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Geostatistical analysis of porosity distribution from well log data, in part of Bornu Basin, North-eastern part, Nigeria Using Kriging and Co-Kriging methods

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ABSTRACT

The porosity distribution from well log data of five oil wells, in part of Bornu basin, using Kriging and Co-Kriging methods was analyzed. The results shows that the North- Eastern part of the study area depicts a well developed sand region for hydrocarbon accumulation with porosity distribution ranging from 0.15 to 0.2 with Kinasar-1, and Masu-1 wells showing an excellent distribution. The effect of intrusive bodies for which the basin is well noted for on the porosity distribution was clearly shown in Kinasar-1, Wadi-1 and Gaibu-1 oil well. The Southern regions of the study area have poor porosity distribution ranging from 0.5 to 1.0. The depositional current at the North was high and very low at the South suggesting that the sediments were deposited during the transgressive phase.

Keywords: *porosity, Kriging, Cokriging, depositional, transgressive*

INTRODUCTION

Exploration activities commenced in the Chad Basin in 1976 and continued till 1996. During this Period 33,000Km of 2-D Seismic data was acquired, processed and interpreted and Twenty three wells were drilled. Exploration activities were 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 Exploration activities commenced in the Chad Basin in 1976 and continued till 1996. During this Period 33,000Km of 2-D Seismic data was acquired, processed and interpreted and Twenty three wells were drilled. Exploration activities were 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 similaritygeological 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 NNPC present exploration strategy.Currently, about three thousand five hundred and fifty (3,550) square kilometers of high resolution seismic data has been acquired by IDSL a subsidiary of NNPC, in partnership with BGP of China, in addition to the previously acquired data.

This quest for expanding Nigeria economic revenue through hydrocarbon exploration in the Borno basin has long started and the pursuit which is yet unsuccessful would permit a chance to every reasonable idea(s) in bringing success to the venture. The above information formed the backgroung of this reseach: to find out the distribution of the porosity within the basin using geostatistical methods in view of the huge financial resources that the federal government have deplored into the Basin.

Geology of the study area

The study area lies within the Northeast-southwest direction of Bornu basin. It is along latitude 12^{o}19’N and 12^{o}28’N and longitude 13^{o}10’E and 13^{o}25’E. It covers an area of about 20 by 40 kilometer square of the total land mass of the basin. In concessional map of the basin, it is located in Oil Prospecting Lease (OPL) 721 and 722 with part of the study area within OPL732 and 733 (Fig. 1).

One of the commonest structural features that the basin is well known for are faults that involve the basement and resulting horst, graben, related features and detached faults occurring within the basin which is in response to basinal deformation [2], [8] . Other registered structural features of the basin are fold, buried hills, basement horsts and intrusive bodies [1], [9] [10], and [4].

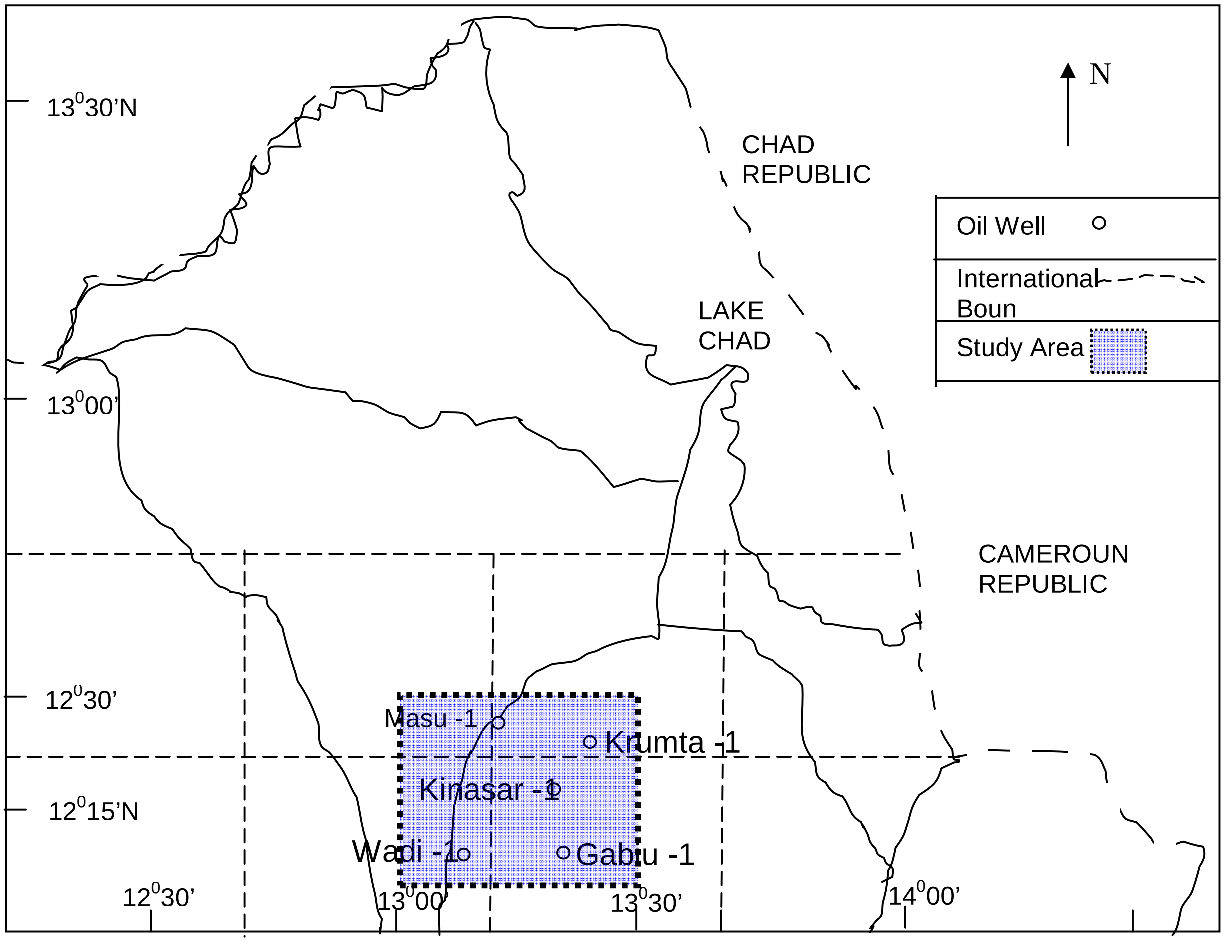

Fig. 1 : Map of the Study area in Borno Basi

MATERIALS AND METHODS

The major materials used for this work are well log data from five oil wells namely Kinasar -1, Krumta -1, Gaibu -1, Masu -1 and Wadi -1 spatially located in Borno basin with an average depth of about 28km, location map of the study area, Stanford Geostatistical Modeling Software (SGeM), VESPER. A visual study of the well log signatures for the five well was done, to ascertain porous and permeable zones. Afterwards, the well log signatures were then digitized at an interval of 5m for the five wells. The following parameters were read from the oil well data, gamma reading (GR), deep Resistivity (ILD), sonic transit time (ΔT), flushed zone resistivity (SN), bulk density (RHOB), Caliper reading and depth (CALI). Table 1 shows the depth investigation of each well under studied.

Using the relevant geophysical formula(s), [7], [6], and Hallenberg 1984) the porosity values from sonic tools and density tools were computed using Microsoft Excel. Kriging was carried out vertically using VESPER Software (along the well depth), for all the wells. The plots were inspected visually to marked depths that displayed excellent porosity values for cokriging using SGeMs Software on the horizontal axis. This was done based on similar porosity behavior among the wells at that depth.

RESULTS AND DISCUSSION

Increase in depth decreases porosity and increases velocity. This is accountable to the normal compaction trend of geologic formation with depth. The greater the overburden, the greater the pressure which decreases the separating distances of the formation grains. Based on this natural principle, the porosity plots for each of the wells after kriging was reviewed; porosity distribution for each well and the causatives for distorted porosity trend were also discussed.

Porosity Distribution for Kinasar-1 from Kriging

Kriging belongs to the family of linear least squares estimation algorithms. The aim of kriging is to estimate the value of an unknown real-valued function, *f*, at a point, *x**, given the values of the function at some other points, $x_1 \ldots x_n$ (Delfine and Delhomme,1975). A kriging estimator is said to be linear because the predicted value is a linear combination that may be written as
.

The weights λ_i are solutions of a system of linear equations which is obtained by assuming that *f* is a sample-path of a random process *F(x)*, and that the error of prediction which can be written as is to be minimized in some sense

$$\hat{f}(x^*) = \sum_{i=1}^{n} \lambda_i(x^*) f(x_i)$$

$$\varepsilon(x) = F(x) - \sum_{i=1}^{n} \lambda_i(x) F(x_i)$$

Fig. (2) shows the porosity plot from density tool for Kinasar-1 after kriging. The porosity value was decreasing gradually with depth, which is a normal trend from about 0.4 to 0.38 between depths of about 450m down to about 1200m before a rapid fluctuative decrease took over, dropping the porosity value to as low as 0.36 and as high as 0.39 between depths of about 1200m to 1700m where the gradual decrease in porosity. The rapid and erratic porosities below this depth shows that the well, might have cut across intrusive bodies which the basin is well known for.

Porosity Distribution for Masu-1

Fig. 3 shows the density porosity plots for Masu-1 after kriging. The plots suggest a normal compaction trend for this well. Porosity distribution for the well started with a high porosity at the shallow part and decrease gradually as the well depth is increased. At depths of about 2700m, the plots show a more decrease in porosity down the well to depths of about 3000m. Distribution for this well range between 0.33 and 0.38 for porosity computed from density tool

TABLE 1 ***Well location and wirelines log used for the study***

Well	Drilling depth Range (m)	Type of log		
		Lithology	Resistivity	Porosity
Gaibu-1	25-4620	CAL.,GR. SP	MSFL, ILD	ΔT, RHOB
Kinasar-1	45-4665	CAL. , GR	SN & ILD	ΔT, RHOB
Krumta-1	15-2950	CAL. , GR	SN & ILD	ΔT, RHOB
Masu-1	1996-3104	CAL. & GR	MSFL& ILD	ΔT, RHOB
Tuma – 1	33-3628	CAL. , GR	SN & ILD	ΔT, RHOB
Wadi -1	539-3225	CAL. , GR	SN & ILD	ΔT, 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*
ΔT = *Sonic*
LoRHOB = *Density Log*

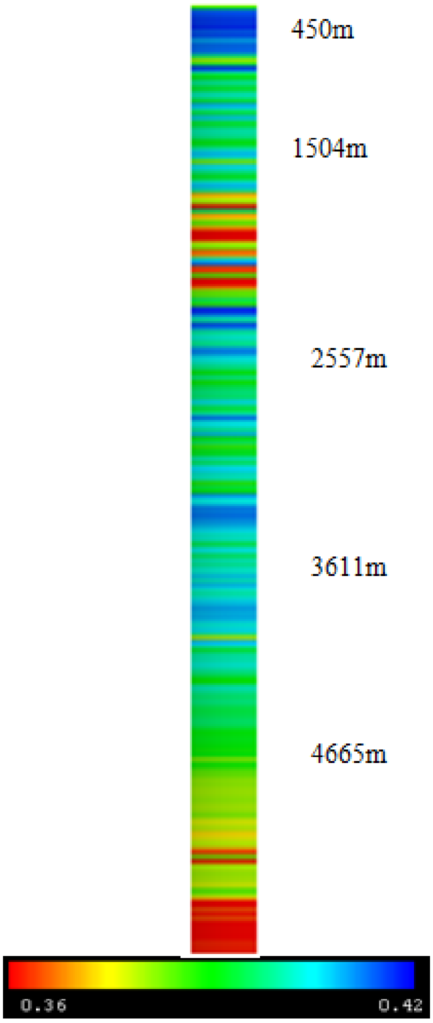

Fig. 2: Porosity Plots for Kinasar-1 after Kriging

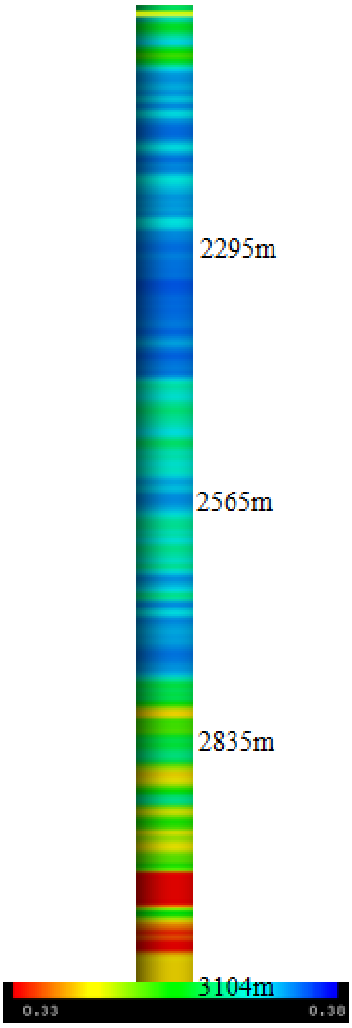

Fig. 3: Porosity Plots for Masu-1 after Kriging

Porosity Distribution for Krumta-1

Fig. 4 shows the density porosity plot for Krumta-1 after kriging. Sediment compaction with respect to depth suggests a mixed trend for the plots, which show fairly uniform porosity distributionl. At depths of about 1400m, the plots show a sharp decrease in the porosity distribution within a thickness of about 200m. The porosity value at this anomalous depth dropped down to about 0.35 and 0.05 for this well. The normal trend is seen after this depth and the porosity distribution continue to decrease down the well to as low as 0.25.

Porosity Distribution for Wadi-1

The compaction trend disturbances encountered at many depths suggested a mixed trend for Wadi-1. Within the depth of about 1900m for the plot (Fig. 5), a thick porosity anomaly is observed. This zone suggests an interception of the Wadi-1 well with an intrusive body. However, the well did not maintain a normal compaction trend.

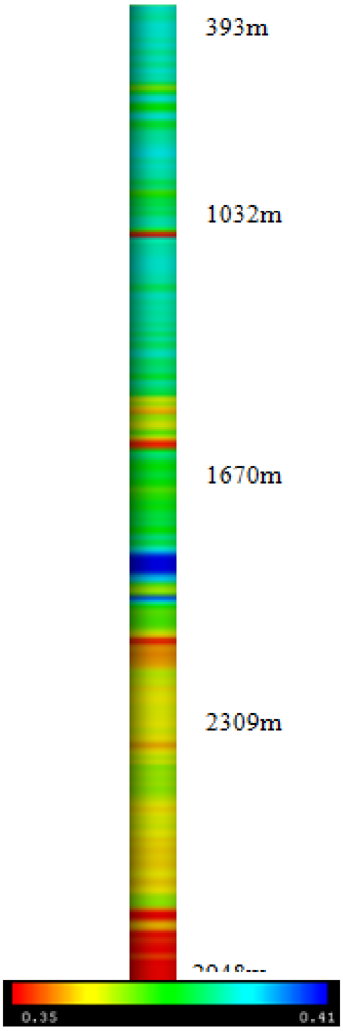

Fig. 4: Porosity Plots for Krumta-1 after Kriging

Porosity Distribution for Gaibu-1

Figure 6 shows the sonic porosity plot for Gaibu-1 well. This well maintained a normal compaction trend at most unlike other wells. A gradual decrease in porosity distribution took place at the depth of about 2500m which recorded porosity value as low as 0.01. This anomaly terminated at the depth of about 3400m where the porosity value suddenly increased to about 0.1. This zone suggests an interception of the Gaibu-1 well with an intrusive body. Density porosity could not be computed for Gaibu-1 well to enable comparism with result gotten from sonic tools. This is because there was no bulk density recorded for the well in log data used for this study.

Cokriging Results

Cokriging is an extension of kriging used when estimating a one variable from two variables. The two co-variables must have a strong relationship and this relationship must be defined [5]. Use of cokriging require s the spatial covariance model of each variable and the cross-covariance model of the variables. The method can be quite difficult to do because developing the cross-covariance model is quite complicated. Practice in minning industry limits cokriging to the case when the variable being estimated is under sampled with respect to the second variable. If all samples have both variables, industry has found no benefit gained from the use of cokriging.

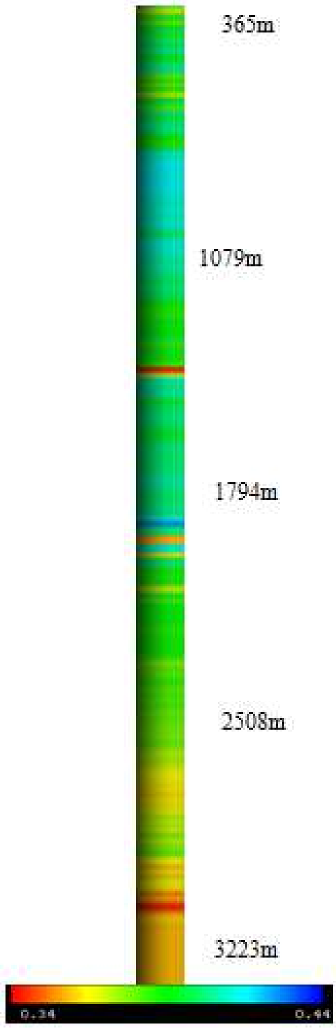

Fig. 5: Porosity Plots for Wadi-1 after Kriging

The depths selected for Cokriging were depths of at about 2100m, 2400m, 2700m and 2910m. The different distributions for each zone and the rate at which the distribution vary were reviewed for each depth. Rapid and gradual changes in porosity are observed within zones of clustered and widespread contours respectively. Contours diverging outward the study area show a gradual change in porosity towards that direction while contours converging as they leaves show a more rapid change towards their direction.

Porosity Distribution at the Depth of 2100m

Fig.7 depicts execellent porosity distribution dominating the north-east and north-west region with porosity value as low as 0.19 at the depth of 2100m from cokriging of porosity values obtained from sonic tool. This figure suggests that the sand within this area at this depth is well developed. The distribution in between the east and the west show a fair distribution of sediments and the porosity is changing rapidly towards the east and gradually towards the west, both varying within 0.26 and 0.36. The south-east zone possesses poorly distributed sand which is also shown by fig.8 (cokriging of porosity values obtained from density tool) , this figure further suggest a rapid porosity changes within the north-east zone of the map. Gradual porosity changes remains within the southern region.

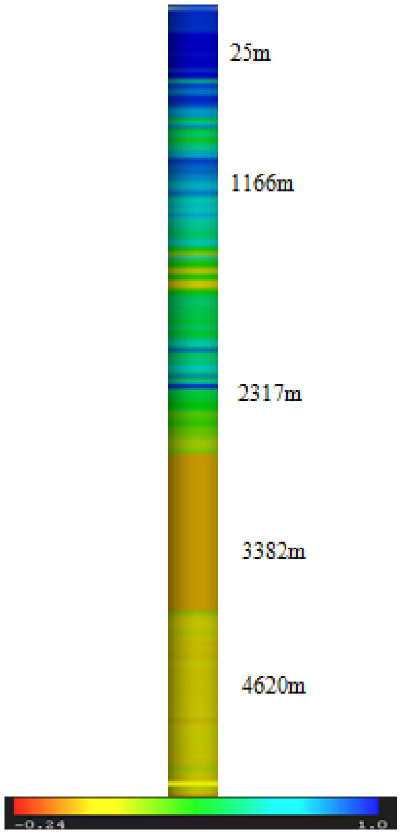

Fig. 6: Porosity Plots for Gaibu-1 after Kriging

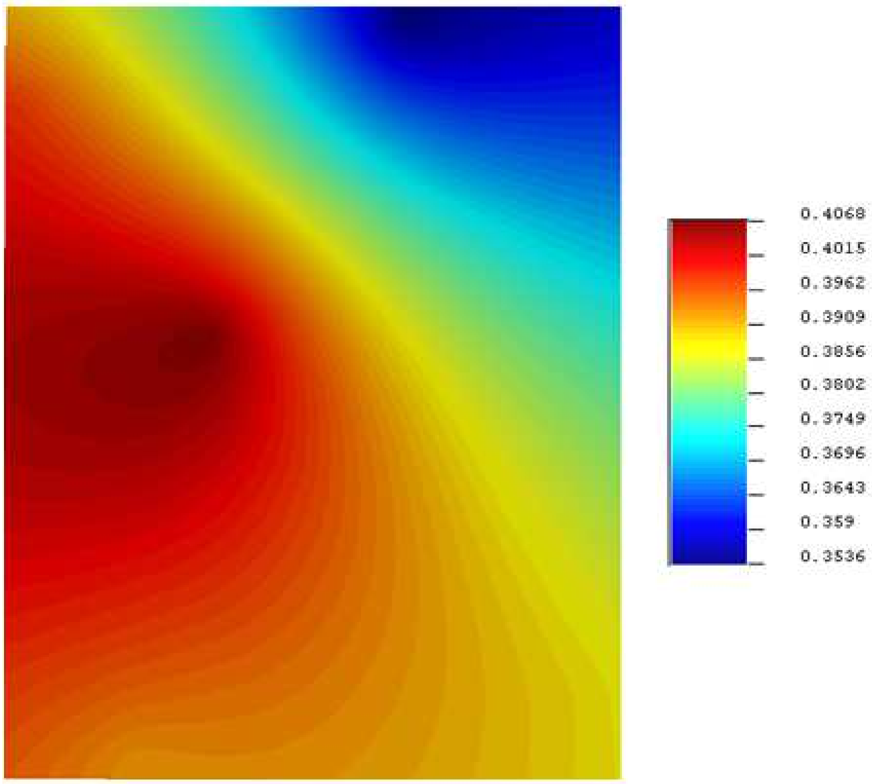

Fig. 7: Porosity distribution from sonic tools within the depth of about 2100m after Cokriging

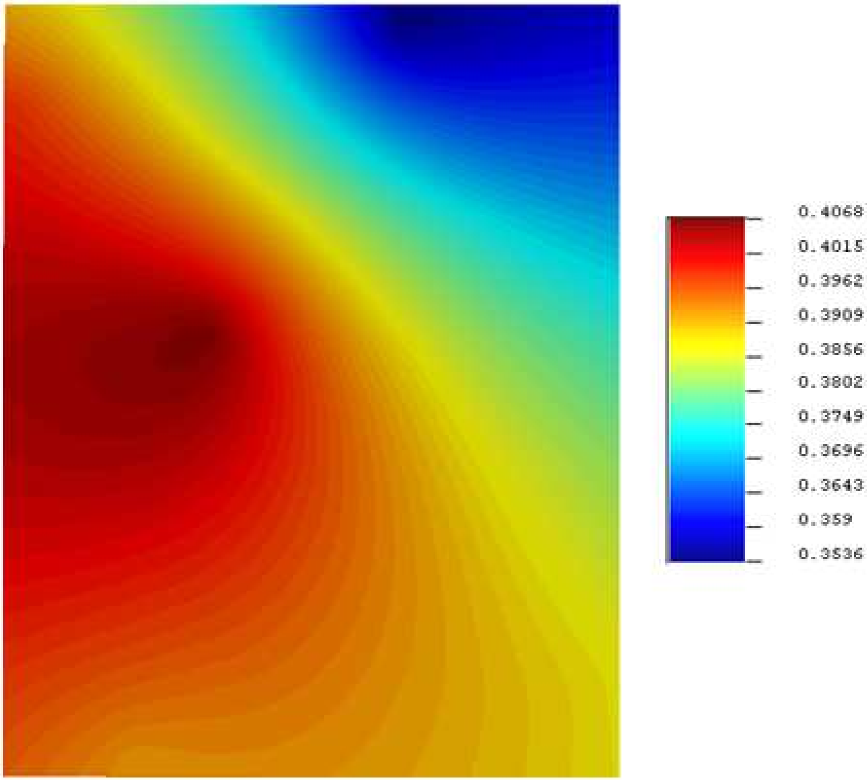

Fig. 8: Porosity distribution from Density tools within the depth of about 2100m

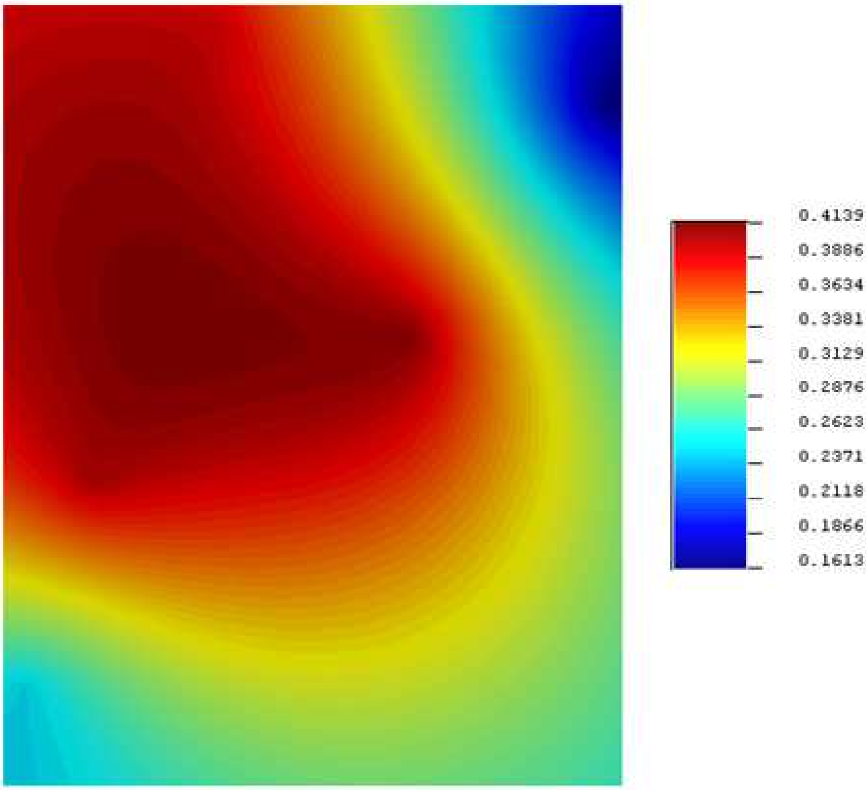

Fig. 9: Porosity distribution from sonic tools within the depth of about 2400m after Cokriging

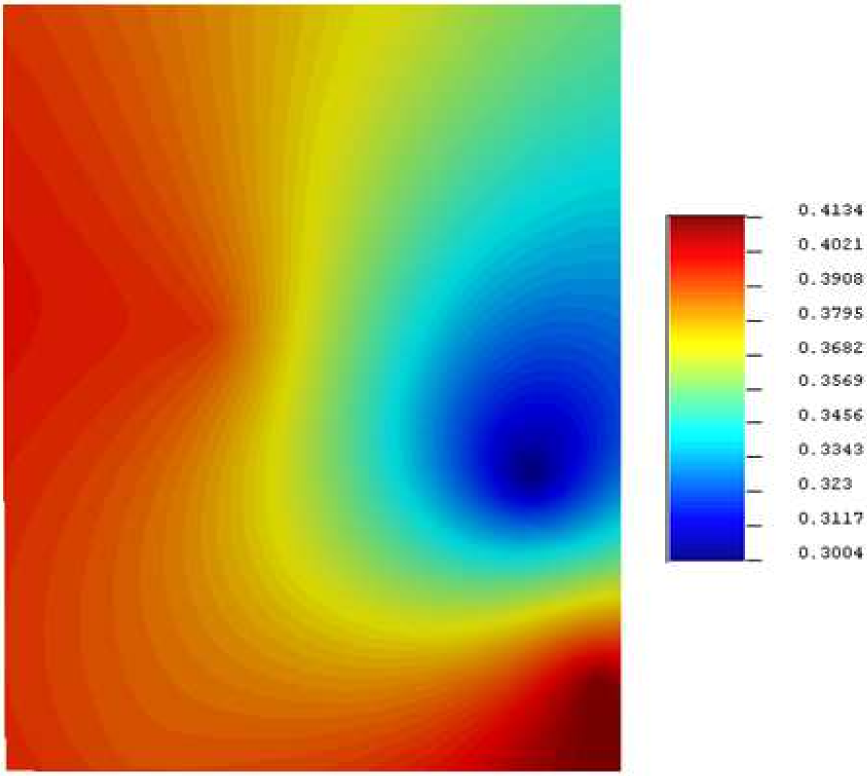

Fig. 10: Porosity distribution from density tools within the depth of about 2400m after Cokriging

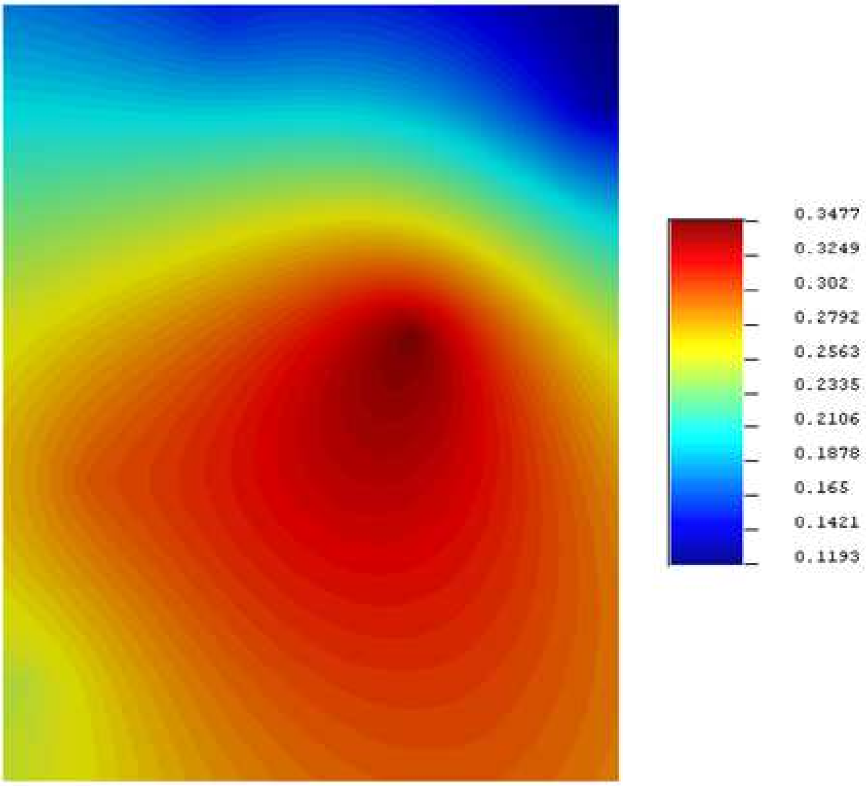

Fig. 11: Porosity distribution from sonic tools within the depth of about 2700m after Cokriging

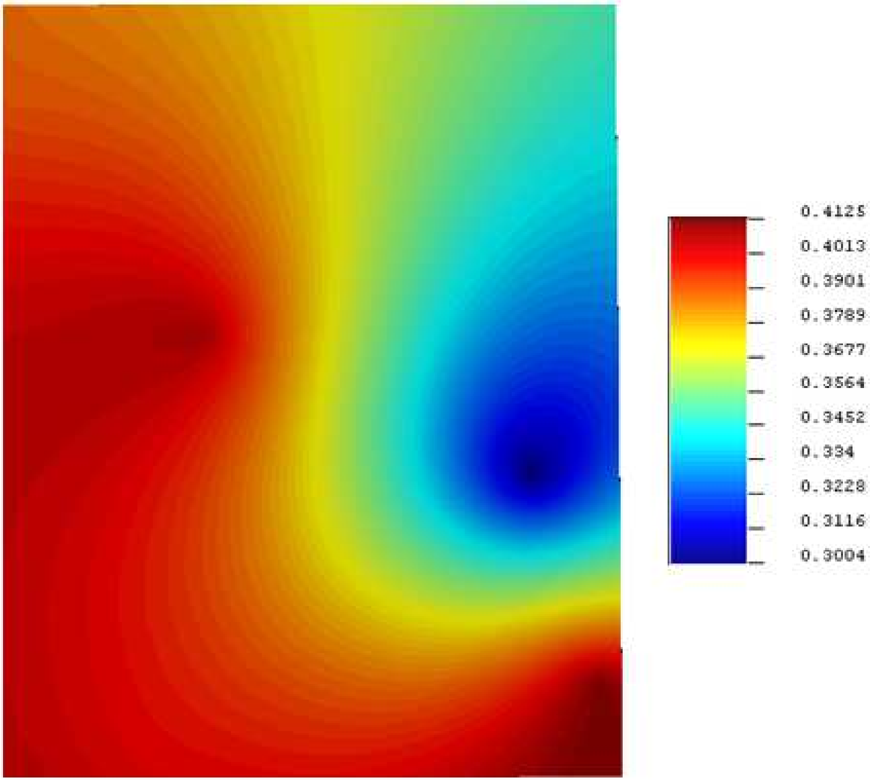

Fig. 12: Porosity distribution from density tools within the depth of about 2700m after Cokriging

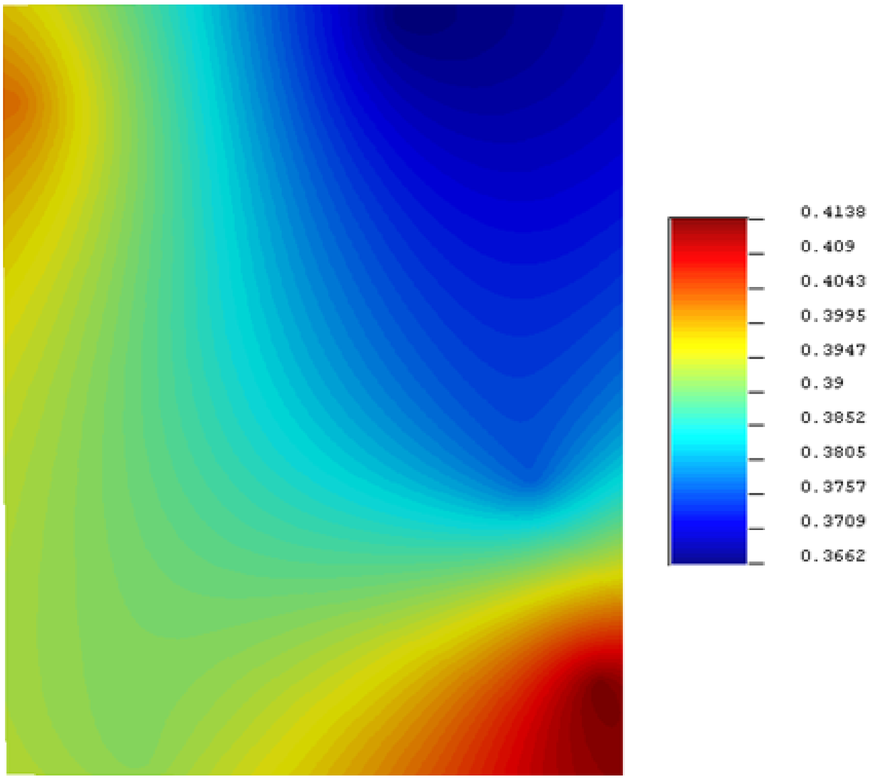

Fig. 13: Porosity distribution from sonic tools within the depth of about 2910m after Cokriging

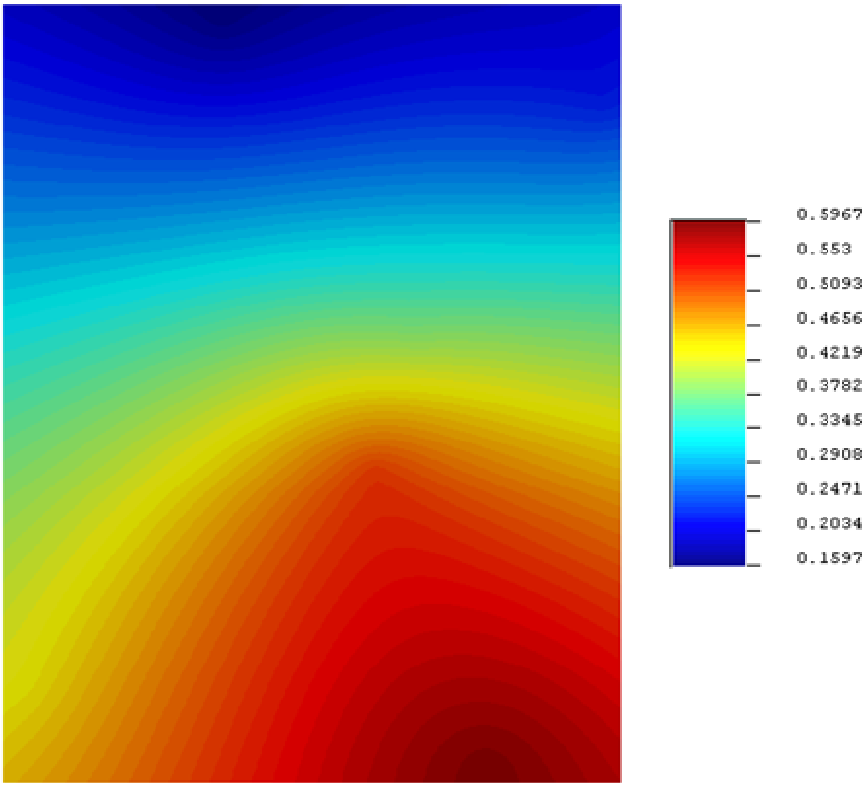

Fig. 14:Porosity distribution from sonic tools within the depth of about 2910m after Cokriging

Porosity Distribution at Depth 2400m

Figure 9, which shows the porosity distribution at the depth of about 2400m agreed with the above discussed plots however, region of excellent porosity distribution is within the north-east zone only. Fair distribution took the rest part of the map dropping to as low as 0.31, and the distribution within the north-west show less compaction and gradual changes within the region. However, rapid changes in porosity were within the north-east and a gradual change dominated zones of south-east and west which is also buttressed by the porosity plot from density tools at the same depth (Fig.10). The south-east show continues increase downward with a gradually increasing pattern, on the western region. There is a gradual porosity change ranging between fair and poor distribution towards the north and south flank respectively.

Porosity Distribution at Depth 2700m

Figures 11 and 12 show the distribution of porosity from the sonic tools and density tools at 2700m. In fig. (11) the north-east region is more compacted and possesses well developed sand, with excellent porosity distribution of value as low as 0.15 and this region maintained increasing porosity gradient eastwards and decreasing gradient westward which might be accounted to the paleocurrent. Depositional current at the north was high and low at the south during the sediment deposition and this suggests that the sediments maybe deposited during the transgressive phase if the pattern is the primary porosity trend. The plot for the density tools agreed with this suggestion though the depositional pattern suggested differs. The poor porosity zone (fig. 12) concentrated more at the east, coming down to the south.

Porosity Distribution at Depth 2910m

The last depth (2910m) plotted share similar attributes with the previous depths discussed. Figure (13) and (14) shows the distribution of porosity for sonic and density tools at depth of about 2910m. The north-east and west maintained excellent porosity distribution and fair distribution. A steadier gradient can be seen at this depth as suggested by the plots, which shows a steadier wave current along the study area at this depth. With this evidence, it can be suggested that the sediments were deposited during a regressive phase of the marine sediments. The southern region maintained high porosity at this depth

Geophysical Implication of Porosity Distribution

Every geologic formation is prone to incorporate materials (fluid) other than sediments. The sediments will however be saturated with these materials depending on the availability of the material, the volume offered by the sediments, preservative mechanisms (traps) and the orientation of the material with respect to gravity. Distribution of porosity within an area can be used to ascertain the material (fluid) migration, accumulation and existence within the area. Porosity range between 0.15 and 0.2 are excellent zone for accumulation and migration of hydrocarbon as seen within the north-east region of Figures 11, 13, 15 and 17. Sand within this region is well developed and will support an inference of hydrocarbon accumulation. Porosity between 0.3 and 0.4 are however considered fair porosity distribution. This region is shown in the figures also but more between the north and south. In this region, accumulated hydrocarbon is prone to have migrated to another region since the region is still porous after being saturated by hydrocarbon. Poorly distributed zone is shown within the southern region. Porosity in this area ranges within 0.5 and 1. The zone is too porous to suspect saturation of fluid in the sediments largely because most of the intrusive bodies for which the basin is noted for are within this region, thus there is a probability that previously accumulated fluid has migrated to another section if encountered in a reservoir.

Hydrocarbon Potential of the Study Area

Analysis of sonic and density porosities of Kinasar-1, Gaibu-1, Wadi-1, Krumta-1 and Masu-1 well using kriging and cokriging suggests that the north-east region of the study area possess porosity which tends to be favourable to hydrocarbon migration and accumulation provided other indices are present.

CONCLUSION

Well log data from five oil wells namely; Kinasar -1, Krumta -1, Gaibu -1, Masu -1 and Wadi -1 were analyzed using well log techniques to estimate the porosity and geostatistical techniques (kriging and cokriging) to analyse the porosity distribution within the same area, with a view of ascertaining region of probable porosity distribution, to help confirm the hydrocarbon potential of the study area. Sonic and density porosities were obtained for the wells and the analyzed plots suggested the North-East region of the study area to possess porosities that tend to support hydrocarbon accumulation and migration provided the other indices are present. The porosity trend suggested by the result is along the NE-SW of the basin which is the direction of major faults within the basin.

Information from the attempts made to perforate success reveal that a more quantitative approach should be applied as a method in studying the basin to enable an enhancement and exploitation of the potentials of every result yielding research in the basin.

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