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Foraminiferal Stratigraphy and Paleoecological Interpretation of Sediments Penetrated by Kolmani River -1 Well, Gongola Basin, Nigeria

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Abstract Foraminiferal investigation of the Kolmani River -1 well yielded a total of forty two (42) species. The foraminiferal assemblages comprise 86% arenaceous benthonics, 4% calcareous benthonics and 8% planktonic foraminifera. Few ostracod and gastropods shells were recovered and they make up the remaining 2% of the assemblages. Quantitative and qualitative analyses of the recovered foraminifers were used to interpret the age, paleoecology, paleobathymetry and paleoenvironment of the sediments penetrated by the well. Three foramineferal assemblage zones consisting of Agathamina sp.2, Haplophragmoides bauchensis and Heterohelix moremani-Haplophragmoides talokensis Assemblage Zones were identified in the drilled interval of Kolmani River -1 Well. These zones are dated Campanian-early Santonian, early Coniacian-early Turonian and early Turonian-late Cenomanian respectively. The paleobathymetry ranges from Inner to Outer neritic suggesting water depths of less than 200 m. The overall depositional environments varies between coastal plain/estuarine to open marine setting. The dominance of agglutinated foraminiferal species such as Ammobaculites sp, Haplophragmoides sp, Miliammina sp and Trochamina sp suggest restricted, low oxygen bottom water conditions for most of the paleoenvironments.

Keywords: *foraminifera, arenaceous, benthonic, planktonic, palaeobathymetry, neritic, estuarine, open marine*

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1. Introduction

The sediments used for this study were obtained from the Kolmani River -1well (interval 900 ft-9140 ft). The well was drilled by Shell Nigeria Exploration and Production Company (SNEPCo) as part of their oil exploration programme in Inland basins of Nigeria. Kolmani River 1 Well was drilled in the Gongola Basin, northern Benue Trough, Nigeria on Latitude 10°07'03.9" N and Longitude 10°42' 43.8"E in the present Gombe State of Nigeria. The lithology is dominated by shale (2700 ft – 8000 ft); sandstone (900ft - 2100 ft; 8200 ft - 8600 ft and 9000 ft - 9140 ft); and siltstone (8400 ft - 8800 ft). The shales are generally grey in colour, fissile, and laminated; and are composed of dominant clay minerals, micas, calcite, pyrite and carbonaceous materials. Coal occurs at the depth of 3300 ft and within interval 7200 ft - 7800 ft. Few papers have been published on the foraminiferal biostratigraphy of the northern Benue Trough (Petters, 1979, 1980, 1982, 1983; Obaje, 1994; Obaje et al, 2000, Sani, 1999; Abubakar and Obaje, 2000). These studies were based on the surface outcrop samples. The obvious limitations of using outcrop samples which can only collected where the rocks are exposed and are prone to weathering results in poor recovery of forms, low confidence data and very poor time/stratigraphic resolution.

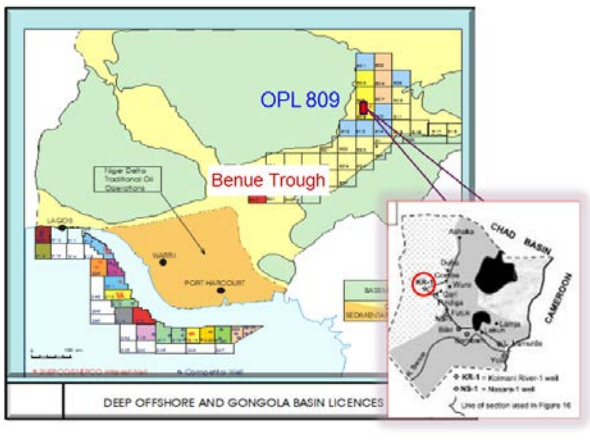

Figure 1. Geological Map of Nigeria showing the Gongola basin and Kolmani River-1 Well (modified from www.indigopool.com/nigeria/channel)

In this study, well samples have been used to enhance better and systemic analysis of the foraminiferal contents in the samples for a more coherent data for higher resolution stratigraphic interpretation. The result of the analysis will be used to evaluate the age, paleobathymetry and paleoenvironments of deposition of sediments within the Gongola Basin.

2. Geological Setting and Stratigraphy

The Benue Trough is an intracratonic Cretaceous Basin, underlying a large part of Nigeria and extending in the Southwest - Northeast direction for about 1,000 km in length from the Bight of Biafra to Lake Chad, and overlying the Precambrian Basement Complex of the West African Mobile belt. Its structural origin is related to the opening of the South Atlantic Ocean (Benkhelil, 1989) and is part of series of Cretaceous rift basins that formed the West and Central African Rift System (WCARS) (Guiraud and Maurin, 1992). The Trough contains as much as 6000 m (20,000 ft) of Cretaceous –Tertiary sediments of which those predating the middle Santonian have been compressionally deformed, faulted, and uplifted in several places. Compressional folding during the middle Santonian tectonic episode affected the whole of the Benue Trough and was quite intense, producing more than 100 anticlines and synclines (Benkhelil, 1989). The Benue Trough is geographically sub-divided into lower, middle and upper Benue Trough (Petter, 1982). The Upper Benue Trough is further sub-divided into three basins: the east–west trending Yola Basin (Yola Arm), the north – south trending Gongola Basin (Gongola Arm) and the northeast– southwest trending Lau Basin (Guiraud, 1990; Dike, 2002).

Sedimentation in the Gongola basin began with the deposition of the continental Bima Sandstone which unconformably overlies the Precambrian Basement Complex. The Bima Sandstone was derived from the granitic Basement Complex. It consists of feldspathic sandstones and clays which pass upwards into coarse to medium grained sandstones with less feldspar. Guiraud (1990) subdivided the sandstone into three members namely; the Upper Bima (B_3), the Middle Bima (B_2) and the Lower Bima (B_1). Allix *et al.* (1981) using palynological data from outcropping layers of the Bima Sandstone dated the formation as Late Aptian - Early Abian. The Bima is conformably overlain by Yolde Formation consisting of a variable sequence of sandstones and shales. The sandstones are thin-bedded at the base, followed subsequently by alternations of sandy mudstones and shelly limestone (Whiteman, 1982). The Pindiga Formation which is dominantly marine shale with limestone at the base overlies the Yolde Formation. The formation is believed to be deposited under marine conditions that prevailed during the early – late Turonian and Coniacian times in the northern Benue Trough. The Gongila and the Fika Formations are the lateral equivalents of the Pindiga Formation (Zarborski et al., 1997). The Pindiga Formation is overlain by the Gombe Formation. The Gombe Formation is made up of three major lithofacies: (1) alternating beds of silty shales and fine-medium grained sandstones with ironstone intercalations, overlain by (2) medium grained quartz arenites with occasional and iron oxide cement. The third lithofacies is a brick-red coloured, fine - medium grained sandstone, with tabular cross-bedding, highlighted by layers and streaks of pure white sandstones (Zarboski et al., 1997). The youngest formation in the Gongola basin is the Kerri-Kerri Formation. It is represented by the gently dipping continental conglomerates, sandstones, siltstones and clays which overstep the Gombe Formation onto older Formations. Due to the faulted and folded nature of Gombe Formation, the continental clastics of the Kerri-Kerri Formation reaches a thickness of over 320 meters though variable thicknesses occur in the eastern margin of the basin due to irregular tectonic features and small inliers. Adegoke et al. (1979) assigned Paleocene age to the Formation using pollen data. The stratigraphic succession of the northern Benue Trough is shown in Table 1 below.

Table 1. Lithostratigraphic subdivision of Gongola Basin, Northern Benue Trough. (Modified from Obaje, 2003)

AGE		FORMATION	LITHOLOGY	EOD
Tertiary	Maast.-Paleoc.	KERRI-KERRI FM.	Conglo	Continental
Upper Cret.	Camp.-Early Santonian	GOMBE FM.	Sandstone-Shale Siltstone-Lignite	Deltaic-Open Marine
		PINDIGA FM.	Black Shales-Limestones	
	Coniacian-Cenom	YOLDE FM.	Shale-Sandstones	Shallow Marine
Lower Cret.	Albian	BIMA FM.	Sandstone	Continental

3. Materials and Methods

3.1. Sedimentological Description

Sedimentological description of the samples using the petrologic microscope was done. The composition (sand-silt-shale percentages and environmentally sensitive minerals and accessory present), texture (grain size, sorting and roundness), fossil fragments and colour were described. A graphic log of lithologic, compositional and textural data was produced using the SEDLOG Graphic Software. Based on these, the lithofacies and depositional environment were interpreted for the drilled section was interpreted.

3.2. Foraminiferal Preparation and Analysis

50 grams of each sample was taken in a pre-washed and labeled aluminum bowl. The bowl containing each sample from a particular depth/ interval was labeled for identification and placed on the electric hot plates. They were allowed to stand on the hot plate for an hour. The hot samples were transferred to a fume cupboard using a long tug and clean water was added to completely cover the samples in the bowl. The samples were soaked in ordinary water for four days, to enable the clays to break down sufficiently for complete disaggregation.

The soaked samples were washed, using a 43µ microns sieve in a running sink until the water coming out of the sieve was clean. The clean residue retained in the sieves were transferred back to the aluminum bowl and dried on the hot plate. The drying was carefully supervised to avoid over-heating of the samples. The dried samples were sieved and separated into three fractions, the fine (63 microns + dust below), the medium (125 microns) and the coarse (250 microns). These were transferred into phials. WIRD HEEBRUGG binocular (reflecting) microscope (50 x magnifications) was used for picking and analysis of the recovered foraminifera. The dried samples were sparingly scattered on the picking tray and scanned through under the microscope. Recognizable forams were picked with a picking pin and dropped into forams (Card) slides. The picked forams were sorted into identical forms which were gummed onto the slides and eventually covered with a cover slip for analysis. The analysis was done by sorting the recognised forms into different foraminiferal groups (Benthonic, Calcarous and Planktonic) and sizes, then genera and species. The identification and analysis of the picked foraminifera was done with the aid of relevant publications such as Petters (1982), Holger Gebhardt. (2004) and Shell Petroleum Development Company (SPDC) Forams training slides.

4. Results.

4.1. Lithofacies Sequence

Sedimentological analysis shows that the sequence comprise sand, shale, siltstone and sandy mudstone with intercalations of carbonates and coal at some intervals. The sandstones vary in grain size from fine- through medium to very coarse sands. The grains are angular to rounded and well to moderately sorted. The shales and mudstones are grey to dark grey in colour. They present blocky fissility with very thin silty/sandy lamination at various intervals. Coal fragments were noted in the upper intervals. The environmentally sensitive minerals and accessory present include pyrite, mica, carbonaceous fragments, ferruginous materials and shell fragments. Result of the sedimentological description is summarized in Figure 2.

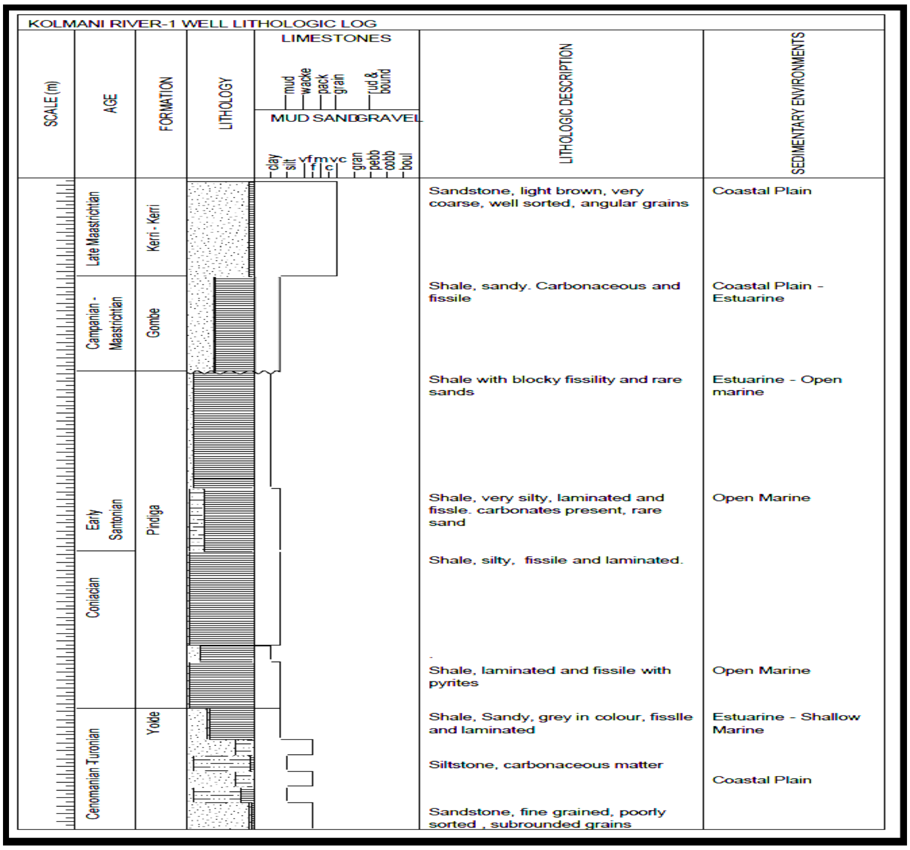

Figure 2. Lithofacies and Depositional Environment in Kolmani River 1 Sequence

4.2. Foraminiferal Results

The results of the foraminiferal analysis show relatively high abundance and low diversity of species. The assemblage is dominated by agglutinated benthonic forams, consisting more than twenty six (26) species. There are about eight (8) species of calcarous benthonics and planktonics forams each. Some of the forms are highly degraded due to a combination of possible factors which include sub-optimal storage conditions and salinity crisis that prevailed during the Cretaceous. The species recovered include; *Agathamina* sp.2, *Ammobaculites* spp, *Ammoscalaria pseudospiralis*, *Ammobaculites bauchensis*, *Ammobaculites pindigensis*, *Ammobaculites jessensis*, *Ammobaculites coprolithiformis*, *Ammobaculites* sp. 2A, *Ammobaculites compressa*, *Ammobaculites numahensis*, *Ammobaculites exiguus*, *Ammobaculites fragmentarius*, *Ammotium spp.*, *Cyclammina* sp.3, *Haplophragmoides pindigensis*, *Haplophragmoides talokoensis*, *Haplophragmoides* spp., *Haplophragmoides bauchensis*, *Miliammina telemaquensis*, *Miliammina* spp., *Miliammina petila*, *Miliammina pindigensis*, *Miliamina petila*, *Reophax spp.*, *Reophax minuta*, *Reophax guineana*, *Trochamina afikpoensis*, *Textularina spp.*, *Trochamina* spp., *Bolivina* sp.4, *Cristellaria* sp.13, *Egerella scabra*, *Gyroidina soldaii giradana Pseudobolivina varianta*, *Praebulimina exigua*, *Valvulineria* sp.8, *Planktonic spp.*, *Globigerinelloides* spp., *Hedbergella* spp., *Heterohelix Globulosa*, *Heterohelix moremani*, *Heterohelix reussi*, *Ostracoda* and *Gastropoda*. Figure 3 shows some of the forms recovered while the distribution of the species is presented on the distribution chart (Table 2).

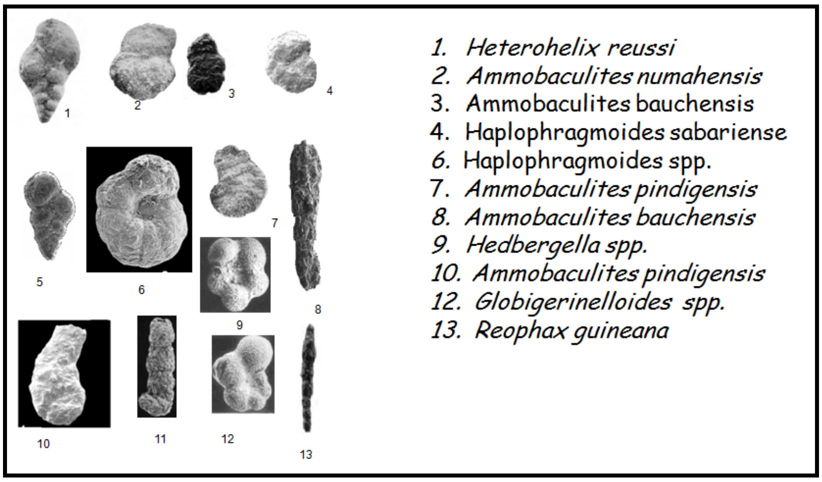

Figure 3. Some of the Foraminifera Species identified in the Well

Table 2. Foraminiferal distribution chart for Kolmani River 1 Well

FORAMINIFERAL DISTRIBUTION CHART FOR KOLMANI RIVER -1

DEPTH	LITHOLOGY	SAMPLE	CALCAREOUS FORAM: *Bolivina sp.4 (SPDC)*	*Egerella scabra*	*Pseudobolivina variante*	*Cristellaria sp.13 (SPDC)*	*Valvulinaria Sp.8 (SPDC)*	*Gyroidina soldaii giradana*	*Nonion sp.2 (SPDC)*	*Praebulimina exigua*
3960	SHALE	CU	1	1	1					
4380		CU			1					
4800		CU								
4980		CU								
5400		CU								
5600		CU								
5810		CU								
6000		CU					1			
6200		CU						1		
6400		CU								
6600		CU								
6800		CU								
7000		CU								
7200		CU								
7400		CU				2			1	
7600		CU								
7800		CU								
8000		CU								
8800	SILT	CU								
9000	SST	CU								
9100		CU								
9140		CU								1

DEPTH	ARENACEOUS FORAM: *Ammobaculites bauchensis*	*Ammobaculites spp.*	*Ammoscalaria pseudospiralis*	*Miliammina polita*	*Agathamina sp.2 (SPDC)*	*Ammobaculites coprolithiformis*	*Ammobaculites jessensis*	*Reophax guineana*	*Textularia spp.*	*Ammobaculites sp.2A (SPDC)*	*Reophax minuta*	*Ammobaculites exiguus*	*Ammobaculites pindigensis*
3960	3	7	1	2									
4380	50	5			5	2	12	7	3				
4800	8							1	5	20	1		
4980	3	40	1	5				10	2		4	1	1
5400		26	1										
5600		48											
5810		15											
6000	42					5			2		2		
6200	5												
6400	9												
6600	17	2											5
6800													11
7000													
7200		6											
7400	6	22											
7600						1							
7800		1											
8000	10	7											
8800		86											
9000		2			3								
9100		6											
9140		1											

DEPTH	*Ammotium spp.*	*Haplophragmoides bauchensis*	*Haplophragmoides pindigensis*	*Trochamina afikpoensis*	*Ammobaculites compressa*	*Miliammina spp.*	*Reophax spp.*	*Ammobaculites numahensis*	*Miliammina telemaquensis*	*Trochamina spp.*	*Ammobaculites fragmentarius*	*Haplhragmoides talokesis*	*Haplophragmoides spp.*
3960													25
4380													
4800													12
4980	1	82	10	16									
5400				4	2	2	8						12
5600													56
5810													67
6000								5					12
6200													
6400		16											32
6600						6			9	24			12
6800								12					67
7000			13										3
7200													4
7400			2					1			3		17
7600								3				59	
7800													6
8000													
8800													
9000	5												
9100													
9140													

DEPTH	PLANKTONIC FORAM: *Globogerinoides spp.*	*Hedbegella spp*	*Heterohelix globulosa*	*Heterohelix reussi*	*Guembelitria spp.*	*Planktonic spp.*	*Guembelitria sp.2*	*Heterohelix moremani*	*Gastropods (9160)*	*Ostracoda (8990)*	FORAM DIVERSITY	TOTAL ABUNDANCE	BIO - FACIES	PALEOBATHYMETRY	FORAM. ZONES	DEPTH
3960											8	42	MN-ON	MN-ON	AGATHAMINA	3960
4380	25	30				47					11	206	ON			4380
4800						1					7	56	MN-ON			4800
4980											13	288	ON		Haplophragmoides bauchensis	4980
5400											7	264	MN-ON			5400
5600											2	109	IN-MN	IN-MN		5600
5810											2	83	IN-MN			5810
6000											7	69	MN-ON			6000
6200			1	2			3				5	20	IN - MN			6200
6400											3	59	IN-MN			6400
6600											7	77	MN-ON			6600
6800											3	93	MN-ON	MN-ON	Heterohelix moremani- Haplophragmoides talokensis	6800
7000											2	17	IN	INNER NERITIC		7000
7200											2	11	IN			7200
7400											8	55	IN			7400
7600											3	63	IN			7600
7800											2	12	IN			7800
8000											2	17	IN			8000
8800											1	93	IN			8800
9000				1	2			2			6	7	IN			9000
9100							1				3	7	IN			9100
9140							1	2			3	3	IN			9140

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4.3. Interpretation and Discussion

4.3.1. Age dating and Zonations

Three Assemblage Zones have been interpreted for Kolmani River-1. They are *Agathamina* sp.2 Assemblage Zone, *Haplophragmoides bauchensis* Assemblage Zone and Heterohelix *moremani-Haplophragmoides talokensis* Assemblage Zone.

***Agathamina*-2 Assemblage Zone**

Interval: 3960 ft-4800 ft

Age: Campanian - Early Santonian

This zone is characterized by the occurrence of *Bolivina* sp.4, *Eggerella scabra*, *Pseudobolivina variant*, *Agathamina* sp.2 and a very high abundance of planktonic species including *Hedbergella* spp., *Globigerinelloides* spp. and planktonic spp. *Agathamina* sp.2 is restricted to this zone. Its co-occurrence with other species listed above has proved useful in dating this interval as late Campanian. Some of the forams species such as *Ammobaculites coprolithiformis*, *Ammobaculites bauchensis* and *Pseudobolivina variant* were used by Petters (1982) to date sediments in the Anambra Basin and the Upper Benue Trough as Campanian-Turonian. *Agathamina* sp.2 was first described by Shell Petroleum Development Corporation (SPDC) biostratigraphers and was used to date F1200 (SPDC foram zonation) as Cretaceous. The choice to name this zone after this foram species arose from its restricted occurrence within this zone.

Gebhardt (1998) also described *Ammobaculites coprolithiformis* and *Bolivina* sp.4 in the Anambra Basin and gave their age as Campanian -Maastrichtian. This zone corresponds to the palynozone of the *Longapertites marginatus* Assemblage Zone, and therefore corroborates the late Campanian age for this interval.

Haplophragmoides bauchensis Assemblage zone.

INTERVAL: 7980 ft-6600 ft.

Age: Coniacian-Early Turonian.

This zone is marked by First Occurrence (FO) and acme event of Haplophragmoides bauchensis. The zone is also characterised by the presence of Heterohelix globulosa, Valvulineria sp.8, Gyroidina solaii giradana, Haplophragmoides pindigensis, Trochamina afikpoensis, Ammobaculites compressa and Reophax spp. This interval is dated Early Santonian - Late Turonian based on the occurrence of Haplophragmoides bauchensis and Haplophragmoides pindigensis. These species were initially reported by Petters (1980; 1982) in the Northern Benue Trough. He assigned an early Santonian – late Turonian age to the sections containing these forms.

Heterohelix moremani- Haplophragmoides talokensis Assemblage Zone.

Interval: 6800 ft-9140 ft.

Age: Early Turonian- Late Cenomanian.

This zone is characterized by the occurrence of Heterohelix moremani, Haplophragmoides talokensis, Miliammina petila, M. telemaquensis, Ammobaculites numahensis, LDO of Ammobaculites pindigensis, Heterohelix reussi, Guembelitra sp.2 and Praebulimina exigua. An Early Turonian - Late Cenomanian age is suggested for this interval due to the occurrence of Heterohelix moremani, Miliammina telemaquensis, Heterohelix reussi and Ammobaculites numahensis. These species were used to date the Nkalagu Formation as Turonian - Early Cenomanian by Gebhardt (2004) and sediment of northeast sedimentary basins by Petters (1980, 1982).

4.3.2. Palobathymetry

Interval: 3960-5400 ft Middle - Outer Neritic (MN-ON)

This interval has been interpreted as middle – outer neritic based on the maximum occurrence of planktonic forams. The total planktonic foraminiferal count is one hundred and seventeen (117) and a diversity ranging between one and eleven (Table 2 and Table 3). The abundance of planktonic forams increases with increase in water depth (Brasier, 1980). Well-developed and large-sized arenaceous benthic forams such as *Haplophragmoides, Trochamina,* and *Ammobaculites* species are common. These species suggest inner Neritic – Bathyal depths. The sizes and abundances reduce with shallower bathymetry. Abubakar (2011) reported *Haplophragmoides, Bolivina* and *Nonionella* species in the outer neritic - upper bathyal environments in the same Gongola Basin. He also noted that the dominance of the agglutinated (aranaceous) taxa within the section analyzed signifies episodic fluctuations in the development of oxygen minimum zone in the outer shelf. Table 3 shows the foraminiferal abundance and diversity in numbers while the distribution chart (Table 2) shows the forams/taxa distribution.

Table 3. Paleobathymetric checklist for the Kolmani River-1

Depth	LITHOLOGY	Sample type	Total For am Abundance	Total Foram Diversity	Total Planktic Aburadanoe	Total Planktic Diversity	Total Benthic Calcareous Abund	Total Benthic Calca reous Diversity	Total Benthic Arenaceous Abund.	Total Benthic Arenaceous Diversity	Miscella neous		Paleo Bathymetry
3960	SHALE	CU	42	9	0		3	3	36	5	3	MN-ON	MIN-ON
4380		CU	206	11	117	3	1	1	88	8	0	ON	
4800		CU	56	7	1	1	0	0	55	6	0	MN-ON	
4980		CU	288	18	0	0	0	0	288	18	0	ON	
5400		CU	264	8	0	0	0	0	264	8	0	MN-ON	
5600		CU	109	2	0	0	0	0	109	2	0	IN-MIN	IN-MIN
5810		CU	83	3	0	0	1	1	82	2	0	IN-MIN	
6000		CU	69	7	0	0	1	1	68	6	0	MN-ON	
6200		CU	20	4	3	2	1	1	5	1	8	IN-MIN	
6400	SILT	CU	59	4	0	0	1	1	57	3	1	IN-MIN	
6600	SANDSTONE	CU	77	9	1	1	0	0	76	8	0	MN-ON	MIN-ON
6800		CU	93	6	1	1	0	0	92	5	0	MN-ON	
7000		CU	17	3	0	0	0	0	17	3	0	IN	INNER
7200		CU	11	3	1	1	0	0	10	2	0	IN	
7400		CU	55	9	0	0	2	2	52	7	0	IN-MIN	
7600		CU	63	3	0	0	0	0	63	3	0	IN	
7800		CU	12	3	0	0	0	0	12	3	0	IN	
8000		CU	17	2	0	0	0	0	17	2	0	IN	
800		CU	93	4	2	1	0	0	91	3	0	IN	
9000		CU	7	5	4	3	1	1	2	1	0	IN	
9100		CU	7	2	2	1	0	0	6	1	0	IN	
9140		CU	3	2	2	1	0	0	1	1	0	IN	

Interval: 5600 ft-6400 ft

Paleobathymetry: Inner - Middle Neritic (IN-MN)

This interval is interpreted as inner-middle marine due to reduced abundance and diversity of all the foram groups. Species like *Haplophragmoides, Trochamina, and Ammobaculites*, which exhibited high abundance and diversity in the previous interval witnessed a reasonable reduction. *Heterohelix globulosa, H. reussi and Guembelitria sp.2* also occurred within this interval. Non-keeled thin shelled planktonic foraminifera such as *Heterohelicids* and *Hedbergellids* which has been interpreted as shallow water dwellers (Gradsein et al., 1999) were present in this interval, though they are also known to occur in moderately deep marine environment.

Interval :6600-6800 ft - Middle - Outer Neritic (MN-ON)

This interval is interpreted as Middle - Outer Neritic (MN-ON) based on increasing abundance and diversity of *Haplophragmoides* species (Table 2).

Interval : 7000 – 9140 ft - Inner Neritic

The lowest abundance and diversity of forams assemblage in the well section analyzed was recorded in this interval. *Cristellaria sp. 13*, a fluvial species was recorded at this interval (Overell, 1995). This suggests a fluvio-marine setting and nearness to the shoreline. There are occasional events of high abundance of some selected aranaceous forams in this interval but the overall assemblage depicts inner neritic water depth. The Kolmani River-1 well paleobathymetry therefore ranges from littoral to outer neritic. Figure 4 shows the palaeobathymetric curve for Kolmani River-1 well.

4.3.3. Paleoecological Modelling

Paleoecological interpretation of ancient sediments has always been made on the premise that each benthonic fossil occurrence indicates a range of possible water depths which that fossil could tolerate (Gebhardt, 2004). This is done by comparism with modern ecological systems and their fauna, although some taxa are believed to have changed their environmental preferences through time. Species diversity is another general indicator of how conducive the environment may be for some foramineferal taxa to populate. Low numbers of species suggest environmental stresses while high diversity suggests equable conditions (Murray, 1994).

The occurrence of some diagnostic benthonic species allowed the definition of minimum and maximum water depths for different parts of well section. *Ammobaculites* and *Haplophragmoides* species occurred in almost all samples in the Kolmani River-1 well as shown in table 2. Hence a general paleoecological interpretation for the well was done. The co-occurrence of restricted marine species like *Bolivina sp*, *Praebulimina exigua*, *Nonionella* Sp.2, *Valvulineria* sp. and unrestricted species of *Ammobaculites*, *Miliamina*, *Haplophragmoides* etc. indicate occasional marine incursion within their depth of occurrences.

The predominance of arenaceous forms shows low-oxygen concentrations for most parts of the basin (Gebhardt, 1998). This could be as a result of increasing input of organic matter from the incoming fluvial systems.

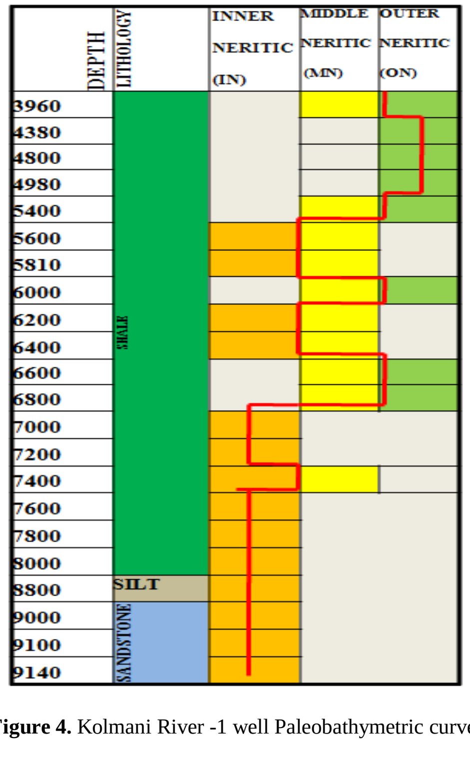

Figure 4. Kolmani River -1 well Paleobathymetric curve

According to Gebhardt, 1998, the genera *Ammobaculites, Miliammina* and *Ammotium spp.* are infaunal deposit feeders that live on muddy substrates in brackish to normal marine salinities from marsh to bathyal environments. They tolerate low oxygen levels. *Haplophragmoides* species is also an infaunal, detritivore that is common in muddy to sandy substrates in environments ranging from marsh to bathyal. It is primarily a marine genus but has also been reported from hyposaline lagoons and estuaries. *Textularia* species is noted to inhabit normal marine environments ranging from lagoonal to bathyal. They live epifaunally on hard substrates, muddy silts and sands. The genus *Bolivina*, thrives in muddy sediments of inner-shelf to bathyal environments. It is probably a detritivore and lives infaunally or epifaually under marine salinities (Gebhardt, 1998).

4.3.4. Salinity

The shell type (Agglutinated, Porcelaneous calcareous and Hyaline calcareous) ratios triangular plot in a sample of foraminifera is used in salinity and paleoenviromental interpretation (Murray, 1974). The proportions of these shell types have been successfully used in distinguishing brackish from hypersaline and normal marine environments.

The plot of the foraminifera recovered the Kolmani River-1 well fell within quadrant for the normal marine marshes (Figure 5).

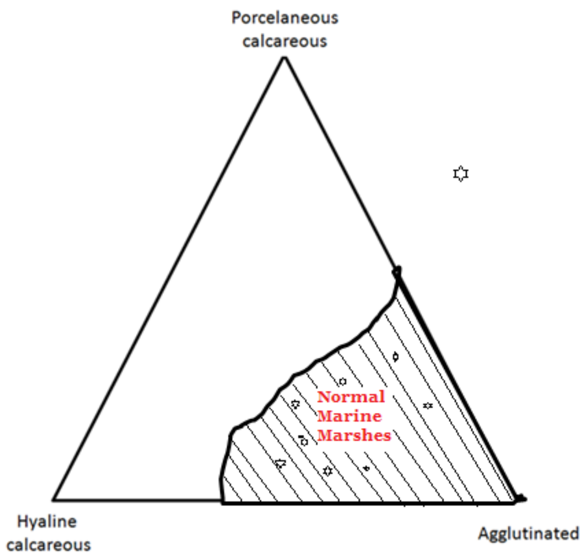

Figure 5. Shell type ratio triangular diagram for Kolmani River-1

Alpha diversity index plot (Figure 6) has to do with the number of benthonic species in a standard-sized sample (Murray, 1974). The general pattern recognizable in marine environments today shows increasing diversity away from shore (i.e., with increasing water depth). It is established that the higher the α-index value, the deeper marine is the depositional environment (Nagy *et al.*, 2000). Alpha diversity index tends to be more effective in delineating environments even in situation where natural post depositional processes of dissolution succeeded in changing the original foram assemblages to secondary assemblages as seen the Gongola basin (Petters, 1982).

The αlpha diversity index for the Kolmani River-1 well ranges from 1- 6 (Figure 6). An α-index value of 1-5 is interpreted as hyposaline marshes – hyposaline shelf sea while alpha index above 5 indicates shelf sea of normal salinity. This therefore implies that the pale environment of deposition for sediment penetrated by the well varies from estuarine to outer shelf setting with low-oxygen and restricted bottom water conditions.

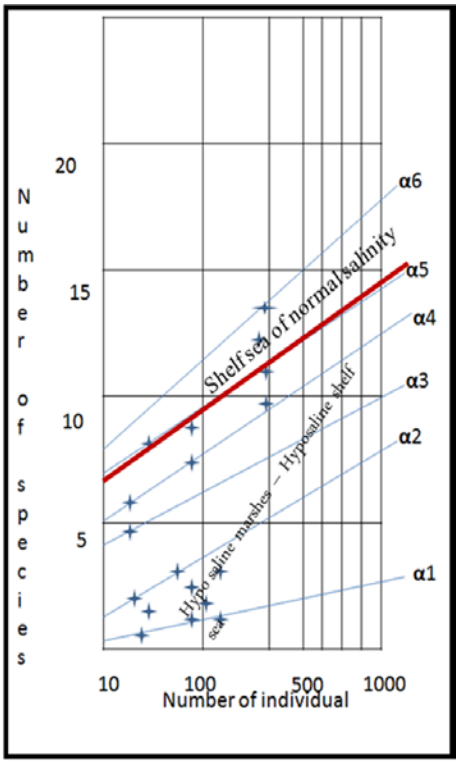

Figure 6. Alpha diversity indices values for Kolmani River-1 well

5. Depositional Environment

Depositional environments of sediments in the studied well section have been deduced from sedimentological, foraminiferal and Paleoecological data. From 900 ft – 2100 ft the medium - coarse grained sands with moderate sorting, sub-angular quartz grains and presence coal fragment/ carbonaceous material suggest deposition in a coastal plain setting, possibly in delta plain or estuary. The absence of forams and dominance of spores corroborate this interpretation. The interval 2700 ft – 3300 ft is interpreted as shallow marine on the basis of lower sand percentage (40% sand; 60% shale). The near-equal content of sands and shales may suggest a parallic environment for this interval (see Figure 2). No forams were noted in this interval but relatively high percentage of palynomorphs.

The interval 3960 ft – 7600 ft of the well section shows considerable deepening with a predominantly blocky, dark grey and calcareous shale lithofacies. The sand percentage varies from 0-10%. This interval may be interpreted as open marine environment based on recorded highest abundance of planktonic and benthonic forams assemblage as forams abundance and diversity increases with water depth (Murray, 1994). The interval 7800 ft - 9140 ft (TD) shows relative shallowing. The sand percentage increased relatively, suggesting a coastal plain setting. The reduced abundance and diversity of forams occurrences recorded in this interval supports this interpretation. The presence of a fluvial foram species- *Cristellaria* sp.13 (Overell, 1995) further supports that this interval was deposited in a continental-parallic environment. The dominance of agglutinated foram species such as the *Ammobaculites*, *Haplophragmoides*, *Miliammina* and *Trochamina* suggest restricted, low oxygen bottom water conditions for most part of the well section of Kolmani River-1. The presence of *Heterohelix* and *Globogerine* shaped taxa in the planktonic assemblage support this assertion.

6. Conclusions and Discussion

The recovered foraminifera species have been used to zoned the sections penetrated by Kolmani River -1 well into three assemblage zones. The analysis of the results shows that the well passed through three formations in the Gongola Basin namely; the Gombe, the Pindiga and the Yolde Formations. The *Agathamina* sp.2 Assemblage Zone correlates with the Gombe Formation which is dated Campanian - Early Santonian. The *Haplophragmoides bauchensis* Assemblage Zone covers the upper part of Pindiga Formation and is dated Coniacian-Early Turonian. The *Heterohelix moremani-Haplophragmoides talokensis* Assemblage zone is a concurrent zone ranges from the Early Turonian (lower part of Pindiga Formation to the Late Cenomanian (Yolde Formation). This indicates that the Pindiga Formation is diachronous in age and ranges from the Coniacian – Turonian while the Yolde Formation is Cenomanian in age. This corroborates with the view of Abubakar et al. (2011) (Figure 7).

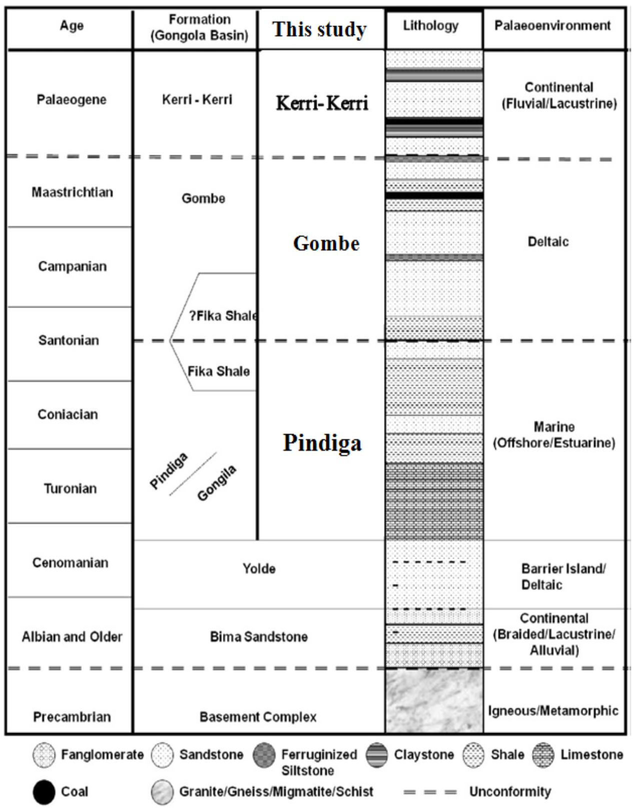

Figure 7. Stratigraphic units of the Upper Benue Trough (after Abubakar et al., 2011)

Under normal circumstances, benthonic arenaceous foram species and benthonic calcareous species are more useful in paleoenvironmental, paleoecological and paleobathymetric interpretation while the planktonic foraminifera are used for age zonations. In this study, all the groups have been integrated to achieve a high resolution age dating, zonation, paleoenviromental and paleobathymetry reconstruction. This method was adopted due to the fact that some of the recovered forams are highly degraded and could not be properly identified to the species level. Petters (1978) reported what he called poor forams quality due to the generally shallow and marginal water conditions that prevailed in the northeastern Benue Trough and noted as an impediment to the use of foraminifera in dating sediments in the area. There is also conspicuous absence of keeled planktonic foraminifera and this has made high resolution biostratigraphic zonation in this basin quite challenging. All these challenges could be attributed to the salinity/oxygen crises reported in the Cretaceous of the world's ocean, epicontinental oceans and in the Benue Trough during the Cretaceous (Petters, 1978).

Depositional environments and paleo-water depths were interpreted in this study based on the relative abundance and diversity of some index foraminifera and the provinciality of the benthonic forms. The overall depositional environment of the basin ranges between coastal plain/estuarine- open marine setting. The water depth ranges from inner to outer shelf setting suggesting that water depths did not exceed 200 m and the salinity ranges from hyposaline – normal marine marshes. The dominance of agglutinated benthonic forams and presence of *heterohelix* and globigerine-shaped planktonics indicate significant anoxia (low-oxygen concentration) and bottom water restriction (Murray, 1994). There was strong oxygen minima caused by reduced oceanic circulation, high organic productivity and the increased supply of organic matter to the oceans and epicontinental seas during the extensive mid-Cretaceous transgression (Schlanger and Jenkyns, 1976). It is believed that the large amount of organic matter supplied to the Benue Trough may have generated anaerobic bottom water conditions during the time, this resulted to poor communication and reduced circulation within the environment.

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