^{0}48.071’	18	36.0	27.4	32.0	13.0	30.0	5.33	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Wate r level m bgl	Bore-hole depth, m bgl	Geother - mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annua l					
16	Obene Keana	8008.664' 8047.730'	125	38.0	27.4	30.0	13.6	23.7	-1.69 ?	
17	Obene	8008.752' 8047.832'	135	36.0	27.4	32.0	13.3	20.0	8.00	
18	Obene	8008.933' 8047.794'	135	37.0	27.4	31.0	10.4	18.0	3.33	
19	Permanen t Site Secr. Keana	$8^0$10.205' $8^0$40.528'	166	33.0	27.4	32.0	7.3	32.8	4.88	
20	Ameri Keana	$8^0$08.755' $8^0$47.369'	133	30.0	27.4	32.0	7.3	32.8	4.88	
21	Keana GGSS	$8^0$08.095' $8^0$47.369'	148	32.0	27.4	31.0	10.0	45.0	1.33	
22	Keana Mosque	$8^0$08.505' $8^0$47.417'	123	32.0	27.4	32.0	9.0	28.0	5.71	
23	Keana	$8^0$09.051' $8^0$47.506'	120	30.0	27.4	29.0	8.0	32.0	-4.38 ?	
24	Adidi	$8^0$10.361' $8^0$48.167'	159	33.0	27.4	30.0	4.7	28.0	-1.43 ?	
25	Aloshi	$8^0$14.235' $8^0$48.167'	196	32.6	27.5	31.0	5.2	40.0	1.50	1.45
26	Aloshi	$8^0$14.189' $8^0$48.146'	198	30.0	27.5	31.0	6.1	38.0	1.32	
27	PHC Aloshi	$8^0$14.339' $8^0$48.094'	201	29.0	27.5	31.0	4.8	33.0	1.52	
28	Agaza	$8^0$17.228' $8^0$48.409'	186	29.0	27.5	30.6	6.0	31.0	0.32	0.92
29	Agaza	$8^0$17.234' $8^0$48.398'	160	29.0	27.5	31.0	5.7	33.0	1.52	
30	General Hospital Toto	$8^0$23.053' $7^0$04.960'	155	28.0	27.5	31.0	4.6	28.0	1.79	
31	Shafan Kwotto	$8^0$18.903' $7^0$05.640'	173	28.0	27.5	31.0	4.6	28.0	1.79	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Wat er leve l m bgl	Bore-hole depth, m bgl	Geothe r-mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annu al					
32	Shafan Abakpa (Sofiyo)	$8^0$17.108’ $7^0$05.328’	238	28.0	27.5	31.0	6.0	23.0	2.17	
33	Toto Central School	$8^0$23.419’ $7^0$04.844’	150	31.0	27.5	32.0	5.0	35.0	4.29	5.52
34	Toto Kofa	$8^0$23.434’ $7^0$04.484’	143	30.0	27.5	33.0	4.5	37.0	6.76	
35	Adadu	$8^0$22.283’ $7^0$05.070’	139	32.0	27.5	31.0	5.2	33.0	1.52	
36	Ukya Primary School	$8^0$24.799’ $7^0$03.689’	166	29.0	27.5	32.0	6.2	32.0	4.69	
37	Ukya Sabo Primary School	$8^0$24.869’ $7^0$03.726’	106	29.0	27.5	32.0	5.9	30.0	5.00	3.84
38	ECWA Rafin Kunama	$8^0$23.902’ $7^0$04.254’	134	29.0	27.5	31.0	5.2	27.0	1.85	
39	Govt. Junlor Secondar y Sch. Ugya	$8^0$12.231’ $7^0$09.673’	207	28.0	27.4	31.0	6.4	29.8	2.01	3.83
40	Ugya	$8^0$12.295’ $7^0$09.714’	206	28.0	27.4	31.0	5.6	32.0	1.88	
41	PHC Ugya	$8^0$12.239’ $7^0$09.715’	209	28.0	27.6	33.0	5.8	31.6	7.59	
42	Knyehu 1	$8^0$04.346’ $7^0$10.528’	97	28.0	27.4	31.0	13.4	34.6	1.73	1.86
43	Kanyehu 2	$8^0$04.402’ $7^0$10.672’	100	28.0	27.4	31.0	12.3	30.1	1.99	
44	Sogene	$8^0$01.549’ $7^0$11.356’	74	29.0	27.3	33.0	14.2	32.0	8.44	3.97
45	Sogene Gbagyi	$8^0$01.506’ $7^0$11.371’	72	29.0	27.3	28.7	7.8	28.0	-5.71 ?	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother-mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annu al					
46	Umaisha Market	$8^0$00.584’ $7^0$11.337’	51	28.0	27.2	30.5	7.5	26.0	1.15	
47	Umaisha Central Prim. Sch.	$8^0$00.954’ $7^0$11.413’	66	27.6	27.2	30.7	7.6	25.0	2.00	
48	Angwan Pakachi Umaisha	$8^0$00.408’ $7^0$11.173’	57	27.6	27.2	31.0	5.0	28.0	2.86	
49	Ohimege Palace Umaisha	$8^0$00.535’ $8^0$11.260’	64	28.0	27.2	31.0	5.2	22.0	3.64	
50	Usha Kudu	$8^0$11.361’ $7^0$52.653’	33	29.0	27.5	30.2	2.7	28.0	-1.07 ?	
51	Mararaba Udege Market	$8^0$18.422’ $7^0$48.370’	44	39.2	27.3	30.7	5.8	20.0	2.00	
52	Agbazo	8018.847’ 7047.568’	44	30.0	27.3	30.7	5.5	22.0	1.82	
53	PHC Mararaba Udege	8018.635’ 7048.460’	43	30.0	27.3	30.7	8.2	32.0	1.25	
54	Akum	8018.306’ 7057.084’	105	29.8	27.3	30.6	6.7	24.0	1.25	
55	Odeni Gida	8017.306’ 7056.753’	127	29.8	27.3	30.7	6.5	28.0	1.43	
56	Ajaga	8020.642’ 7036.061’	234	29.2	27.2	31.0	5.8	27.0	7.41	
57	Zherugba	8022.547’ 8030.469’	215	28.0	27.1	32.1	6.2	30.0	6.66	
58	Abioga	8023.582’ 8031.136’	202	28.0	27.0	30.5	8.2	35.6	1.40	
59	Gidan Ausa	8024.132’ 8029.582’	178	28.2	27.0	31.2	7.2	32.4	3.70	
60	Angwan Agyaragu	8024.246’ 8032.410’	194	29.0	27.0	31.0	11.0	43.7	2.29	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother - mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
61	Gidiye	8023.584’ 8033.207’	208	29.1	27.0	30.9	9.2	29.6	3.04	
62	Agyaragu	8024.513’ 8033.126’	211	29.8	27.0	30.0	8.0	42.0	0.00 ?	
63	Angwan Anaka Dugura	8024.437’ 8035.554’	211	30.0	27.0	30.5	7.2	36.0	1.39	
64	G S S Duduaura	8025.279’ 8035.666’	212	30.0	27.0	30.7	6.8	32.8	2.13	
65	PHC Gidiye	8023.526’ 8032.291’	208	29.0	27.0	30.6	5.5	35.0	2.29	
66	Agwade Kasuwa	8026.484’ 8038.529’	229	29.2	27.0	30.5	5.8	34.0	1.47	
67	Iponu	8002.323’ 8007.180’	170	29.0	27.2	30.8	3.4	38.0	1.58	
68	PHC Agbashi	8000.211’ 8007.115’	127	29.0	27.2	30.5	5.2	35.0	0.85	
69	PHC Rukubi	8055.523’ 8018.102’	75	30.0	26.7	30.8	5.6	32.0	3.44	3.38
70	Rukubi	8055.378’ 8018.264’	82	30.0	26.7	30.7	5.7	30.0	3.33	
71	Akpanaja	8047.593’ 8025.002’	79	29.8	26.5	30.6	6.2	40.2	2.73	
72	Adoka	8012.543’ 8026.305’	184	30.0	26.3	31.0	6.8	41.0	1.70	
73	Nasara Estate	$8^0$52.444’ $8^0$32.462’	161	31.6	26.2	30.9	6.7	58	2.93	
74	Makurdi Road	$8^0$28.569’ $8^0$32.327’	172	31.0	26.9	30.3	7.2	62.3	0.64	1.12
75	School of Nursing Lafia	$8^0$28.562’ $8^0$32.194’	151	31.0	26.9	30.3	6.8	56.0	1.67	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother - mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
76	PHC T/ Kauri	$8^0$29.150’ $8^0$32.076’	178	31.0	26.9	30.0	8.1	45.2	2.21	
77	T/Kauri	$8^0$29.132’ $8^0$32.047’	178	32.0	26.9	30.8	10.6	48.1	1.87	
78	Millionaire ’s Quarters Lafia	$8^0$30.578’ $8^0$31.103’	183	31.7	26.8	30.8	11.2	67.0	1.49	
79	Sabon Pegi	$8^0$29.283’ $8^0$31.456’	190	39.0	26.9	31.0	7.1	37.0	2.97	1.58
80	T/Kauri	$8^0$29.091’ $8^0$32.148’	182	29.0	26.9	30.0	9.8	52.0	0.19	
81	T/Amba 1	$8^0$29.091’ $8^0$30.112’	62	29.0	26.9	30.6	8.7	52.0	1.35	
82	T/Amba 2	8029.153’ 8030.039’	169	29.0	26.9	30.5	8.4	48.0	1.25	1.47
83	T/Amba	8029.090’ 8029.548’	171	29.0	26.9	30.7	7.9	44.0	1.82	
84	T/G Sandra	8030.220’ 8031.066’	195	30.0	26.8	30.5	6.8	42.0	1.67	2.07
85	National Supply Lafia	8030.184’ 8031.471’	204	30.0	26.8	30.9	7.5	47.2	2,33	
86	Bukan Sidi	8031.270’ 8031.471’	169	29.0	26.8	30.8	7.8	45.0	2.22	
87	Bukan Sidi	8031.224’ 8031.071’	183	29.0	26.8	31.4	6.2	38.0	4.21	
88	PHC Assakio	8035.120’ 8050.203’	158	30.0	27.0	33.3	2.6	42.0	7.86	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother-mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
89	Ashige	8034.045’ 8048.180’	158	30.0	27.0	32.8	6.3	44.0	6.36	
90	PHC Adogi	8031.254’ 8038.414’	208	31.0	26.8	33.5	6.5	43.0	8.60	
91	Sabon Gida	8037.286’ 8056.368’	130	33.0	27.0	30.0	4.8	52.0	0.00 ?	1.02
92	L. Benue Sabon Gida	8037.246’ 8056.433’	134	33.0	27.0	31.0	5.1	49.0	2.00	
93	Assakio	8035.577’ 8050.595’	157	29.0	27.0	32.0	3.8	38.0	5.26	
94	Assakio Free Flow	8036.084’ 8050.707’	170	29.0	27.0	34.1	0.00	58.0	7.07	
95	Ugah	8041.293’ 8048.340’	140	30.0	26.9	33.3	4.7	47.0	7.23	6.24
96	Ugah	8041.295’ 8048.346’	140	29.0	26.9	32.0	4.8	40.0	5.25	
97	Fadaman Bauna	8044.529’ 8045.258’	189	29.0	26.5	32.6	3.7	32.0	9.66	
98	Wuji	8048.012’ 8042.424’	240	30.0	26.2	32.3	4.2	45.0	6.89	
99	Arikiya	8049.456’ 8040.268’	188	30.0	26.2	33.4	4.5	47.0	8.94	5.52
100	Shabu	8034.354’ 8032.303’	151	30.0	26.2	30.0	2.5	38.0	2.10	
101	Shabu	8034.212’ 8033.320’	148	29.0	26.8	34.2	3.6	36.0	12.22	4.30
102	Shabu Palace	8034.290’ 8033.169’	146	28.0	26.8	30.0	3.9	42.0	0.66	
103	Shabu Palace	8034.286’ 8033.161’	151	29.0	26.8	32.0	4.0	46.0	4.78	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother - mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
104	PHC Shabu	8034.287’ 8033.170’	158	29.0	26.8	31.0	3.2	38.0	3.16	
105	Kwandere 1	$8^0$34.064’ $8^0$30.040’	147	28.0	26.8	31.0	5.8	62.0	1.94	2.84
106	Kwandere 2	$8^0$34.193’ $8^0$29.524’	149	28.0	26.8	32.0	7.6	58.0	3.79	
107	Kwandere 3	$8^0$34.129’ $8^0$29.805’	151	2.79	26.8	31.0	6.5	43.0	2.79	
108	Kaffin Wambai	$8^0$32.580’ $8^0$27.090’	128	28.0	26.8	32.0	4.8	64.0	3.44	
109	G S S Kaffin Wambai	$8^0$32.454’ $8^0$27.169’	140	28.0	26.8	32.0	4.4	59.0	3.73	
110	B.A.D	$8^0$35484.’ $8^0$22.191’	126	29.0	26.9	32.0	3.6	46.0	4.56	1.83
111	B.A.D	$8^0$35.507’ $8^0$22.198’	122	30.0	26.9	31.0	4.3	52.0	2.12	
112	B.A.D	8035.548’ 8022.317’	202	29.0	26.9	30.0	4.3	33.0	0.30	
113	PHC B.A.D	8036.310’ 8022.176’	136	29.0	26.9	30.0	4.0	30.0	0.33	
114	College of Agric. Lafia	8033.222’ 8032.426’	166	28.0	26.8	30.0	4.5	38.0	0.66	0.66
115	College of Agric. Lafia	8033.222’ 8033.055’	170	29.0	26.8	30.0	4.2	35.0	0.66	
116	Ayire	8000.532’ 8053.521’	64	28.0	27.2	29.0	5.2	37.0	-3.24 ?	
117	Oshigu	$8^0$00.889’ $7^0$55.681’	66	29.0	27.2	31.0	4.6	42.0	1.90	
118	Bakono Jumat Mosque	$8^0$14.220’ $7^0$34.679’	104	29.0	27.3	31.0	3.9	32.0	2.19	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother - mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
119	PHC Oguba	8^{0}09.874' 7^{0}33.791'	100	28.0	27.3	32.0	4.6	34.0	5.00	
120	Ushata 1	8^{0}05.265' 7^{0}50.071'	103	29.0	27.2	31.0	4.3	30.0	2.67	
121	PHC Loko	8^{0}00.134' 7^{0}50.274'	67	28.0	27.2	32.0	3.8	33.0	5.45	
122	Baure	8^{0}07.318' 9^{0}12.332'	136	28.0	27.2	31.0	4.8	45.0	1.78	
123	Gidin Kade	8^{0}06.180' 9^{0}16.502'	132	28.0	27.2	33.0	2.8	32.0	8.75	
124	Tunga	8^{0}00.590' 9^{0}19.315'	64	28.0	27.2	29.0	3.0	28.0	-4.29 ?	
125	Gidam	8^{0}04.214' 9^{0}08.560'	123	29.0	27.2	30.0	3.2	29.0	-0.68 ?	
126	Mahanga	8^{0}08.570' 9^{0}01.131'	104	30.0	27.2	29.0	5.2	36.0	-3.33	
127	Awe 1	8006.291' 9008.325'	132	32.0	27.2	34.0	6.4	45.0	8.44	5.62
128	PHC Awe	8006.042' 9001.532'	114	32.0	27.2	33.0	8.0	30.0	9.33	
129	Awe 2	8006.314' 9008.570'	126	30.0	27.2	32.0	12.0	32.0	5.62	
130	Awe 3	8006.448' 9008.452'	132	29.0	27.2	31.0	10.0	42.0	1.90	
131	Awe 4	8006.451' 9008.448'	135	28.0	27.2	31.0	11.0	35.0	2.29	
132	Awe Police Station	8006.500' 9008.338'	125	28.0	27.3	34.5	16.0	68.0	6.18	
133	Kanje 1	8^{0}13.441' 9^{0}05.128'	169	29.0	27.2	31.0	6.2	34.0	2.35	2.42

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother-mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
134	Kanje 2	$8^0$13.784’ $9^0$13.347’	164	28.0	27.2	31.0	6.8	32.0	2.50	
135	Azara	$8^0$21.525’ $9^0$14.502’	127	29.0	27.2	33.0	4.3	38.0	7.37	
136	Azara	$8^0$22.116’ $9^0$14.557’	105	28.5	27.2	32.0	4.5	34.0	5.29	
137	PHC Ribi	$8^0$21.576’ $9^0$01.191’	164	29.0	27.3	31.0	6.0	35.0	2.00	Cluster with 139,140
138	Wuse	$8^0$22.245’ $9^0$15.455’	124	28.0	27.2	31.0	3.5	28.0	2.86	
139	Ribi	$8^0$22.077’ $9^0$07.416’	155	29.0	27.3	31.0	3.0	33.0	2.12	Bholes 137,139, 140=2.10
140	Ribi	$8^0$22.012’ $9^0$07.178’	152	29.0	27.3	31.0	3.5	32.0	2.19	
141	PHC Burum Burum	$8^0$31.277’ $8^0$09.022’	157	28.0	27.4	31.0	3.4	36.0	1.66	
142	Burum Burum	8031.373’ 8018.579’	149	28.0	27.0	32.0	3.6	42.0	4.76	
143	PHC Rutu	8025.550’ 8014.077’	149	29.0	27.1	31.0	3.2	35.0	2.57	
144	Alagye	8021.293’ 8015.399’	121	28.0	27.2	31.0	4.2	40.0	2.00	
145	Emir Palace Doma	8023.096’ 8021.016’	148	29.0	27.1	32.0	4.5	45.0	4.22	3.32
146	Doma Opp. Police Station	8023.282’ 8021.019’	157	29.0	27.1	31.0	4.0	37.0	2.43	
147	Govt. College Doma	$8^0$23.138’ $8^0$22.102’	175	30.0	27.1	31.0	5.0	30.0	3.00	
148	Millionaire’s Quarters Doma	$8^0$24.182’ $8^0$22.032’	166	29.0	27.1	31.0	7.2	42.0	2.14	

S/ No	Name of the borehole	Coordi-nates,	Elevation m asl	Tempera-Ture, ^{0}C		Water tem-pera-ture ^{0}C	Water level m bgl	Bore-hole depth, m bgl	Geother-mal gra-dient, ^{0}C/100 m	Geother-mal gra-dient, me-dian for the cluster
				Air at Site	Mean Annual					
149	Millionaire's Quarters Doma	$8^0$24.182' $8^0$21.590'	169	29.0	27.1	31.0	8.0	33.0	2.73	
150	Ogene	$8^0$23.153' $8^0$21.492'	171	28.0	27.1	32.0	3.7	31.0	6.13	

Successive number or identification number of borehole is the same as on the map in Fig. 13. Coordinates were measured with satellite navigator, its horizontal accuracy 3.0 m, vertical accuracy probably is less than five metres ; Temperature of air was measured in shadow, one metre above ground surface, with mercury maximum/minimum thermometer graduated 0.1 ^{0}C; Mean annual Stevenson screen ground surface temperature for each borehole was read from the map of temperatures in Nigeria prepared by Schoeneich (1997); Water temperature measured at the bottom of each borehole, with the maximum/minimum mercury thermometer graduated 0.1 ^{0}C. Water level was measured with water level indicator while borehole depth and temperature at depth was measured with a rope (marine rope) and metric tape; for calculation of geothermal gradient, mean annual earth Temperatures, assumed to be equal to Stevenson screen ground surface temperature plus 3 ^{0}C, were used.

Figure 13 show borehole location map used to compiled Tables 3 and 4. These were all used to construct figure 16.

Springs and free flowing thermal boreholes were located in Figure 13, showing geological map of the study area.

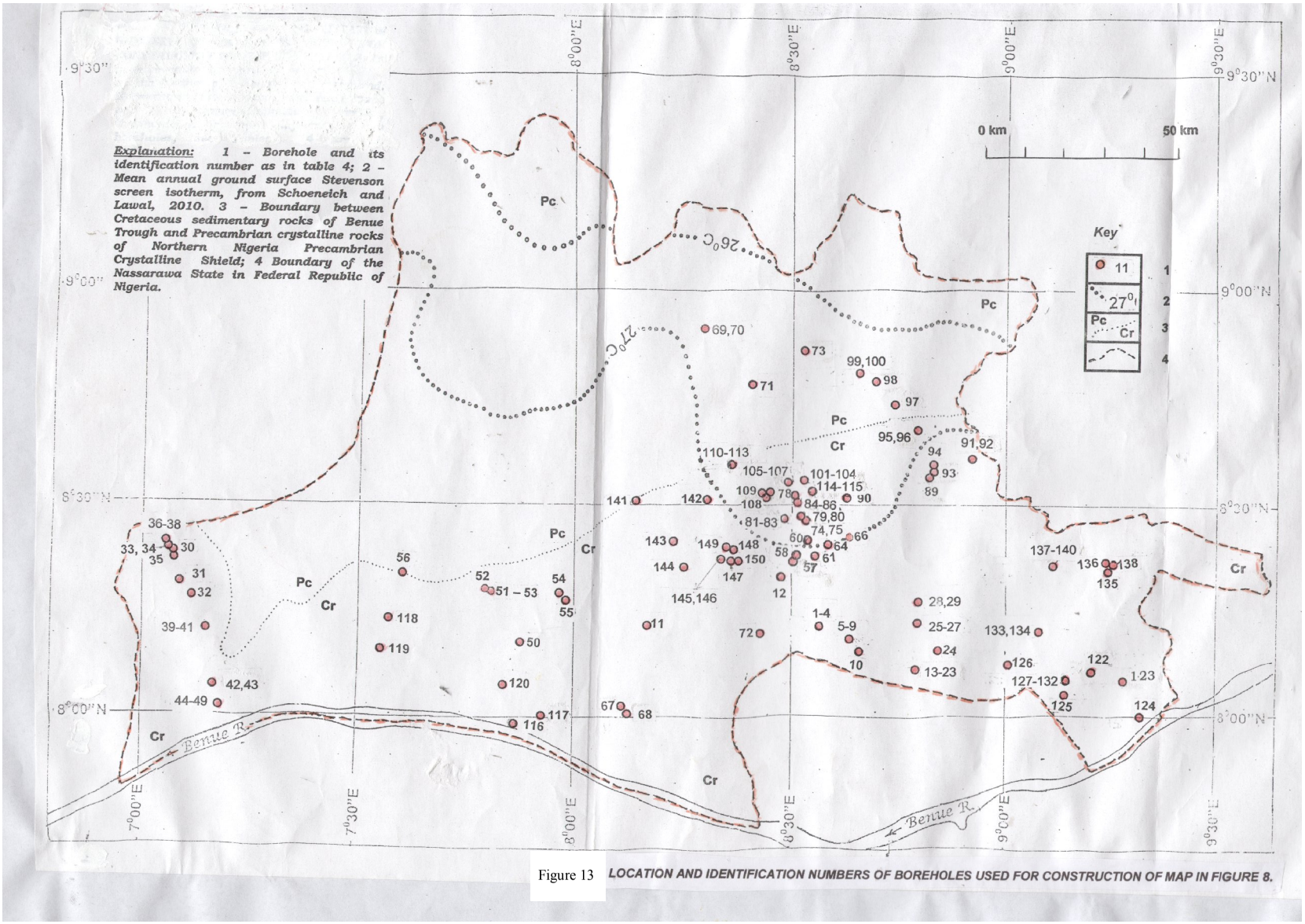


Figure 13 LOCATION AND IDENTIFICATION NUMBERS OF BOREHOLES USED FOR CONSTRUCTION OF MAP IN FIGURE 8.

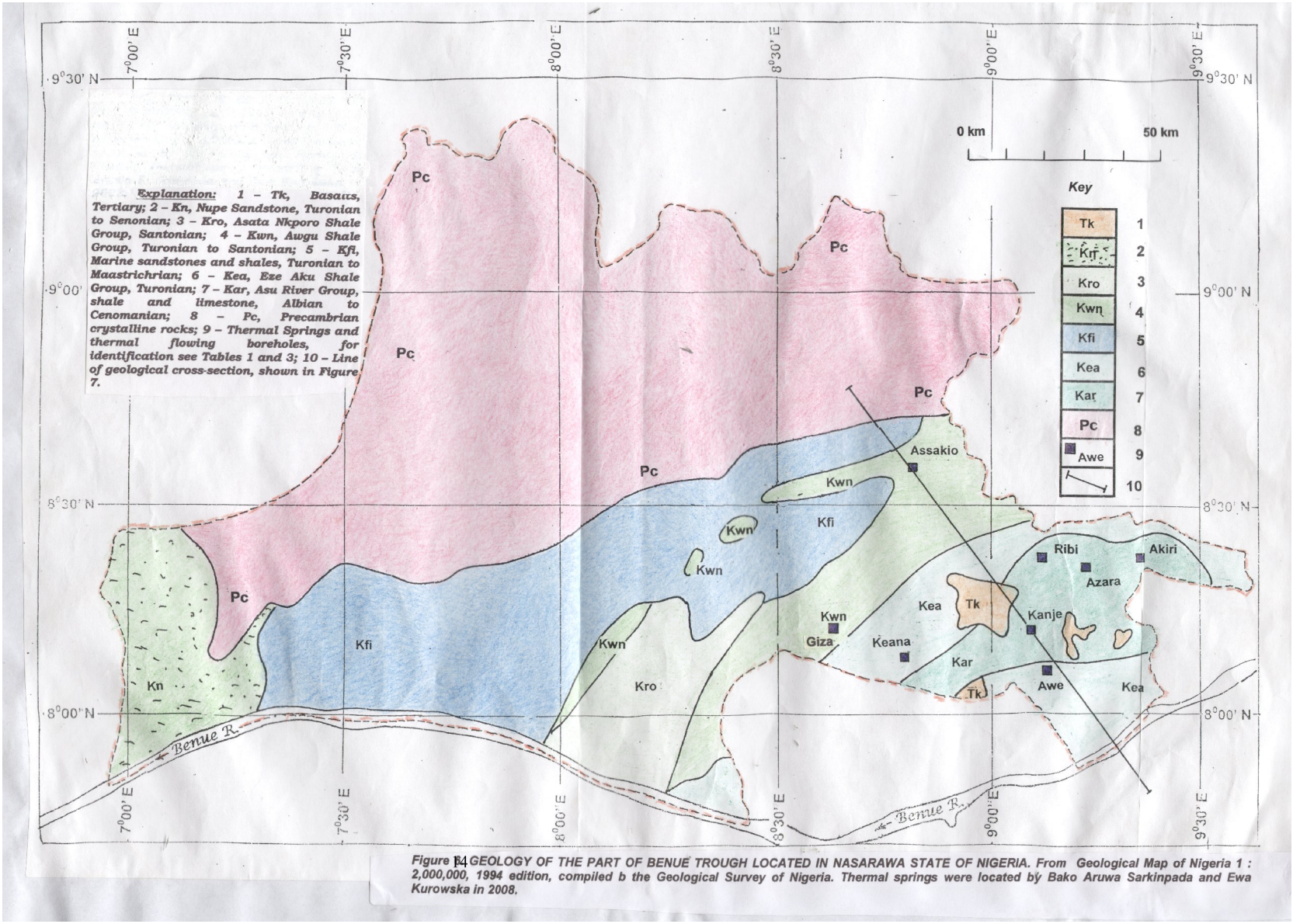


Figure 14 GEOLOGY OF THE PART OF BENUE TROUGH LOCATED IN NASARAWA STATE OF NIGERIA. From Geological Map of Nigeria 1 : 2,000,000, 1994 edition, compiled b the Geological Survey of Nigeria. Thermal springs were located by Bako Aruwa Sarkinpada and Ewa Kurowska in 2008.

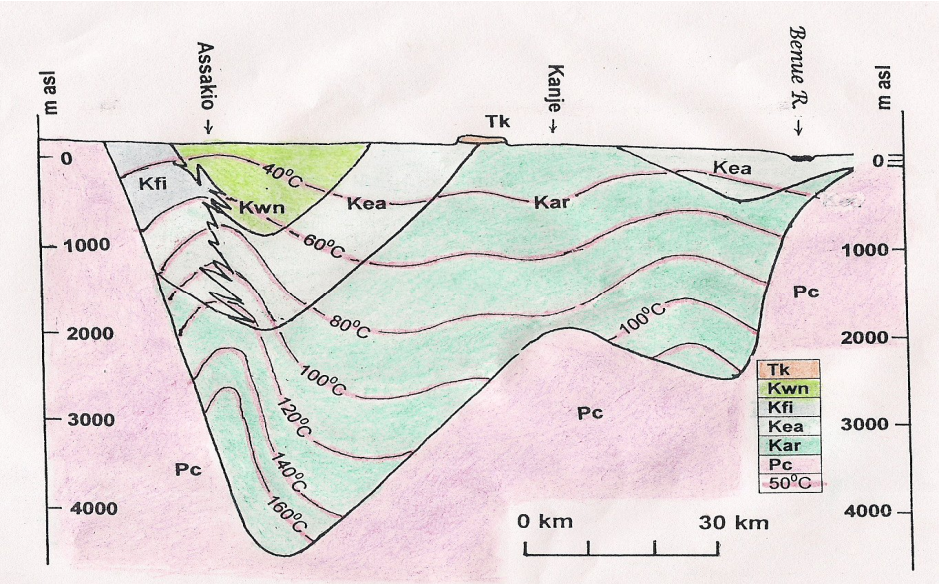


Figure 7. GEOLOGICAL CROSS-SECTION.

Location of this cross section is shown in maps in figures 2 and 3. Explanation: Tk- Tertiary basalts, Kwn- Awgu Shale Group, Coniacian-Santonian; Kfi- Marine facies, Turonian-Maastrichtian; Kea-Eze aku Shale Group, Turonian; Kar-Asu River Group, Albian-Cenomanian; Pc- Crystalline rocks of Precambrian. Assakio-location of flowing thermal borehole; Kanje-location of thermal spring; 50^{o}C- Geoisotherm, from Figure 16.

The Figure 16 – map of geothermal gradient, plotted from data contained in Tables 3 and 4.

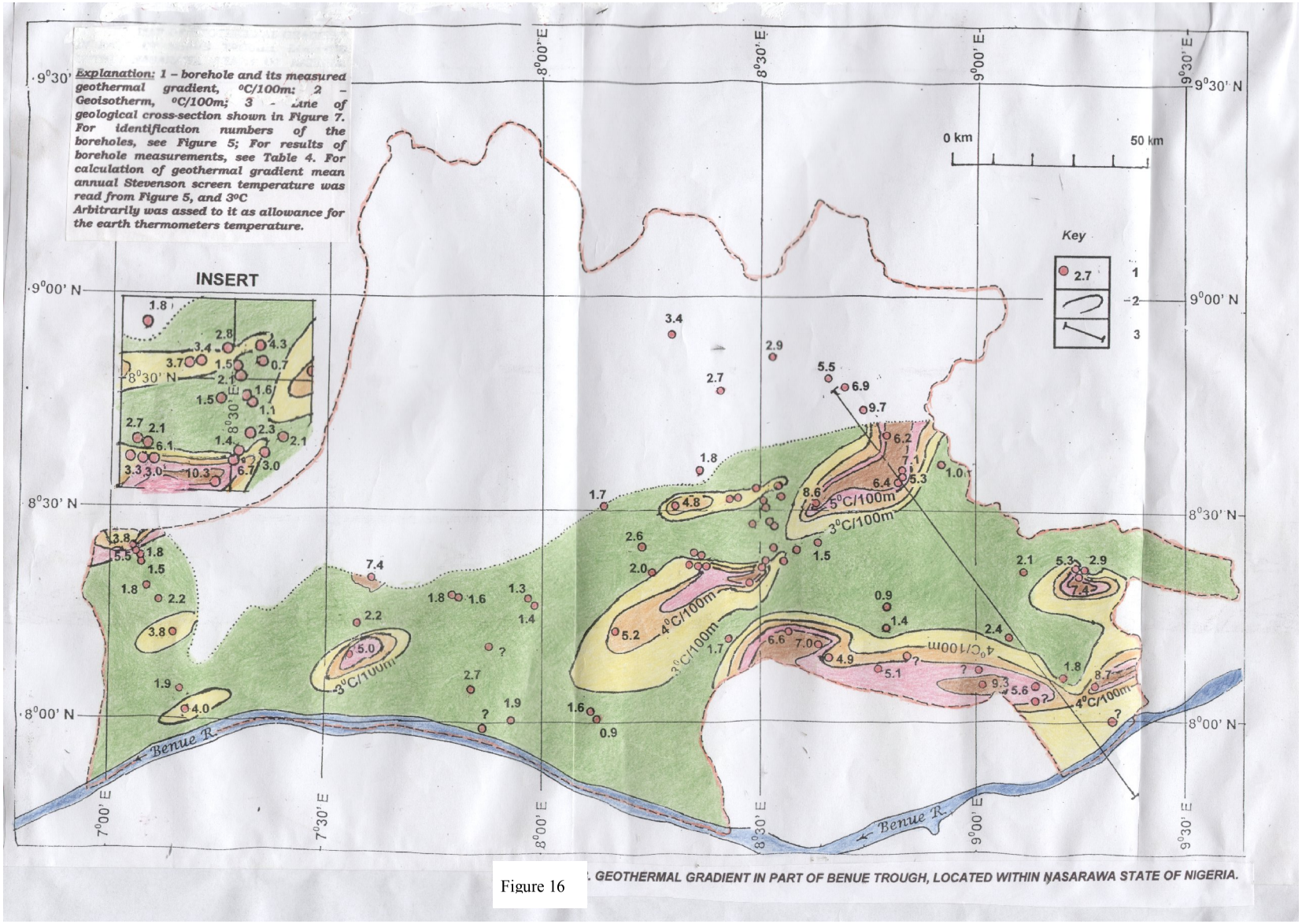


Figure 16

. GEOTHERMAL GRADIENT IN PART OF BENUE TROUGH, LOCATED WITHIN NASARAWA STATE OF NIGERIA.

This map contains contribution made by this research to the knowledge of regional geology (geothermic) of Nigeria and is discussed at length in the following chapter where these results are analyzed.

The geothermal cross-section in Figure 15 drawn through the two maps – geological map in Figure 6 and geothermal map in figure 16, showing the stratigraphy and geothermic in vertical section, adds the third dimension to the two most important maps. Every spring has been located on a topographical map on scale 1:50,000, in Figures 5 to 12. Their exact location, with use of coordinates, was never done before, although some of them were mentioned by previous authors, discussing various aspects of geology in Benue Trough. The two thermal, free flowing boreholes were also located on topographical map on scale 1: 50,000, shown in Figures 15 and 16.

Twelve photographs, the most important among them those showing dying traditional salt mining from saline springs, were taken during the field work and are presented in Plates1 to 12.

Chapter 5 DISCUSSIONS OF RESULTS

5.1. Geothermal Gradient

The geothermal gradient map (Fig. 16) shows that in the southeastern part of the study area around the Awe – Keana anticlines, there exists an elongated geothermal anomaly in the SW-NE direction corresponding to the structural trends in the region. The peak of this geothermal anomaly is marked by the geothermal gradient 9.3^0C/100m around Awe area, compare to the general values of about 1.5-2.5^{0}C/100m outside the anomalous areas.

Furthermore, temperatures at great depths around these anomalous areas will yield greater amount of geothermal energy; for example, a borehole at depth of 1000m within these area with geothermal anomaly 9.3^0C/100m will be :- since geothermal gradient at 100m= 9.3^0C then at 1000m it be 1000/100m x 9.3^0C = 93.0^0C.

Therefore, the geothermal gradient map gives some indications of subsurface temperature distribution in this part of the Middle Benue Trough. It will therefore be useful in assessing the geothermal potential of the area, in understanding more about the geology and the structures as well as the general hydrogeology especially groundwater flow velocities and artesian water flow of the Trough.

5.2. Possible Source of The Geothermal Anomalies

On the general note, sources of geothermal energy include earth core, radioactive isotopes, margins of crustal plates and Geopressure system. The earth core has temperature over 4,000^{0}C and continuously streaming out heat towards the surface by conduction. It therefore means that at any location on the earth, the temperature of the rocks below the surface increases with depth on average at a rate of 25 to 30^{0}C/km or 2..5 to 3.0^{0}C/100m. The radioactive isotopes disintegrate and generate energy contributing to the general heat flow. Radioactive isotopes, mainly uranium (U), thorium (Th) and potassium ^{40}K, release

significant amount of heat during disintegration (Goguel, 1976). Margins of crustal plates have also been recognized as source of the more obvious high grade geothermal resource. However, these sources of heat are transferred to the earth's surface via magma genesis, mechanisms of transport of melt through the crust, changes in petrologic and physical properties during its rise, interaction of melt and hot rock with meteoric water and brines, and the eruption phenomena (Edwards *et al,* 1982).

Therefore in the warm springs of the study area, it is obvious that the heat is as a result of the intrusion of molten magma originating from great depth, evidenced primarily by the occurrence of the volcanic rocks available in the study area as suggested by McConnell (*fide* 0ffodile, 1976). This is clear from the map of geothermal gradient (Fig.16). Areas such as Awe, Akiri, Assakio, Keana and Azara fall within the Awe-Keana anticlines where very high geothermal anomalies occur. In each of these areas, outcrops of volcanic rock (Tertiary Basalts) are seen in the near vicinity as presented in the map of geology of the part of Middle Benue Trough (Fig.14).

McConnell (Offodile, 1976) also writes that "the brines are not connate in origin, and that the springs represent a late hydrothermal phase of an expiring period of recent volcanic activity". In support of his theory he writes that "volcanic rocks of comparatively recent igneous intrusion occur near all the brine springs e.g. Mamfe and Moi-lgbo, with relatively high percentage of bicarbonates and carbonates, which further suggests their volcanic origin. He adds that in the Moi-lgbo samples the percentage of bicarbonates varies from 0.076 to 0.078, though only a trace of carbonate is present. Looking at the mineralization (6644-50736 mg/l), it is more convincing that the water of the thermal springs is of connate origin. It is an established fact that in the folded and faulted areas, the anomalies of heat flow reflect

geological structure in which the presence of water within the fissure or fault zone is of particular importance in the formation of thermal anomalies because of possible convection. Geopressure systems could also be responsible for heat generation. These are usually found in deep sedimentary basins, down to about 8,000m, where insufficient sediment compaction has taken place over geologic time and where an effective cap rock (e.g. shale) exists. Compaction leads to conditions whereby water is squeezed out of the intestinal pore spaces of clay sediment. An internal pressure greater than the normal hydrostatic pressure at that depth is imparted to the geofluids under compaction. This over pressured water systems can be associated with higher than normal temperature gradient (Edwards et al, 1982). In the study area, it is likely that the thermal springs are associated with the geo pressure system arising from Cretaceous sediments which are here more than 4000 m thick (Fig. 2 & 4).

Chapter 6 SUMMARIES, CONCLUSIONS AND RECOMMENDATIONS

This research has substantially achieved its objectives (establishing the geothermal energy potential) it has set out. The temperatures of thermal springs and of the groundwater in boreholes in the Sedimentary Hydrogeological Province of Nasarawa State were measured. Geothermal gradient has been calculated and the first map of geothermal gradient in this area has been produced. Areas with the highest geothermal gradient, so called geothermal anomalies, were identified both on the Awe Anticline and on Obi Syncline (compare Figures 16, 15 and 14). Deeper boreholes have higher temperature as in the case of free flowing boreholes in Giza and Assakio respectively (boreholes No. 6 and 94 in Table 4).

The temperatures of those springs are the surface thermal manifestations of the heat stored underground; the water is heated by the geothermal gradient under the surface at depth where the source water bearing layer is located; when the water is coming to the surface as the effect of some Hydrogeological conditions it brings the thermal energy which we can measured with thermometer to know the temperature; all the mentioned springs (Akiri, Awe, Keana, Azara, Kanje and Ribi thermal springs) have temperatures higher than average annual temperature of the air which proves that the energy the water brings to the surface comes from the earth underground and the water is an indicator of possible geothermal anomaly of the area.

To develop geothermal energy on a commercial scale for utilization, identification of geothermal anomalies, as it was done for the first time in this work, and understanding their genesis and geometry is a must. Some of the geothermal anomalies identified in this research are high, above 9 ^{0}C/100m as it is in the Awe geothermal anomaly, Giza geothermal

anomaly or Assakio Geothermal Anomaly, that very large quantities of heat are brought close to the ground surface. It is also obvious that geothermal exploration is aimed at locating a geothermal system from which energy can be economically extracted. High geothermal gradients are a prerequisite for any type of geothermal system. To know the real values - real amount of the energy underground some further advanced calculations must be done. It is possible to evaluate the amount of geothermal energy and show the results as figures but it would need much more time and effort.

Therefore the exploration which will follow the effort presented in this research work should concentrate on a more detailed studies of the geothermal anomalous areas identified in Figure 16 in this research work by way of calculating the rate of terrestrial heat flow through multiplying gradient (G) and Rock conductivity (C.). Also the type and nature of geothermal reservoir must be known.

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