REASSESSING THE HYDROCARBON POTENTIAL OF BORNU BASIN THROUGH ELECTROFACIES AND DEPOSITIONAL ENVIRONMENT ANALYSIS

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ABSTRACT

Hydrocarbon potential of the Borno Basin through electrofacies and depositional environment analysis was carried out from well log and seismic reflection data to reassess the potential of the Basin. The reflection configuration pattern from the seismic reflection lines is characterized by variation from parallel, continuous and strong amplitude to sub parallel, chaotic discontinuous and low amplitude which indicate a variation from a low energy basinal setting of uniform rate of continental deposition to high energy environment of monolithologic deposits. Furthermore, the derivable log signatures shows a variation from serrated mud/sand to serrated blocky to serrated funnel and bell shapes with depth. This implies stable massive mud/sand rich basin wide environment to an upward regressive sequence of bar deposit followed by a deltaic estuarine clastic sediment to gradual upward transgressive decrease in grain size to a fluvial point bar deposit. This environment are known to be hydrocarbon province.

INTRODUCTION

The Bornu Basin has been under geological/geophysical investigation by many geoscientists such as Nwaezeapu (1992) Ilozobhie *et al.* (2014) and Obi, *et al.* (2015), most of which is as a result of Federal Government interest in ascertaining the Hydrocarbon potential of the Basin, a follow up of the discovery of commercial quantities of Hydrocarbon in the Chad Basin of the neighboring Chad Republic that share the same geological setting with the Bornu Basin.

The Bornu Basin has shown evidences of being a hydrocarbon province such as the presence of hydrocarbon harboring features like faulted anticlines, faulted fold, multiple folds, growth faults, basement detached and basement involved faults, appreciable thickness of sediments availability of trapping mechanism etc. However, it is on record that despite the above promising features and coupled with the huge financial resources the federal government has plugged into the search for commercial quantities of hydrocarbon, the basin is still reported to be a non commercial basin. Thus the aim of this study is to carry out a lithofacies and depositional environment analysis of the basin in order to reassess its geophysical implication to the hydrocarbon prospect of the Basin

METHODOLOGY

Location of the Study Area

The study area is situated onshore and lies within the Northeast Southwest direction of the basin. It is along latitude 12^0 19^1N and 12^0 28^1N and longitude $13^0 10^1$E and 13^0 25^1E (Fig. 1). Accessibility is by road and air.

Depositional Environment

Paleo environments are ancient environmental conditions that prevailed when the rocks were formed. The characteristics behaviours of the SP and the Gamma log shapes have commonly being used to infer the environment of deposition especially where the log have not been significantly influenced by borehole and equipment conditions but the Gamma ray is preferred to the SP log because the curve gives greater variety of shapes showing greater details, more character and relatively easier to interpret. Dixon *et al* (1992) accepted it as standard technique which is useful in their interpretation of siliciclastics depositional facies in northwestern Canada. Schlumberger (1985)

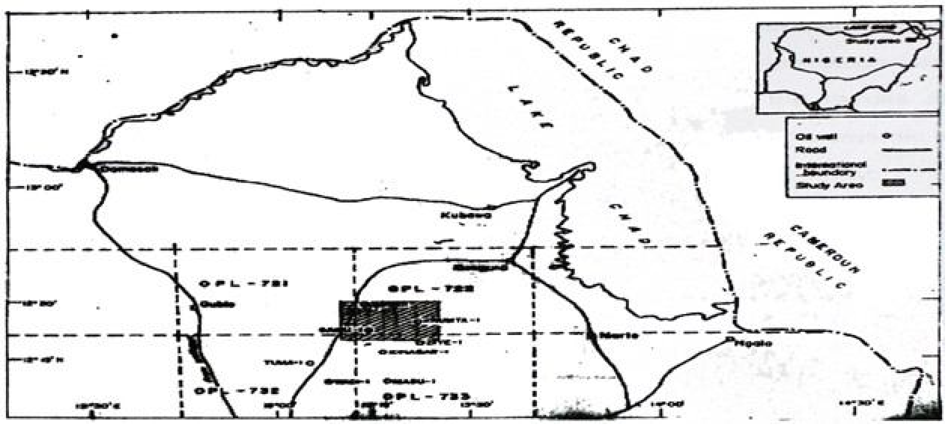

Figure 1: The location of the study area

Figure 2 illustrates typical GP log shapes found in deltaic reservoir with their associated environments. It also shows environmental reconstruction of a west Niger Delta Field using the GR log shapes. The interpretation of the GR log shapes was carried out for all the wells supplied for this research.

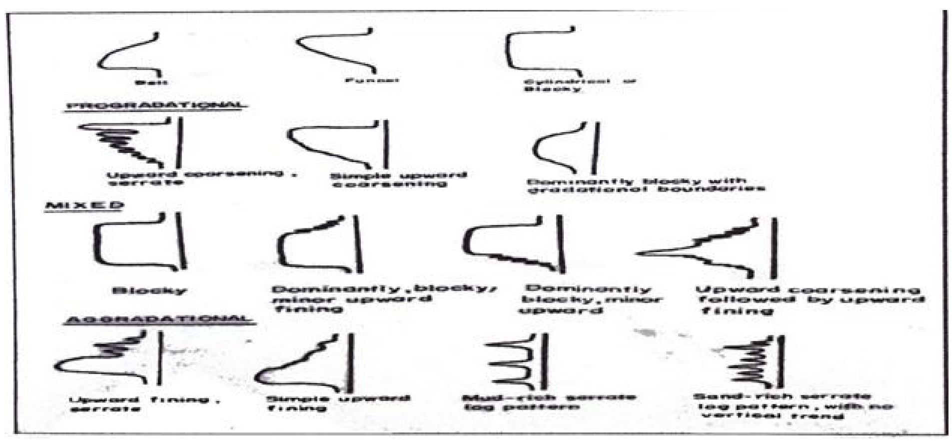

Fig. 2 Log Shape grouping (Tyler and Ambrose, 1986).

Twenty-three migrated seismic reflection lines (Fig. 3) and soft copies of six well data namely Gaibu-1, Kinasar-1, Krumta-1, Masu-1, Tuma-1 and Wadi-1 from the study area were converted to well curves using developed the Visual basic plotter manager (Ilozobhie and Obi, (2010). These were studied and analyzed with the log signatures and reading facilitated the identification of subsurface geologic formation. The distribution of the various logs and depth of survey are shown in Table 1.

Since the GR logs from all the wells exhibited almost similar character in their signature within the study area, depositional environment from well logs shape was carried out using the GR log of the wells. Dominant log shapes from the plotted well log data are the serrated-blocky/cylindrical, serrate- bell and serrate – funnel. (Rider 1986, Atlas 1987 and Ilozobhie *et al.* 2009). Seismic sequence interpretation is the sub division of the seismic section into depositional sequences. A reasonable approach to seismic sequence interpretation requires first, the identification of sequence boundaries by picking out the angular unconformities and relevant reflection termination (Cox, 1996). True Onlap have been described as the most reliable base discordant criterion while toplap is commonly used to identify the top of a sequence. For sequence boundary the boundaries picked are traced laterally into areas where they are conformable. The sequence is followed on a grid to map their outlines and thickness. Seismic facies was done by using reflection attributes such as types of reflection terminations associated with the boundary of seismic facies, configuration of the reflection pattern within the unit and external form of the shape of the unit are the three major criteria used for identifying seismic facies from the seismic data.

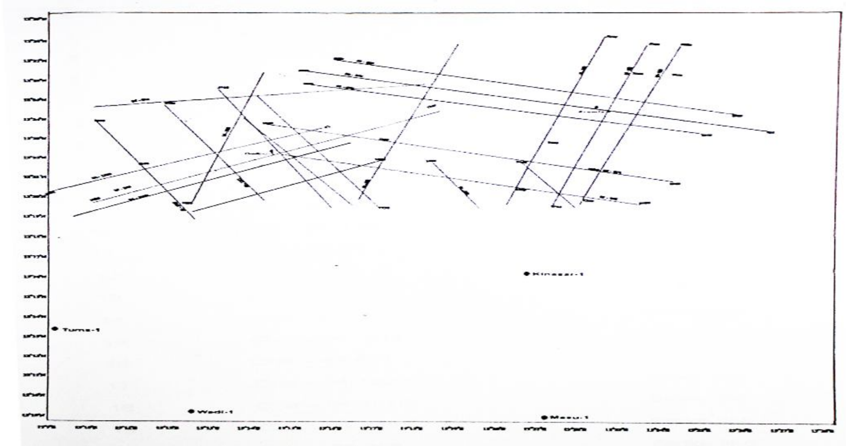

Fig.3 Situation map showing the direction of Seismic lines within the study area

RESULTS AND DISCUSSION

Figures 4 to 9 shows apparent variation in depositional environment at the time of sediments deposition. This variation clearly relates to the energy of deposition which is by extension has much significance on the mineralogy and composition of the various units within the study area. Furthermore, going by the stratigraphic interval assigned to the various depositional environments and conditions which may have prevailed at the time of the basin evolution, it is clear that the blocky shape predominantly signified massive sediment deposition in a marine basin wide setting. This could be interpreted to reflect a stable deposition in an environment with large accommodation space subordinate to this include the funnel and bell shapes with several sand lenses whose origin varies from being essentially point bars to channel fills. The observable depositional conditions deduced from the log shapes indicate rapid variations in tectonic events during deposition.

Table 1. Well location and wirelines log used for the study

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

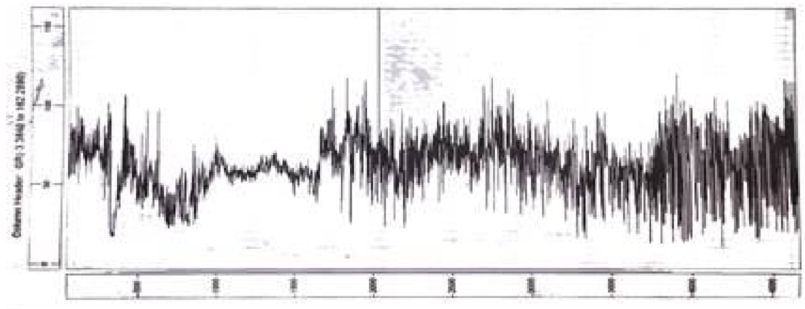

Fig. 4. Gamma Log shape of Kinasar-1

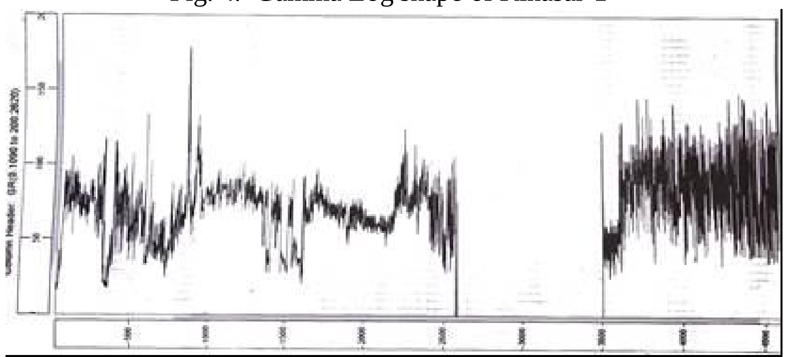

Fig. 5: Gamma Log Shape of Gaibu-1

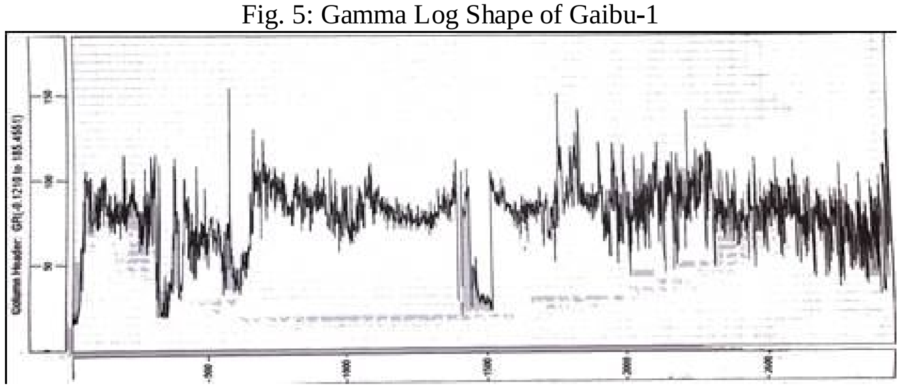

Fig. 6: Gamma Log Shape of Krumta-1

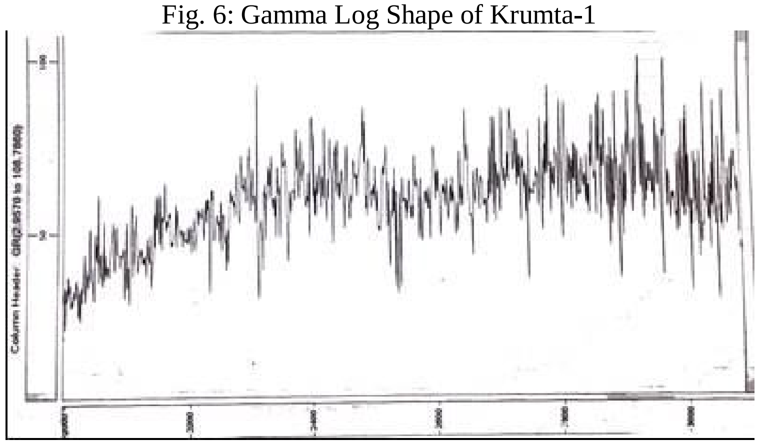

Fig. 7: Gamma Log Shape of Masu-1

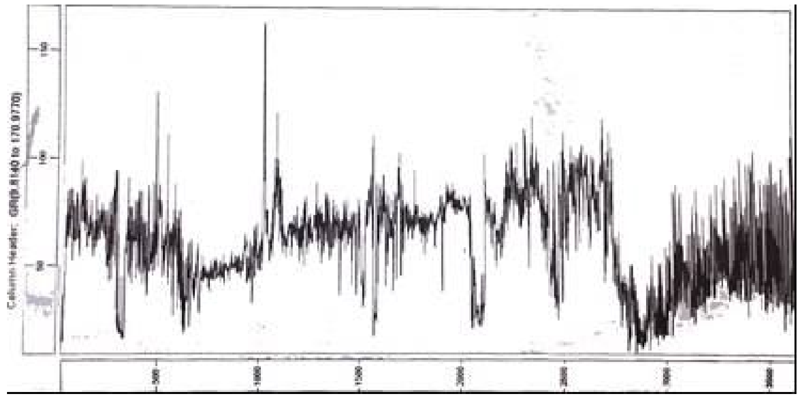

Fig. 8: Gamma Log Shape of Tuma-1

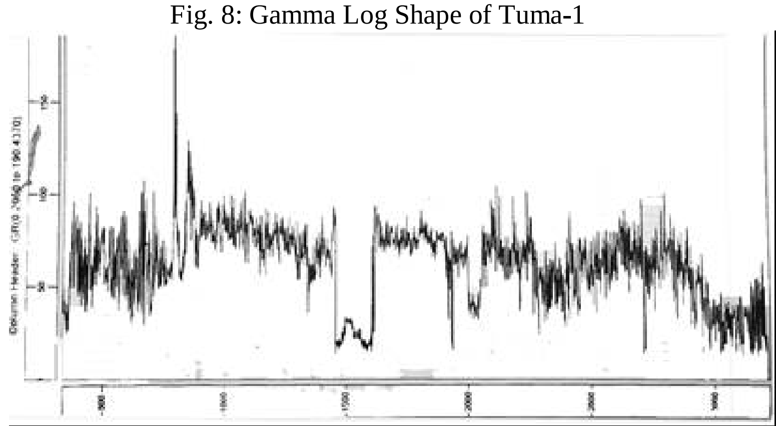

Fig. 9: Gamma Log Shape of Wadi-1

The mud rich serrate and sand rich serrate log pattern with no vertical trend from 100 – 300m depth is a clear indication of a stable massive mud rich and interbedded sand rich basin wide environment of the Chad Formation, while the progradational serrated funnel shape from 320m to 400m depicts an upward sequence such as bar deposit coarsening which may indicate a regressive sequence a likely onset into the Kerri – Kerri Formation.

The Deltaic estuarine clastic sediment of the Gombe sandstone can be seen by the dominantly blocky shape of the GR log from 450m – 825m. The intercalated sandy units of the Fika shale formation is identified by the serrated bell shape of the (825m – 945m) on the GR log from a gradual upward decrease in grain size, depicting fluvial point bar sand. From depth interval 945m to 1795m, the block serrated shape signifies a massive deposition of sediments in a marine basin wide setting. The serrated funnel (progadational) shape observed from 1795m to 1850m depth is characteristic of sandstone that coarsens upward. The marine transgressive environment of the Gongilla Formation interbedded with massive deposition of sediment is inferred from the serrated bell (aggradational) shape and few serrated blocky shape evident within a depth interval of 1850m to 2850m. The transgressive lower Gongilla prograding marine (mainly shales) is indicated by the Bell shape (2850m – 3250m) showing an upward coarsening sequence indicating a deltaic or shallow marine progadation.

The Bima sandstone of the basin which represents the basal units directly overlying the basement complex is a regressive sandstone unit recognized by the alternating serrated bell shape with minor blocky serrated shape of the GR log shape from 3250m – 4650m.

Electrofacies Analysis

Chad Formation

Electric log analyzed over this formation shows that this formation consists primarily of shale with minor massive sand deposit. It extends from 100m to 450m. This unit shows relatively constant values on the caliper, Gamma ray, Deep induction (ILD) and sonic logs from 100m to 320m and within the interval of 320m to 450m is an identified permeable sand zone with high Caliper log value Deep Induction (ILD) recorded values are relatively high. The GR log generally gave very low values.

Kerri - Kerri Formation

The Kerri - Kerri Formation range from 450m to 620m. It is characterized by intercalation of the shale and sand bodies. There is a gradual increase in GR Log value throughout the formation with relatively constant values from deep induction resistivity and sonic logs

Gombe Sandstone

As a transitional sequence underlying the Kerri Kerri Formation, it has a depth range of 625m to 865m. There is gradual build up in the sand content of this formation from 625m to 735m, 740m to 820m and 825m to 865m. Generally, there is gradual decrease in the GR ray log values until just towards the end of the formation where an abrupt increase in the measured GR log values becomes apparent. However, the ILD log values steady increase in values at the shallower section but toward the end there is also a sharp decrease in value on the contrary the sonic log show opposite signature character

Fika Shale

Deductions from the electric logs show that this formation consists primarily of shales with minor limestone and subordinate amount of intercalated sand extending from 865m to 1795m. The Fika shale member from 865m to 1250m is 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

Gongila Formation

The Gongila Formation is about 2455m thick ranging from a depth value of 1850m to 3250m. It is made up of shale bedded sandstones and alternating sandy mudstone. For the purpose of this study, this formation is divided into an Upper and Lower Gongila member. The Upper Gongila range from 1850m to 2510m and is identified based on the following log properties; gradual decreasing Gamma ray log values, relatively increase in resistivity values and low sonic travel. The Caliper log shows permeable zone with clear separation to the right of its signature from that of the GR log from 1850m to 2400m while from 2400m to 2485m the log is on gauge indicating the bit size to be same as the hole diameter. Generally, the above properties indicate a sequence of sandstone bed with shales intercalation. The Lower Gongila ranges from 2510m to 3250m depth. This zone shows averagely low gamma rag values with few permeable zones as indicated by the Caliper log. The resistivity log shows increasing values toward the end of this zone with the sonic travel time also reading very low values toward the end of the zone. This may indicate the clean sandstone beds. The Caliper is on gauge within the following depth ranges 2700m to 2830m and 3025m to 3060m, considered to be composed of tight siltstones.

Bima Sandstone

It ranges between 3250m to 4650m. It consists of Bima and Pre Bima Sandstone. The depth range of 3250m to 3300m show high values on the resistivity logs, low Gamma ray and sonic travel time values. The permeable tendency of this zone is shown by the high Caliper log reading. The depth of 3300m to 3500m shows alternatively low and high values of Gamma ray while the resistivity log maintain a gradual decline in value alongside an increasing trend in the sonic travel time value. Within this region, the Caliper log show deflection to the left of the gamma ray signature (3405m to 3495m) indicating small borehole diameter. The separation between the gamma and Caliper log is still showing a porous and permeable sandy.

Between 3500m to 4410m depths, there is a progressive increase in resistivity value, accompanied with gradual decrease in both sonic travel time and Gamma ray values. This area indicates porous and permeable zones. However, between 4410m to 4585m, there is a marked decrease in resistivity value. On the other hand, whereas the sonic travel time curve indicates constant low log values, there is an inconsistency in the measured Gamma ray log values which tend towards a defined low decreasing trend on the log. This zone is also permeable and porous sandstone.

Seismic Sequence Analysis
Six sequences were mapped within the study area (Fig.10)

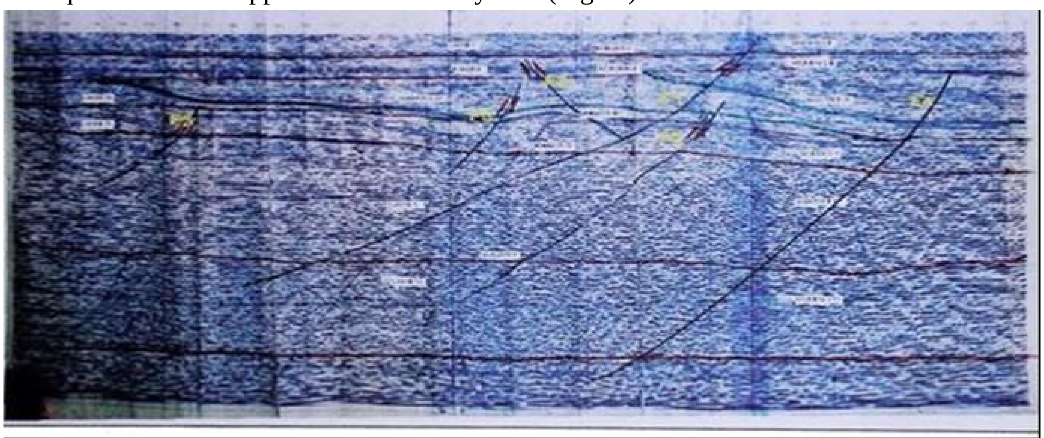

Fig.10 A Dip line from the study area showing six mapped sequences

Sequence I
This displays a sequence of parallel beds with a characteristic sigmoidal to oblique to parallel reflection pattern. This sequence correspond to 234m depth and composed of low density clayey material having an internal velocity of 1542m/s. The sequence is not folded but one major fault cut across it. The unit is interpreted as a typical condensed section as shown from both log and seismic reflection data. It is correlated with the top of the Chad Formation of the study area. The parallel configuration of reflection within the sequence indicates a uniform rate of deposition on a subsiding shelf or stable basin plain in a low energy basinal setting.

Sequence II
The reflection patterns is characterized by parallel and sub parallel but fairly discontinuous, high amplitude reflections attributed to uniform rate of deposition and high energy environment such as upper shore face, estuarine, fluvial or even Aeolian environment (Adeigbe and Salufu, 2009, Onu, 2017). Its stratigraphic interval lies between 234m to 610m depth (376m in thickness) and velocity of about 1725m/s. This reflection attributes combined with velocity information reveal a deposition of continental sediments composed mainly of sand and clay in a uniform environment. This sequence has been correlated to be part of the Kerri Kerri Formation with the Chad Formation.

Sequence III
This sequence top boundary is marked by angular unconformity with the overlying beds while the lower boundary is conformable surface with underlying sequence. The thickness of the sequence is 1768m. The lithologic characteristic of the binding sequence is mainly of sandy

composition with and velocity ranging between 1790m/s and 2480m/s. The sequence is greatly disrupted by Faulting and Folding. Few sub- depositional packages lacking inlateral extent (due probably to erosion or other geological processes) and which pinches out against the uppermost boundary of this unit are apparent.The sequence is characterized by continous, parallel, high-amplitude reflections pattern suggesting extensive deposition of sediments with highly contrasting acoustic impedance in a low stand system tract with infrequent lateral variation in facies in a relatively quiet basin condition. This feature likely confirmed the sequence to be Kerri – Kerri formation and part of the Gombe Sandstone. Located within this sequence is sub sequence IIIb

Sequence IV

Sequence IV is marked by discontinuous reflection with minor continous reflections starting with a continous, parallel, relatively high amplitude reflection pattern that grades to low amplitude, low continuity and reflectively chaotic reflection pattern. This shows a graduation from low high energy deposits to a monolithologic unit deposited in an environment of uniform energy. It has an approximate thickness of 1768m with velocity between 1790m/s to 2603m/s. This sequence grades from the marine shale of the Fika Shale Formation into the topmost part of the Gongila formation evident from the low continuity low chaotic reflection attributes as seen at the lower part of the sequence boundary

Sequence V

The thickness of this sequence is about 3088m with velocity between 2185m/s to 3153m/s. The top of this sequence is bounded by partly continous, high amplitude reflection and the latter part by discontinuous reflection pattern at an approximate reflection time of 1.5sec (Fig.10). The bottom boundary part is marked by partly concordant surface and disconcordant, while the central part shows a reflection pattern that is highly chaotic (likely indicating intrusive presence) and the extreme ends is continuous, alternating low and high amplitude reflection pattern. This is correlatable to the part of the Gongila Formation to Bima Formation.

Sequence VI

The sequence lies directly over the basement with its lower boundary defining an unconformity surface at 5.1sec (12750m depth) and has concordant upper boundaries of high amplitude and high continuity at the beginning and end. The central part of the sequence is grossly marked by chaotic reflection pattern indicating high energy setting. The seismic facies pattern suggests a fluvial environment of deposition. The sequence with all these characteristics conforms to the documented information on the Bima sandstone

CONCLUSION

Reassessing the hydrocarbon potential of Bornu Basin was done using the electrofacies and depositional concept derivable from seismic and well log data was done. The sequence analysis revealed six sequences whose boundary were demarcated using the acceptable reflection configuration of Onlap, Toplap, and Angular Unconformity while the reflection pattern from the shallower depth (0.3 – 2.0 sec) is characterized by configurations of parallel and sigmoid-oblique types which are of high to moderate amplitude and good continuity reflection with discontinuous reflection at some point. The deeper portion (2.0 – 5.0sec) consists basically of parallel continous, moderate amplitude to sub-parallel, chaotic discontinuous and low amplitude which indicates a variation from a low energy basinal setting of uniform rate of continental deposits to high energy environment of monolithologic deposits. The GR log signature of the wells vary from serrated mud/sand rich log pattern with no vertical trend to serrated blocky shape, serrated funnel and bell shapes. This analysis shows deposition on a stable massive mud/sand rich basinwide environment to an upward regressive sequence of bar deposit followed by deltaic estuarine clastic sediments to a gradual upward transgressive decrease in grain size to a fluvial point bar deposit. This depositional and elecrofacies analysis greatly confirmed the area to be a hydrocarbon province.

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