IJASRM

International Journal of Advanced Scientific Research and Management, Volume 3 Issue 1, Jan 2018.

www.ijasrm.com

ISSN 2455-6378

Foraminifera Biostratigraphy of Opolo-5 Well Western Niger Delta, Nigeria

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Abstract

Biostratigraphic and paleoecological studies of foraminifera in the Opolo-5 well within depth slice 3125ft and 8150ft (953m and 2484m) was conducted to establish both bio/ecozones of the sediments penetrated by the well. Two planktonic and four informal benthonic zones are established. They are *Globoquadrina dehiscens* and *Globigerinoides ruber* Planktonic zones as well as *Cyclamina cancellata, Lenticulina inornata, Marginulina costata/ Quinqueloculina microcostata* and *Heterolepa pseudogeriana* informal zones. They range between Late Miocene to Early Pliocene. Wall structure discrimination ternary plots indicate the influence of salinity in the foraminiferal distribution. Normal marine to hypersaline environment is inferred for the upper horizons of the investigated section between depth slice 5030-3170ft (1533-966m), brackish to normal marine for depth slice 6230-5030ft (1899-1533m) while the deeper horizon beyond 6230ft (1899m) are brackish. The various morphological forms indicate inner to middle shelf environment of deposition for the depth of investigation. The inference is corroborated with tau values less than 100 signifying low depth about 40m bathymetry.

Keywords:*Foraminifera, Biozones, Ecozones, Niger Delta*

1. Introduction

Biostratigraphy and paleoecological studies constitute veritable tools in basinal analysis. Variation in morphotypes of fossil foraminiferal tests, to a large extent, expresses the conditions and events of the paleoenvironment of sediment deposition. The use of morphotypes as paleoenvironment indicator therefore is unequivocal as the body forms of such fossilised organisms evolved from adaption in order to proffer solutions to myriads of environmental pressures. The factors influencing the occurrence and distribution of associations of foraminifera in any environment is both abiotic and biotic. Nevertheless, the complex interplay of important primary abiotic factors of salinity, temperature, substrate type, dissolved oxygen content, nutrient supply, and current strength have a far reaching effects on the availability of forms. Murray (2001) in his study of benthic foraminifera was able to establish patterns of distribution and the dynamics of the fossil community. Each species has different factors limiting distribution in variable environments. Foraminifera retrieved from well and outcrop studies, in the Niger Delta oil province and its associated Benue Trough, are considerably presented by several workers (Adegoke et al., 1971, 1976; Petters, 1979, 1982; Seiglie et al, 1982, Ojo, 1996; Ozumba, 1997; Fadiya, 1998; Okosun and Liebau, 1999; Goki et al., 2007 and Opeloye, 2012). This present study will complement the existing data and will provide additional information for the existing dataset on the stratigraphic column of the Niger Delta oil province. Opolo-5 well is located in the western Niger Delta within the OML-95 (Fig. 1).

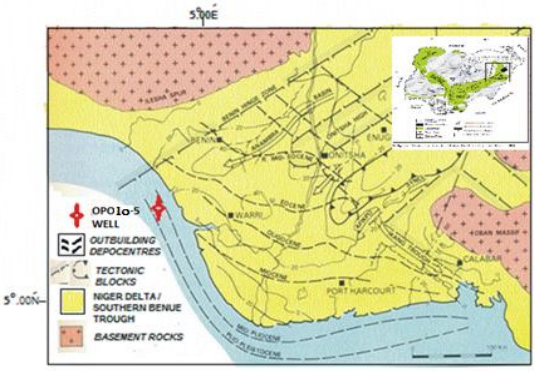

Fig. 1: Niger Delta Oil Province showing location of Opolo-5 well(modified after Whiteman, 1982)

2. Method of Study

A total of 84 ditch cutting samples obtained at every 60ft (18m) from a depth range of between 3125ft (953m) and 8150ft (2484m) were used for the study. 20g by weight of each of the samples was soaked in water to disaggregate the sediments. The soaked samples were sieve-washed using a sedimentological sieve size of 63µm under a jet-stream of water. The sediment residue was transferred into well labelled porcelain dishes, dried in the oven at temperatures maintained at 50°C for 24 hours and observed under a reflected light stereoscopic binocular microscope.

Identification of the recovered foraminifera species was done by consulting relevant foraminifera catalogue(s) and relevant published literatures like Agip S.p.A/Pandani (Dondi and Barbieri, 1982), Loeblich and Tappan (1988), Cushman (1970) etc. Pictures of some of the foraminiferal species were taken using an attached camera (Plate 1)

3. Results

3.1 Lithostratigraphy of Opolo – 5 Well

The sequence is composed of interbedded sands and shales with varying sand to shale ratio (Fig.2). The sands were generally thicker over intervals 3125 – 4310ft (953 -1314m), 5030 – 6230ft (1533m-1899m) and 7490 – 8150ft (2283-2484m) and become thinner elsewhere in the sequence. Three texturally distinct sand types were recognized within the sequence. Over the upper part (3125 – 5330ft/953m-1625m), the sands are milky white to buff, dominantly fine-grained, occasionally medium to coarse/very-coarse – grained, moderately well sorted and sub-angular to sub-rounded. Within the middle portion of the well (interval 5330 – 7550ft/1625-2301m), the sands are milky white, predominantly fine to very fine grained, slightly medium to coarse – grained, well sorted and sub-angular. The sands of the lowermost interval (7550 – 8150ft/2301-2484m) are milky white, coarse to very-coarse – grained and granular, occasionally medium – grained, poorly to moderately sorted and sub-rounded to sub-angular.
The shales are grey, dark grey to brownish grey, platy to flaggy and blocky, they are moderately hard. A rare to abundant glauconite pellets and rare to few mica flakes were noted almost throughout the sequence. Shell fragments occur in rare to abundant quantities over the interval 3125 – 6410ft (953-1954m). Ferruginous materials persist throughout the sequence with occasional occurrences of carbonaceous detritus and pyrites.

3.2 Foraminifera Biozonation

Eight (8) planktonic and thirty-two (32) benthonic species in addition to indeterminate species were recorded (Table 1 and Fig. 3). The stratigraphical pattern of distribution implies that there are two planktonic foraminiferal zones and four informal benthonic zones. The establishment of these zones followed the rule of the American Commission on Stratigraphic Nomenclature (1961).

Planktonic Foraminifera zonation

Globoquadrina dehiscens Zone: The top of the zone is characterised by the first down-hole occurrence (FDO) of *Globoquadrina dehiscens* at 4130 – 4070ft (1259-1241m) in the well and also the last appearance datum (LAD) of *Globigerina praebulloides* at the same depth. The probable base of the zone was put at the 5030 – 4970ft (1533-1515m), below which no planktonic foraminifera were recorded. The zone is characterised by the presence of *Globorotalia continuosa* and *Globigerina* sp. This zone is equivalent to zone 'N18' of Blow (1969). It is equivalent to the upper parts of *Globorotalia menardii* zone of Bolli (1957) and *Globigerina nephthenes* zone of Blow (1959). The age of the zone is put at Late Miocene – Early Pliocene. The intervals below the base of this zone are undefined, because of the absence of planktonic foraminifers, which could have been used to ascertain the zones to which these deeper parts belong.

Globigerinoides ruber Zone: The base of the zone is characterised by the last appearance of *Globoquadrina dehiscens* at 4130 – 4070ft (1259-1241m) in Opolo-5 Well. The top of the zone was not encountered but the zone is characterised by the presence of *Globigerinoides ruber* at 3230 – 3170ft (985-966m) in the well. The following planktonic species characterise the zone: *Globigerinoides immaturus*, *Neogloboquadrina dutertrei* and *Globorotalia menardii*. This zone is equivalent to the lower part of zone N19 of Blow (1969) and upper part of the *Globorotalia crassaformis* zone of Berggren (1977) and *Globigerina nepenthes* zone of Thunnel (1981). It also conforms to the lower part of the *Globorotalia inflata* zone of Jenkins (1966), *Globigerina bulloides* of Bolli (1957) and the *Sphaeroidinella Seminulina* zone of Blow (1959). The age of the zone is Early Pliocene

Informal Benthonic Foraminiferal Zonation

Cyclammina sp. */Cyclammina cancellata* Informal Zone (7490 – 6290ft/2283-1917m):
This zone is characterised by the restricted occurrence of *Cyclammina cancellata*, *Cyclammina* sp., *Reophax* sp., *Trochammina* sp. etc., with both the base and top of the zone being marked by the first and last concurrent occurrence of *Cyclammina* sp. and *Cyclammina cancellata* (Fig 3). Nearly all the agglutinated benthonic species recovered from this well have their representatives in this informal zone, this includes *Alveolophragmium crassum*, *Cyclammina cf. minima*, *Valvulina flexilis*, *Trochammina* sp., *Reticulophragmium venezuelanum*, *Reophax* sp., *Karreriella subcylindrica* etc. This zone spans through the Late Miocene age.
Lenticulina inornata Informal Zone (6290 – 5510ft/1917-1679m): The base of the zone is defined by the quantitative base occurrence of *Lenticulina inornata* and the last appearance datum (LAD) of *Cyclammina* sp. with the first appearance datum (FAD) of *Quinqueloculina* sp. The top of the zone is marked by the remarkable constant presence of *Marginulina costata* at depths shallower than 5510ft (1679m) and reduction in the dominance of *Lenticulina inornata* from 100% at 5990ft (1826m) and 5330ft (1625m) to about 55.6% at 5510ft (1679m). Other associated benthonic species that helped in defining this zone are

IJASRM
International Journal of Advanced Scientific Research and Management, Volume 3 Issue 1, Jan 2018.
www.ijasrm.com
ISSN 2455-6378

Epistominella vitrea, *Quinqueloculina* sp. and *Heterolepa pseudoungeriana*. This zone contains about least benthonic assemblage with *Lenticulina inornata* dominating. This zone spans through the Late Miocene age.

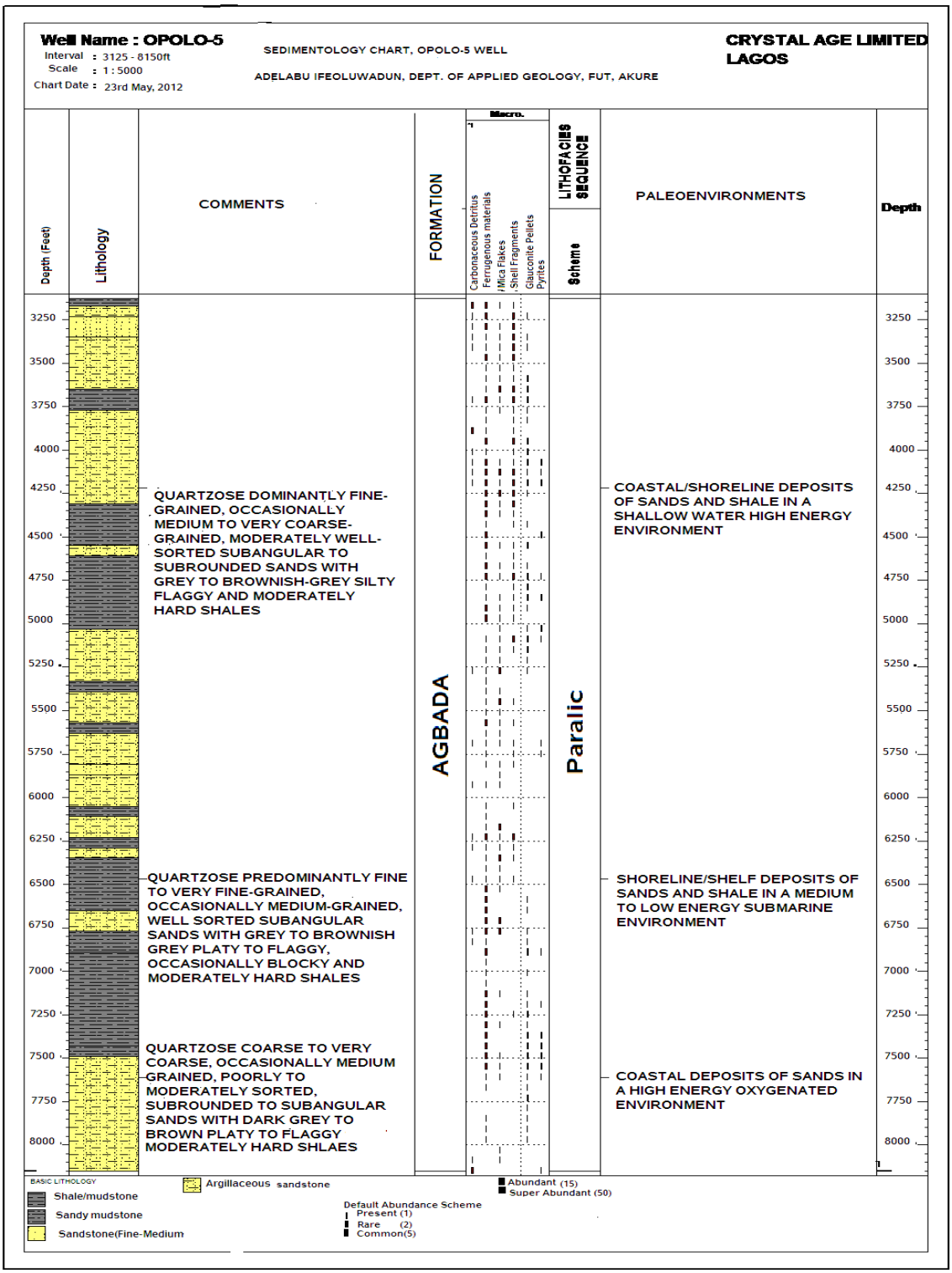

Fig.2: Lithologic Section of Opolo-5 Well, showing the different lithologies and the varying occurrence of accessory minerals

Marginulina costata/ Quinqueloculina microcostata Informal Zone (5510 – 4070ft/1679-1241m): The base of the zone is delineated by the last downhole occurrence (LDO) of *Marginulina costata* and the upper part is defined by the first downhole occurrence (FDO) of *Marginulina costata* together with *Quinqueloculina microcostata*, *Cibicides* sp., *Buliminella* sp. and *Ammonia beccarii*. Other associated benthonic species of this zone include *Amphycoryna scalaris caudata*, *Ammonia beccarii*,

Quinqueloculina sp., *Q. lamarckiana*, *Q. microcostata*, *Uvigerina peregrina*, *Rosalina globularis*, and *Cibicidoides ungerianus* etc, some of which have their first and last appearance within this zone. The interval contains the largest benthonic assemblage both quantitatively and in diversity (Fig. 3). It is also the interval with the highest calcareous benthonic abundance and diversity. The age of this zone is Late Miocene/Early Pliocene.

Heterolepa pseudoungeriana Informal Zone (4070 – 3125ft/1241-953m): The base of this zone is defined by the first downhole occurrence (FDO) of *Marginulina costata*, and quantitative occurrence of *Heterolepa pseudoungeriana*. The top of the zone was not encountered as it is still continuous to shallower depths beyond 3170ft (966m). The *Heterolepa pseudoungeriana* zone is characterised by the dominance of *Heterolepa pseudoungeriana* and the restricted occurrence of *Heterolepa floridana*, the zone is dated as Early Pliocene

3.3 Foraminifera paleoecology

Diversity and Abundance

None of the identified species really showed total dominance numerically over the others apart from the calcareous *Lenticulina inornata*, *Heterolepa pseudoungeriana* and *Quinqueloculina* sp. species, which were consistently present at intervals 3170 – 6290ft (966-1917m) with *Lenticulina inornata* being nearly the most ubiquitous. Unlike the shallower horizons, agglutinated species dominated the deeper depths with *Cyclammina* sp. common in these parts. The other foraminifera species recorded are either rare occurring or too short ranging; some of which include the *Ammonia beccarii*, *Marginulina costata*, *Uvigerina peregrina* and the arenaceous *Haplophragmoides* sp., *Valvulina flexilis* among others.

Wall Structure

In the upper parts of the well, from about 5030 – 3170ft (1533-966m), there was a dominance of calcareous benthonic foraminifers, *Heterolepa pseudoungeriana*, *Cibicides* sp., *Marginulina costata*, *Rotalia* sp., *Buliminella* sp., *Quinqueloculina* sp., *Heterolepa floridana* etc., with a rare occurrence of an agglutinated form of *Ammobacculites* sp. Just below this depth, at 5510 – 5030ft (1679-1533m), there was a noticeable decrease in the number of calcareous benthonic foraminifers and an obvious swell in the agglutinated forms especially *Haplophragmoides* sp., *Reticulophragmium* sp., and *Alveolophragmium crassum* and some indeterminate agglutinated forms. From depth slice 6230 – 5510ft (1899-1679m), a few calcareous species among which are *Quinqueloculina* sp., *Heterolepa pseudoungeriana* and *Lenticulina inornata* with the latter being the most prevailing. The deeper horizons are conspicuously colonised by agglutinated species which include, *Cyclammina* sp., *Trochammina* sp., *Valvulina flexilis*, *Karreriella subcylindrica*, *Reophax* sp.

Paleotemperature and Paleodepths

Records of forms identified in the investigated well are climatic specific: The upper section of the investigated well indicates *Heterolepa floridana*, *Heterolepa pseudoungeriana*, *Quinqueloculina* sp. and *Lenticulina inornata*, which thrive in warm to cool temperatures. In the interval at 4070 – 4970ft (1241-1515m) of the well, *Ammonia beccarii*, *Buliminella* sp., *Marginulina costata* are the forms which Murray (1991) indicated a shallow depth environment (below 50m) and as low as 15°C temperature for maximum breeding.

Planktic: Benthic (P/B) Ratio, Tau Value and General Mode of life

Planktonic foraminifera were only recorded between 3170 – 5030ft (966-1533m), and the calculated planktonic to benthonic ratio ranges from 3% to 67% with a general low diversity of forms. In contrast, at 3170 – 3230ft (966-985m), an abnormally high P/B ratio was recorded (Table 1), The Tau values recorded at horizons where planktonic forms occur range from 66 – 198 (Table 1).

In the upper parts of Opolo – 5 well (3170 – 4070ft/966-1241m), there is an observed dominance of hard substrate genera, *Heterolepa* (hard substrates) and *Quinqueloculina* (attaching to plants or sediments). The other segment of the well below the upper interval down to 7490ft (2283m) are populated by genera inhabiting muddy/sandy substrates especially *Ammonia* (muddy sand); *Uvigerina*, (muddy sediment); *Lenticulina*, (mud); *Cyclammina*, (mud and sand).

At, 3170 – 4070ft (966-1241m), only epifaunal genera occur *Heterolepa*, *Quinqueloculina* and *Lenticulina*. The first infaunal genera were observed at 4070 ft/1241m (*Cibicides*, *Buliminella*) and from this depth down to 7490ft (2283m), both infaunal and epifaunal genera were observed in no particular order such as *Epistominella*, *Trochammina*, *Uvigerina*.

The feeding strategy of the foraminifera are not ordered but vary within assemblages. Some are passive suspension feeders (e.g. *Cibicides*, *Cibicidoides*, *Heterolepa* etc), while others are herbivores (e.g. *Trochammina*, *Rosalina*, *Quinqueloculina* etc.) and detritivores (e.g. *Reophax*, *Lenticulina*, *Cyclammina* etc).

IJASRM
International Journal of Advanced Scientific Research and Management, Volume 3 Issue 1, Jan 2018.
www.ijasrm.com
ISSN 2455-6378

Table 1: Planktonic and Benthonic compositions of Opolo-5 Well

DEPTH (ft)	TOTAL PLANKTICS	TOTAL BENTHICS	TOTAL	P/B (%)	tau
3170 - 3230	2	1	3	67 : 33	67
3230 - 3290	1	2	3	33 : 67	66
3290 -3350	-	1	1		
3590 -3650	-	3	3		
3650 -3710	-	1	1		
3770 - 3830	-	9	9		
3830 - 3890	2	12	14	14 : 86	168
3890 - 3950	-	8	8		
3950 - 4010	-	1	1		
4010 - 4070	-	1	1		
4070 - 4130	2	66	68	3 : 97	198
4130 - 4190	-	9	9		
4190 - 4250	1	12	13	8 : 92	96
4250 - 4310	-	6	6		
4370 - 4430	-	3	3		
4430 - 4490	-	3	3		
4550 - 4610	-	2	2		
4670 - 4730	-	7	7		
4730 - 4790	-	3	3		
4790 - 4850	-	2	2		
4850 - 4910	-	8	8		
4910 - 4970	1	4	5	20 : 80	80
4970 - 5030	2	13	15	13 : 87	169
5030 - 5090	-	9	9		
5210 - 5270	-	1	1		
5330 -5390	-	3	3		
5390 - 5450	-	4	4		
5450 - 5510	-	9	9		
5510 - 5570	-	3	3		
5630 - 5690	-	2	2		
5750 - 5810	-	4	4		
5810 - 5870	-	1	1		
5870 - 5930	-	2	2		
5930 - 5990	-	1	1		
5990 - 6050	-	2	2		
6050 - 6110	-	5	5		
6110 - 6170	-	2	2		
6170 - 6230	-	9	9		
6230 - 6290	-	1	1		
6470 - 6530	-	3	3		
6530 - 6590	-	2	2		
6590 -6650	-	2	2		
6650 - 6710	-	6	6		
6770 - 6830	-	1	1		
6830 - 6890	-	1	1		
6950 - 7010	-	1	1		
7070 - 7130	-	1	1		
7130 - 7190	-	8	8		
7190 - 7250	-	4	4		
7250 - 7310	-	8	8		
7310 - 7370	-	7	7		
7370 - 7430	-	2	2		
7430 - 7490	-	1	1		

Total = total benthic + total planktic
P/B = Planktic : benthic ratio in percent
Tau = Gibson (1989) tau value which is %planktics * no of benthic species

IJASRM

International Journal of Advanced Scientific Research and Management, Volume 3 Issue I, Jan 2018.

www.ijasrm.com

ISSN 2455-6378

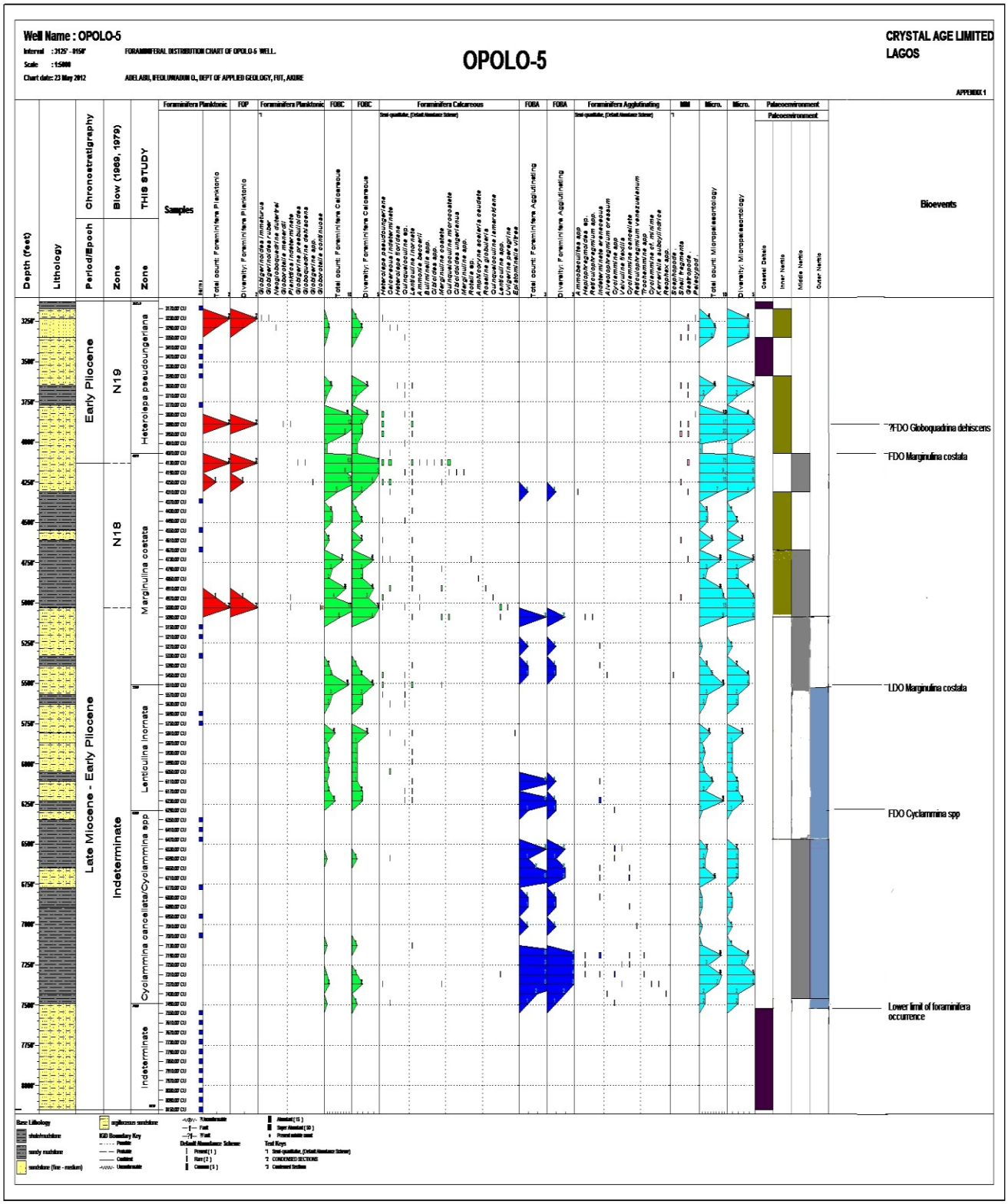

Fig. 3: Foraminiferal chart of Opolo-5 Well

IJASRM
International Journal of Advanced Scientific Research and Management, Volume 3 Issue I, Jan 2018.
www.ijasrm.com
ISSN 2455-6378

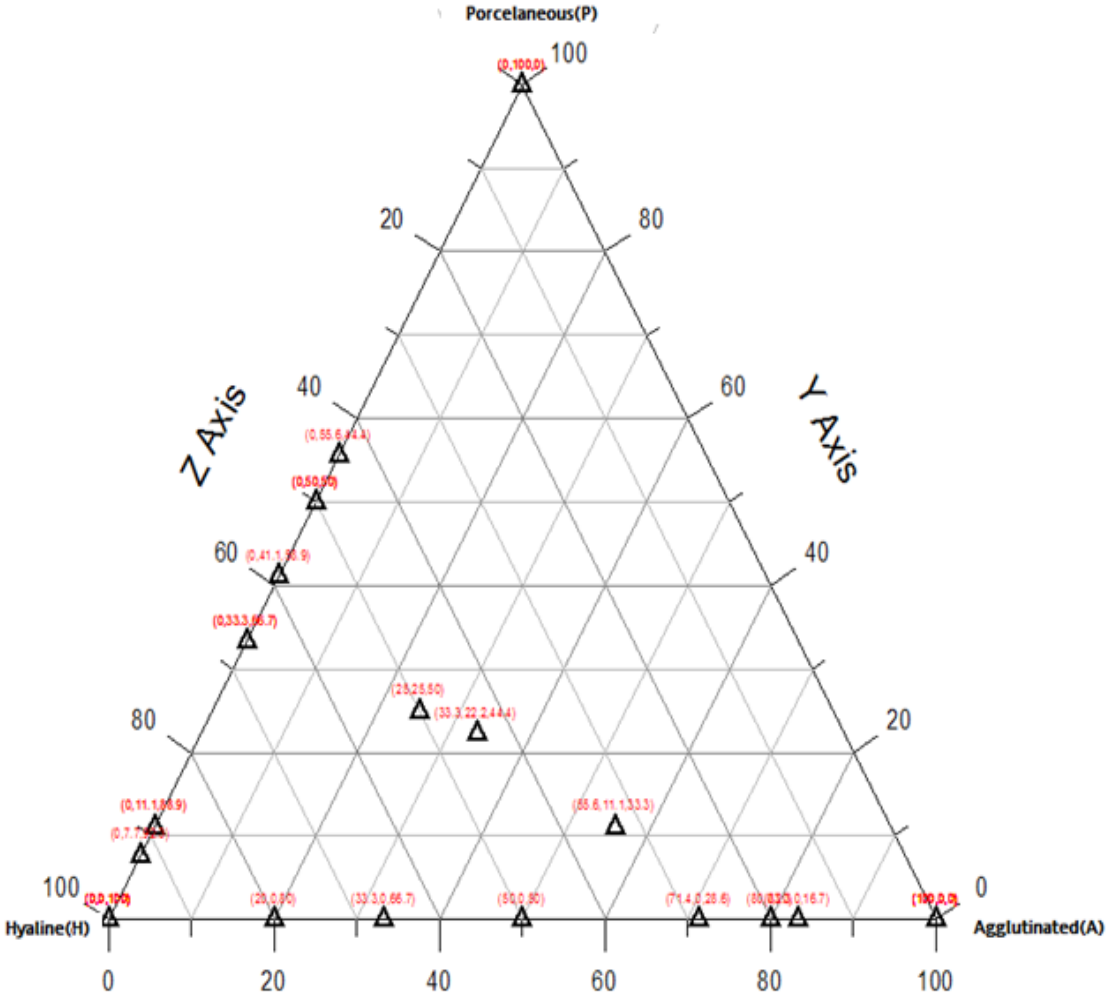

Fig. 4: A plot of wall structure environmental fields of Opolo-5 Well. The points that fall close to the agglutinated (X-axis) axis are brackish environments while those that move away are towards Porcelaneous (Y-axis) axis are hypersaline and those that move towards the hyaline (Z-axis) axis are normal marine

4. Discussion

The high proportion of sand and the ubiquitous occurrence of ferruginous materials alongside few occurrences of carbonaceous detritus, mica flakes and shell fragments especially in the upper and lower segment of the well are consistent with a generally high energy, shallow water regime of sedimentation. The presence of carbonaceous particles and detrital mica is suggestive of rapid deposition of sediments (Selley, 1985). The very fine to fine – grained nature of the sands of the middle portion (Fig. 2) at intervals 5330 – 7550ft (1625-2301m) and the predominance of shales, suggest a deposition at some considerable distance far from sediment source area and possibly in a low energy (relatively deep marine) environmental settings. The presence of pyrite and glauconite as well as rare occurrences of carbonaceous detritus over some intervals suggests a reducing marine environmental condition in a low energy environment.

None of the identified species really showed total dominance numerically, although calcareous *Lenticulina inornata* was ubiquitous in the upper segment while *Cyclaminna cancellata* and *Cyclaminna* sp are the common ones in the lower segment of the well. The observed pattern of the segregation of agglutinated species in the lower segment and the hyaline /calcareous species in the upper segment, could be as a result of preferential dissolution as opined by several workers, notably, Berger, (1970); Speijer and Schmitz, (1998) as well as Nguyen *et al*., (2009). However, employing ternary plot of wall structure environmental fields of Murray (1991) (Fig. 4), the upper segment of the well, from 5030 – 3170ft (1533-966m) is inferred as normal marine/hypersaline environment; due to the dominance of hyaline forms as well as the common to abundant genera of porcelaneous *Quinqueloculina microcoastata* and *Quinqueloculina lamarckiana* (Fig. 3). From 5510 – 5030ft (1679-1533m) may be brackish to normal marine due to the fair occurrence of agglutinated forms, while the horizons between 6230 – 5510ft (1899-

1679m) may likewise be normal marine due to the prevalence of hyaline forms. Finally, the deeper horizons, from 7490 – 6230ft (2283-1899m) are brackish. Agglutinated forms thrives in brackish environments (Murray, 1991), where salinity is hyposaline between 0 – 32‰. The wall structure information therefore, clearly depicts a correlation between the observed distribution pattern and the paleoenvironments.

The Planktonic-Benthonic distribution pattern is reflective of an inner shelf (open sea) to middle shelf (open sea) depositional environment. The low diversity of the forms however prevented extension of the paleobathymetry to continental slope. The Tau values recorded range from 66 to 198. The values at this planktonic-benthic horizon indicate bathymetry a little greater than 40m. This further gives credence to the deduction of inner to middle shelf environment of deposition. In terms of paleo-temperatutue, the identified forms are climatic diagnostic: The upper section of the investigated well is inferred as having hot to cool temperatures. The middle interval segment is cool with an inferred temperature about 15°C. The sudden occurrence of some deep water calcareous species namely *Uvigerina peregrina* (mid-shelf – bathyal; Adegoke *et al.* 1976), *Epistominella vitrea* (shelf – bathyal), and fairly deep *Rosalina globularis* (0 – 100m) etc., coupled with some cold – temperate agglutinated forms of *Haplophragmoides* sp., *Reticulophragmium* sp. and *Alveolophragmium crassum* at depths 4910 – 5450ft (1497-1661m) could be associated to deepening coupled with a change in temperature and probably a change in salinity. Adegoke *et al.* (1976) recognised a progression from *Hanzawaia concentrica* and *Rectuvigerina nicoli* associations on the inner shelf of Niger Delta to *Uvigerina peregrina* association from mid-shelf to bathyal. Based on the occurrence of *Uvigerina peregrina*, a mid-shelf environment of deposition is proposed for this interval (4970 – 5510ft/15151679m) and from 5510 – 6230ft/1679-1899m may be mid-shelf to outer shelf because of the dominance of *Lenticulina inornata*. Temperatures here are probably cold because of the record of *Uvigerina peregrina, Epistominella vitrea,* and *Lenticulina inornata* species

The lower parts of the well, from 6170ft (1881m) to the last non – barren sample, 7490ft (2283m), are dominated by species with affinities for cold temperature. *Karreriella subcylindrica*, found within this segment, thrives at temperatures below 10°C and dwells in outer shelf to bathyal environments. *Reophax and Cyclammina* species are also cold temperature forms found in depths exceeding 100m (Murray, 1991).

5. Conclusion

The lithostratigraphic analysis revealed that Opolo-5 well consist of interbeds of sandstone and shale of a paralic lithofacies sequence belonging to the Agbada Formation of the Niger Delta. The percentage of sand was, at most intervals, between 35-65%. The deposition of sand particles along with few carbonaceous detritus indicates a high – medium energy environment while the presence of fine grained sediments, shale, along with mica flakes is indicative of low – medium energy submarine conditions. Ferruginous materials were ubiquitous, indicating the environment of deposition is fairly oxygenated probably on exposure during shoaling of the sea. In the same vein, the presence of carbonaceous detritus and detrital mica attest to terrigenous influence (non-marine). However the predominance of glauconite indicate a general marine setting of depositional environment.

Eight planktonic and thirty-two benthonic species of foraminifera were clearly identified, Two formal zones established are *Globoquadrina dehiscens* and *Globigerinoides ruber*. Four informal benthonic foraminifera zones were inferred: the *Cyclammina cancellata/ Cyclammina* sp. zone, dated Late Miocene; the *Marginulina costata/Quinqueloculina microcostata* zone, (5510 – 4070ft/1679-1241m), dated Late Miocene to Early Pliocene; the *Lenticulina inornata* zone (6250 – 5510ft/1905-1679m), dated Late Miocene and the Early Pliocene *Heterolepa pseudoungeriana* zone (4070 – 3125ft/1241-953m).

The paleocological analysis of the well revealed that the foraminiferal distribution was determined by mostly factors of wall structures, plankton/benthnic ratio and their mode of life especially the feeding strategy. However abiotic factor of salinity allow discrimination of normal marine/hyper saline environment prevailing in the upper segment and the brackish species flourishing in the lower parts. The paleotemperature indicated by the distribution of the forms are mainly warm to cool. Conclusively the sediments of Opolo-5 well in the Niger Delta were deposited in a shallow marine setting.

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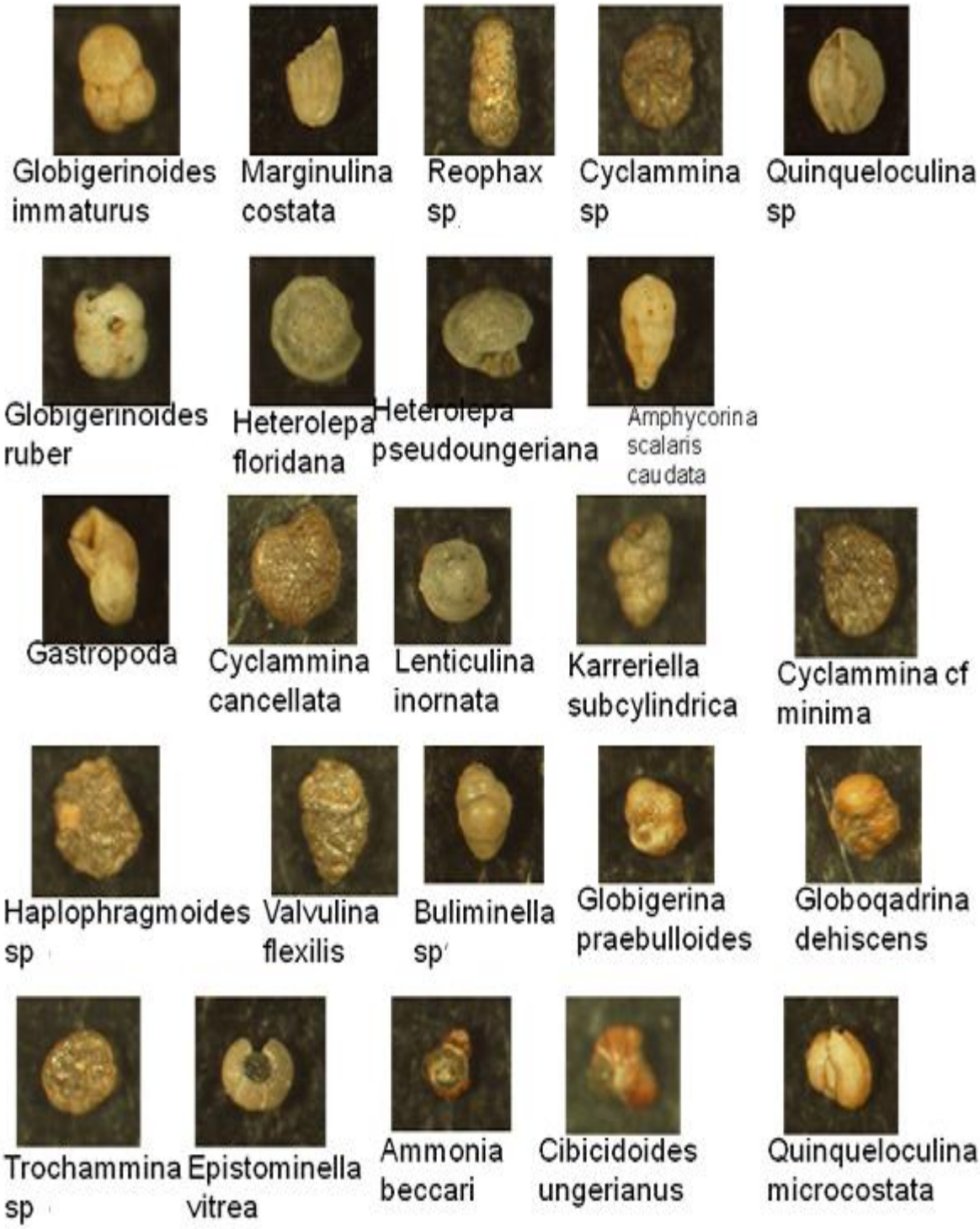

Plate 1: Recovered foraminifera tests. Pictures taken with koolpix 6000 camera (Mag. x 40)