

**INVESTIGATION OF FORMATION TEMPERATURE DISTRIBUTION OF THE  
TURONIAN- MAASTRICHTIAN FIKA SHALE FORMATION FROM WIRELINE LOGS,  
IN PART OF BORNO BASIN, NORTHEASTERN NIGERIA**

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**ABSTRACT:** *The distribution of Formation Temperature of the Fika Shale Formation within part of Bornu basin from five wireline logs was investigated. The area under studied covered about 20 by 40 kilometre square of the total land mass of the basin. The Fika shale sequence were identified at 865m to 1795m in Kinasar well, 640m to 1990m in Krumta, 980m to 1620m in Masu, 700m to 2710m in Tuma, 710m to 2220m in Wadi. The plot of the entire Formation Temperature of the study area reveals remarkable steep variations in temperature with increased range from 680C to 1280C starting from the southern western region to the north western region. This is possibly due to substantial temperature enhancing effects of the underlying basement complex. Interestingly, it was also observed that the minimal temperature variation occurred with approximately 20C/ meter across the field and this also lays credence to the fact that the notable subsurface geothermal variation may be recent events initiated by the near- surface magmatic intrusive events which may have had adverse effects on the overlying sedimentary cover. Furthermore, it is suggested that the probability of hydrocarbon is better in the south eastern region than the north western region although the steep temperature variation of 20C/ meter may perhaps reduce this possibility.*

**KEYWORDS:** wireline, sequence, basement, credence, geothermal and magmatic

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## **INTRODUCTION**

The Nigerian sector of the Chad Basin provides possible source rocks, reservoir beds and structural environment required for the formation of hydrocarbon. But just like any other rift related basin, the rapid sedimentation often leads to facies changes which often result into difficulty in noticing probable sources and reservoirs in such a well processed seismic section. Poor resolution due to limitation in acquisition and processed data has further hampered subsurface interpretation from seismic section. Proper environmental depositional study of the Basin may also be limited owing to obliterated consequences of sedimentation processes.

Temperature is the first most important factor for thermal maturation and help to determine the resultant hydrocarbon type. It is often measured with the aid of temperature logs which have many applications, with the most common being to identify zones producing or taking fluid. Bottom hole temperature is the temperature in the borehole at total depth at the time it is measured. In log interpretation, the bottom hole temperature (BHT) is taken as the maximum recorded temperature during a logging run, or preferably the last of series of runs during the same operation. The Formation

Temperature is the temperature of the unperturbed formation. However, during the drilling process, there is great alteration of the temperature of formation immediately surrounding the well. The temperature change is affected by the duration of drilling fluid circulation, the temperature difference between the reservoir and the drilling fluid, the well radius, the thermal diffusivity of the reservoir and the drilling technology used. Given these factors, the exact determination of formation temperature at any depth requires a certain length of time in which the well is not in operation. One of the major methods developed to estimate formation temperature from Bottom hole temperature is the Kutasov and Eppelbaum method (2003). A critical understanding of the variation of Formation Temperature within an identified source rock formation as conceived in this research will go a long way to give an idea about the maturation of the source rock and in general, the hydrocarbon prospect of the Basin.

### **Geophysical activities in the Basin**

Exploration activities commenced in the Basin in 1976 and continued till date. During the initial Period of data acquisition about 33,000Km of 2-D Seismic data was acquired, processed and interpreted. Twenty three wells were drilled out of which two recorded non-commercial gas discoveries. Exploration was then suspended in the Chad Basin in 2000 for lack of commercial discoveries. The new drive to get oil in the Chad Basin followed the commercial discoveries in the neighbouring Niger, Chad and Central African Republics in their portions of the Chad Basin. This spurred the need to further appraise the Nigerian portion of the Chad Basin and Benue Trough due to similarity in their geological setting.

In 2002, the federal government directed that the data generated should be evaluated to further ascertain the prospectivity of the Basin. A Consortium of 10 consultants was engaged to carry out integrated studies utilizing all the generated data. The study formed the basis for Nigerian National Petroleum Corporation (NNPC), present exploration strategy. Three thousand five hundred and fifty (3,550) square kilometers of high resolution seismic data was planned to be acquired in two years. The data acquired will be processed and evaluated to identify drillable locations. To this end, NNPC has deployed state of the art technology in the present data acquisition and will continue to do so in all aspects of exploration including drilling. All these efforts will lead to clearer definition of the prospectivity of the basin. The seismic activities were carried out by the Integrated Data Services Limited (IDSL) which is a subsidiary of the NNPC, and BGP, a subsidiary of China National Petroleum Corporation (CNPC).

Currently, eight phases (about 1,962sqkm) out of the planned 12-phase project to cover the 3,550 square kilometres (sqkm) have been acquired and processed until insurgency necessitated the suspension of operation.

### **Aim of present studies**

Any prospective petroleum sediment must have a good quality source rock, good reservoir and seal lithologies, favourable regional pathways and trapping mechanisms. It is an established fact that the Fika and Gongila Shale are the main source rocks in Chad Basin, while the reservoirs may be provided by Gombe Sandstone and in the Bima Sandstone facies of the basin. Also, the intrusive sills

can provide good seal for hydrocarbons. The aquifers within the Chad Formation can act as a conduit for hydrocarbon to the surface. Ayoola et al (1982) Ajayi and Ajakaiye (1983) Cratchley et al (1984) Avbovbo et al (1986) and Adepelumi et al (2010). Despite the identified favourably conditions enumerated above and the huge amount of resources the Federal government had plunged into their quest to discover hydrocarbon within the basin and considering the reasons adduce by geoscientists concerning the prolific nature of the basin such as the poor knowledge of the Nigerian sector of the Chad Basin, especially with respect to source rock development. Nwazeapu, (1992), Nwankwo and Ekine,( 2009) and Ilozobhie et. al (2009). Thus the thrust of this study shall investigate into the Formation Temperature distribution within one of the major source rock Formation within the Bornu Basin: the Fika Shale, in order to ascertain their effect on the hydrocarbon potential of the basin.

### **Location of study Area**

The study area lies within an approximate location of latitude  $12^{\circ} 09'N$  and  $12^{\circ}26'N$  and longitudes  $15^{\circ}12'E$  and  $15^{\circ}24'E$  and it covered an area of about 20 by 40 kilometre square of the total land mass of the entire basin (Fig. 1.0). In the concessional map of the basin, it is located in the oil prospecting lease (OPL) 721, 722, 732 and 733. The altitude of the basin dropped from 350m at the western margin to about 300m along a distance of roughly 240km indicating a gentle slope towards lake Chad. The area of study is situated onshore and accessibility is by road and air.

### **The Fika Shales of Borno Basin**

The Fika Shale is mainly dark to blue black shale overlying the Gongila Formation. These are completely marine shales consisting of blue black shales occasionally, gypsiferous with thin limestone intercalation (Okosun 1995). The thickness varies from about 1000m in the NorthWestern margin to about 500m in the NorthEastern margin. Volcanic intrusive which occurs as diorites sills are present at several horizon of the formation (Okosun,1995 and Avbovbo et al 1986). The unit is diachronous, dating from Turonian to Maastrichtian in age. The relative abundance of arenaceous benthic foraminifera within the Fika shale point to the prevalent of near shore environment just like the source of marine water during the period is believed to be through the Tran Sahara sea way (Avbovbo et. al, 1986).

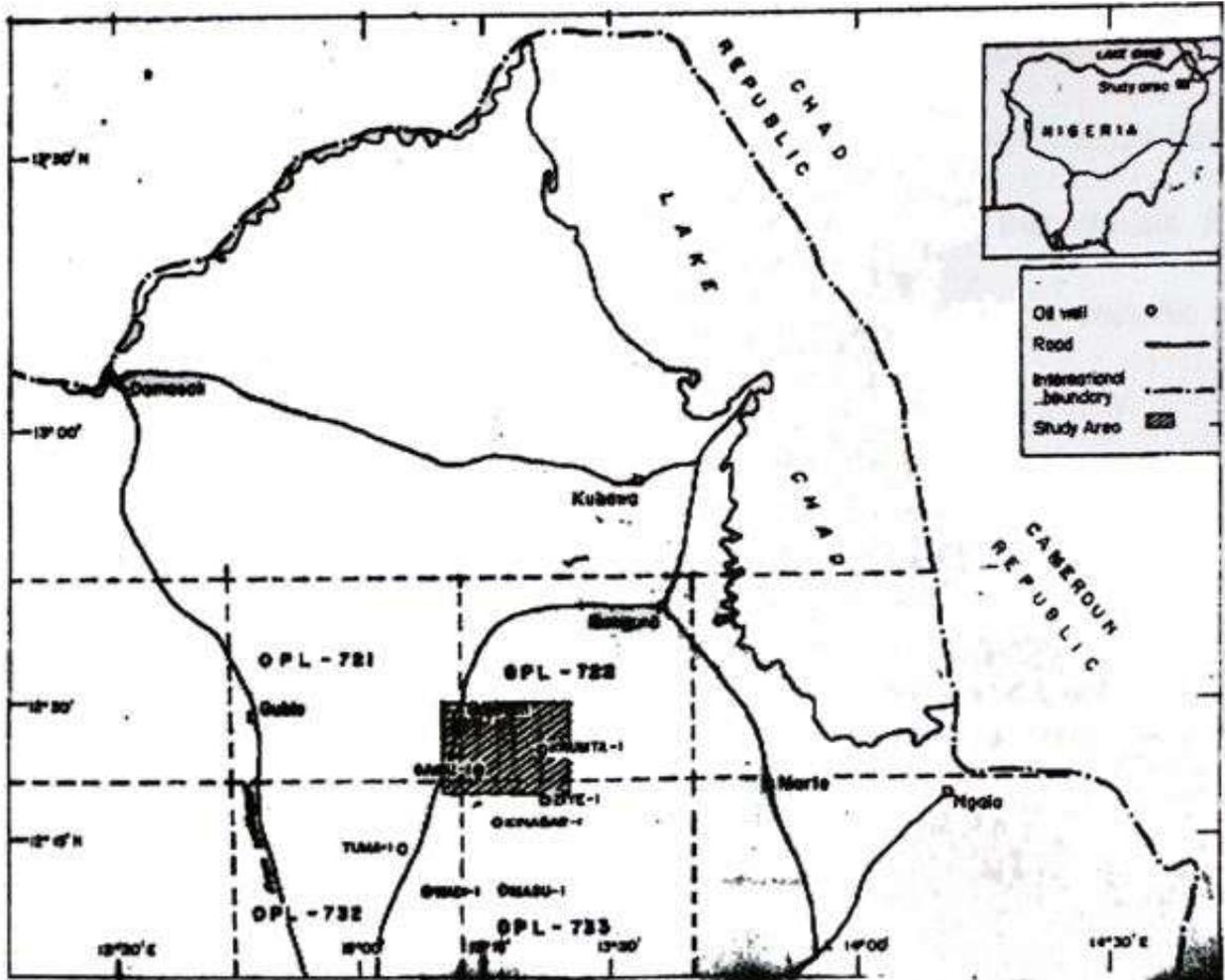


Fig. 1.0: Location map of Bornu Basin. Shaded section represent area covered in the study

### Data acquisition and analysis

#### Acquisition

Soft copies of digital well data were supplied for this work. The soft copies of the well data given are Kinasar-1 (12°19'N 13°17'E), Tuma-1 (12°15'N 13°05'E), Wadi-1 (12°09'N 13°09'E), Masu-1 (12°10'N 13°18'E), Gaibu-1 (12°23'N 13°14'E), Krumta-1(12° 26'N 13° 23'E). This data were plotted by a developed visual basic plotter manager to facilitate the demarcation of bed boundaries and formations identification. Table.(1.0) shows the wireline logs and the depth of investigation.

#### Identification of the Fika Shale

In this study, the gamma ray log signatures were utilized to delineate the sediments bed boundaries for the various formations (sandstone, shale and siltstone) encountered.

Deductions from the electric logs show that this formation consists primarily of shale with minor limestone and subordinate amount of intercalated sand extending from 865m to 1795m. Kinasar well reveals the Fika shale member from 865m to 1250m to be a shaly sequence with intercalations of sand (865m – 975m and 1045m – 1250m). This strata is recognized by high Gamma ray values (except in the intercalated areas), high sonic travel time for shale zone but moderately low area of sands. A thick sequence of shale occurs between 1250m to 1450m. It is recognized by high Gamma ray value and relatively high resistivity and high sonic travel time. Toward the end of the Fika Shale Formation (1450m to 1850m) there is a gradual increase in resistivity values with high gamma values with high sonic travel time compared to earlier zone. The log characteristics above indicate unconsolidated shale.

The Fika Shale was identified in the Krumta well within the depth range from 640m to 1990m by the high Gamma ray values with high sonic travel time. The Intercalation sequence ranges from 640m to 1110m. Most of the remaining section of the Fika shale depicts shaly sequence throughout ranging from 1110m to 1990m as reflected by high values of gamma ray, Resistivity and Sonic logs. The depth range of the Fika sequence identified within Masu, Tuma and Wadi ranges within 980m to 1620m, 700m to 2710m and 710m to 2220m respectively.

### **Computation of Formation Temperature**

The formation temperature within each of the interested formation from each well was computed using the Borehole Temperature (BHT) values as displayed on the well header after which the BHT values were corrected. Several correction methods have been proposed by many authors (Henrikson and Chapman, 2002; Onuoha and Ekine, 1999). In this study the BHT drilling effects were corrected by using an AAPG gradient correction factors (Table 2.0). The approach allows corrections to be made on individual recorded BHT data. The corrected BHT values were converted to the Formation Temperature using the Schlumberger correction chart (GEN- 5). Table (3.0) shows the computed formation temperature for Fika shale at various coordinates and depths, this was done for the remaining four wells. Since all the given well data are from vertical well, the position of each of the well were posted on the corresponding depth point using the coordinate of such point to generates maps that shows the distribution of Formation Temperature within each well. Most importantly, in order to have an ideal about the variation of the Formation Temperature within the study the computed values were posted on the situation map using the coordinates of each depth points and are contoured using available contour software.

**TABLE 1.0**  
**Well location and wirelines log used for the study**

Well	Drilling depth Range (m)	Type of log		
		Lithology	Resistivity	Porosity
Kinasar-1	45-4665	CAL. & GR	SN & ILD	$\Delta T$ & RHOB
Krumta-1	15-2950	CAL. & GR	SN & ILD	$\Delta T$ & RHOB
Masu-1	1996-3104	CAL. & GR	MSFL & ILD	$\Delta T$ & RHOB
Tuma – 1	33-3628	CAL. & GR	SN & ILD	$\Delta T$ & RHOB
Wadi -1	539-3225	CAL. & GR	SN & ILD	$\Delta T$ & RHOB

**Key:**

CAL.	=	Caliper log
SP	=	Spontaneous Potential Log
GR	=	Gamma Ray Log
SN	=	Short Normal Log
MSFL	=	Microspherical Focus Log
ILD	=	Deep Induction Resistivity Log
$\Delta T$	=	Sonic Log
RHOB	=	Density Log

**Table 2.0:** Additions for correction of logged Bottom Hole Temperatures to True Formation Temperatures based on API method (Neglia, 1979).

Depth (m)	Added temperature quotient (°C)
500	4.0
1000	7.5
1500	11.0
2000	14.0
2500	16.0
3000	17.5
3500	18.0
4000	18.0
4500	17.0
5000	15.0
5500	11.0
6000	4.5

**Table 3: Computed Formation Temperature values with coordinates and depth in one of the well name Kinasar well**

Depth (m)	Latitude (°)	Longitude (°)	Formation Temperature within Fika Formation (°C)
865	12° 16' 22 <sup>11</sup>	15° 20' 32 <sup>11</sup>	60
915	12° 16' 24 <sup>11</sup>	15° 20' 33 <sup>11</sup>	62
965	12° 16' 25 <sup>11</sup>	15° 20' 34 <sup>11</sup>	59
1015	12° 16' 27 <sup>11</sup>	15° 20' 35 <sup>11</sup>	63
1065	12° 16' 29 <sup>11</sup>	15° 20' 37 <sup>11</sup>	66
1115	12° 16' 30 <sup>11</sup>	15° 20' 38 <sup>11</sup>	67
1165	12° 16' 31 <sup>11</sup>	15° 20' 39 <sup>11</sup>	66
1215	12° 16' 35 <sup>11</sup>	15° 20' 42 <sup>11</sup>	69
1265	12° 16' 42 <sup>11</sup>	15° 20' 43 <sup>11</sup>	72
1315	12° 16' 43 <sup>11</sup>	15° 20' 46 <sup>11</sup>	74
1365	12° 16' 44 <sup>11</sup>	15° 20' 47 <sup>11</sup>	79
1415	12° 16' 45 <sup>11</sup>	15° 20' 49 <sup>11</sup>	81
1465	12° 16' 47 <sup>11</sup>	15° 20' 53 <sup>11</sup>	84
1515	12° 16' 48 <sup>11</sup>	15° 20' 55 <sup>11</sup>	86
1565	12° 16' 49 <sup>11</sup>	15° 20' 57 <sup>11</sup>	87
1615	12° 16' 51 <sup>11</sup>	15° 20' 58 <sup>11</sup>	90
1665	12° 16' 52 <sup>11</sup>	15° 20' 59 <sup>11</sup>	90
1715	12° 16' 52 <sup>11</sup>	15° 21' 01 <sup>11</sup>	91
1765	12° 16' 56 <sup>11</sup>	15° 21' 03 <sup>11</sup>	90
1795	12° 16' 57 <sup>11</sup>	15° 21' 04 <sup>11</sup>	90

## RESULTS AND DISCUSSION

### **Kinasar**

The Formation Temperature (FT) within this field ranges within 30<sup>0</sup>C to 76<sup>0</sup>C (Fig. 2.0) the temperature variation is gentle toward the South Eastern region, with the North – Eastern part of the well is much steeper, having high Formation temperature ranging between 64<sup>0</sup>C to 76<sup>0</sup>C, the North Western part displace temperature range between 44<sup>0</sup>C to 58<sup>0</sup>C. The distribution of the temperature is along the South Western - North Eastern direction with the central part showing a range between 54<sup>0</sup>C to 62<sup>0</sup>C.

### **Krumta**

The outward steepy spreading of the temperature values from the westward side of the study area is clearly seen on this map likely indicating rapid variation in geothermal. The North – Eastern part showing relatively high Formation Temperature from 85<sup>0</sup>C to 100<sup>0</sup>C (Fig. 3.0). The North Western part ranges from 50<sup>0</sup>C to 90<sup>0</sup>C. The central part shows relatively low temperature distribution from 55<sup>0</sup>C to 70<sup>0</sup>C. The distribution still maintain the North Eastern – South Western pattern.

### **Masu**

The Temperature of the Formation ranging within 56<sup>0</sup>C to 108<sup>0</sup>C. The well exhibit evenly distribution of temperature within the South central region (Fig.4.0). The Upper part (North Eastern) shows high formation Temperature values ranging within 86<sup>0</sup>C to 108<sup>0</sup>C. The direction the Temperature is trending is still South Western North Eastern direction.

### **Tuma**

The Formation Temperature ranges from 80<sup>0</sup>C to 195<sup>0</sup>C trending South Western - North Eastern direction with the Central region having Formation Temperature ranging from 120<sup>0</sup>C to 130<sup>0</sup>C and the North Eastern part temperature values between 160<sup>0</sup>C to 165<sup>0</sup>C while the South Eastern part depicts high temperature values within 175<sup>0</sup>C to 195<sup>0</sup>C (Fig.5.0)

### **Wadi**

There is a progressive build up of the formation temperature in the South Western – North Eastern direction with the Southern part clearly showing this build up (Fig.6.0). The South Eastern part shows high temperature values between 160<sup>0</sup>C to 210<sup>0</sup>C while the central portion has relatively low temperature values from 120<sup>0</sup>C to 145<sup>0</sup>C.

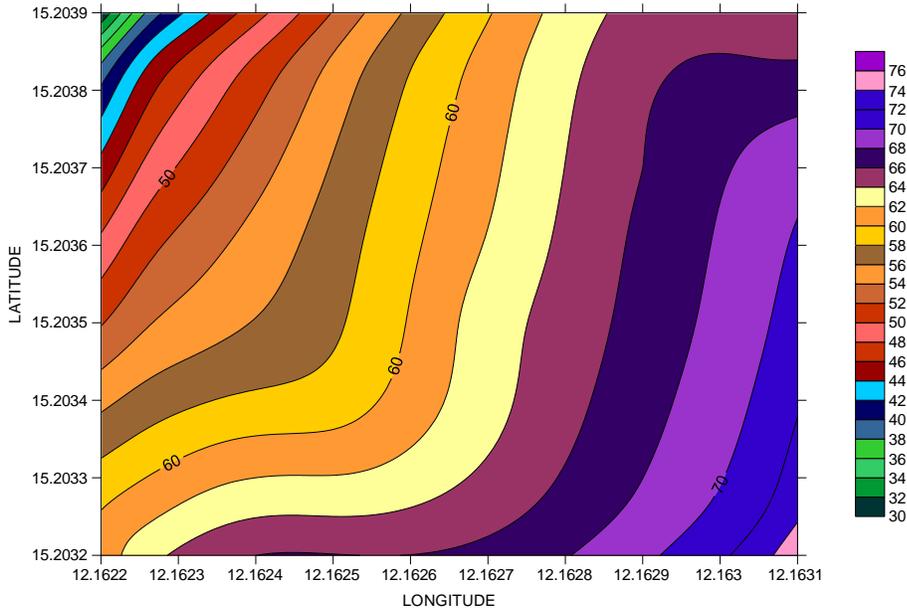


Fig. 2.0: Formation temperature map within Fika Formation in Kinsar well

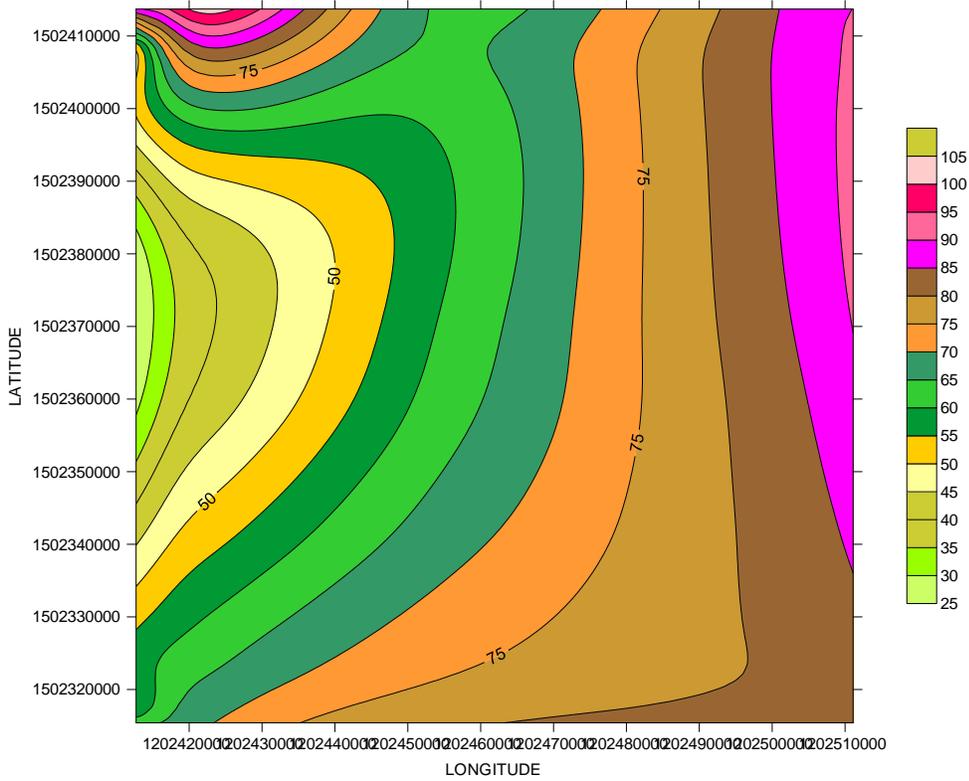


Fig.3.0: Formation temperature map within fika formation in Krumta well

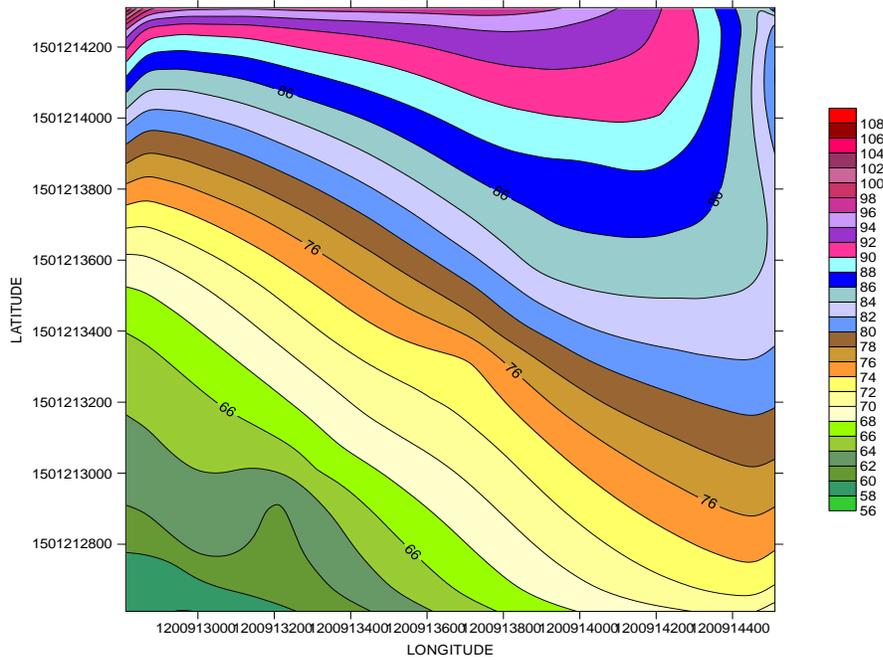


Fig.4.0: Formation temperature map within fika formation in Masu well

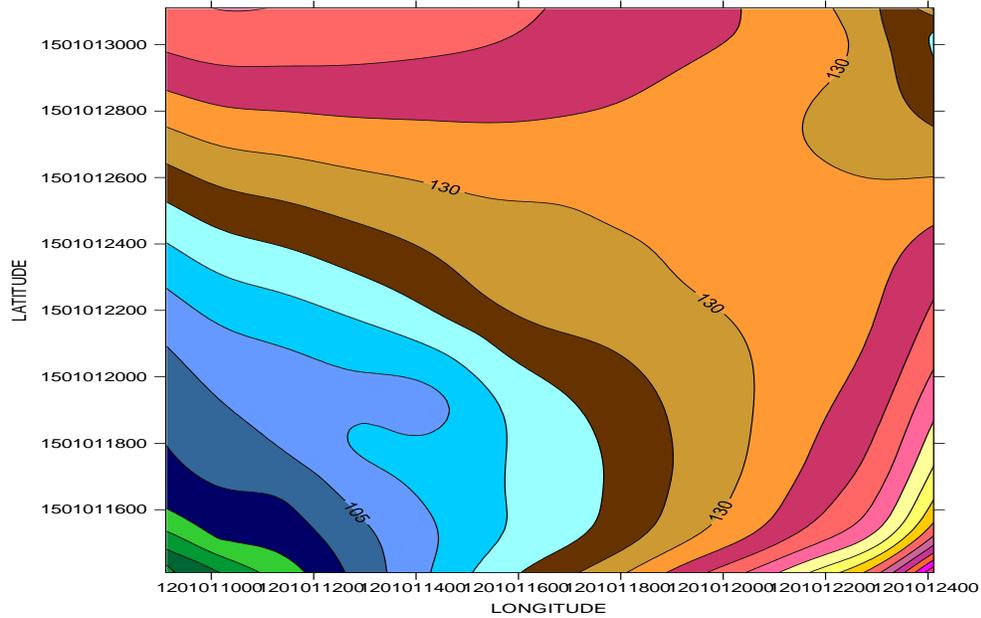


Fig. 5.0: Formation temperature map within fika formation in Tuma well

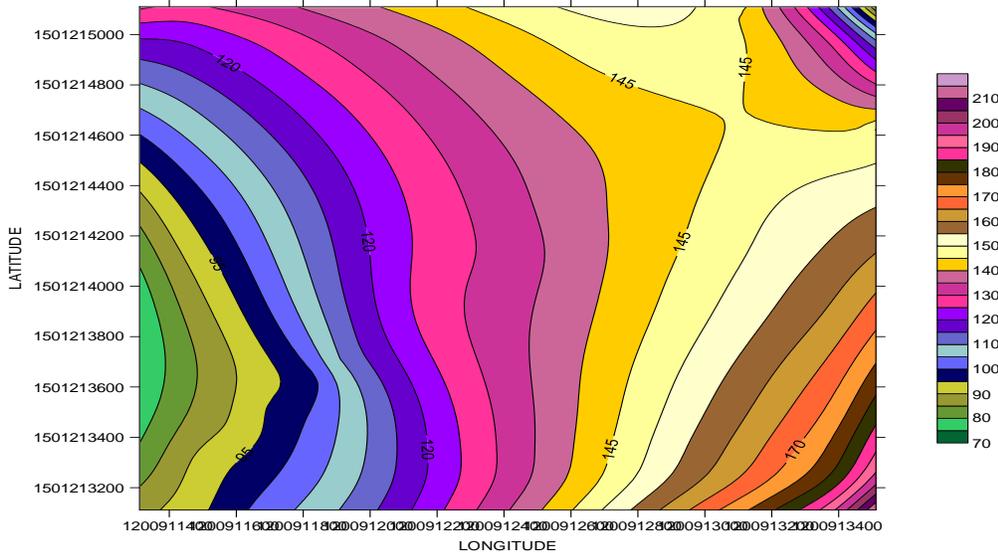


Fig.6.0: Formation temperature map within Fika formation in Wadi well

#### Formation Temperature analysis within the study area

A critical investigation of the map of all the wellbore temperatures shows remarkable steep variations in temperature with increased range from  $68^{\circ}\text{C}$  to  $128^{\circ}\text{C}$  starting from the southern western region to the north western region (Fig.7.0). This is possibly due to substantial temperature enhancing effects of the underlying basement complex. Interestingly, it was also observed that the minimal temperature variation occurred with approximately  $2^{\circ}\text{C}/\text{meter}$  across the field and this also lays credence to the fact that the notable subsurface geothermal variation may be recent events initiated by the near-surface magmatic events which may have had adverse effects on the overlying sedimentary cover.

The north east to south west region showed diagonally uniform cross sectional temperatures ranging from  $90^{\circ}\text{C}$  to  $102^{\circ}\text{C}$ . This suggests that possible hydrocarbon potential occurrences in this field may have better prospects from the central region with an average temperature of  $98^{\circ}\text{C}$  to the south eastern region with the least temperature of  $68^{\circ}\text{C}$  as long as favourable sedimentary covers exist. Furthermore, it is suggested that the probability of hydrocarbon is better in the south eastern region than the north western region although the steep temperature variation of  $2^{\circ}\text{C}/\text{meter}$  may perhaps reduce this possibility.

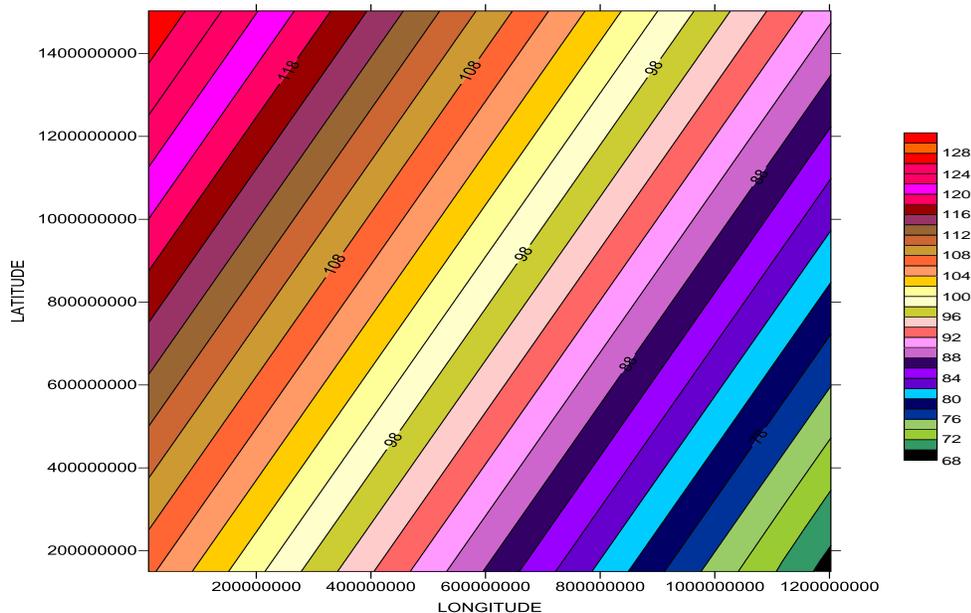


Fig. 7.0: Formation temperature map within the study area

## CONCLUSION

The formation Temperature distribution within Fika Shale source rock of the Bornu basin was investigated. The linear increase of temperature with depth was evident throughout the study area within each well especially within Krumta and Kinasar wells while Masu, Tuma and Wadi shows high formation temperature variation with depth. The spatial variation of Formation Temperature clearly shows that some area (the south western region to the north eastern region) depicts steeply variations in temperature ( $68^{\circ}\text{C}$  to  $128^{\circ}\text{C}$ ) this is attributed possibly to substantial magmatic intrusive bodies which the basin is noted for within this region this may be responsible for non availability of hydrocarbon within the basin since the formation temperature within this region is very high for liquid hydrocarbon to accumulate.

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