GEOPRESSURED AQUIFERS AND _GEO THERMAL GRADIENT IN THE CHAD FORMATION IN BORNO STATE NIGERIA

by

MUHAMMAD TUKUR ASKIRA

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AS PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF SCIENCE (HYDROGEOLOGY) DEGREE IN THE DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE, AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA.

Department of Geology-
Faculty of Science
Ahmadu Bello University
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Zaria, Nigeria

July, 1987.

DEDICATION

This work is

dedicated to my parents.

CERTIFICATION

This project entitled: GEOPRESSURED AQUIFERS AND GEOTHERMAL GRADIENT IN THE CHAD FORMATION IN BORNO STATE by Muhammad Tukur Askira, meets the regulations governing the award of the degree of Master of Science (HYDROGEOLOGY) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Date: 8.01.1988

Chairman, Supervisory Committee

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Member, Supervisory Committee

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Head of Department

(Name and Signature)

Date: 15-2-88

Dean, Postgraduate School

DECLARATION

I certify that this thesis is based on the results of research carried out by me, that it is my own composition, and that it has not previously been presented for a higher degree. Information derived from the unpublished and published work of others has been acknowledged in the text.

Signature of Candidate

July 1987.

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My gratitude is due to the following:

(1) My supervisor, Dr. Schoeneich, for his guidance and ideas given to me. His determined patience for going through the manuscript and the constructive suggestions which enabled me to successfully write up of the project, are very much appreciated.

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(3) a) Borno State Ministry of Agriculture.

b) Borno State Water Board.

c) Chad Basin and Rural Development Authority.

d) Lake Chad Research Institute.

e) Lake Chad Basin Commission.

f) Maiduguri Airport.

g) Borno Accelerated Development Area Programme (BOADA).

I acknowledge the above Organizations for the help they gave by supplying me with data on boreholes, surface temperature, water quality and climate. I am also very grateful for the individual helps given to me by many people in these organizations who I cannot name.

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they gave me are well acknowledged.

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(7) Finally, I am indebted to my employers, Borno State College of Basic Studies and Borno State Government for giving me the sponsorship to undertake the course.

ABSTRACT

Temperature maps were produced based on the data collected on:

(a) Water temperatures from 63 boreholes tappinq water from the artesian aquifers of the Chad Formation,

(b) Mean annual ground surface temperature for the state.

Temperatures of ground surface and water in the borehole. were plotted on X-axis against depths to the mid screen positions in boreholes on Y-axis of a graph. Based on this, the map of the geothermal gradient was produced. The map shows NW _ SE elongated geothermal anomalies possibly correspond to troughs in the basin or correspond to fracture zones through which intrusions took place or represent concentrations of radioactive materials in the sediments or in the basement below; while the cool anomalies correspond to the ridges in the basin.

Using the graphical extrapolation method, the temperature maps at 100m above mean sea level, at sea level. -100m below mean sea level and at -200m below mean sea level were produced.

The geothermal gradient in the basin ranges between 2.00 and 6„00 °C/100c and there is a general trend that the gradients are higher towards the lake.

Areas with higher gradients reflect higher water temperatures and this affects the PH and Eh of water.

The warm artesian waters have low pH values and this coupled with the high temperatures, increase the dissociation rates of some elements (eg. Fe^{++} end Na^{+}) and salts. The higher iron concentrations in the waters from the Chad formation aquifers could therefore be related to the high temperatures.

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ABBREVIATIONS

epm	-	equivalent per mole
L/S	-	litres per second
mamsl	-	meters above mean sea level
mbmsl	-	meters below mean sea level
M.A.	-	Middle Aquifer
L.A.	-	Lower Aquifer
U.A.	-	Upper Aquifer
G	-	Gravel
S	-	Sand
C	-	Clay
SL	-	Silt
TDS	-	Total Dissolved Solids
ppm	-	parts per million
EC	-	Electrical conductivity

Chapter 1

INTRODUCTION

1.1 Objectives of the Project

The objective of the project is to investigate the temperature gradient in the Chad Formation of Borno State based on the data of numerous boreholes drilled in the area. The possibility of exploiting the heat reservoir for the generation of electricity and to see if minerals could be extracted from the steam and the super heated water at great depths was also considered. The investigation is also aimed at finding more information about the geology of the Chad Basin sediments, especially the nature of the aquifer sediments, levels at which the aquifers are found and their areal extent. It also examines the effect of temperature on the water quality.

1.2 Location, Extent and Accessibility

The study area is located in the extreme North Eastern part of Nigeria, bordering Chad, Cameroun and Niger Republics. It covers more than half the total area of Borno State and is approximately situated within the latitudes 11°N and $13^{\circ}10"$N and longitudes 10°E and $14^{\circ}30"$E, covering an area of about 85,400km^2 (Figs. 1 and 3).

The area is easily accessible with a good network of highways and secondary roads.

1.3 Previous Work

A lot of investigations have been carried out by groups of workers such as Barber, 1965, Barber and Jones, 1968,

LOCATION MAP OF THE AREA

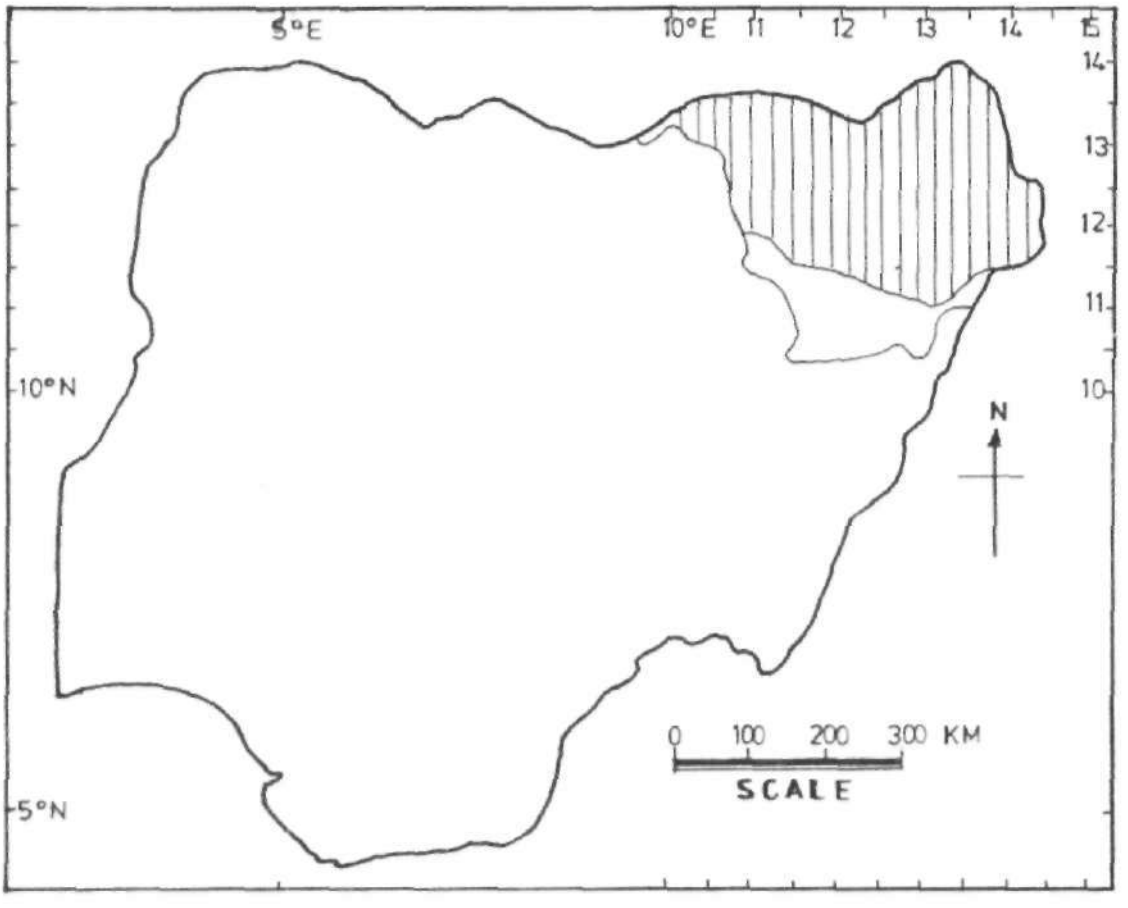


FIG. 1

Carter et al., 1963, du Preez, 1965, and others for the Geological Survey of Nigeria. The purpose of their investigation was to determine the geology of the area and to evaluate the extent of the artesian aquifers and the possibilities to exploit them as the source of water for this semi-arid region.

Later investigations carried out by consultants in the nineteen seventies for the Borno State Government, Federal Department of Water Resources, Chad Basin and Rural Development Authority and Lake Chad Basin Commission were all aimed at evaluation and exploitation of the water resources in the Chad Formation.

Up to date there has never been any significant research aimed at investigating the temperature gradient in the aquifers of the Chad Formation, though Miller, et al (1968) carried out a research work and came to a conclusion that water temperature of 31^{o}C is obtained at a depth of 36m below the surface for the Chad Formation.

1.4 Methods of Investigation

Mean annual surface temperatures for the area under investigation were gathered at different meteorological stations in the State manned by Borno Accelerated Development Area Programme (BOADAP), Borno State Water Board, Lake Chad Research Institute and Maiduguri International Airport. A surface temperature map was produced based on the data collected, (see Fig. 13). Temperature at any point on the map serves as a reference surface temperature used in the extrapolation of temperatures at different depths, which in turn were used to produce temperature maps for the respective

depths. The mean annual surface temperature represents the mean daily temperatures for twelve months in the year summed up over twelve.

Temperature data for aquifers from which boreholes tap water were read at the surface during the pumping tests. Readings were taken after many hours of pumping. It is done in this way to enable the water temperatures at the surface to stabilize, because it loses heat to the surroundings during ascent in the borehole. From the initial stages of pumping, more heat is lost, but as the surroundings get warmed up, the rate of heat loss decreases until it approaches a static level, i.e. when the readings are taken. The temperature read will therefore be only slightly less than the water temperature in the aquifer.

On the basis of the mean annual temperature on the ground surface and the approximate water temperature in the aquifer measured at the surface, temperatures at various depths were extrapolated using a graphical method as follows:

Depth of borehole is plotted on the Y-axis against temperature on the X-axis. Mean annual surface temperature reading for that location is plotted on the graph and that coincides with the elevation of the borehole with reference to the sea level at that point. Another point for the water temperature is plotted on the graph, and this point coincides with the mid screen position at the bottom of the borehole. Elevation of the mid screen position is also referred to the sea level. The two points are joined with a straight line and the line is extended to depth. Temperature for any

desired depth can be read from the graph. (see fig. 2). Note that the graph will not continue as straight line when the basement is reached because the temperature gradient in the basement is less.

For illustration purposes, the following data are considered:

A borehole located at Kukareta, 350m. above mean sea level, taps water in the middle aquifer at 400m depth. The water temperature during pumping test was 40°C and the mean annual surface temperature for Kukareta is 30°C.

From the graph (fig. 2). the extrapolated temperatures for the following depths are:

+	300	mamsl	-	31.4°C
+	200	mamsl	-	33.9°C
+	100	mamsl	-	36.3°C
		sea level	-	38.9°C
-	100	mbmsl	-	41.2°C
-	200	mbmsl	-	43.7°C
-	300	mbmsl	-	46.2°C

As indicated in the appendix, water temperature readings are representative of the aquifers of the Chad Formation of Borno State. Apart from the temperature data, lithological logs, drilling and casing depths data plus location coordinates for all the boreholes were collected for the purpose of the investigation.

1.5 Relief and Drainage

The area is generally a flat lying sedimentary terrain

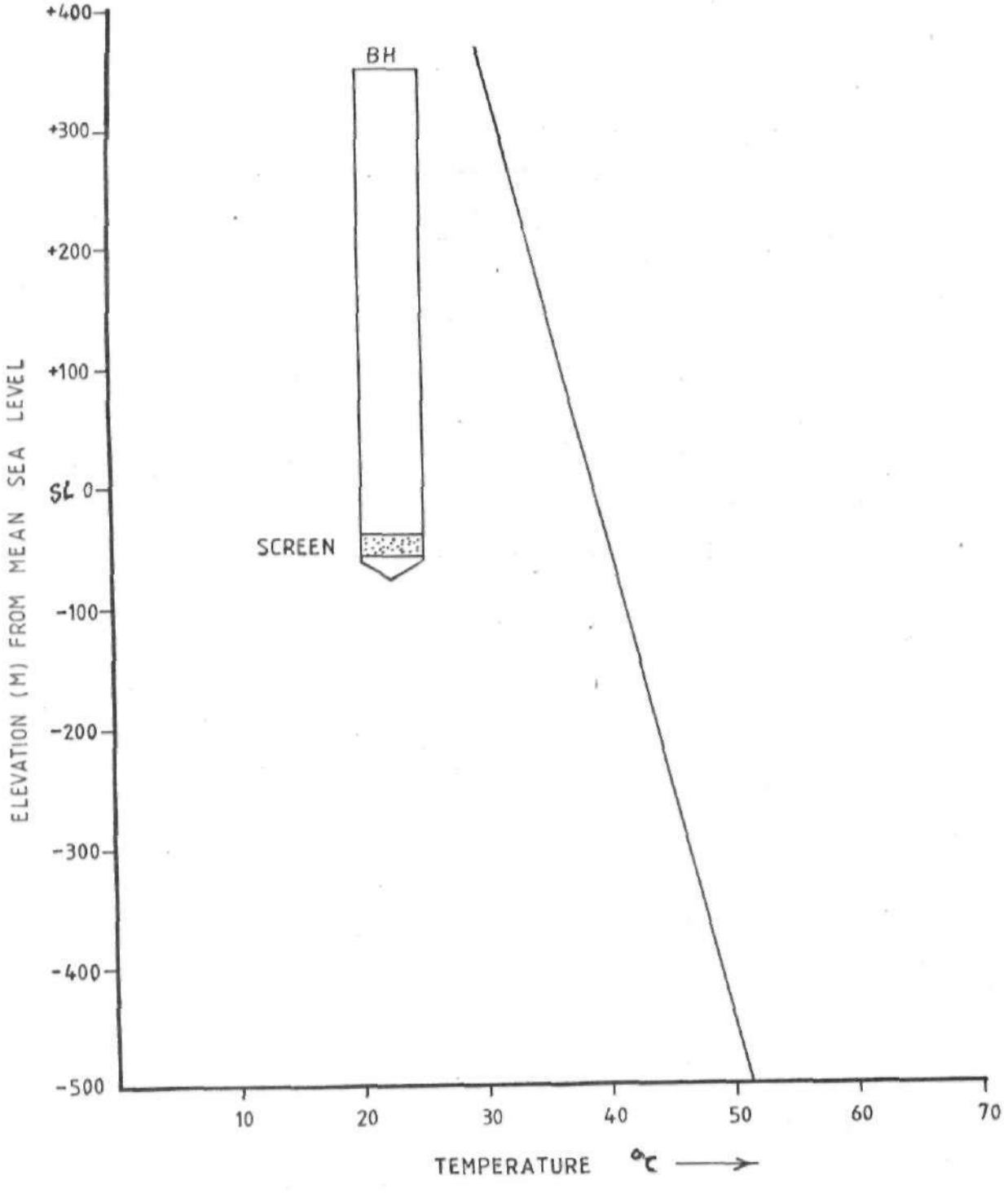


Fig. 2. Graphical representation of Geothermal Gradient

with some undulations produced by ancient sand-dunes and abandoned stream courses. The land surface generally dips towards lake Chad, with the lowest elevation of about 280m above mean sea level on the lake shores. Towards the periphery of the basin, the elevation of many areas reaches 450m above mean sea level.

Over all drainage of the area is simple Main rivers like the Yadzaram, Kumadugu gana and Kumadugu Yobe flow into Chad following the general dip direction of the terrain. These rivers have their catchment areas in the high surrounding basement regions.

The undulating nature of the terrain controls the drainage pattern of minor rivers and streams. Water from the streams and rivers normally ends up recharging the aquifers in their vicinity.

1.6 Climate, Vegetation and Land Use

The area has a semi desert climate with rainfall ranging from 600mm in the southern part to about 300 mm in the northern part during wetter years. Maiduguri recorded a rainfall of 457 mm in 1985 and 517.5 mm in 1986.

The vegetation is a sahel savannah type, with low grasses and thorny bushes. On the shores of Lake Chad, Savannah wood land exists.

The area is suitable for short period varieties of crops like millet, guinea corn and groundnuts. The black clay soils (Firgi) covering the eastern part of the region near Lake Chad are very fertile and suitable for wheat

cultivation. The activities of the Chad Basin and Rural Development Authority are concentrated in this area.

Chapter 2.

GEOLOGY AND HYDROGEOLOGY

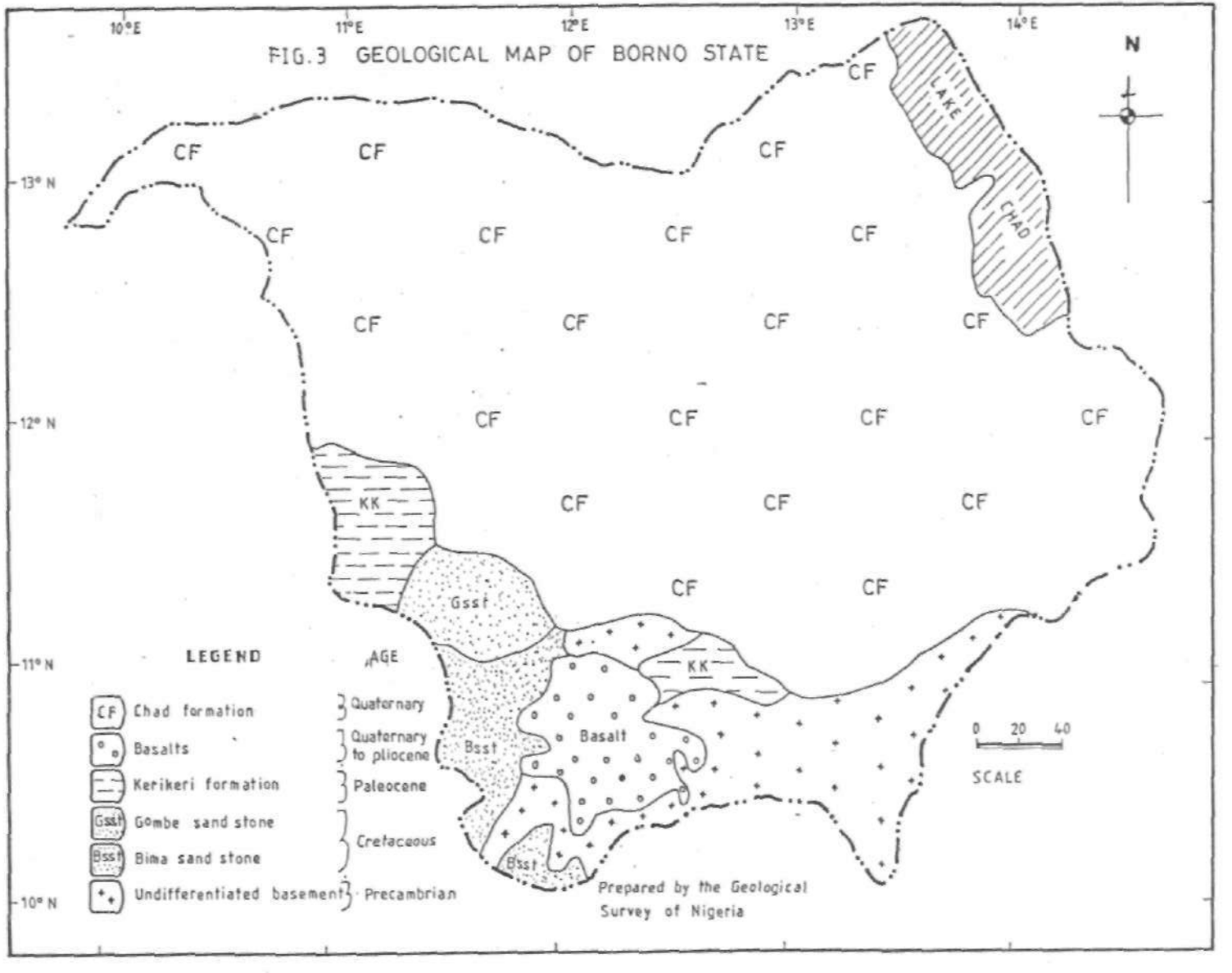
2.1 Cainozoic Chad Basin

Most parts of Chad Basin are occupied by Quaternary sands and alluvium called the Chad Formation which overlie older sediments in many areas, (Barber, 1965). It is an inland drainage depression bordered by both basement and Lower Paleozoic sediments. During the Quaternary period, the areal extent of Lake Chad was greater than it is now and it spilled over into the Benue River.

The present Lake Chad lies at about 280m above sea level with Chari as the main river draining into it from Chad republic. The rivers that drain into the Lake Chad from the Nigerian portion of the basin include: Kumadugu Yobe, Kumadugugana and Yadzaram.

Geophysical evidence (Cratchley 1960) revealed that the deepest part of the sedimentary basin extends North - East from the Benue Trough, beneath Lake Chad and on towards the north eastern boundary of the Basin. Beneath Maiduguri it is 2,500m deep and about 4,000m around Gajiram.

Lithological information exists only for the top 1,044m of the sedimentary sequence of the basin beneath Maiduguri. Recent drillings for oil near Gajigana, about 60 km north of Maiduguri has revealed more of the sequences. Continuity of the Cretaceous sediments beneath the Chad Formation has bee


FIG.3 GEOLOGICAL MAP OF BORNO STATE
10°E
11°E
12°E
13°E
14°E
13° N
12° N
11° N
10° N
N
LAKE CHAD
CF
KK
Gsst
Bsst
Basalt
LEGEND
AGE
CF Chad formation
Basalts
Kerikeri formation
Gsst Gombe sand stone
Bsst Bima sand stone
Undifferentiated basement
Quaternary
Quaternary to pliocene
Paleocene
Cretaceous
Precambrian
0 20 40
SCALE
Prepared by the Geological Survey of Nigeria

proved and depth of 3,640m has been drilled through without reaching the basement (see Fig. 4).

Of all the thickness of sediments in the Chad Basin, the upper 1,000m of the total consists of Chad Formation clays and sands of Quaternary age. The rest is made up of the Cretaceous sediments.

The Quaternary Chad Formation rests unconformably on the older-beds. It buries a varied topography and consists of fluviatile and lacustrine clays and sands; with lenses of diatomites up to a few meters thick, (Wright, 1985). Bones of mammals have been recovered, but few other fossils are found, apart from diatoms, which indicate a Lower Pleistocene age. Tattam (1943) discovered a jaw of a hipopotamus in a dug well at 60m depth and based on this he assigned a Quaternary age to the Chad Formation. In the deeper parts of the basin, where the Chad Formation may reach 1,000m, the stratigraphic succession probably extends down into the Pliocene.

Detailed information of the Nigerian sector of the Chad Basin is provided by the numerous boreholes drilled in Borno state to evaluate and exploit the artesian water (see Fig.5).

In 1950 work was started on the drilling of the Maiduguri Deep Test Hole (222 MA) which was to have been pushed to a depth of 1220m to investigate the possibility of finding deep water - bearing levels in the Chad Formation sediments, but Barber and Jones (1960) recorded that the hole was abandoned at 1044m. A complete lithological description of

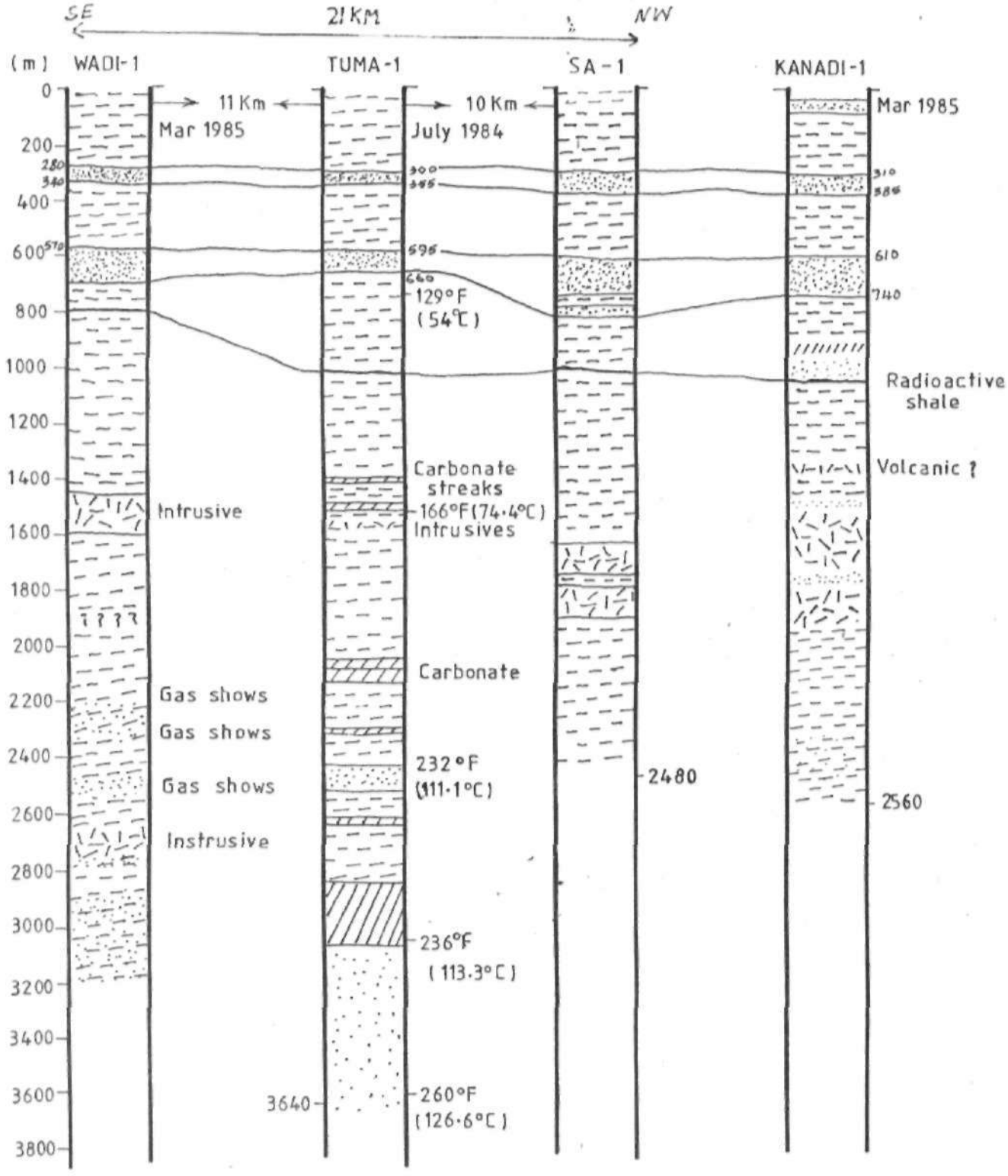


Fig. 4 Recent deep drillings for oil in the Chad BASIN near Gajigana, Borno State.

Shale Sand Volcanics Highlyradioactive shale

Anhydritic $CaCo_3$

SCALE 1:200

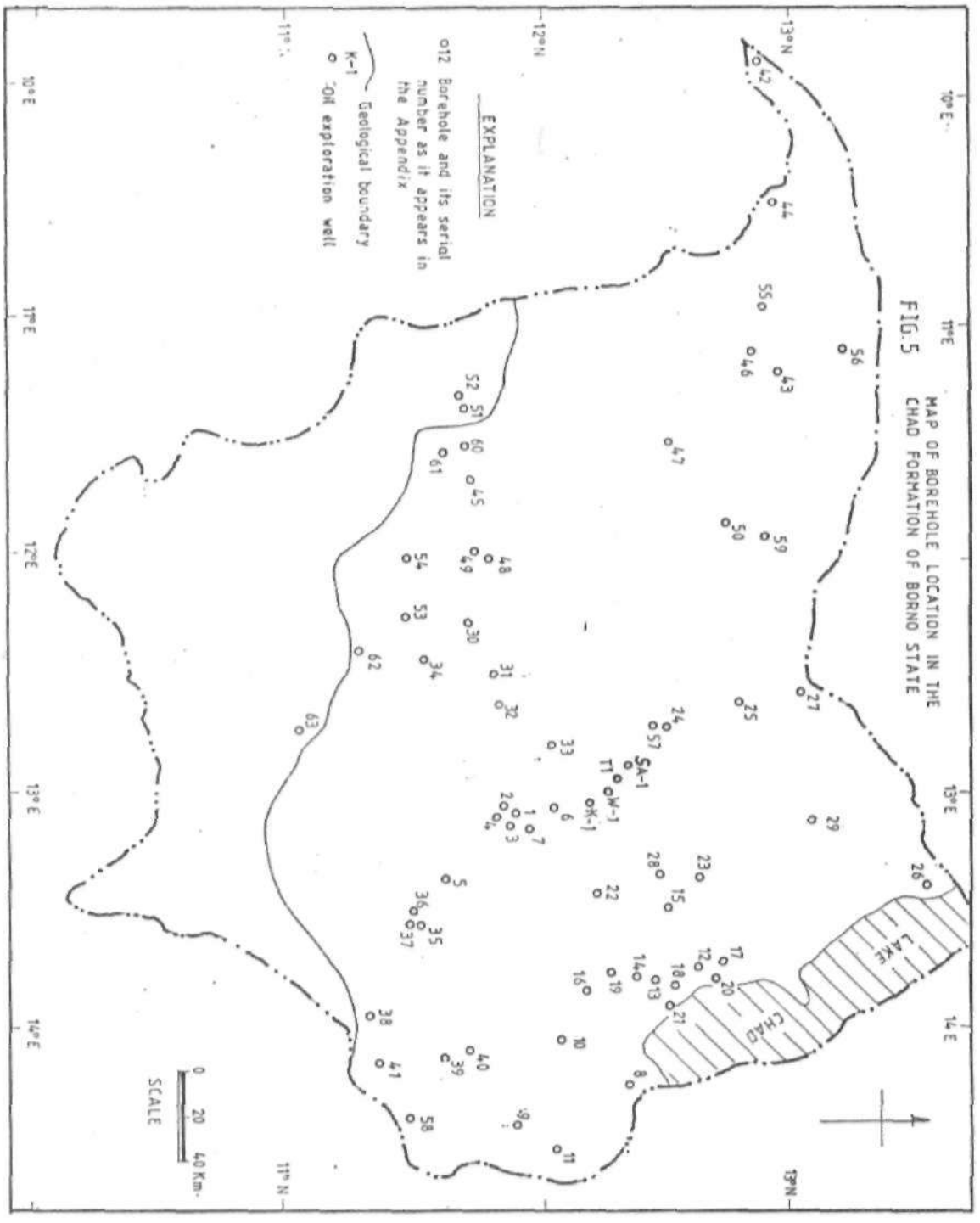


FIG.5 MAP OF BOREHOLE LOCATION IN THE CHAD FORMATION OF BORNO STATE

the formations encountered by the hole is not available. All that is known is that thick sandy beds were penetrated between 426.7 and 579.1m, and that very thick Cretaceious sediments - mainly black marine shales - occur between 623.9 and 1044m. However, there are complete lithological descriptions for the boreholes recently drilled under Maiduguri reaching 643m, (see appendix).

These show that lithologies seen in the surface outcrop extend to depths of hundreds of meters with clays as the dominant lithology. There are thick sands and sandstone lenses, which are the aquifers and bands of diatomites also occur at deeper levels. Numerous boreholes drilled in the formation exploit water from three levels of aquifers designated by Barber (1965), as the Upper, Middle and Lower aquifers, (see Fig. 8).

There is a great lateral variation, with the sands occuring as lenses of variable thickness among the clays, which are bluish or grey and contain small amounts of calcareous materials (Wright, 1985). Shaly layers occur at deeper levels. The sediments accumulated in a fluviatile and lacustrine environment, the sandy lenses probably laid down as alluvial fan deposits along lake margins in times of flood. The clays represent deposition under less turbulent conditions, either away from the lake shores or at times of low river flow. The deposition of the diatomite also occured under quiet conditions, when little detrital material entered the lake and the fragile diatom skeletons could accumulate.

Apart from the lateral variation in thickness of the sands of the aquifers, they display grain size variation, ranging from silty sands to gravel. The aquifers become dominantly gravelly towards the periphery of the basin as revealed by boreholes in Banki, Gulumba, Dar-El-Jamal in Bama Local Government Area. The gravelly nature of the sands could also be seen in boreholes in Damboa and Nguru Local Government Areas.

Some of the sands of the Chad Formation are aeolian sands deposited as sand dunes. They are thick enough to serve as aquifers in the extreme North of Borno state, in Kukawa, Geidam and Nguru local Government Areas. Typically, they are fine grained and well sorted. Such aquifers hardly exceed 70m depth. Sanding is a common problem of boreholes in these areas and all wells are therefore gravel packed.

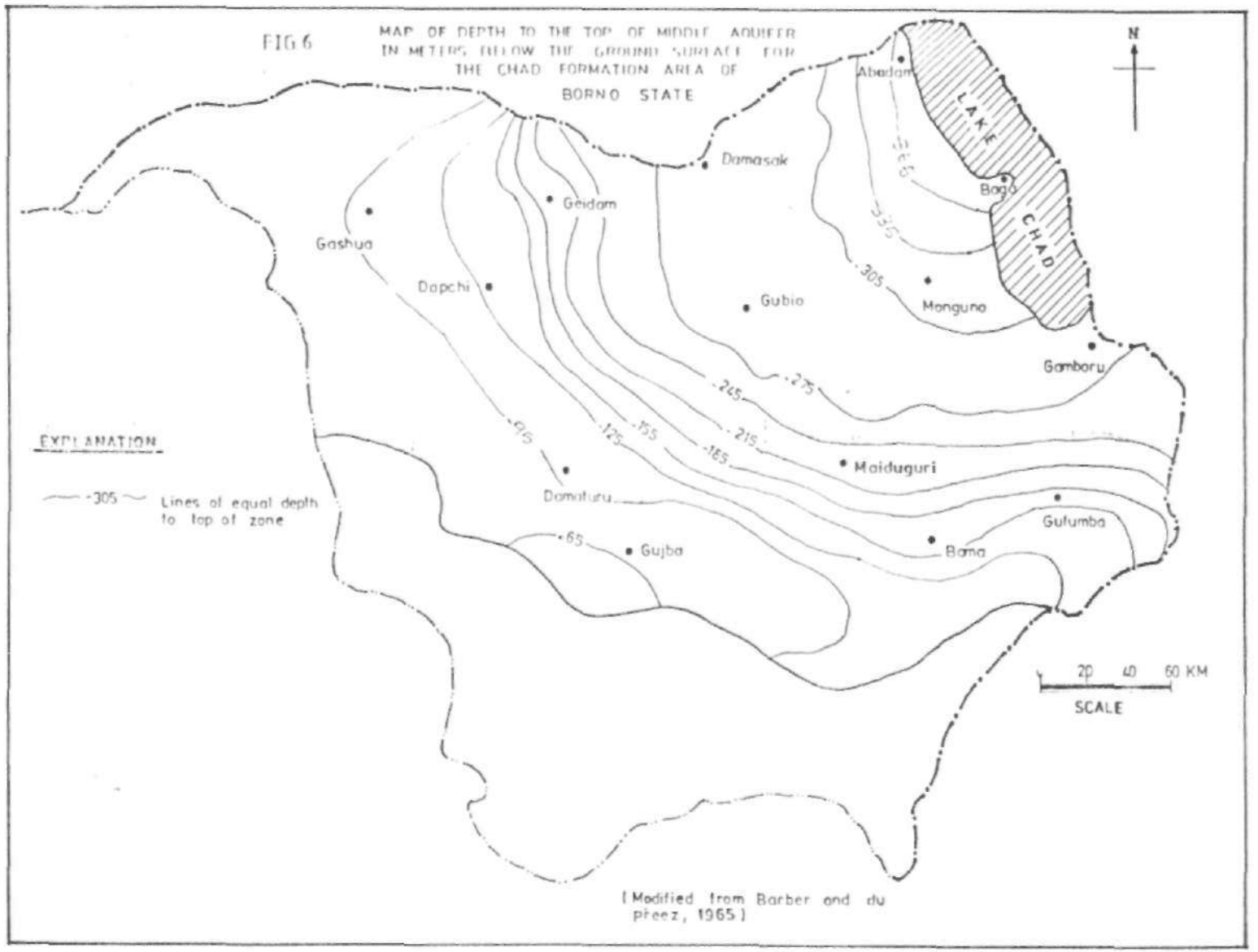
From the above discussions, it can be seen that the later history of the Chad Basin was a vast plain with many rivers draining into one or more lakes, probably well vegetated and well stocked with animals. Towards the end of the Quaternary, the climate became more arid with aeolian dune sands accumulating in the northern part by about 20,000 - 40,000 years ago. A more humid period returned between 9,000 to 5,000 years ago when Lake Chad reached its maximum extent (Mega Chad), and Lake beds formed overlying the older dunes. Servants (1970) traced the dunes beneath the lake deposits by echo sounding in the neighbouring Chad Republic.

This indicates that the lake bottom was once dry. The boundary of Mega Chad is marked by a prominent ridge called Bama Ridge in Borno State (Burke et al., 1976b.). It is traced running NW - SE passing through Maiduguri to Bama. The sediments of the Bama ridge are mainly gravelly sands with clays.

The sequence of the sediments of the Chad Formation dip towards Lake Chad reflecting the slope of the surface topography. The lake itself is 280m above sea level while Maiduguri which is 150 km south west of the lake is 330 m above sea level.

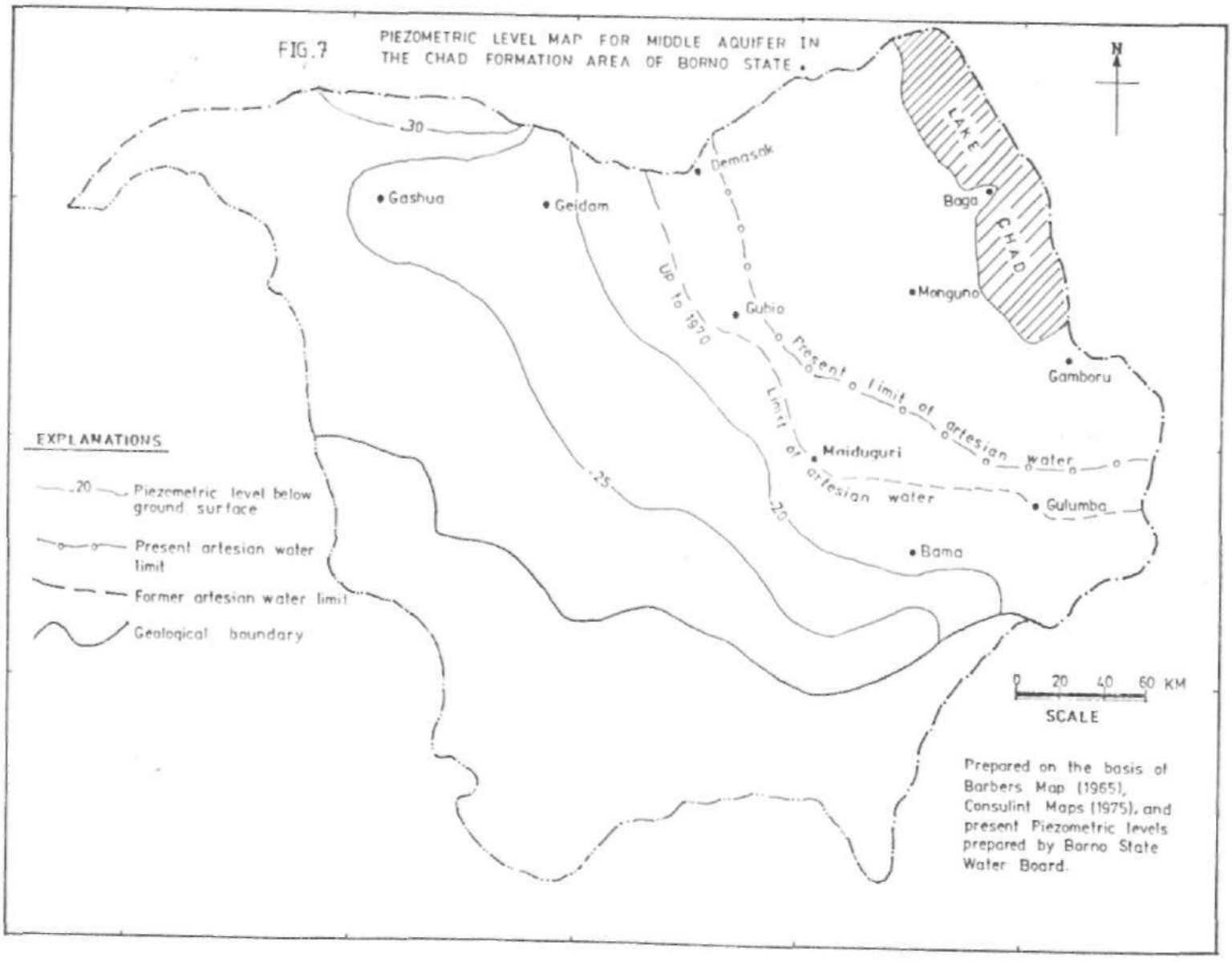
Durotoye (1974) pointed out that there is an abrupt thickening of the Chad Formation sediments inside the Bama Ridge. Borehole records confirm the general thickening of the sediment sequence of the Chad Formation towards Lake Chad. The Upper Aquifer is found as patches all over the formation area. The Middle aquifer is found at about 200m depth under Maiduguri. Closer to the lake, boreholes tap water at depths of 300 - 370m in the Middle Aquifer. This is seen in boreholes located in Monguno, Kukawa and Ngala Local Government Areas (see Fig. 6). The Middle Aquifer in these areas, is overlain by a clay and shaly clay aquiclude of about 300m thick, and it is under high pressure with water temperatures relatively higher compared to the temperature of water in the same aquifer at Maiduguri and other places further away from the lake.

FIG 6 MAP OF DEPTH TO THE TOP OF MIDDLE AQUIFER IN METERS BELOW THE GROUND SURFACE FOR THE CHAD FORMATION AREA OF BORNO STATE



(Modified from Barber and du Preez, 1965)

FIG.7 PIEZOMETRIC LEVEL MAP FOR MIDDLE AQUIFER IN THE CHAD FORMATION AREA OF BORNO STATE.



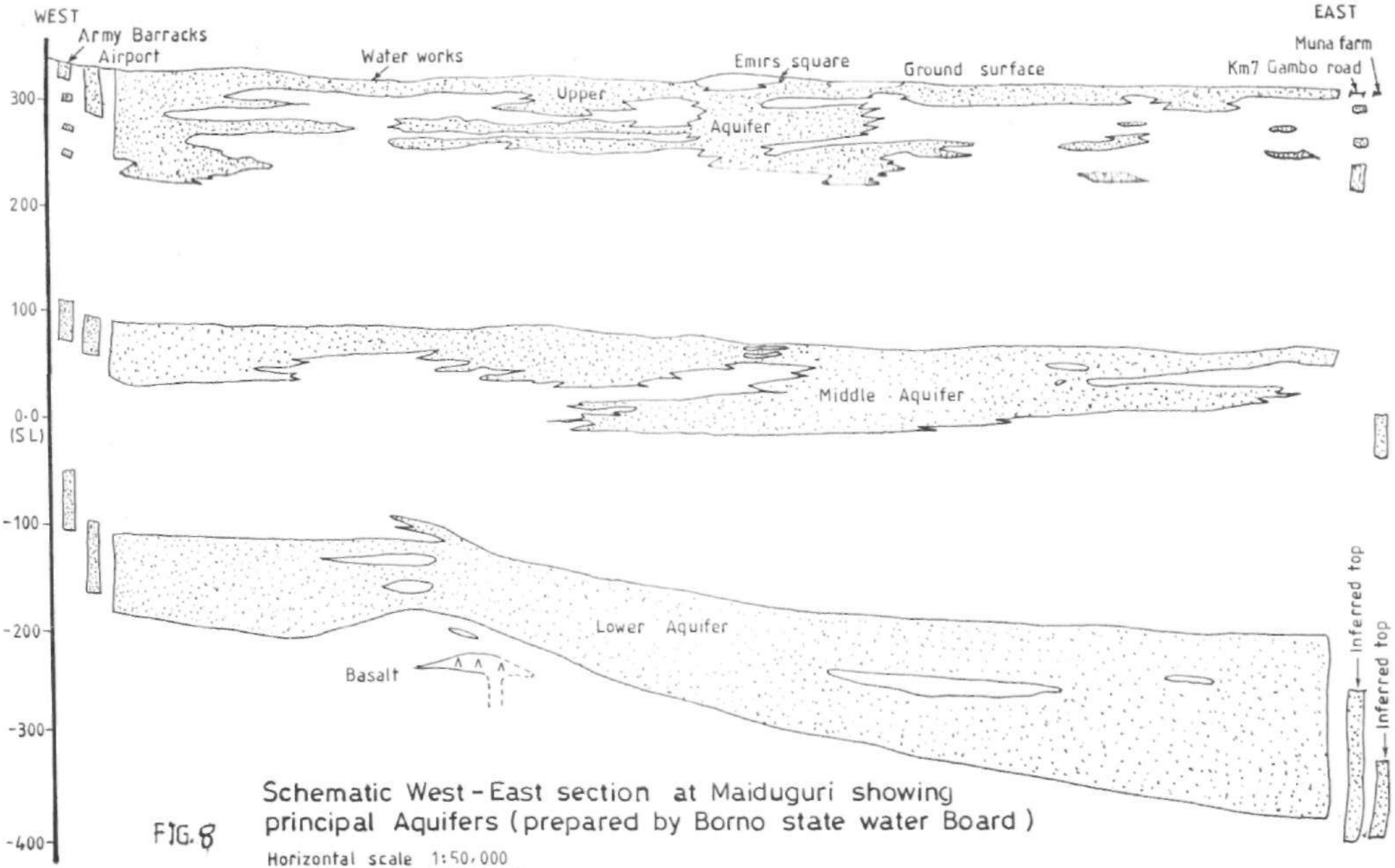


FIG. 8

Schematic West - East section at Maiduguri showing principal Aquifers (prepared by Borno state water Board)

Horizontal scale 1:50,000
Vertical scale 1cm to 50m

The artesian pressure head decreases with distance from the lake to a subartesian situation with thinner confining clay aquiclude. For example, the confining clay under Maiduguri is 180m thick and the piezometric head is 30m below the ground surface. It used to be 10m below the ground surface but continuing extraction of water has made it go down. A thin layer of the Upper Aquifer is present on the clay deposit in some places around the town.

The Lower Aquifer under Maiduguri is separated from the Middle Aquifer by a confining clay layer of about 280m thick. It was a free flowing aquifer in the early nineteen seventies, with pressure level of 10m above the surface. Over extraction has now caused the head to go down to a depth of about 40m below the ground surface. Water temperatures from the aquifer ranges between 48 - 50°C At Gajigana, 60 km. North of Maiduguri, the Lower Aquifer is found at a depth of about 600m below the ground surface in the oil exploration wells. A deep borehole drilled by Chad Basin and Rural Development Authority near Lake Chad has indicated that the Lower Aquifer has been reached at a depth of 800m.

Hydraulic characteristics of the Chad Formation aquifers are highly variable because of the vertical and horizontal variation in lithology and aquifer thicknesses Transmissibilities are highly variable although the aquifers are generally very productive.

Many test and production holes have been sunk in the Upper Aquifer in the state. It consists of beds and lenses of coarse and very coarse sands, sometimes clayey or gravelly, interbedded in what is predominantly clayey formation. The lenses vary in thickness, lithology and permeability. Test data from different parts of the state show that the transmissibility values range between 7.50×10^{-5} - 1.00×10^{-3} m^2/s.

The Middle Aquifer which is a confined Aquifer has been encountered within the Chad Formation throughout the State. It consists of sands ranging from coarse to fine; sometimes clayey or cemented and occuring in beds or thin layers interbedded in the Chad Formation clays. The aquifer ranges in thickness from 15 to 30m. Its top is marked by a level of oxidized clayey sands or clay ranging in colour from yellow to red. The waters of this aquifer are always under pressure, and in the vast area between Maiduguri and Lake Chad the pressure is sufficient to ensure that boreholes are free flowing with high yields near the lake in Monguno and Kukawa Local Government Areas.

Using a modified Theis - Jacob formula for artesian aquifers, transmissibilities obtained from pumping tests vary from 2.50×10^{-5} m^2/s to 7.68×10^{-4} m^2/s.

The Lower Aquifer under Maiduguri has been found at depths between 420 - 510m. It is formed of fine to coarse sand with levels of sandstone, clayey sand, sandy clay alternating with clays. The permeable levels are the sands and sandstones whose thicknesses vary from 1.5m to 4.5m. The

same horizon is represented at Muna farm some 19 km NE of Maiduguri by a few thin bands of sandstone, and at Kunasi by some 19m of practically impermeable clayey sand. Transmissibilities for the aquifer as determined from pumping tests range between 1.2×10^{-4} m^2/s to $2.50 \times 2.50 \times 10^{-4}$ m^2/s.

Aquifers in the Chad Formation are shallower and tend to converge near the periphery of the basin. This is common with boreholes in Bama and Damboa Local Government Areas. Where Middle and Upper Aquifers exist in these areas, they cannot be distinguished. Around Bama for example, the two aquifers form a continous phreatic zone of gravels and coarse to silty sands with thin clay layers. This zone extends from 40 to 200 m below the ground surface. In some places it is phreatic from the ground surface down to the basement.

In the neighbouring countries of Cameroun, Chad and Niger Republics, it has been ascertained that the recharge regions of the Middle Aquifer are near the periphery of the basin and the recharge water flows underground towards the lake. This, however, is not for certain in Nigeria, though Barber (1965) has argued that it could be the same for the whole Chad Basin.

Elsewhere in the Chad Formation area, the Upper Aquifer is not generally confined. It receives its recharge water from the rain during the rainy season and from the seasonal Streams and Perennial Rivers flowing over the plain. These

Rivers and Streams recharge the aquifer in their immediate vicinities. The abnormal water table rise in the Upper Aquifer during November - December noted at Maiduguri is explained by the high water discharges in the River Ngadda at the end of the rainy season in September to October. Hand dug wells that tap water in the upper freatic zone of the Chad Formation in the northern part of Borno State, went dry during the drought periods of 1983 - 84. The water level in the Upper Aquifer went down as far as 50 m below the ground surface. All the boreholes which also tap water from the Upper Aquifer stopped functioning because their pumping levels lie between 30 - 40m below the ground surface.

However, as more rain started to fall from 1985, the Upper Aquifer was recharged, and most of the wells which went dry in 1984 are now productive as the water level has now risen to about 25m below the ground surface.

2.2 Cretaceous Chad Basin and the Basin Subsidence

According to Barber (1965), the history of the Chad Basin began during the Upper Cretaceous when 1000 m of continental sediments consisting of Bima Sandstones were deposited unconformably on the Precambrian basement. The Gongila Formation, a mixed limestone shale, was deposited by marine transgression on the Bima sandstone. These beds are overlain by marine Fika Shales of Turonian to Cenomanian age. Towards the end of the Cretaceous an esturine - deltaic environment prevailed and the Gombe Sandstone was deposited

with intercalations of siltstones, shales and ironstones. The Paleocene marked the period of deposition of the Kerikeri Formation.

The Chad Formation overlies these Cretaceious marine sediments in the basin, (see Fig. 9). These Cretaceous sediments occupy the north eastern end of the Benue Trough where it enters the Chad Basin. Borehole data indicate that they thicken considerably towards the north east. More than 400 m have been proved beneath Maiduguri and 3000 m beneath Gajigana, (see Figs. 9 and 4 respectively). Under Maiduguri, they consists of the Kerikeri Formation (a paleocene continental sediment), Gombe Sandstones, and Fika shales. These Formations outcrop in the south west of Borno state and boreholes in Fika, Fune and parts of Gujba Local Government Areas tap water from the sandstones of the Kerikeri Formation and Gombe sandstone. Marine Cretaceous sediments could exceed 4000m in thickness in the deepest parts of the basin, but insufficient borehole data are available to determine the extent of correlation between sediments in the main part of the basin and those exposed in the west.

There is little evidence of significant Lower to Middle Tertiary sedimentation, which means that after the sea withdrew at the end of Cretaceous, the Chad Basin must have been an area of non marine deposition and remained so far almost the whole of Tertiary, (Wright, 1985). The Kerikeri Formation, a Paleocene Continental Sediment was deposited

during this break. French equivalent for the Kerikeri Formation, as described by Lake Chad Basin Commission for the whole Basin, corresponds to the phreatic Lower zone aquifer of Lower Pliocene and Terminal Continental Aquifers (Lower, Middle and Upper), See Fig. 9. As the period of sedimentation resumed after the break, which led to the deposition of Chad Formation, the Basin started to subside again at about 2.00 m.y ago and this can be associated with the uplift of the swells round the basin that lead to the difference in height which was necessary for the sedimentation to begin. The uplift was associated with the onset of late Tertiary - Quaternary volcanism on the Jos and Biu Plateaux, (Burker et al., 1976).

Some basic intrusive materials have been encountered in deep borcholes in Maiduguri and a deep test hole sunk near Bama (Bama Deep Test Hole No. 3 GSN 2975) also encountered basaltic lava at a depth of 215 m. The basalt could have been extruded from faults along the edge of the Chad Formation basin and to some extent contemporaneous with the deposition of the Formation. Indirect proof of the existence of buried faults is provided by the presence of basalts, phenolites and rhyolite lavas (usually associated with deep tension fractures in the earth's crust) which outcrop in some areas around the margins of the basin between the Chad Formation and its basement.

Geophysical evidence provided by Cratchley (1960), suggests that Cretaceous beds fill the broad troughs within the basement. One major trough with a WSW - ENE trend has

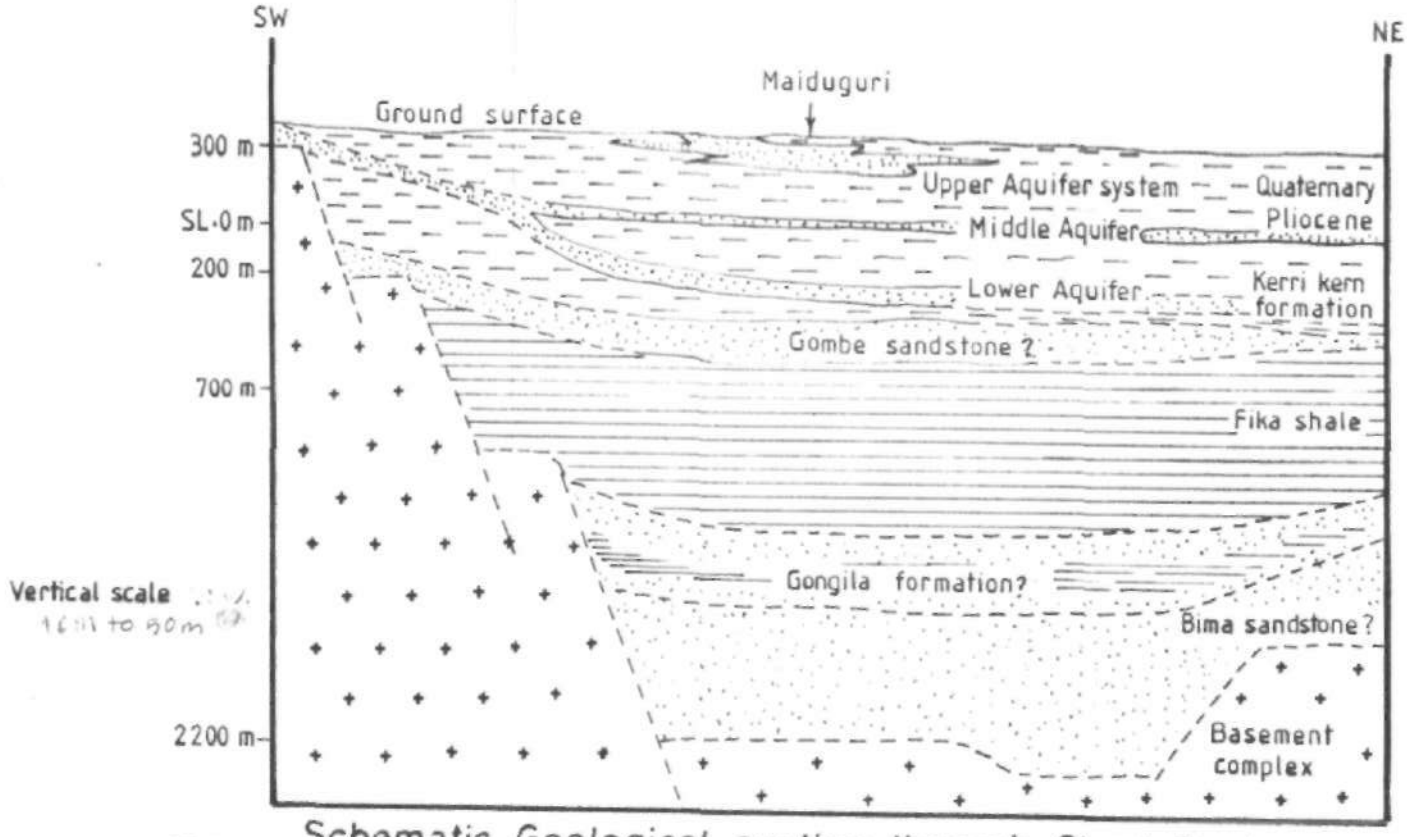


FIG. 9 Schematic Geological section through Chad Basin at Maiduguri (prepared by Chad basin commission).

a depth of 3500 m and is filled with 3000 m of Cretaceous sediments. The troughs in the Chad Basin have a similar trend to structures in the Benue valley and may have formed either by rift faulting or folding, (Cratchley, Ajakaiye and Louis, 1984). Furon (1963) suggested that the Chad Basin was a tectonic cross-point between a NE - SW trending Tibesti - Cameroun trough and a NW - SE trending Air - Chad trough.

Chapter 3

GEOTHERMICS AND HYDROCHEMISTRY

3.1 Geothermal Gradient

Water temperatures from boreholes tapping the Upper Aquifer range between 29 - 33°C. For the Middle Aquifer, the range is between 34 - 51°C, and for the Lower Aquifer, which has been reached only under Maiduguri, has a range of 47 - 50°C.

Many boreholes tap water from the Upper Aquifer all over the Chad Formation in the State where the aquifer is found, and the small temperature differences are mainly due to the depth at which water is being tapped. This aquifer interacts with the atmosphere in most places.

The Middle Aquifer is the most exploited in the state. Many boreholes tap water from it all over the Chad Formation. It has the highest temperature range (34 - 51°C) and this could be due to many reasons:

(1) Some of the boreholes tapping water from the Middle Aquifer also tap water in the Upper Aquifer. For example, borehole Number 31 located at Benisheik, is screened at two positions: 47.39 - 53.47m in the Upper Aquifer and 159.53 - 165.61m in the Middle Aquifer. The mixing of the cool water from the Upper Aquifer and the warm water from the Middle

Aquifer is responsible for the lower temperature of $33^{0}C$ which is not expected of the Middle Aquifer.

(2) The Middle and Upper Aquifers converge towards the margins of the basin. In places like Bama, Kumshe, etc. the two aquifers merged and form a continous unconfined freatic zone. The free interaction between the aquifer and the atmosphere is responsible for the low water temperatures. Boreholes number 35, 36 and 37 have temperatures of $31^{o}C$, $35^{o}C$ and $34^{o}C$ respectively. They are screened at depths of between 123m to 184m below the ground surface. Expected temperatures should be higher than these if only the confined Middle Aquifer is being tapped.

(3) The depth at which the aquifer is found at a particular location. There is a general trend of dip and thickening of the Chad Formation sediments towards Lake Chad. For example, along a SW to NE direction from Benisheik through Maiduguri to Lake Chad, it can be seen that the top of the Middle Aquifer is found at a depth of 150m below the ground surface at Benisheik, and the water temperature is $33^{o}C$ (BH'S No. 31, taps Middle and Upper Aquifers); at Mainok, between Maiduguri and Benisheik, the top of Middle Aquifer is at 221m and the water temperature is $34^{o}C$. At Maiduguri most of the Middle Aquifer boreholes tap water at depths between 22[illegible] - 240m below the ground surface, water temperature in most of the

wells is 38°C. Between Maiduguri and Monguno, most boreholes tap water in the Middle Aquifer at depths between 290 - 310m below the ground surface. Water temperatures range between 39 - 48°C. Examples: BH S. No. 28, located at Dawula, taps water at 307 - 313m below the ground surface and the water temperature is 47°C. BH S.No. 23, at Kumaliwa, with screen position at 323 - 353m, and the water temperature is 48°C. Well S.No. 26 located at Abadam on the lakeshore, taps water at 340 - 364m below the ground surface and the water temperature is 50°C.

From the above examples it can be seen that there is a gradual increase of depth to the top of the Middle Aquifer towards the lake, (see fig. 6). The increase in temperature with depth also follows the same trend. It can also be observed that there is a greater increase in temperature with depth from Maiduguri towards the lake along this trend. The rate of increase per every 100m depth is evaluated below using the data in the example above.

Location	Midscreen Position (m)	Water temper-ature (°C)	Surface temper-ature (°C)	Geothermal Gradient (°C/100m
Mainok (West of M/guri)	221	34	28	2.7
Maiduguri	240	38	2•	3.75
Dawula	310	47	3•	5.5
Kumuliwa	340	48	30	5.3
Abadam (on lake shore)	350	5•	32	5.2

Gradient Calculations in $^{o}C/100m$

The Geothermal Gradient is computed using the formula

$$G = \frac{(T - t)\ 100}{D}$$

where G = Geothermal gradient

T = Temperature of water in ^{o}C pumped from the well at the end of the pumping test.

t = Mean annual temperature at the ground surface, in ^{o}C.

D = Mean depth to the Midscreen interval, in meters from the ground surface.

Mainok - $\frac{(34 - 28)\ 100}{221}$ = $2.7^{o}C/100m$

Maiduguri = $\frac{(38 - 29)\ 100}{240}$ = $3.75^{o}C/100m$

Dawula = $\frac{(47 - 30)\ 100}{310}$ = $5.5^{o}C/100m$

Kumaliwa - $\frac{(48 - 30)\ 100}{340}$ = $5.3^{o}C/100m$

Abadam - $\frac{(50 - 32)\ 100}{350}$ = $5.2^{o}C/100m$

From the above gradient of $2.7^{o}C/100m$ West of Maiduguri to about $5^{o}C/100m$ near Chad Lake, it is apparent that the gradient increases along this trend. The increasing gradient indicates that the basin is deeper and the sediments are thicker towards the lake.

3.2 Explanations to the temperature maps

The temperature maps include:

(1) Map of mean annual surface temperature (fig. 13).

(2) Temperature map at 100m above mean sea level, (fig. 14).

(3) Temperature map at sea level, (fig. 15).

(4) Temperature map at - 100m below mean sea level, (fig. 16).

(5) Temperature map at - 200m below mean sea level, (fig. 17).

The surface temperature map was based on the data of mean annual surface temperatures measured at different meteorological stations all over Borno State and supplied by the Ministry of Agriculture, Borno Accelerated Development Area Programme (BOADAP), Lake Chad Research Institute, Borno State Water Board, Maiduguri International Airport and Chad Basin and Rural Development Authority.

The rest of the temperature maps were drawn with the sea level as the reference point. The sea level is chosen instead of the ground surface because of the complicated nature of the surface topography, which is made of hills, valleys, high regions and low regions.

Temperatures start to increase with depth immediately from below the ground surface or immediately after the zone of surface influence irrespective of the surface topography.

This increment is in accordance with the geothermal gradiant.

From the maps, it appears that temperatures are higher in the West than in the East (near the lake). The high temperature areas in the West stand at least 400m above mean sea level, while in the East, near the lake, the highest land surface stands at 280m above sea level. When the temperature at sea level is considered, temperatures of up to 47°C are measured in the west, while the highest temperature measured near the lake is 44°C. There are at least 400m of sediments overlying the sea level in the west, while in the east, there is only 280m of sediments overlying the sea level. Despite the low temperatures at sea level near the lake, it will be seen that the temperature gradient is higher there when it is evaluated.

Example

$$\text{West} - \frac{(47 - 30)\ 100}{400} = 4.25^{\circ}\text{C}/100\text{m}$$

$$\text{East} - \frac{(44 - 31)\ 100}{280} = 4.7\ \text{C}/100\text{m}$$

The values of the calculated pradients are approximate because the surface temperatures used affect the calculation. Moreover there might be some errors in the methods used in reading the water temperatures as well as in reading the surface temperatures.

Secondly, temperature gradient is steeper with depth, but in the calculations, it is assumed that there is a uniform gradient with depth in the sediments. In addition, all the wells used are shallow water wells. The few oil exploration wells have shown approximately the same gradient (2.6 - 3.2°C/100m) as the shallow water wells in the same locality.

Anomalous temperature gradients which could be due to valleys and ridges in the basin floor, concentrations of radio active materials in the sediements and in the underlying basement rocks of the basin exist in isolated areas in the depression, but because of insufficient borehole data it is assumed that the general increase in the temperature gradient is towards the lake which reflects the increasing thickness of the sediments in the basin.

Parameters in table 1 were used to produce the of Geothermal gradient for the Chad Formation area, (Fig. 10). From the map, cool and warm anomalies would be observed and these may be due to the reasons stated above.

3.3 Possible Sources and Reasons for the High Temperatures as such Shallow Depths

(1) During the process of deposition of sediments in a sedimentary basin, temperature rise accompanies burial. As the earlier sediments are buried deeper by the accumulation of later materials, more pressure is exerted at the bottom.

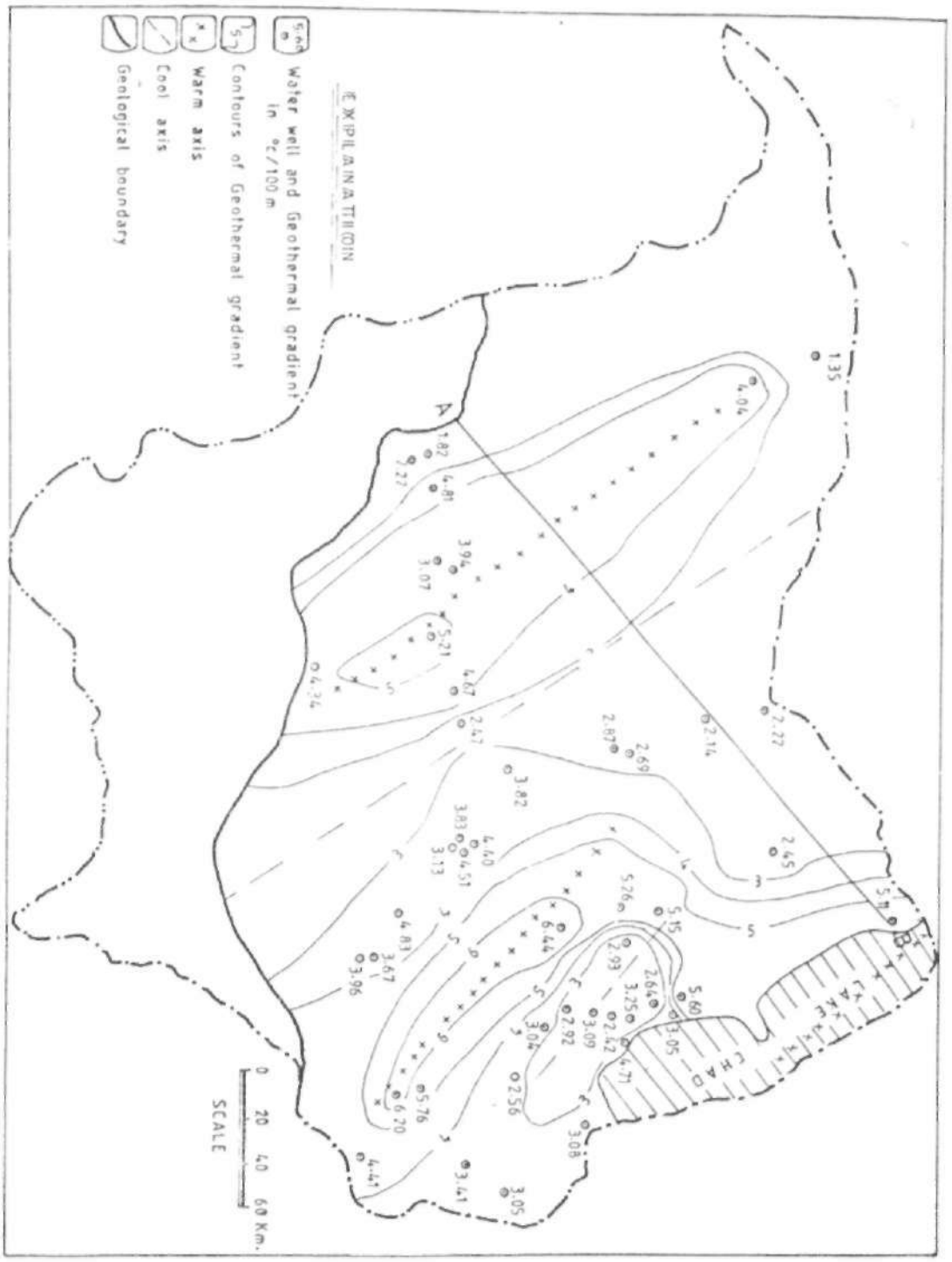


Fig. 10 Map of Geothermal gradient in the Chad formation area of Borno State.

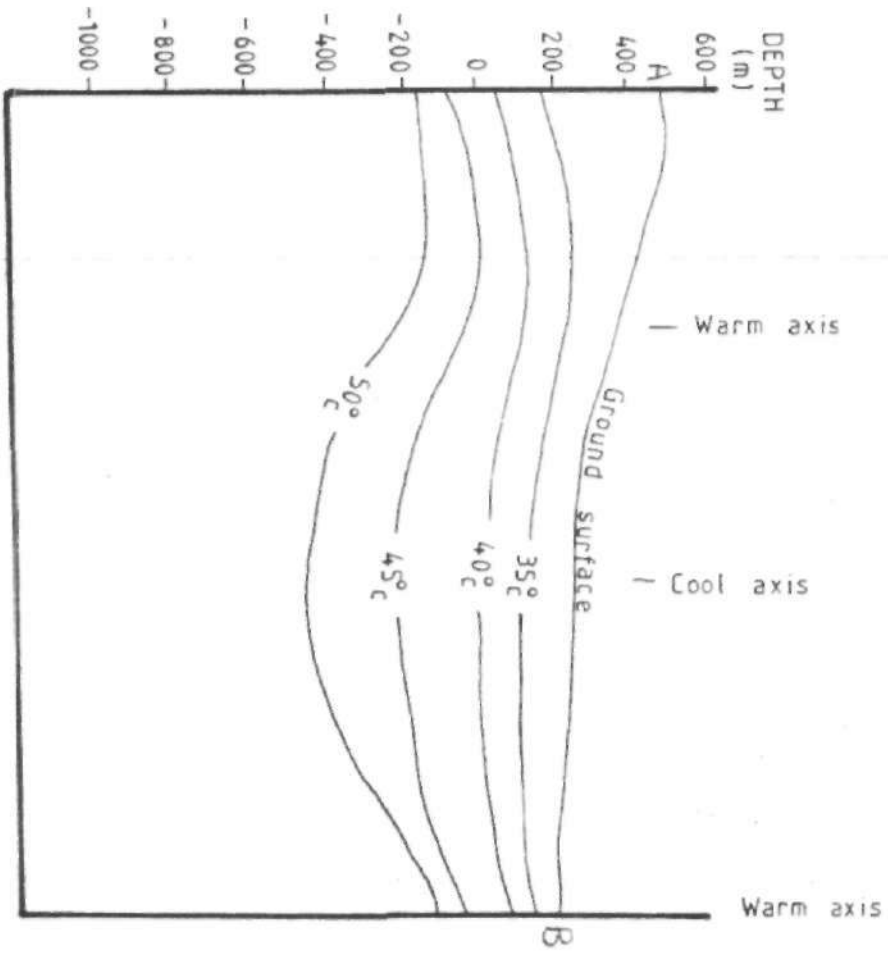


Fig. 11 Geothermal cross-section in the chad formation.

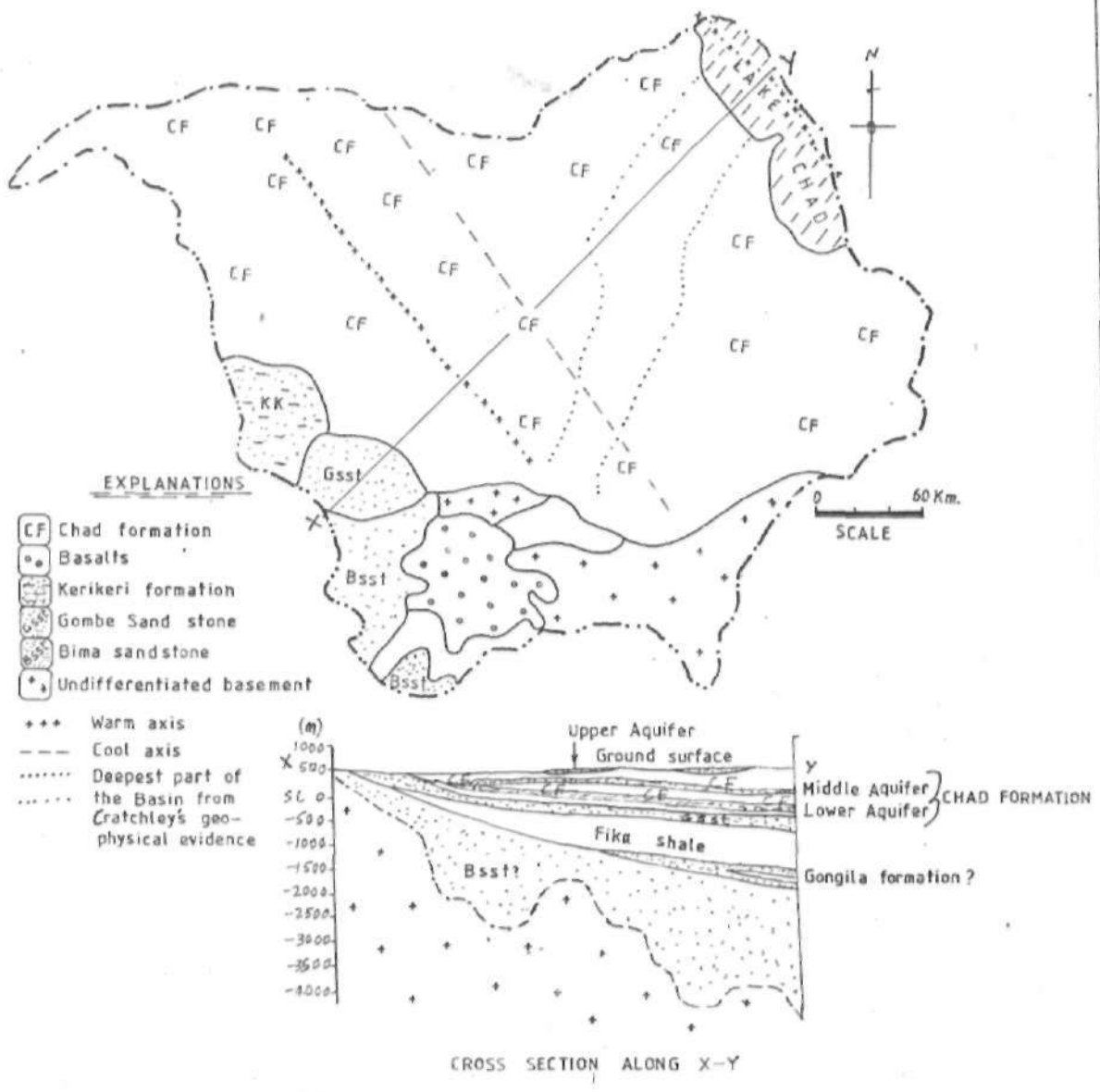
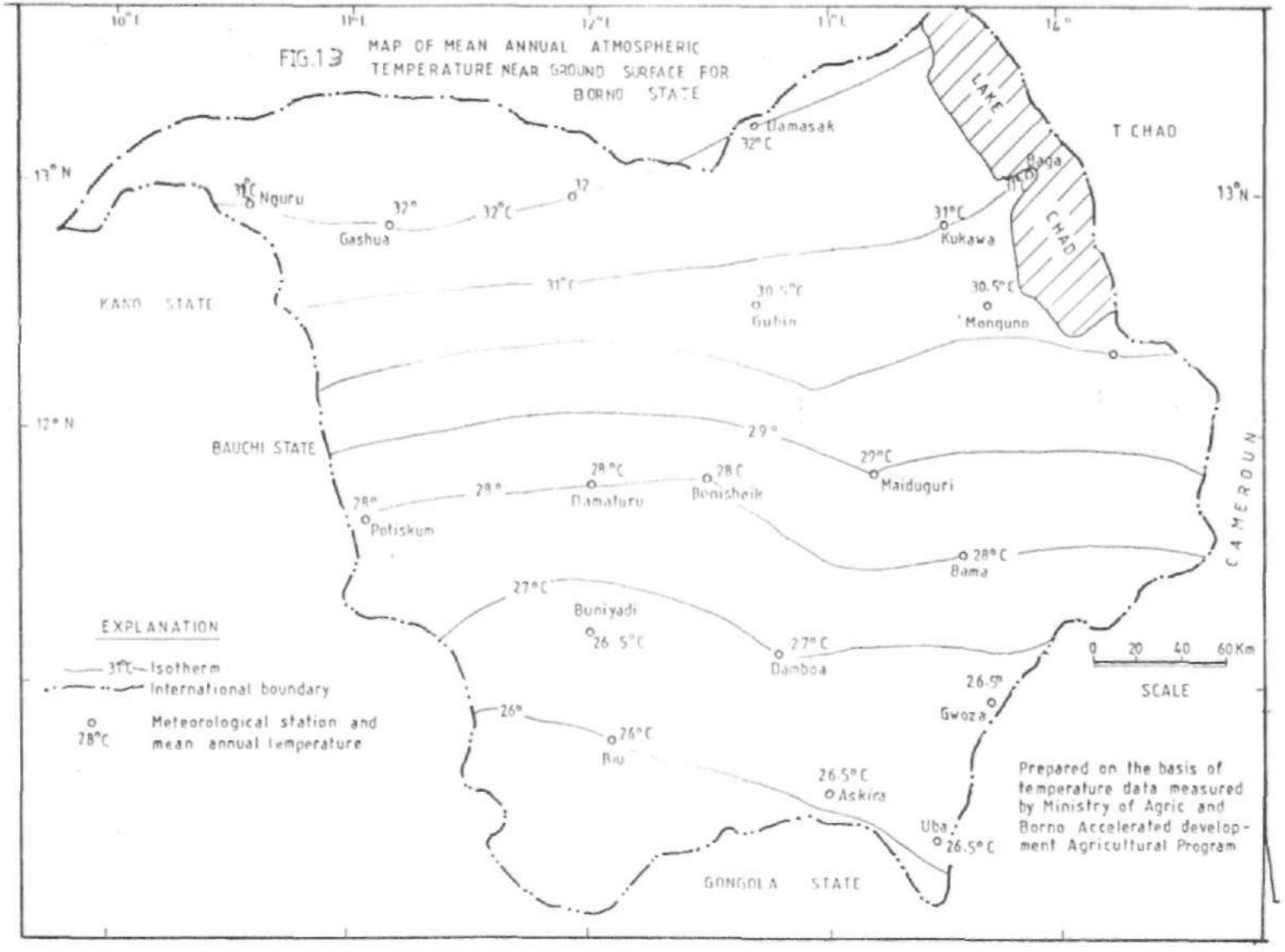


Fig. 12 Geological map showing the relationship between the inferred thicknesses to the basement, the geothermal gradient anomalies and the deepest part of the basin from geophysical evidence.


FIG.13 MAP OF MEAN ANNUAL ATMOSPHERIC TEMPERATURE NEAR GROUND SURFACE FOR BORNO STATE
10°E
11°E
12°E
13°E
14°
13°N
12°N
LAKE CHAD
T CHAD
CHAD
CAMEROUN
KANO STATE
BAUCHI STATE
GONGOLA STATE
Damasak 32°C
Nguru 31°C
Gashua 32°C
32°
32°C
32
Kukawa 31°C
Baga
31°C
30.5°C
Gubio
30.5°C
Monguno
29°
29°C
Maiduguri
28°C
Damaturu
28°C
Bonisheik
28°
28°
Potiskum
28°C
Bama
27°C
Buniyadi
26.5°C
27°C
Damboa
26.5°
Gwoza
26°
26°C
Biu
26.5°C
Askira
Uba
26.5°C
EXPLANATION
31°C Isotherm
International boundary
28°C Meteorological station and mean annual temperature
0 20 40 60Km
SCALE
Prepared on the basis of temperature data measured by Ministry of Agric and Borno Accelerated development Agricultural Program

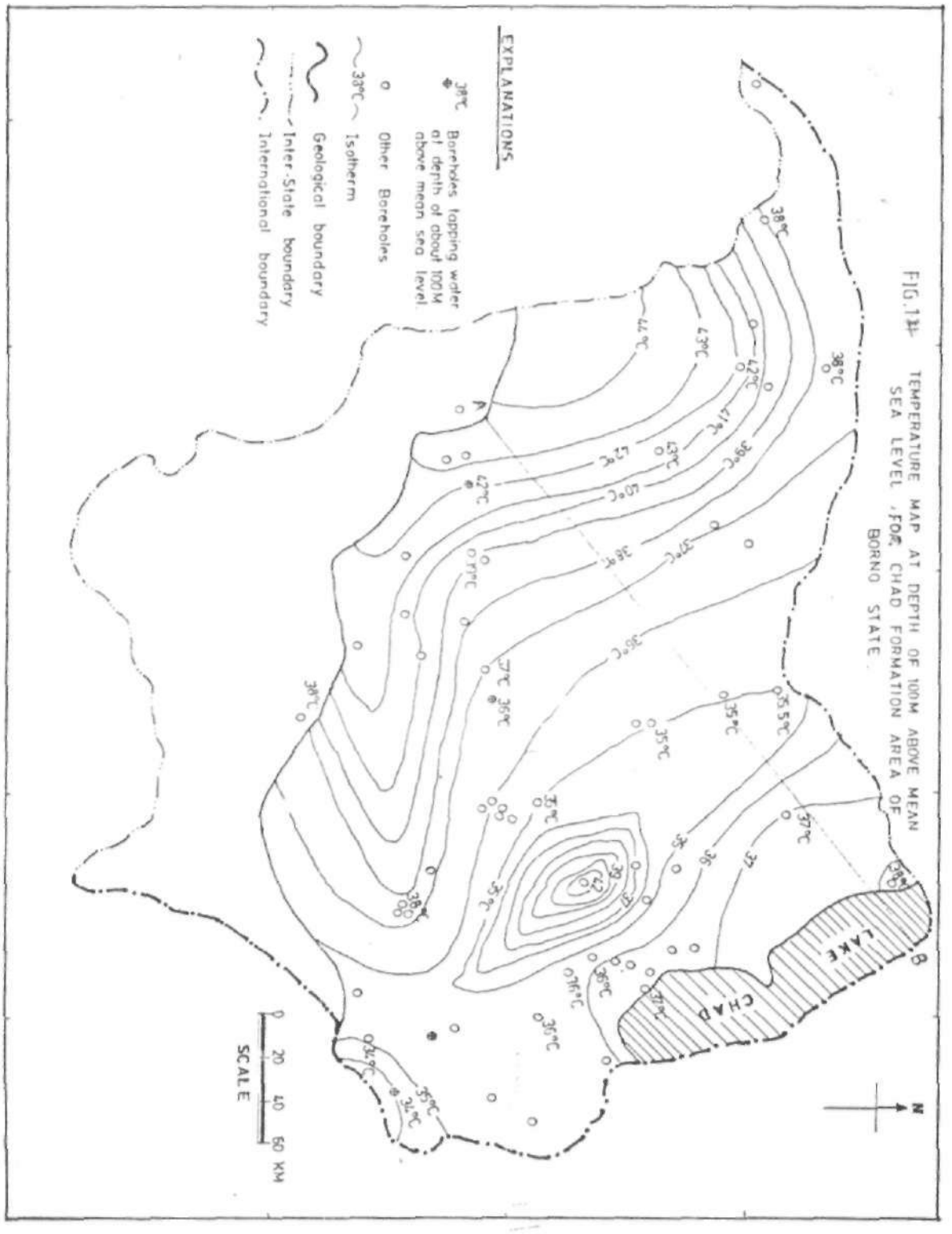


FIG. 14 TEMPERATURE MAP AT DEPTH OF 100M ABOVE MEAN SEA LEVEL FOR CHAD FORMATION AREA OF BORNO STATE

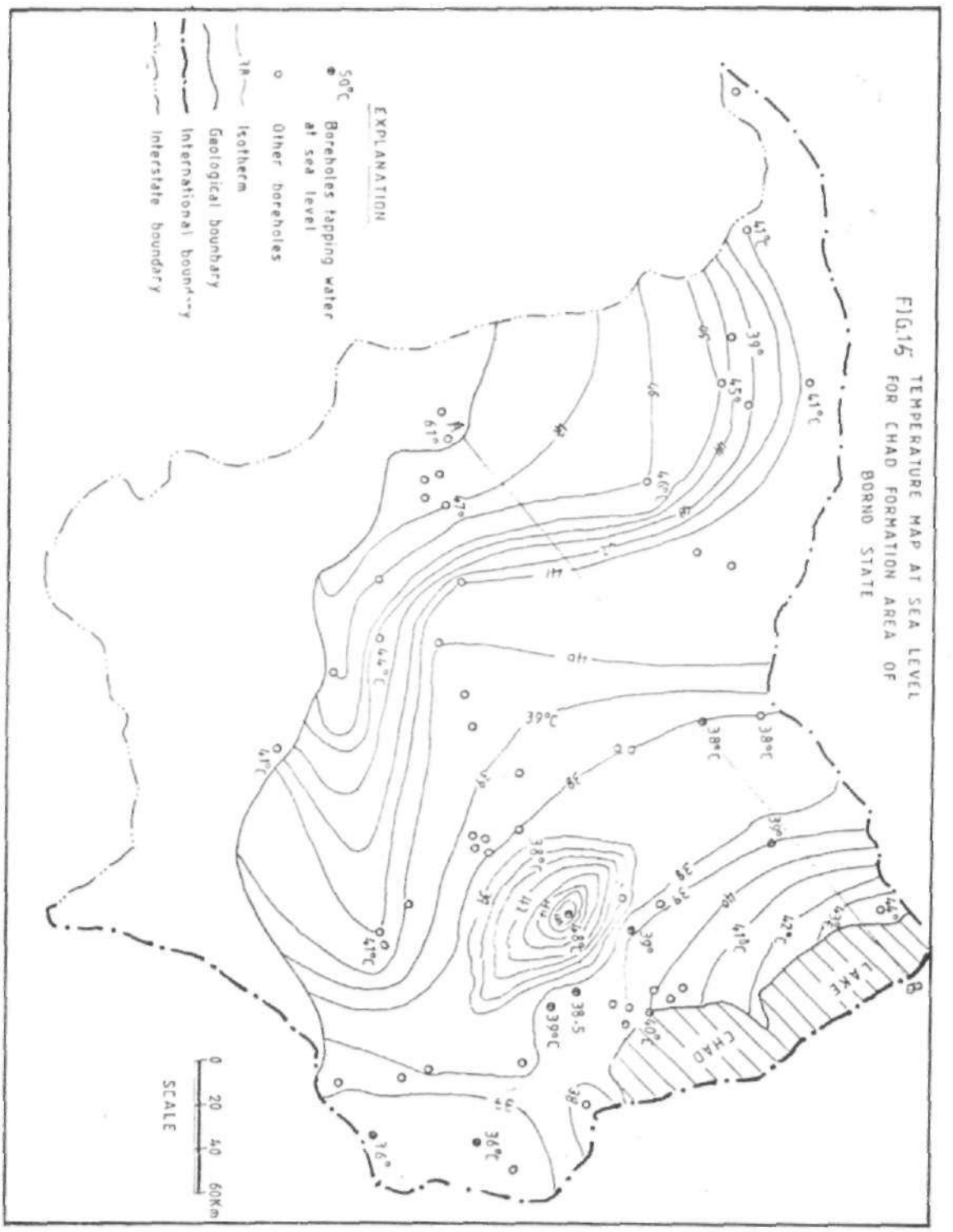


FIG.15 TEMPERATURE MAP AT SEA LEVEL FOR CHAD FORMATION AREA OF BORNO STATE

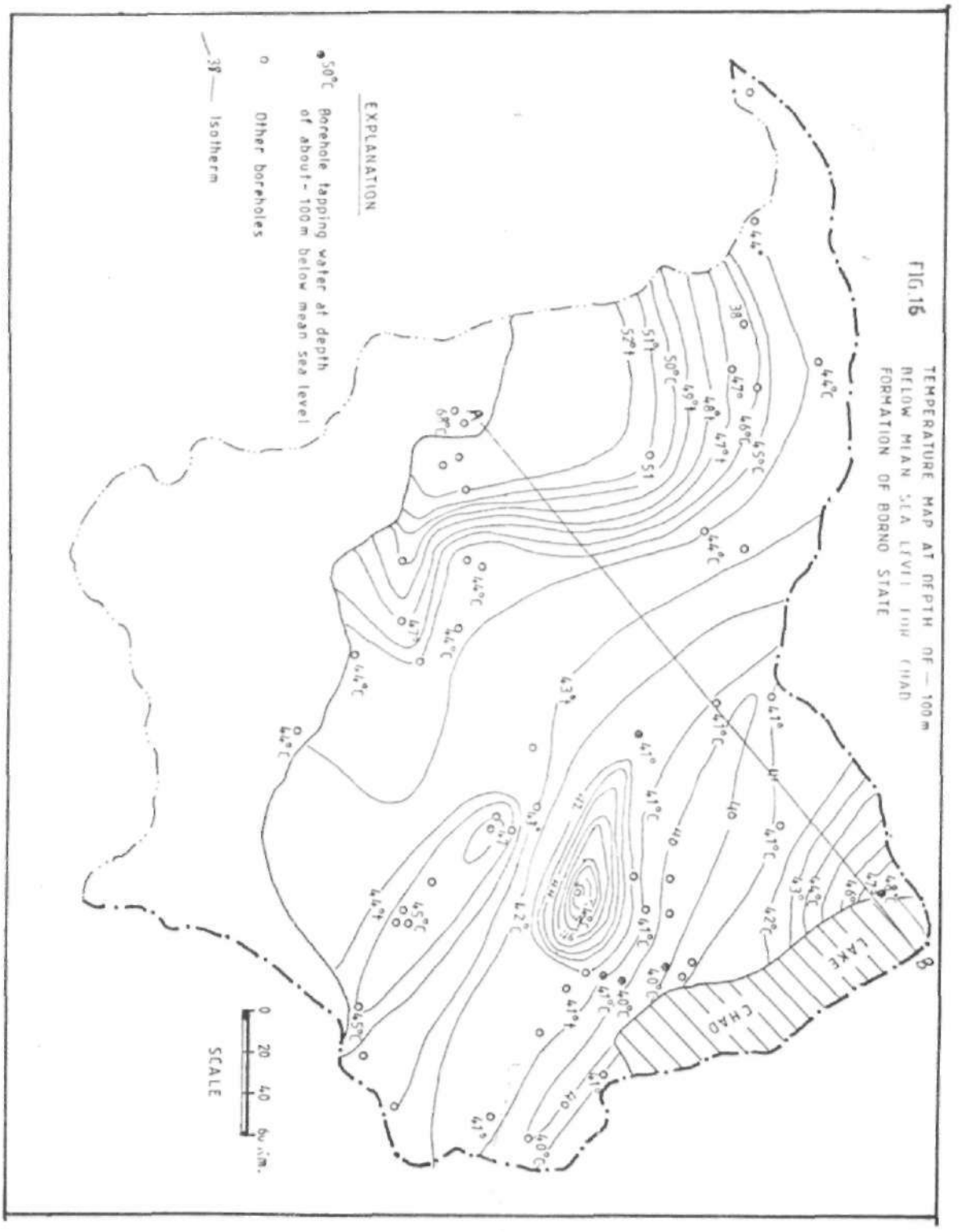


FIG. 15 TEMPERATURE MAP AT DEPTH OF — 100 m BELOW MEAN SEA LEVEL FOR CHAD FORMATION OF BORNO STATE

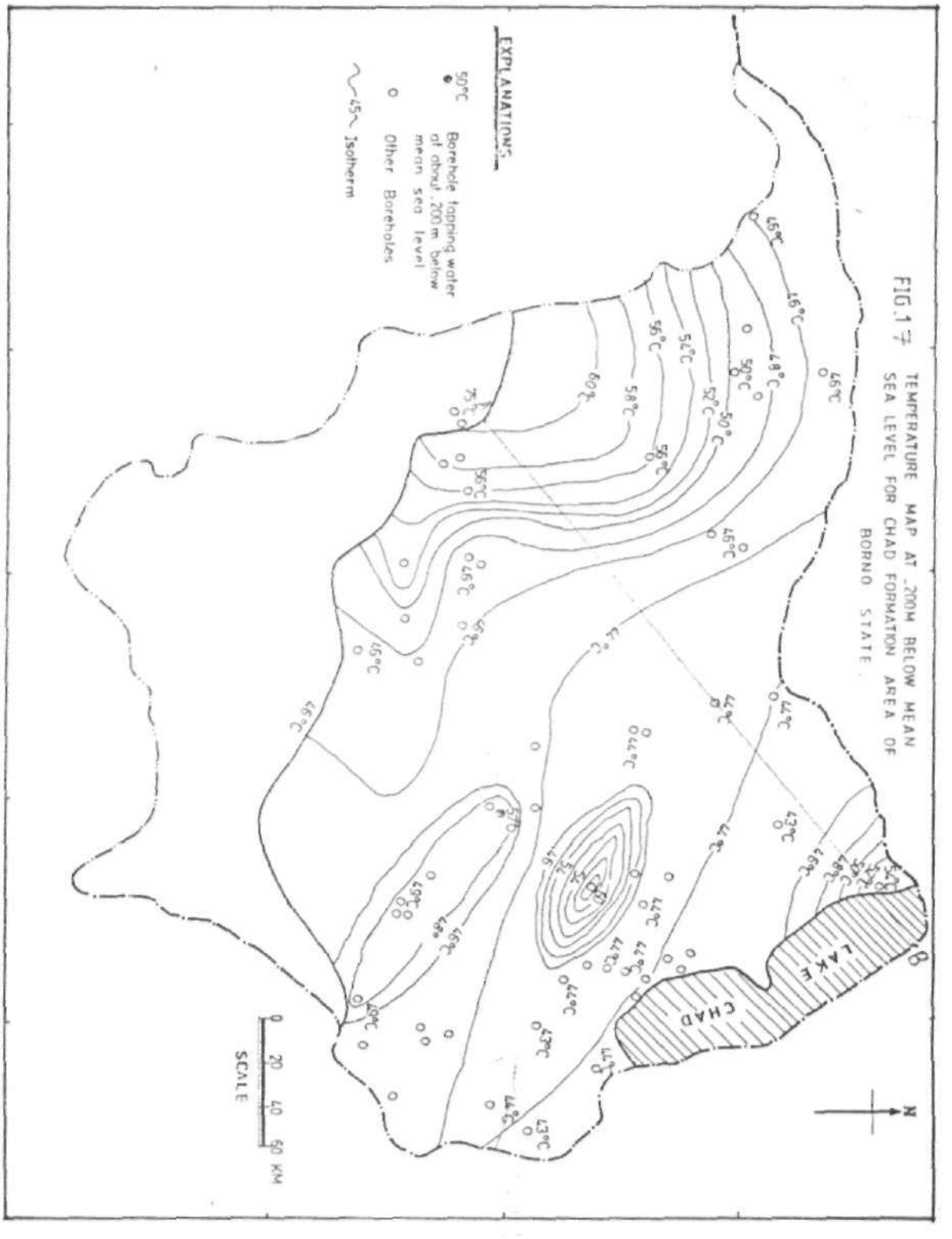


FIG. 17 TEMPERATURE MAP AT -200M BELOW MEAN SEA LEVEL FOR CHAD FORMATION AREA OF BORNO STATE

TABLE 1: PARAMETERS OF WATER WELLS USED FOR ELABORATION OF GEOTHERMAL GRADIENT

Borehole Number	Depth to the mid of screer in meters from ground surface	Water Temperature °C	Ground Surface Temperature °C	Durational pumping test in hours	Geothermal gradient °C/100m
245/MA	477.54	50	29.0	28	4.4
268/MA	472.15	47	28.90	6	3.83
P 267	465.34	50	29.0	48	4.51
266/MA	581.4	47	29.0	30	3.13
27/513/KDG	200.47	38	28.3	8	4.63
16/68/NL	292.98	39	30.0	12	3.08
16/53/GG	264.4	38	29.0	7	3.41
16/96/NG	261.50	36	29.3	12	2.56
16/61/OG	278.73	38	29.5	7	3.05
15/237/NG	316.42	39	30.5	8	2.69
15/226/MTL	339.31	38.4	30.2	8	2.42
15/225/ZG	336.92	40.4	30.0	7	3.09
15/238/BNK	294.46	39	30.4	7	2.93
15/235/MU	309.23	39	29.6	7	3.04
15/228/NG	345.87	50	30.6	7	5.60
15/286/SUG	283.84	38	29.7	14	2.92
15/227/NGO	298.46	40	30.3	7	3.25
15/223/NGL	307.76	40	30.6	8	3.05
15/321/Tb	311.87	45	30.3	15	4.71
15/222/ED	328.74	51	29.8	24	6.44
15/224/Kum	338.09	48	30.6	7	5.15
15/200/GU	352.93	40	30.5	7	2.69

Borehole Number	Depth to the mid of screen in meters from ground surface	Water Temperature ^{o}C	Ground Surface Temperature ^{o}C	Duration pumping test in hours	Geothermal gradient $^{o}C/100\,m$
15/231/KR	307.76	38	31.2	9	2.14
15/339/AB	352.00	50	32	20	5.11
14/236/LD	324.00	39	31.8	48	2.22
16/95/DL	310.00	48	30.3	47	5.26
15/347/SM	306.00	39	31.5	45	2.45
25/173/KT	234.21	40	27.8	72	5.21
26/260/BSK	106.50	33	28	22	4.67
26/261/MN	230.93	34	28.3	19	2.47
14/294/MG	282.52	40	29.2	18	3.82
23 - BA	182.42	31	28.0	48	1.65
22 - BA	191.61	35	28.0	50	3.67
33 - BA	153.78	34	27.9	8	3.96
16/62/WL	141.96	36.9	28.1	7	6.2
28/142/GL	150.66	37	28.3	7	5.26
25/190/FN	155.66	39	27.8	8	4.81
36 - GA	99.04	36	32	96	4.04
13/297/DPL	159.84	37	30.7	48	3.94
5 - DA	155.24	34	27.9	8	3.94
I - DA	266.54	36	27.8	7	3.07
25/154/GB	189.22	33	27.0	8	2.65
12/374/TT	169.50	35	32.7	8	1.35
15/365/GB	369.00	41	30.4	10	2.87
28/158/DBZ	186.00	36	27.8	8	4.41
Mashio	120.6	30	27.8	8	1.82
Ban Alewa	108.2	30	27.6	10	2.22
26/315/GM	142.5	33	26.8	10	2.34

Heat is produced by compression. Such geopressured zones are geothermal fields that have attracted attention in the last ten years or so, (Lumb, 1981). These are most likely to occur in deep sedimentary basins where fossil ground water has become locked up in sediments, and as the rocks become depressed, have been raised to higher temperatures, and to maintain the pressure, a deep cap rock is required.

Those eopressured zones that have been investigated to date have been associated with deep oil fields, for example, in the American Gulf States, and their discovery was a by-product of petroleum exploration.

The high pressured, warm water artesian aquifers of the Chad Formation appear to be a typical geopressured systems. The thick clay deposits which confine the aquifers are good insulators of heat. According to Muffler (1981), a geopressured reservoir may just be regarded as a high pressure sealed container filled with porous material saturated with compressed water and dissolved gas. Pull out the plug and the water and the gas flow out. Left to run in this mode, this process would in effect give us all that water held in pressure above the natural pressure. This is however a fraction of the fluid that is available in the aquifer.

(2) Radioactive disintergration in some materials such as shales in the sediments may contribute heat to the thermal gradiant in the basin.

More especially where there is concentration of radioactive elements in the granitic and metamorphic basement rocks underlying the basin, the heat produced flows into the sediments, (Rinehart, 1980).

Recent oil well logs in the basin revealed that there is a continuous 10m thick shale layer which is highly radioactive at about 1000m below the ground surface, (fig. 4). The layer could contribute heat to the sediments.

(3) The source of heat could be from igneous activities. Much of the earth's crust is heavily fractured and fissured close to the surface to form faults. Generally the faults are most profuse in geologically active areas such as: sedimentary areas, rift valleys, ocean ridges, plate boundaries, subduction zones and volcanic regions, (Muffler, 1981). They are the response of rock mass to stress in the earth's crust which result from earth movement and tectonism. Deposition of sediments causes stresses to develop. Fracturing relieves the stress. The deep tension faults provide the channels through which magma flows out through the crust and intrude into the sedimentatary basin. The heat which the magma carries provide the energy for heating the water, (see fig. 18).

Chad Basin, which is a sedimentary basin, can be related to this general situation. Geophysical measurements, using refraction seismic method have shown

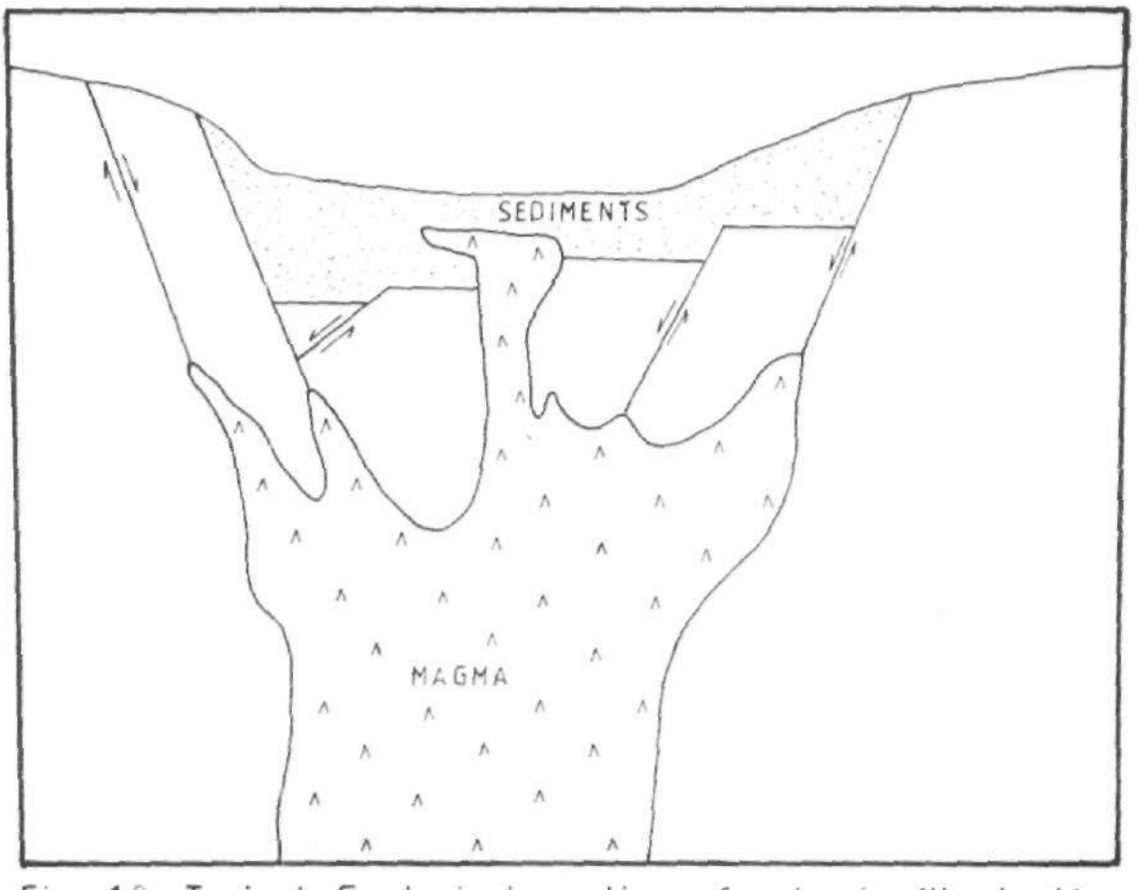


Fig. 18 Typical Geological section of a basin illustrating magmatic intrusion in the sediments which serve as heat source.

A RIFT BASIN IN NEVADA
(Adapted from Rineheart, 1980).

that the basin floor is made up of complicated valleys and grabens produced by series of step faulting, (Cratchley, 1960). Such faults provide the outlet for the basaltic intrusions in the sediments of the Chad Basin.

(4) It can also be argued that radiation from the sun might have contributed some heat. According to Todd (1980), variations in solar energy create periodicities, both diurnal and annual in temperatures below the surface. The insulating qualities of the earth's crust rapidly damp the large temperature range found at the ground surface so that only shallow ground water display any appreciable fluctuation in temperature. The surface influence is therefore confined to the upper thin layer of the earth's crust about 10m deep. Below the zone of surface influence, the increase in temperature with depth is in accordance with the geothermal gradient. In the zone of surface influence there is an inflow of heat during hot periods and outflow of heat in the cold periods (Heath and Trainer, 1968).

In Maiduguri and other towns in Borno State, water in pipes shallowly buried in sands becomes heated up because of the high radiation from the sun between the months of March to May. Sometimes water temperatures reach 40^{0}C in the afternoons, but thereafter, cools during the night. The heat received at or near the surface does not affect water

temperatures deep in the boreholes. Waters pumped out immediately from aquifers have constant temperatures, irrespective of the time of the year, i.e 33°C - 35°C for Upper Aquifer, 38 - 39°C for Middle Aquifer and 48 - 50°C for Lower Aquifer. All these figures are for Maiduguri town. From the temperature figures it can be seen that water stagnant in shallow pipes could acquire temperatures higher than natural water temperatures in the Upper and Middle Aquifers during afternoons of hot period. Care has to be taken in treating temperature gradient with depth in such areas, so that the zone of surface influence does not affect the computation of the gradient.

3.4 Effect of Temperature on TDS, pH of the Water and associated problems

High temperature increases dissociation rates of dissolved and undissolved mineral elements, and when these elements are released in their ionic forms, most of the time they result in pH falls. In case of total dissolved gases, the higher the temperature, the less the amount of dissolved gases, this is because gases are less soluble in water of high temperature.

The changes may be negligible at lower temperatures, but as temperatures become higher, they play an important role in determining the pH and TDS of water, (Swine and Schneider, 1971). The relationship between pH and TDS as shown by consulint (1973), is:

$$\frac{EC}{TDS} = K$$

Where K = 0.55 - 0.75, a constant

and is valid with pH range of 6 - 9.

EC = electrical conductivity

(measure of the dissociated elements)

in mhos

TDS = Total dissolved solids in parts

per million (ppm).

The equation indicates that TDS is higher at lower pH.

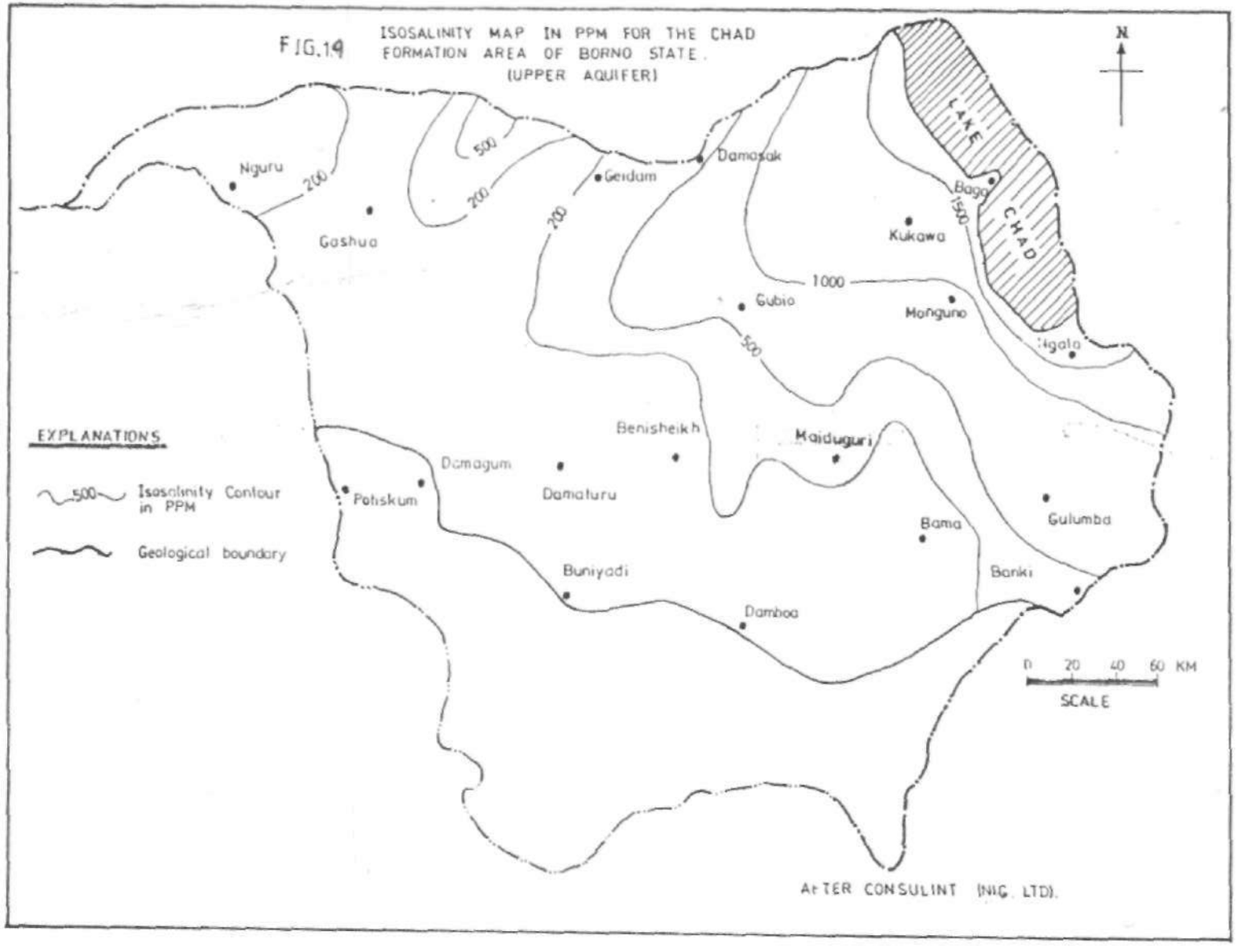
Water Mineralization of the three aquifers in the Chad Formation vary (Consulint Nig. Ltd.), 1975). At Maiduguri the Upper Aquifer is the least mineralized with TDS value of 240 ppm. Ca^{++} and Na^{+} are predominant among the cations with Fe^{+++} constituting about 0.15 ppm of the TDS. The TDS of Lower Aquifer is 280 ppm and it has the highest concentration of Fe^{+++}, constituting about 0.56 ppm of the TDS. Na^{+} is predominant among the cations. In the three aquifers, HCO_3 - is the predominant anion (see tables 2, 3 and 4).

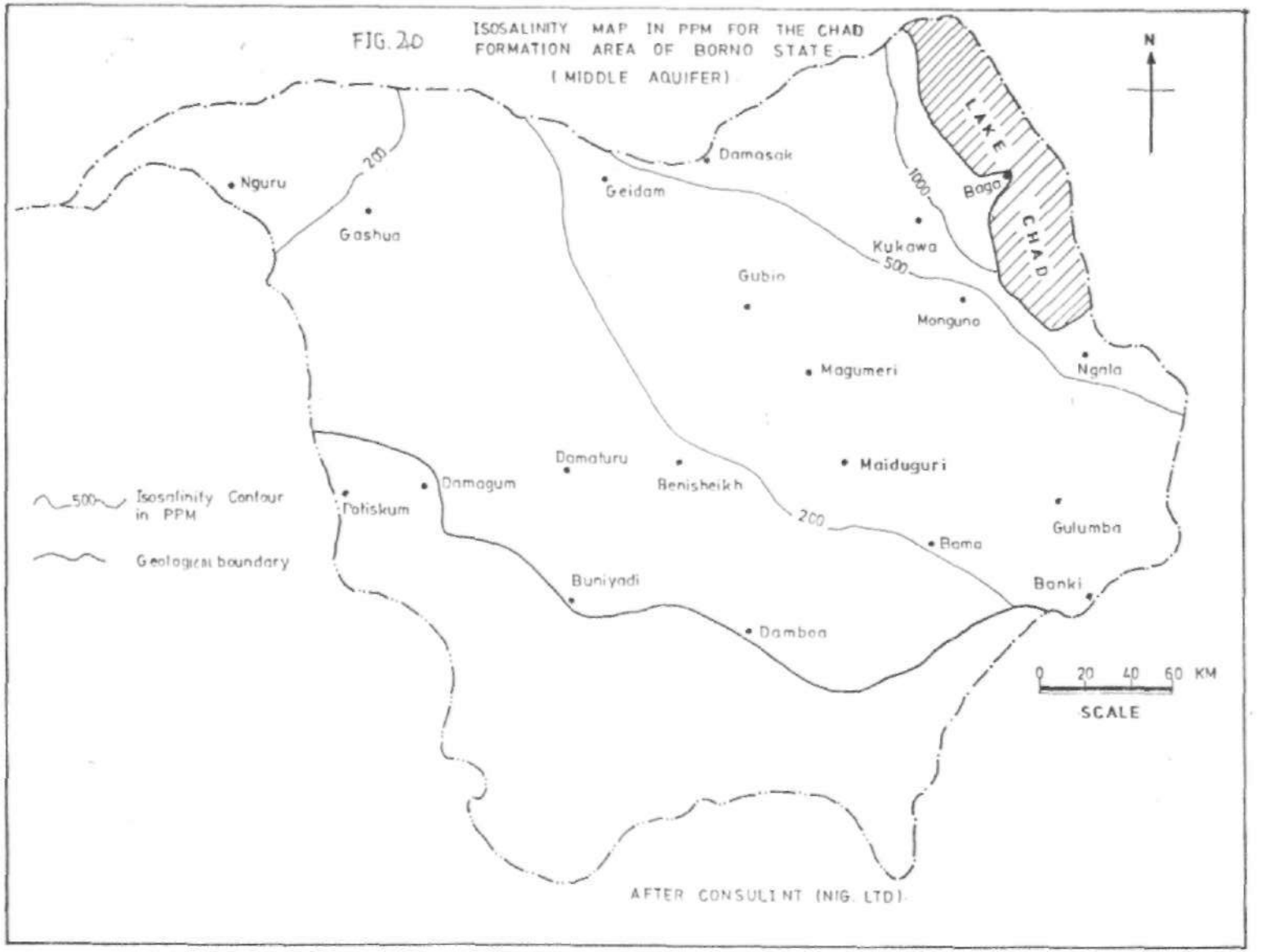
From Consulint maps, the trend of mineralization varies towards the lake. Total dissolved solids (TDS) increases towards the lake in both Upper and Middle Aquifers, with the Upper Aquifer having the higher TDS near the lake, with about 1500 ppm, while the Middle Aquifer has about 1000 ppm. Fe^{+++} concentration also increase towards the lake.

Among the anions, Cl^- and SO_4^{--} become more dominant in the same trend. It is to be noted that the lower Aquifer has been reached only under Maiduguri, therefore, there is no idea about its mineralization towards the lake. Because of the high salinity of the Upper Aquifer near the lake, water from it is not tapped for use. See figures 19 and 20 for the isosalinity maps of the Upper and Middle Aquifers.

Recent chemical and physical analyses being carried out by Borno State Water Board for all the boreholes in the State have shown that the higher temperature water contain higher dissociated element, Fe^{2+}, and the pH is higher. After coming in contact with the air at the surface, plus the effect of cooling, the iron is precipitated as a brownish iron oxide in pipes, vessels and bottles. This creates a lot of problems in small diameter pipes especially in the rural areas in Ngala, Kukawa and Monguno Local Government Areas. The iron oxide precipitates inside the pipes and reduces the life span of the pipes and screens in boreholes. Borehole screens are blocked and wells stop functioning.

Buckets for fetching water, bottles for keeping water in fridges and other vessels become stained with brownish iron oxide, which is difficult to wash. Sometimes it becomes serious and renders household utensils useless. Water collected in big open reservoirs for use becomes covered with reddish iron precipitate, and this renders the water dirty for


FIG.14 ISOSALINITY MAP IN PPM FOR THE CHAD FORMATION AREA OF BORNO STATE. (UPPER AQUIFER)
N
LAKE CHAD
Damasak
Geidam
Baga
Nguru
Gashua
Kukawa
Gubio
Monguno
Ngala
Benisheikh
Maiduguri
Damagum
Potiskum
Damaturu
Bama
Gulumba
Buniyadi
Banki
Damboa
EXPLANATIONS
500 Isosalinity Contour in PPM
Geological boundary
200
500
700
1000
1500
0 20 40 60 KM
SCALE
AFTER CONSULINT (NIG. LTD).


FIG. 20
ISOSALINITY MAP IN PPM FOR THE CHAD FORMATION AREA OF BORNO STATE
(MIDDLE AQUIFER)
N
LAKE CHAD
Damasak
Bago
Geidam
Nguru
Gashua
200
1000
Kukawa
500
Gubio
Monguno
Ngala
Magumeri
Damaturu
Benisheikh
Maiduguri
Damagum
Potiskum
500 Isosalinity Contour in PPM
Geological boundary
200
Bama
Gulumba
Buniyadi
Banki
Damboa
0 20 40 60 KM
SCALE
AFTER CONSULINT (NIG. LTD)

use though not toxic.

Another minor problem associated with the hot water is that, it cannot be utilized immediately after fetching it from the borehole or tap. It has to stay for some hours to cool before people use it for washings, bathing and drinking. People using water from the hot aquifers have to buy big containers in their houses for keeping the water to cool.

Apart from the iron (Fe^{2+}), the high temperature and pressure waters near the lake contain high concentrations of CI^{-} and SO^{2-}_{4} anions but problems associated with these have not been identified.

The problems caused by high iron concentrations in the deep pressure waters of the Middle and Lower Aquifers are also being experienced in some places using water from the shallow Upper Aquifer. The high iron concentration in shallow low temperature water of the Upper Aquifer could be related to some bacterial activities and surface chemical reactions as explained by Swine and Schneider (1971). According to them, "shallow waters derive their constituents from the atmosphere and from the mineral and bacterial reactions in the soil." Aerated water has an Eh or about + 0.4V and this favours the oxidation of pyrite, often present, albeit, in low concentrations in sedimentary rocks. This in turn yields some soluble iron which is readily deposited as iron oxide under various conditions.

The Eh of shallow ground water is between +0.2 - 0.4V and connate water is between -0.2 to 0.1V, pH being 6 - 8. The mixing will affect the status of iron and other ions. This could be possible where two aquifers have been screened in one borehole.

Table 2. Water analysis at Maiduguri Sample 199 MA
(Upper Aquifer)

Temperature ^{o}C						32.5
PH						7.2
Specific Conductance (umhos)						350
TDS (PPM)						240
Cations	ppm	epm	Anions	ppm	epm	Total PPM
Ca^{++}	28.60	1.43	CO_3^{--}	-	-	
Na^{+}	22.50	0.98	HCO_3^{-}	164.70	2.70	
K^{+}	3.65	0.09	SO_4^{--}	trace	trace	
Mg^{++}	4.24	0.35	Cl^{-}	3.55	0.10	
NH_4^{+}	trace	trace	No_2^{-}	Abun-dant	Abun-dant	
			No_3^{-}	-	-	
			Po_4^{---}	-	-	
		2.85		2.80		
	58.99		168.25	1		227.24
Fe^{+++}						CCO.15

(Adapted from Consulint, 1973)

Table 3: Water Analysis at Maiduguri .

Sample 195 MA

(Middle Aquifer)

Temperature ^{o}C	40.5
PH	6.8
Specific Conductance (Umhos)	445
T.D.S (ppm)	310

Cations	ppm	epm	Anions	ppm	epm	Total PPM
Ca^{++}	7.65	0.38	CO_3^{--}	-	-	
Na^{+}	67.5	2.93	HCO_3^{-}	181.78	2.98	
K^{+}	10.20	0.26	SO_4^{--}	19.58	0.41	
Mg^{++}	3.44	0.28	Cl^{-}	9.60	0.27	
NH_4^{+}	Trace	Trace	NO_2^{-}	-	-	
			NO_3^{-}	-	-	
			PO_4^{---}	-	-	
		3.85			3.66	
	88.79			210.96		299.75
Fe^{+++}						0.15

(Adapted from Consulint, 1973)

Table 4 Water analysis at Maiduguri

Sample 210 MA

(Lower Aquifer)

Temperature °C	50
PH	7.3
Specific conductance (Umhos)	400
TDS (ppm)	280

Cations	ppm	epm	Anions	ppm	epm	Total ppm
Ca^{++}	0.80	0.04	CO_3^{--}	-	-	
Na^{+}	72.0	3.13	HCO_3^{-}	183.0	3.00	
K^{+}	4.4	0.11	SO_4^{--}	Trace	Trace	
Mg^{++}	0.32	0.03	Cl^{-}	8.7	0.25	
NH_4^{+}	Trace	Trace	NO_2^{-}	-	-	
			NO_3^{-}	-	-	
			PO_4^{---}	-	-	
		3.31			3.25	
	77.52			191.70		
Fe^{+++}						0.56

(Adapted from Consulint, 1973)

Well Location	ISOSALINITY (PPM) Upper Aquifer	Middle Aquifer	Lower Aquifer
Baga	1550	1050	
Bama	185	200	
Banki	245	215	
Benisheik	180	198	
Buni Yadi	150	198	
Damboa	194	179	
Damagum	180	175	
Damasak	490	800	
Damaturu	160	160	
Gashua	200	185	
Geidam	210	250	
Gubio	700	400	
Gulumba	520	350	
Kukawa	1400	900	
Maiduguri	230	300	280
Ngala	1400	600	
Nguru	250	250	
Magumeri	285	300	

Chapter 4

CONCLUSIONS, SUMMARY AND SUGGESTIONS

From the discussions it can be concluded that the geology of the Chad Formation has a direct influence on the hydrogeological characteristics of the formation. The interbedding of thick clay layers and lenses of sand created the Geopressured aquifer systems. The decreasing pressure head of the water in the Middle Aquifer is due to the sloping surface topography towards the lake. Nearer to the lake, the topography is lower and the pressure head is above the surface and hence all boreholes are free-flowing. With distance away from Lake Chad the aquifer becomes subartesian. This is because the surface topography is higher than the pressure head. Maiduguri has an elevation of 330m above sea level and the Middle Aquifer is subartesian here, while at Baga (on the lake shore) having an elevation of 280m above mean sea level has a freeflowing Middle Aquifer. Depth to the top of Middle Aquifer at Maiduguri is 240m and for Baga is 350m

The temperature of the water in a geopressured aquifer at shallow depth is a function of the residence time, transmissivity of the aquifer and water movement. This means the longer the water resides in the aquifer without significant movement, it will acquire higher temperatures due to heatflow outwards from the deeper earth's interior and heat produced by radioactivity in shales and clays of the sediments. The confining clays and shales form good insulators. When the Chad Formation is considered with

respect to the above fact, it can be concluded that the water in the middle Aquifer near the lake has resided there for a longer period than away from the lake and has been moving at a very slow rate or almost stagnant Up to 50°C could be obtained in the Middle Aquifer near the lake shore, while the highest water temperature measured in the Middle Aquifer at Maiduguri is 39°C.

Differences in the Middle Aquifer water chemistry possibly reflect the reacharge regions. South of the lake, there is a high concentration of bicarbonates in the water, and the recharge region could be south of the lake. In the west and south-west of the lake, the water is characterised by high concentrations of sulphates and chlorides rather than carbonates. Sulphates predominate in the south east of the lake.

Geopressured systems are heat reservoirs and are normally associated with deep oil fields as in the Gulf states of America and Niger Delta of Nigeria. Such systems could therefore serve as a guide for petroleum exploration. The existence of the similar system in the Chad Basin could indicate a possibility of petroleum occurrence.

The temperature gradient in the basin could be put into practical application in drilling for petroleum. From the temperature maps, levels at which natural cracking of petroleum hydrocarbons occur, and the depths to the temperature at which high heat create drilling problems

could be demarcated. The boundary of critical water temperature (374.2°C) can also be shown in the section.

Because of the complicated nature of the Chad Basin structure, coupled with insufficient geological and geophysical data, it is not possible to determine the depth to the bottom of the Basin. This made it impossible to produce temperature maps to the bottom of the Basin. However, it is hoped that future investigations will give more light on the structure of the Chad Basin.

The relatively high geothermal gradients in the Chad Basin indicates that there could be large geothermal reservoirs at great depths in the sediments. In future the reservoirs could serve as potential sources of geothermal energy which can be exploited for the purpose of generating electricity. Deep wells could be drilled to tap the steam and the super heated water, which would be directly fed into the thermal generators. This will serve as a cheap source of electricity.

The steam and the super heated water may be highly mineralized with certain valuable elements e.g. molybdenum, manganese, boron etc., and serves as a source of the minerals. Coming to the water quality, the TDS values and the concentrations of the various elements in the water from the aquifers lie within the recommended limits for potable water by the World Health Organization. TDS values of over 1000 ppm is not recommended for drinking.

From the isosalinity maps of the Chad Formation in Borno State, it can be seen that the TDS values for both the Upper and Middle Aquifers are up to 1000 ppm near the lake. Waters from boreholes in these areas are too mineralized and most of the problems are caused by high iron concentration. It is recommended that the aeration treatment method be adopted for water from all boreholes. Reservoirs are to be constructed at all borehole sites and water pumped out should be sprayed into the air before collecting into the reservoirs. This will precipitate out the iron to settle at the bottom. The precipitate could be filtered out before the water is pumped into the distribution systems in the towns and villages. For small settlements, the water in the reservoirs will be used directly at the site.

The aeration treatment method is very simple and cheap so that the state will be able to afford it for all the numerous boreholes.

REFERENCES

Anonymous, (up to 1986). Boreholes data In open files reports. Borno State Water Board, Maiduguri.

Barber, W., 1965. Pressure Water in the Chad Formation of Borno and Dikwa Emirates, North Eastern Nigeria. GSN Bulletin No. 35. p.138.

Barber, W. and Jones, D.G., 1968. The Geology and Hydrogeology of Maiduguri, Borno Province. Records of the Geological Survey of Nigeria, 1958. pp.5-20.

Barnea, J. 1973. Geothermal power. In Scientific American, Volume 3, Topic Index 898, W. H. Freeman and Company, San Francisco. p.23.

Beaumont, C. and Sweeny, J.R., 1978. Graben generation of major sedimentary basins. Tectonophysics 50, 19 - 23.

Burke, K., Dessauvagie T.J.F., and Whiteman A.J., 1972. Geological history of the Benue Valley and adjacent areas, Proc. Conf. on African Geology, Ibadan 1970, Department of Geology, University of Ibadan, Nigeria. pp.583 - 608.

Burke, K., 1976a. The Chad Basin: an active Intracontinental Basin. Tectonophysics 36, 197 - 206.

Burke, K., 1976b. Neogene and Quaternary Tectonics in Nigeria. In Geology of Nigeria, C.A. Kogbe (ed). Lagos. Elizabeth Publishing Company. pp.363 - 369.

Carter, J.D., Barber, W., Tait, E.A., Jones G.P., 1953. The Geology of part of Adamawa, Bauchi and Borno Provinces in North Eastern Nigeria. Explanation of 1:250,000 sheets Nos. 25, 37 and 47, Geological Survey Bulletin No. 30. p.109.

Carter, J.D., (ed), 1964. Geological, Map of Nigeria. 1:2,000,000, Geological Survey of Nigeria.

Consulint (Nig.) Ltd. and Consulint International S.R.1. 1973 Urban Water Supply, Maiduguri, Preliminary stage report. pp. 3 - 24.

Consulint (Nig.) Ltd. and Consulint International S.R 1, (Rome 1975). Water Survey of the North Eastern state, Nigeria. Ground Water Investigations: Piezometric and Isosalinity Maps, 1:250,000, sheets Nos. 12, 13, 14, 15, 16, 24, 25, 26, 28 and 35.

Cratchley, C.R., 1960. Chad Basin SW, Bouguer Gravity Contours, 1:500,000, Geol. Surv. Nigeria.

Cratchley, C.R., Jones, G.P., 1965. An interpretation of the Geology and Gravity anomalies of the Benue Valley, Nigeria. Geophysical Paper No. 1, Overseas Geol. Surv. Geophysical Division. London. p.26.

Cratchley, C.R., Louis, P., and Ajakaiye, D.E., 1984. Geophysical and Geological evidence for Benue-Chad Basin Cretaceous rift systems and its tectonic implications. J. Afr. Earth Sci. 140 - 50.

Davis, S.N., De Wiest, R.J., 1966. Hydrogeology. John Willey and Sons Inc. New York, London, Sydney. pp.96 - 128.

Donaldson, I.G. and Grant, M.A , 1981. Heat Extraction from Geothermal Reservoirs. In Geothermal systems, principles and case Histories, L. Rybach and L.J.P Muffler (eds.). John Willey and Sons, Chichester, New York, Brisbane, Toronto. pp.145 - 174.

Durotoye B., 1974. Quaternary sediments in Nigeria. In Geology of Nigeria, C.A. Kogbe (ed.). Lagos. Elizabeth Publishing Company. pp.347 - 369.

du Preez, J.W and Barber, W., 1965. The distribution and Chemical quality of Groundwater in Northern Nigeria. G.S.N. Bulletin No. 36. pp 49 - 57.

Furon, R., 1963. Geology of Africa. Oliver and Boyd Ltd. Edinburgh, London. pp 377 - 378.

Heath, R.C. and Trainer, T.W., 1968 Introduction to Groundwater Hydrology. John Willey and Sons Inc New York. pp. 169 - 177.

Lumb. J.T , 1981. Prospecting for Geothermal resources. In Geothermal systems, principles and case Histories. L. Rybach and L.P.J. Muffler (eds.). John Willey and Sons, Chichester, New York, Brisbane, Toronto. pp. 3, 77 - 103.

Matheis, G., 1974. A short review of the Geology of the Chad Basin. In Geology of Nigeria, C.A. Kogbe (ed.). Elizabeth Publishing Company, Lagos. pp. 289 - 294.

Miller, R.E Johnston, R.H., Olowu, J.A.I. and Uzoma, J.U., 1968. Ground-water Hydrology of the Chad Basin in Borno and Dikwa Emirates, Northeastern Nigeria, with Special Emphasis on the flow life of the Artesian system, U.S.G.S Water Supply Paper 1757 - 1, 1 - 48.

Muffler, L.J.P. Geothermal Resources Assessment. In Geothermal Systems, Principles and Case Histories. L. Rybachand, L.J.P. Muffler (eds). John Willey and Sons, Chichester, New York, Brisbane. Toronto. pp. 193 - 195.

Oxford University Press, 1979. Oxford/Philip Atlas for Nigeria, E.J. Gill (ed.). Oxford University Press, London. pp. 7, 11.

Rinehart, J.S., 1980. Geysers and Geothermal energy. Springer - Verlag Inc. New York. pp. 24 - 42, 92 - 105, 175 - 199.

Rybach L., 1981. Geothermal Systems, Conductive heat flow and Geothermal anomalies. In Geothermal systems, principles and case Histories, L. Rybach and L.J.P. Muffler (eds). John Willey and Sons, Chichester, New York, Brisbane, Toronto. pp. 3 - 31.

Servant, M. and Servant, S. 1970. Les Formations Lacustres et Les diatomees du Quaternaire - Recent du fond de la cuvette Tchadiene. Rev. de Geog. Phy te de Geol. Dyn 12, 63 - 72.

Swine J.D. and Scheneider, J.L. 1971. The Geochemistry of underground water. In Salinity and Water use, T. Talsam and J.R. Philip (eds.). Macmillan Press, London, Basingstoke. pp. 3 - 8.

Tattam, C.M., 1943. A review of Nigeria Stratigraphy. Geological Survey Department, Nigeria. Annual Report 1943. pp. 27 - 46.

Todd, D.K., 1980. Ground Water Hydrology. John Willey and Sons, New York, Chichester, Brisbane, Toronto. pp. 307 - 309.

Whitten D.G.A. and Brooks, J.R.V., 1979. The Penguin Dictionary of Geology. Hazell Watson and Viney Ltd., Aylesbury, Bucks.

Wright, J.B., 1985. Geology and Mineral Resources of West Africa. George Allen and Unwin. London, Boston, Sydney. pp. 94 - 96.

MAMSL = Meters above mean sea level

S = Sand
C = Clay
G = Gravel
SL = Silt
L = Laterite

L.A = Lower Aquifer
M.A = Middle Aquifer
U.A = Upper Aquifer

SNo.	BH NO AND ELEVATION MAMSI	LOCATION TOWN/L.G.	COORDINATES	SCREEN POSITION	TOTAL DEPTH CASED (M)	TOTAL DEPTH DRILLED (M)	LITHOLOGICAL DESCRIPTION	TEMPERATURE DURING PUMPING TEST
1.	245.MA 333	Mai u uri Metro	11°55'10"N 13°10'01"E	451.02 - 462.60m 474.73 - 486.38m 492.46 - 504.06m	521.96m	557.35m	0 - 95, 9 - 12.G, 12-105, 105-1265+ SL 126-4385+C 438-532 G + S + C 532-557 basalt	50°C after 28 hrs. L.A
2.	268/MA 327	Maiduguri Metro	11°55'05"N 13°10'00"E	428.45 - 431.45m 449.75 - 452.75m 467.75 - 479.75m 485.80 - 494.80m 500.85 - 515.85m	527.95m	537.00m	0 - 3 S + SL + C 3 - 145, 14-265 G + SL 265 - 429 C 429 - 535 S + G + L	47°C after 6 hrs. L.A.
3.	P267 330	Maiduguri	11°55'10"N 13°10'03"E	460.76 - 469.91	474.66	481	0 - 100 C + SL 100 - 120 S + SL 120 - 200 L + S 200 - 250 S 250 - 429 C 429 - 470 S 470 - 474 L	50°C after 48 hrs L.A
4.	266 MA 328	Maiduguri Metro	11°55'10"N	539.12 - 623.84	635.9m	643	0 - 105 SL + S + C 105 - 255 S + SL + C 255 - 433 L + SL 433 - 627 G + S 627 - 643 C	47°C after 30 hrs L.A
5.	27/513/KD	KONDUGA Konduga L.G	11°39'05"N 13°2[illegible]'02"E	189.82 - 211.13	212.19 m	225.5	6 - 180S + L 180 - 225.S + SL	38°C after 8 hrs MA
6.	1/1C 330	[illegible] Kudu[illegible]	12°06'55"N 13°0[illegible]'00"E	296.20 - 321.00	322.1	327.00m	0 - 254 SL + S + L + G, 254 - 287 SL + L	39°C after 12 hrs. MA

08

S/No	BH NO AND ELEVATION MAMSI	LOCATION TOWN/L.G.	COORDINATES	SCREEN POSITION	TOTAL DEPTH CASED (M)	TOTAL DEPTH DRILLED (M)	LITHOLOGICAL DESCRIPTION	TEMPERATURE DURING PUMPING TEST
7	27/625/KY 317	Kayamla Konduga LG	11°55'15"N 13°11"05"E	140 - 146	148.00	153.00	0-45C+SL, 45-135C 135 - 153 S	30°C after 24 hrs. U A
8.	16/68/NL 250	Ngala Ngala L.G	12°21'00"N 14°11'30"E	282.31-303.64	304.71	310	0-171 SL + S + C 171 -243 S 243 - 310 S + C	39°C after 12 hrs M.A
9.	16/53/GG 275	Gulgil Ngala L.G	11°56'45"N 14°26'30"E	249.25-279.71	280.79	285	0-177 SL + C 177-280 S + G 280-280 SL + C	38°C after 7 hrs M.A.
10.	16/96/NGW	Ngaiwashe Ngala L.G	12°05'00"N 14°01'05"E	257 - 266	269	273	0-256C, 256-2665, 266 - 274C	36°C after 12 hrs M.A
11.	16/61/DG 250	Dugumashe Ngala L.G	12°07'30"N 14°26'30"E	263.5-293.96	295.06	300.00	0-183 SL+S, 183-263 C+S 263 - 294S +SL, 294-300SL+L	38°C after 7 hrs. M.A
12	15/237/NG 258	Ngollom Monguno LG	12°34'00N 13°43'15"E	305.98-327.36	328.51	333.00	0-51 S+SL, S1-252 L+SL 252-3285, 328- 357L+SL	39°C after 8 hrs M.A.
13.	15/226/ MTL 260	Mutala Monguno L.G	12°23'00"N 13°44'04"E	321.05-357.58	358.64	365.00	0-42S,+SL, 42-294C+SL 294-363S, 363-365S+L	38.4°C after 8 hrs. M.A
14	15/225/ZG 280	Zaan Goniri Munguno LG	12°20'55"N 13°24'41"E	321.69-352.19	353.28	360	0-18SL+S, 18-167 C+SL, 167-310C,	40.4°C after 7 hrs.M.A.

S/No	BH NO AND ELEVATION MAMSI	LOCATION TOWN/L.G.	COURDINATES	SCREEN POSITION	TOTAL DEPTH CASED (M)	TOTAL DEPTH DRILLED (M)	LITHOLOGICAL DESCRIPTION	TEMPERATURE DURING PUMPING TEST
15	15/238/BNK 285	Burniski Monguno L.G	12°28'00"N 13°51'15"E	282.26-306.66	307.72	313.00	0-267SL + C, 267-309S+S, 309-328 SL + L	39°C after 7 hrs M.A
16.	15/235/MU 295	Mugum Monguno L.G	12°12'00"N 13°45'45"E	297.04-321.42	322.49	330.00	0.69 SL+C, 69-296 C 296-341 S+G 341-344 S+SL	39°C after 7 hrs. M.A
17.	15/228/ NGR 300	Ngarana Monguno L.G	12°36'02"N 13°43'35"E	333.66-358.08	359.11	365	0-42 SL+S, 42-314C 314-365 S + G	50°C 7 hrs MA
18	15/227/ NGO 309	Ngalori Monguno L.G	12°31'32"N 13'52'14"E	286.17-310.75	311.91	317	0-27 SL+C, 27-286C, 286-317C	40°C after 7 hrs. MA
19.	15/286/SUG 295	Suguma Monguno L.G	12°17'30"N 13°44'10"E	271.64-296.04	297.1	315	0.30 SL+S, 30-267C, 267-312S, 312-315C	38°C after 14 hrs M.A
20.	15/223/NGL 250	Ngelewa Monguno L.G.	12°53&15"N 13°46'30"E	291.26-324.26	325.35	345	0-132 SL + C-, 132-302C, 302-340 S+G	40°C after 7 hrs. M.A.
21	15/321/Tb 280	Talbari Monguno L.G	12'30'00"N 13°55'00'E	299.77-323.97	328.33	340.9	0-300 C + SL + S, 300-324 S+G+C 324-330 C	45°C after 15 hrs
22	15/222/Bd 305	Bida Monguno	12°15'05"N 13°20'55"E	302.9 - 309.1	360.12	363.5	0-215C+S, 215-320S+G 320-335S, 335-350C+S 350-355S, 355-364C	51°C after 24 hrs

No.	BH NO AND ELEVATION MAMSI	LOCATION TOWN/L.G.	COORDINATES	SCREEN POSITION	TOTAL DEPTH CASED (M)	TOTAL DEPTH DRILLED (M)	LITHOLOGICAL DESCRIPTION	TEMPERATURE DURING
23	15/224/KUM 300	Kumaliwa Monguno L.G	12°34'15"N 13°24'50"E	322.84-353.34	354.41	360	0 - 68 S+SL,68 - 93 SL+C 93-321C,321-354S+SL 354 - 360 C	48°C after 7 hrs.MA
24.	15/200/GU 309	Gubic Kukawa L.G	12°30'00"N 12°40'45"E	344.14-371.72	375	375	0-30S,30-278C 278-271S, 371-375C	40°C after 7 hrs MA
25.	15/231/KR 302	Kareto Kukawa L.G	12°53'15"N 12°30'30"E	291.26-324.26	325.35	345	0-40S,40-287C, 287-321S,321-345C	38°C after 9 hrs. M.A
26	15/339/AB 230	Abadam Kukawa L.G	13°50'00"N 12°30'05"E	340 - 364	364.6	374	0-21S+C,21-346C 346-361S,361-374.5C	50°C after 20 hrs.M.A
27.	14/236/LD 295	Lade Dambua Kukawa L.G	13°05'00"N 12°30'05"E	321 - 327	330	334	0-60S+C,60-320C 320-328S,328-335C	39°C after 48 hrs.M.A
28.	16/95/DL 289	Duwula Monguno L.G	12°30'05"N 13°27"15"E	307 - 313	316	319	0-300C, 300-314S 314-320C + S	47°C after 48 hrs. M.A
29.	15/347 309	Shataram Kukawa L.G	13°05'00"N 13°15'00"E	300 - 306	315	320	0-35,3-299C 299-312S,312-320C	39°C after 45 hrs. M.A
30.	25/173/KT 350	Kukareta Kaga L.G	11°46'38"N 12°12'32"E	105.85-123.85 311.16-314.16 356.67-362.57	371.57	482	0-123S+C,105-123S 123-309SL+C+Laterite 309-315S,315-354C, 354-363S,363-482C	40°C after 72 hrs. M.A
31.	26/260/BSK 396	Benishakh Kaga L.G	11°48'33"N 12°29'29"E	47.39 - 53.47 159.53-165.61	171.74	172.35	0-52C+S,52-64G. 64-150C,150-160S, 160-172.35C	33°C after 22 hrs
32.	26/261/MN 360	Mainok Kaga L.G.	11°49'47"N 12°38'00"E	224.86-237	242	244	0-91S+C,91-221C, 221-238S,238-244 Laterite	34°C after 19 hrs. M.A

1	2	3	4	5	6	7	8	9
33.	14/294/MG 328	Mugumeri Kaga L.G.	12°06'50"N 12°49'45"E	276.44-288.6	295.2	299.8	0-60S+C, 60-275S+C 275-291S, 291-299.8C	40°C after 18 hrs M.A
34.	26/265/DD 355	Didiri Kaga L.G	11°31'38"N 12°24'55"E	65.92 - 71.99	84.00	95	0-16SL, 16-63 C+SL 63-74 SL+C, 74-94SL+S 94-95 basement	35°C after 6 hrs M A
35.	23-BA 268	Bama Bama L.G.	11°32'00"N 13°41'00"E	171.32-193.51	194.59	200	0-42 S+SL, 42-87SL+C 87-200 S+G	31°C after 48 hrs M.A
36.	22-BA 368	Bama Bama L.G.	11°32'00"N 13°41'00"E	180.5-202.71	203.8	210	0-18 S+SL, 18-177S+SL+C 177 - 204 S+SL, 204-210 SL+C	35°C after 5[illegible] hrs MA + UA
37.	33-BA 380	Bama Bama L.G	11°32'02"N 13°41'00"E	123.42-141.42 147.78-165.78 172.15-184.15	189.98	209.5	0-33S, 33-122 C+S, 122-205S, 205-209.5C+S	34°C after 8 hrs UA + MA
38	27/511/DEJ 380	Dar El-Bama L.G	11°19'34"N 13°58'5"E	42.7-64.26	65.36	66	0-12 SL+S, 12-42 SL+C 42-64S, 64-66C	36.7°C after 48 hrs U.A
39	16/62/WAL 385	Walasa Bama L.C	11°34'20"N 14°14'20"E	123.68-160.24	161.31	164.00	0-57 S+SL, 57-123C+S 123-163S, 163-164 bedrock	36.9°after 3 hrs U.A
40.	28/142/GL 390	Gulumba Bama L.G	11°39'11"N	133.9-167.42	168.49	1700	0-75 SL+S, 75-133C+S 133-166S, 160-170 bedrock	37°C after 7 hrs U.A
41.	28/144/KS 345	Kumshe Bama L.G	11°21'20"N 14°21'40"E	46.76-82.77	83.85	85.00	0-69 SL+S-C 69-85 weathered bedrock	30.6°C after 7 hrs U.A
42.	12/317/DM 405	Dolly Machina Nguru L.G	12°82'20"N 9°43'30"E	53.15-59.23	66.13	67	0-12S, 12-52 C+S 52-60S, 60-67C	28°C after 48 hrs U.A
43.	13/289/YF 415	Yusufari Nguru L.G	12°54'00"N 11°10'05"E	70.71-82.85	90	91	0-24 SL+S, 24-50 SL+C 50-68C, 68-83S, 83-90C, 90-91 bedrock	32°C after 8 hrs U.A

1	2	3	4	5	6	7	8	9
44.	12/321/KSG 398	Karasuwagalu Nguru L.G	12°56'00"N 10°05'36"E	46.86-59.0	67	71.00	0-30SL+C, 30-40C 40-59S+SL 59-71 weathered basement	33°C after 7 hrs U.A
45.	25/190/FUN 420	FUNE Fune L.G	11°40'05"N 11°45'00E	141 - 170	177	190	0-125 L+S, 125-175 G+S 175-190 C+S	35°C after 8 hrs M.A
46.	36-GA 453	Gashua Bade L.G	12°52'20"N 11°01'56"E	92.95-105.13	112.15	116	0-29 S+SL, 29-94C 94-112S, 112-116L	36°C after 4 days M.A
47.	13/297/DPC 419	Dupchi Damaturu L.G	12°29'05"N 12°29'17"E	126.44-144.44 187.24-193.24	195.54	214	0-27 SL+S, 27-120S+SL, 120-164S+G, 164-176C 176-140S, 190-244SL+S	37°C after 48 hrs MA
48	SDH 490	Damaturu Damaturu L.G	11°46'05"N 11°58'25"E	116.08-194.39	206.46	230	0-87S+C, 87-1885, 188-190C, 190-230S	34°C after 8 hrs M.A
49.	DA/1 495	Damaturu Damaturu L.G	11°44'20"N 11°57'40"E	242.64-290.44	302.18	314.2	0-15 G+SL+S, 15-59SL+ 59-82 S+G, 82-110C+SL 110-308 G+S	36°C after 7 hrs M.A
50.	13/294/MG 454	Maganna Gudam L.G	12°46'20"N 11°52'05E	64.61-70.88 102.79-108.86	116	123.3	0-21S+L+SL, 21-65C, 65-70S, 70-105C, 105-109S, 109-123L	29°C after 10 hrs
51.	63/80 505	Potiskum Fika L.G	11°42'45"N 11°04'44"E	48.18-54.26	79.	..	0-40S, 40-60 G+S 60-62 C	33°C after 5 days U.A
52.	62/PO 497	Potiskum Fika L.G	11°42'45"N 11°04'36"E	48.18-54.26 66.69-72.77	79.12	91	0-10S, 10-49, C 49-55 G, 55-66C, 66-74.5 S+G, 74.5 - G, C+SS+	33°C after 8 hrs. U.A
53	26!249/GNR 530	Gomiri Gugba L.G	11°29'40"N 12°19'04"E	17.91-26.91 71.76-77.76	79.76	84	0-36 S+SL, 36-75S+L 75-84 basement	30°C after 6 hrs UA + MA

3	2	3	4	5	6	7	8	51. 9
54.	25/154/GB 540	Gujba Gujba L.G.	11°30'00"N 12°00'00"E	58.97-64.97	324.8	325	0-30 S+C, 30-55 SL+C 85-90 S+SL, 90-308C 308-320S 320-325 C	33°C after 8 hrs. UA+MA
55.	12/375/ZM 410	Zaji Maji Nguru L.G	12°54'N 10°50'E	57.1-68.5 74.2-79.9 85.6-91.4	103	125	0-8 claysoil 8-41 G+S,41-52C, 52-71 G+S,71-859, 85-88C,88-95S, 95-122C+S,122-115 basement	33°C after after 6 hrs U.A
56.	12/374/TT 349		13°22'N 11°14'E	163.5-175.5	179	185	0-35S, 35-165L, 165-170 S+C, 170-175S, 175-185 basement	35°C after 8 hrs M.A
57.	15/365/GB 305	Gubio Kukawa L.G	12°28'N 12°45'E	357-381	389	389	0-45S+C,45-332C, 332-369G, 369-386 S+G 386-398 C	41°C after 10 hrs M.A
58.	28/158/DBZ 291	Dabaza, Gama L.G	11°28'N 14°27'E	177-195	202	204	0-13S, 13-173C, 173-204 S	36°C after 8 hrs
59.	56 GE 449	Geidam Geidam L.G	12°50'N 11°50'30"E	31-49	51	150	0-8 SL, 8-31 C 31-100 S, 100-150C	30°C after 6 hrs U.A
60.	Mashio/ Fune 428	Mashio Fune L.G	11°45'N 11°30'10"E	114.6-126.6	128	215	0-28S,28-37C 37-127S 127-215C	30°C after 8 hrs M.A
61.	Ban Alewa 418	Ban Alewa Fune L.G	11°40'30"N 11°30'E	101.6-114.8	116.5	122.38	0-10 Laterite 10-85C,85-117S, 177-122C+S	30°C after 10 hrs

1	2	3	4	5	6	7	8	9
62.	26/303/TLA 450	Talala Damboa L.G	11°10'30"N 12°20'E	19-25	65.08	81.8	0-10S+C, 10-18C 18-26S, 26-81.8C	27°C after 6 hrs
63.	26/315/GM	Gumsuri Damboa L.G	11°05'20"N 12°45'30"E	60-65, 69-69 87-92, 200-210, 200-210, 215-225	257	300	0-122S, 122-132C 132-292S, 292-300 S+C	33°C after 10 hrs

APPENDIX 2

MEAN ANNUAL ATMOSPHERIC TEMPERATURES FOR BORNO STATE. PREPARED BY MINISTRY OF AGRIC AND BORNO ACCELERATED DEVELOPMENT AGRIC. PROGRAM (BOADAP) FOR 1983-85

Town	Mean Annual Atmospheric Temperature (°C)
Maiduguri	29°C
Bama	29°C
Potiskum	28°C
Damboa	27°C
Monguno	30.5°C
Ngala	30°C
Kukawa	31°C
Baga	31°C
Geidam	32°C
Damasak	32°C
Nguru	32°C
Gashua	32°C
Gubio	32°C
Biu	26°C
Uba	26°C
Askira	26°C
Damaturu	28°C
Benisheikh	28.5°C
Gwoza	26.5°C
Buni Yadi	26.5°C