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Foraminiferal and Paleoenvironmental Analysis of Rock Successions in Well X-1, OML 108, Offshore Niger Delta Basin, Southern Nigeria

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Abstract The recent recovery of hydrocarbon in offshore areas of the proliferous Cenozoic Niger Delta has led to a paradigm shift in oil exploration activities even to the deep offshore areas of the delta. Thus, accurate method to reduce exploration risk at this bathymetric setting is required, hence this study. Fifty (50) ditch cutting rock samples from Well X-1, OML 108, Offshore Niger Delta, were processed for their foraminiferal content for the purpose of the paleo bathymetric calibration of the rock succession. Standard methods of foraminiferal processing and analysis were followed for the recovery of the foraminifera, observing all the precautionary measures to improve the quality of the research. The analysis yielded moderately rich and diverse foraminifera consisting twenty- seven (27) planktics, fifty-one (51) calcareous benthic, and twenty-four (24) agglutinated benthic species. Paleobathymetric calibration was based on qualitative and quantitative assemblage patterns of the foraminiferal families and species recovered. Six paleoenvironmental zones ranging from inner neritic to middle and outer neritic to upper bathyal setting is interpreted for the rock succession penetrated by the well interval.

Keywords Paleobathymetry, Niger Delta, Foraminifera, Offshore, Assemblage, Species

1. Introduction

Fifty (50) ditch cutting samples from WELLX-1, OML 108, Offshore western Niger Delta) between interval 8,040ft and 11,010ft (figure 1), were processed for micropaleontological study. The aim was to identify the individual species of the foraminiferal assemblage, their abundance and diversity as well as their stratigraphic distribution and use it to subdivide the section into paleo-ecological zones for the purpose of paleobathymetric characterization of the sediments penetrated by the well interval. The Niger Delta basin is an important hydrocarbon province situated in the West African continental margin. There is a paradigm shift in exploration activities to deep offshore areas following the recent recovery of hydrocarbon in these areas. Foraminifera undoubtedly, is an important micropaleontological tool in basin analysis, contributing in age characterization, correlation, reconstruction of paleoenvironment, paleogeography, as well as recognition of oil and gas horizons. Although there is paucity of published biostratigraphic works by oil companies who treats these data as proprietary, several authors have published on foraminiferal biostratigraphy of the Niger Delta [1-8]. The samples were subjected to standard micropaleontological sample processing techniques and analysis for the recovery of the foraminifera assemblage.

Niger Delta stratigraphy

The stratigraphic setting of the Cenozoic Niger Delta basin has been well described in Short and Stäuble [9], Avbobvo [10], Doust and Omatsola [11], Kulke [12], Stacher [13] among others.

The Niger delta complex is divided into three diachronous formations, that are distinguished mostly on the basis of sand-shale ratios. They are the Akata, Agbada and Benin Formations.

Akata Formation

This formation is the oldest in the basin and underlies the entire delta. It is a uniform shale unit, consisting of dark grey sandy, silty shale with plant remains at the top. The Akata formation is the over pressured sequence believed to have formed during lowstand of sea level when terrestrial organic matter and clay were transported to deep water areas under low energy conditions and oxygen deficiency [13]. The thickness of this sequence is about 7000m in the central part of the basin [11]. This formation crops out offshore in diapers along the continental slope and onshore in the northeastern part of the delta, where they are known as Imo Shale and ranges in age from Paleocene to Recent. The Akata Formation is the source rock of the hydrocarbon in the Niger Delta [14-15].

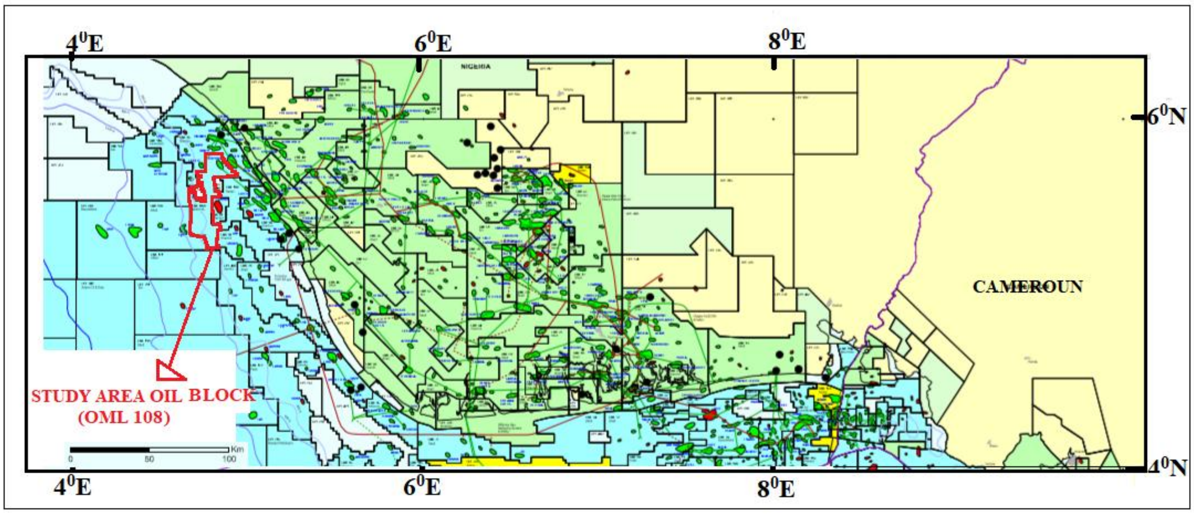

Figure 1: Location of the study area (OML 108) Offshore Niger Delta (Modified from Asadu and Odumoso [16]).

Agbada Formation

The formation is a sequence of alternating shale and sand/sandstone; two subunits: the upper subunit in which the sand/sandstone constitute the thicker part and the lower subunit where shale form the thicker layers are recognized. Agbada Formation is very rich in microfauna which decreases upwards in abundance as the sea prograded. The paralic sequence is present in all depo-belts and ranges in age from Eocene-Recent. It is the hydrocarbon-prospective sequence in the basin with its sands serving as the reservoir rocks while the shales are contributory source rocks and seals [17]. The paralic Agbada formation is the exploration target in the delta between Eocene and Pliocene epoch.

Benin Formation

This formation, comprises of over 90% sandstone with shale intercalations, extends from the west across the entire Niger Delta area and southwards beyond the present coast line. The thickness of the formation varies from 0 to 2100m,characteristicallycoarse grained, gravelly, poorly sorted, sub-angular to well-rounded sands that contain lignite streaks and wood fragment at some horizons. Generally, the formation ranges in age from Oligocene to Recent. Very little hydrocarbon accumulation has been recovered from this highly porous and mainly freshwater bearing sands.

2. Method of Study

Fifty (50) ditch cutting samples were processed for foraminiferal study following the standard practice in the petroleum industry.

Twenty grams (20gm) of each sample were weighed (using a Mettler PC 440 digital balance) and correctly transferred into clean aluminum sample bowls.30 ml of kerosene was poured into the weighed sample while still hot and soaked for two hours. The kerosene was drained out and the samples were soaked in water and washed with a 63-micron sieve with water from a hand directed water jet. The residue was collected, replaced in the sample bowl, dried on the hot plate and then sieved over 20- and 80-microns mesh sieves for the medium and coarse fractions while the finest residue in the receiver was treated as fine fraction. The coarse, medium and fine fractions were then stored in a properly labelled sample phials for picking and analysis. All precautional measures to avoid sample contamination were taken.

The size fractions were examined individually on a picking tray, foraminifera were picked with the aid of a sable brush under a binocular microscope. The various foraminifera taxa encountered in each sample during the picking exercise were grouped and mounted with gum on a micropaleontological slide cavity and covered with a cover slip. These slides were properly labelled with well name and sample depth and arranged serially for identification. The identification of the various foraminifera was done largely by comparison with forms that have been previously described by Sellier de Crivrieux [18], Petters [1], Loeblich, Jr, & Tappan [19], Bolli & Saunders, [20] and other relevant literature published and unpublished.

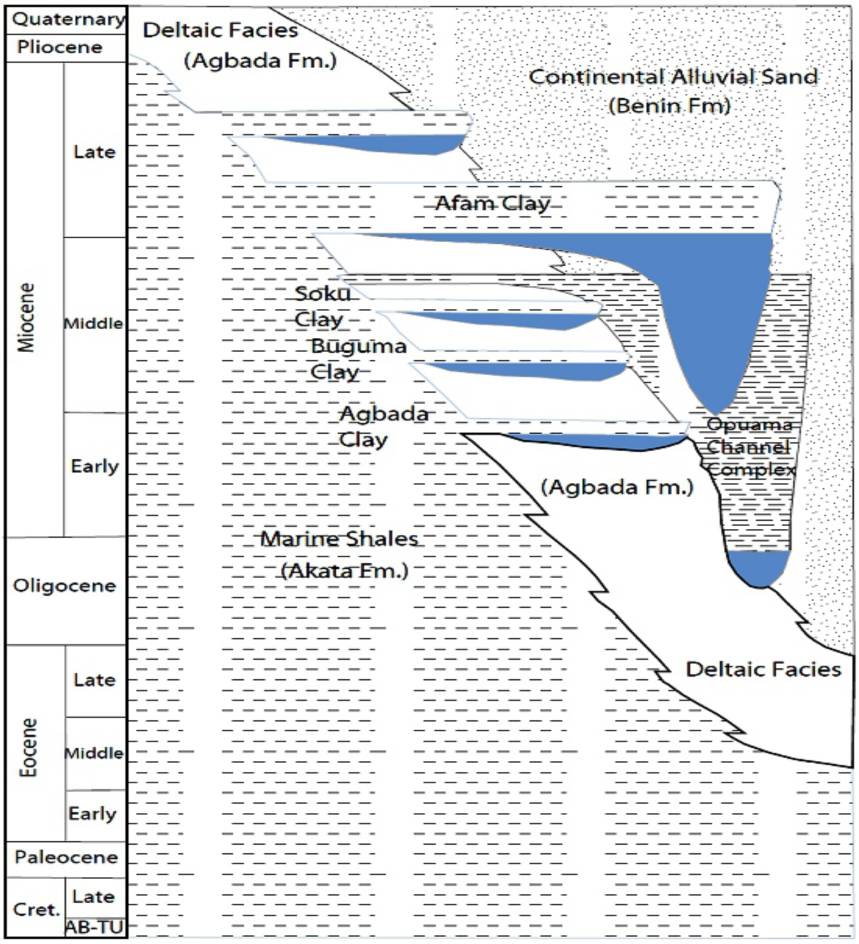

Figure 2: Stratigraphic summary of the Niger Delta (adapted from Doust and Omatsola [11])

Foraminiferal analysis was carried out qualitatively and quantitatively. Foraminiferal specimens were identified to the specific level and/ or generic level, each species/family, counted noting the number of species belonging to the same family to determine how diverse species are in each sample and grouped into planktic and Benthic (Calcareous and agglutinated) foraminifera.

The following bathymetric patterns of the foraminiferal assemblages formed the basis for the paleoenvironmental analysis: The restriction of certain genera and species of benthic foraminifera to specific bathymetric intervals [1, 21] (Benthic forams are accurate sea-level indicators because they have narrow ecological tolerances); benthonic species diversity increases with increasing water depth [22]; Increasing percentage of total planktonic foraminiferal species (%FOP) within an assemblage with increasing water depth [23]; Increase in percentage of calcareous foraminifera (%FOBC) above the carbon compensation depth; the percentage ratio of planktonic to benthonic (%FOP/FOB) distribution in the sample which also increases with increase in the bathymetric contour of the marine environment. Presence or absence of planktic foraminifera also helped in deciphering open ocean environments.

3. Results and Discussions

Foraminifera species recorded consist of twenty-seven (27) planktonic, fifty-one (51) calcareous benthic, and twenty-four (24) agglutinated benthic foraminiferal species. The foraminifera distribution chart of Well X-1 is presented in figure 3. The result of the quantitative analysis is expressed as: Total foraminiferal abundance per sample expressed in absolute numbers of individuals as total micropaleontology, Total foraminiferal diversity expressed in absolute number of species as diversity micropaleontology, Total planktic abundance and diversity, Total calcareous benthic abundance and diversity, Total arenaceous benthic abundance and diversity and Planktic/benthic ratio (table 1 and figure 4).

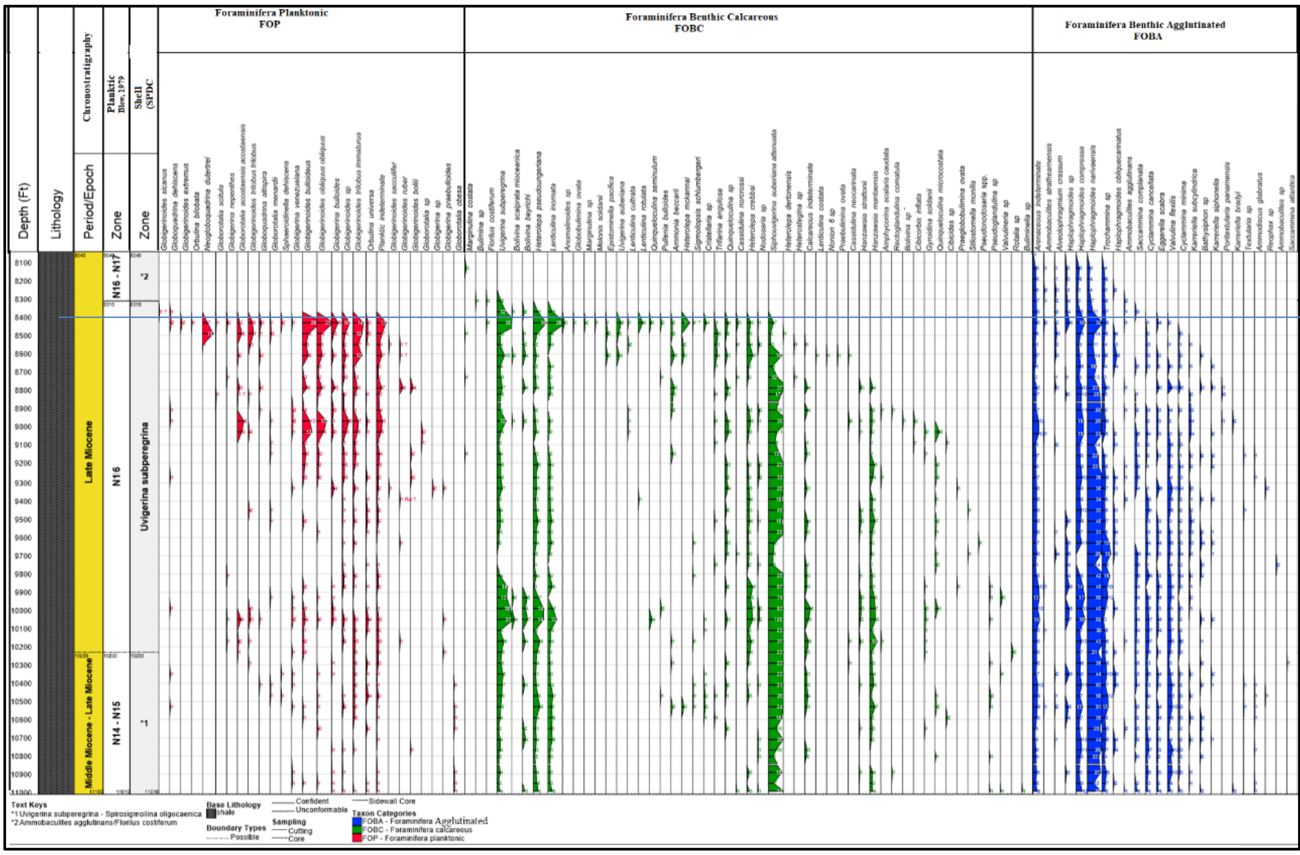

Figure 3: Foraminiferal distribution chart of well X-1

3.1. Paleoenvironmental Synthesis

Details of the paleoenvironmental interpretations are presented as follows:

Interval 8040 to 8370ft :Inner Neritic setting

This interval is characterized by the predominance of the foraminiferal assemblage with the agglutinated benthics occupying ninety-three percent (93-100%) of the total foraminiferal count with the remaining seven percent (0-7%) by the calcareous benthic without any record of the planktics. The recorded agglutinated benthic species are: *Ammobaculites strathearnensis, Alveolophragmium crassum, Haplophragmoides compressa, Haplophragmoides narivaensis, Haplophragmoides obliquecarinatus, Haplophragmoides* sp, and *Trochammina* sp while the calcareous benthic is represented by *Marginulina costata.* These foraminiferal associations suggest an Inner Neritic setting for the stratigraphic interval. Environmental parameters such as organic matter content and not only tidal elevation may have influenced the foraminiferal distribution at this shallow marine setting.

Interval 8370 – 8430ft Outer Neritic Upper Bathyal) setting

The foraminiferal species within this studied interval is characterized by abundant recovery of foraminiferal species. This biofacies zone recorded the highest number of foraminiferal species and highest total count of the planktonic foraminifera. The benthic species recorded include: *Uvigerina subperegrina, Lenticulina inornata, Siphouvigerina auberiana attenuata, Florilus costiferum, Trifarina angulosa, Ammonia beccarii, Heterolepa pseudoungeriana, Epistominella pacifica, Marginulina costata, Bolivina beyrichi, Cassidulina norcrossi, Cassidulina neocarinata, Hanzawaia mantaensis, Haplophragmoides narivaensis, Cyclammina cancellata, Cyclammina minima, Haplophragmoides compressa, Valvulina flexilis, Eggerella scabra, Saccammina complanata, Poritextularia panamensis, Haplophragmoides obliquecarinatus, Ammabaculites strathearnensis, Karreriella subcylindrica, Bathysiphon sp, Karreriella siphonella, Ammodiscus glabratus and Ammobaculites agglutinans.* These foraminiferal benthic species associations suggest an Outer Neritic – Upper Bathyal setting. The percentage planktic/benthic ratio(%FOP/FOB) ranges from 2.8 to 56.5%, while the percentage calcareous benthic (%FOBC) ranges from 38.03 to 62.5% supporting a more open deposition interpreted for this interval. The paleo shelf edge (200m depth of water) is recognized at 8430ft.

Table 1: Abundance, Diversity, percentages and ratios of foraminiferal distribution in well x-1

DEPTH	FOP	FOBC	FOBA	FOB	%FOP	% FOBC	%FOBA	TOTAL FORAM	%FOP/FOB
8040	0	0	1	1	0.00	0.00	100.00	1	0.0
8130	0	2	26	28	0.00	7.14	92.86	28	0.0
8190	0	0	25	25	0.00	0.00	100.00	25	0.0
8250	0	0	27	27	0.00	0.00	100.00	27	0.0
8310	0	7	32	39	0.00	17.95	82.05	39	0.0
8370	2	27	44	71	2.74	38.03	61.97	73	2.8
8430	131	145	87	232	36.09	62.50	37.50	363	56.5
8490	74	37	49	86	46.25	43.02	56.98	160	86.0
8550	30	31	36	67	30.93	46.27	53.73	97	44.8
8610	47	72	56	128	26.86	56.25	43.75	175	36.7
8670	7	18	58	76	8.43	23.68	76.32	83	9.2
8730	13	28	26	54	19.40	51.85	48.15	67	24.1
8790	48	76	83	159	23.19	47.80	52.20	207	30.2
8820	13	32	55	87	13.00	36.78	63.22	100	14.9
8910	16	33	69	102	13.56	32.35	67.65	118	15.7
8970	63	78	77	155	28.90	50.32	49.68	218	40.6
9030	54	42	88	130	29.35	32.31	67.69	184	41.5
9090	6	17	45	62	8.82	27.42	72.58	68	9.7
9150	22	33	65	98	18.33	33.67	66.33	120	22.4
9210	14	53	64	117	10.69	45.30	54.70	131	12.0
9270	14	58	81	139	9.15	41.73	58.27	153	10.1
9330	14	52	94	146	8.75	35.62	64.38	160	9.6
9390	4	36	76	112	3.45	32.14	67.86	116	3.6
9450	9	68	77	145	5.84	46.90	53.10	154	6.2
9510	10	56	96	152	6.17	36.84	63.16	162	6.6
9570	3	47	77	124	2.36	37.90	62.10	127	2.4
9630	4	28	104	132	2.94	21.21	78.79	136	3.0
9690	0	20	91	111	0.00	18.02	81.98	111	0.0
9750	3	16	48	64	4.48	25.00	75.00	67	4.7
9810	7	44	109	153	4.38	28.76	71.24	160	4.6
9870	9	129	114	243	3.57	53.09	46.91	252	3.7
9930	4	121	120	241	1.63	50.21	49.79	245	1.7
9990	10	161	101	262	3.68	61.45	38.55	272	3.8

10050	35	204	122	326	9.70	62.58	37.42	361	10.7
10110	8	39	76	115	6.50	33.91	66.09	123	7.0
10170	15	91	94	185	7.50	49.19	50.81	200	8.1
10230	9	49	62	111	7.50	44.14	55.86	120	8.1
10290	8	45	75	120	6.25	37.50	62.50	128	6.7
10350	9	46	109	155	5.49	29.68	70.32	164	5.8
10410	8	54	112	166	4.60	32.53	67.47	174	4.8
10470	12	56	106	162	6.90	34.57	65.43	174	7.4
10530	10	64	119	183	5.18	34.97	65.03	193	5.5
10590	5	38	84	122	3.94	31.15	68.85	127	4.1
10650	5	29	61	90	5.26	32.22	67.78	95	5.6
10710	1	41	94	135	0.74	30.37	69.63	136	0.7
10770	4	24	82	106	3.64	22.64	77.36	110	3.8
10800	0	18	60	78	0.00	23.08	76.92	78	0.0
10890	5	38	75	113	4.24	33.63	66.37	118	4.4
10950	7	20	48	68	9.33	29.41	70.59	75	10.3
11010	6	52	82	134	4.29	38.81	61.19	140	4.5

Interval 8430to9690ft: Outer Neritic: Setting

This paleo-ecological zone is also characterized by moderate to abundant recovery of foraminiferal species. The benthic species recorded include: *Uvigerina subperegrina, Lenticulina inornata, Siphouvigerina auberiana attenuata, Florilus costiferum, Trifarina angulosa, Ammonia beccarii, Heterolepa pseudoungeriana, Epistominella pacifica, Marginulina costata, Bolivina beyrichi, Cassidulina norcrossi, Cassidulina neocarinata, Hanzawaia mantaensis, Haplophragmoides narivaensis, Cyclammina cancellata, Cyclammina minima, Haplophragmoides compressa, Valvulina flexilis, Eggerella scabra, Saccammina complanata, Poritextularia panamensis, Haplophragmoides obliquecarinatus, Ammobaculites strathearnensis, Karreriella subcylindrica, Bathysiphon sp, Karreriella siphonella, Ammodiscus glabratus, Gyroidina soldanii, Amphycorina scalaris, Rectoglandulina comatula, Cibicorbis inflanata, Quinqueloculina microcostata ,Bolivina* sp, *Cibicides* sp, and *Ammobaculites agglutinans.* These foraminiferal benthic families and species associations suggest an Outer Neritic setting. The percentage planktic/benthic ratio (%FOP/FOB) ranges from 2.4 to as high as 86%, while the percentage calcareous benthic (%FOBC) ranges from 18.02 to 56.25% supporting this assertion.

Interval 9690 to 9,990ft: Middle Neritic to Outer Neritic setting

The foraminiferal species within this studied interval is characterized by few foraminiferal species. The interval recorded common *Hanzawaia strattonii, Amphycorina scalaris caudata, Bolivina scalprata miocenica, Heterolepa crebbsi, Gyroidina soldanii, Haplophragmoides narivaensis, Cyclammina cancellata, Cyclammina minima, Haplophragmoides compressa, Valvulina flexilis, Eggerella scabra, Saccammina complanata, Poritextularia panamensis, Haplophragmoides obliquecarinatus, and Ammabaculites strathearnensis.* The percentage planktic/benthic ratio (%FOP/FOB) ranges from 1.7 to 4.7%, while the percentage calcareous benthic (%FOBC) ranges from 18.02 to 61.45%, indicating Middle Neritic - Outer Neritic setting.

Interval 9,990 to 10,050ft: Outer Neritic to Upper Bathyal setting

The foraminiferal species within this studied interval is characterized by few foraminiferal species. The interval recorded common *Marginulina costata, Bolivina beyrichi, Cassidulina norcrossi, Cassidulina neocarinata, Hanzawaia mantaensis, Haplophragmoides narivaensis, Cyclammina cancellata, Cyclammina minima, Haplophragmoides compressa, Valvulina flexilis, Hanzawaia strattonii, Amphycorina scalaris caudata, Bolivina scalprata miocenica, Heterolepa crebbsi, and Gyroidina soldanii. Karreriella subcylindrica, Bathysiphon sp, Karreriella siphonella, Ammodiscus glabratus and Ammobaculites agglutinans.* (%FOP/FOB) ranges from 3.8 to 10.7%, while the percentage calcareous benthic (%FOBC) ranges from 61.45 to 62.58%. The above foraminiferal association indicate Outer Neritic to Upper Bathyal setting.

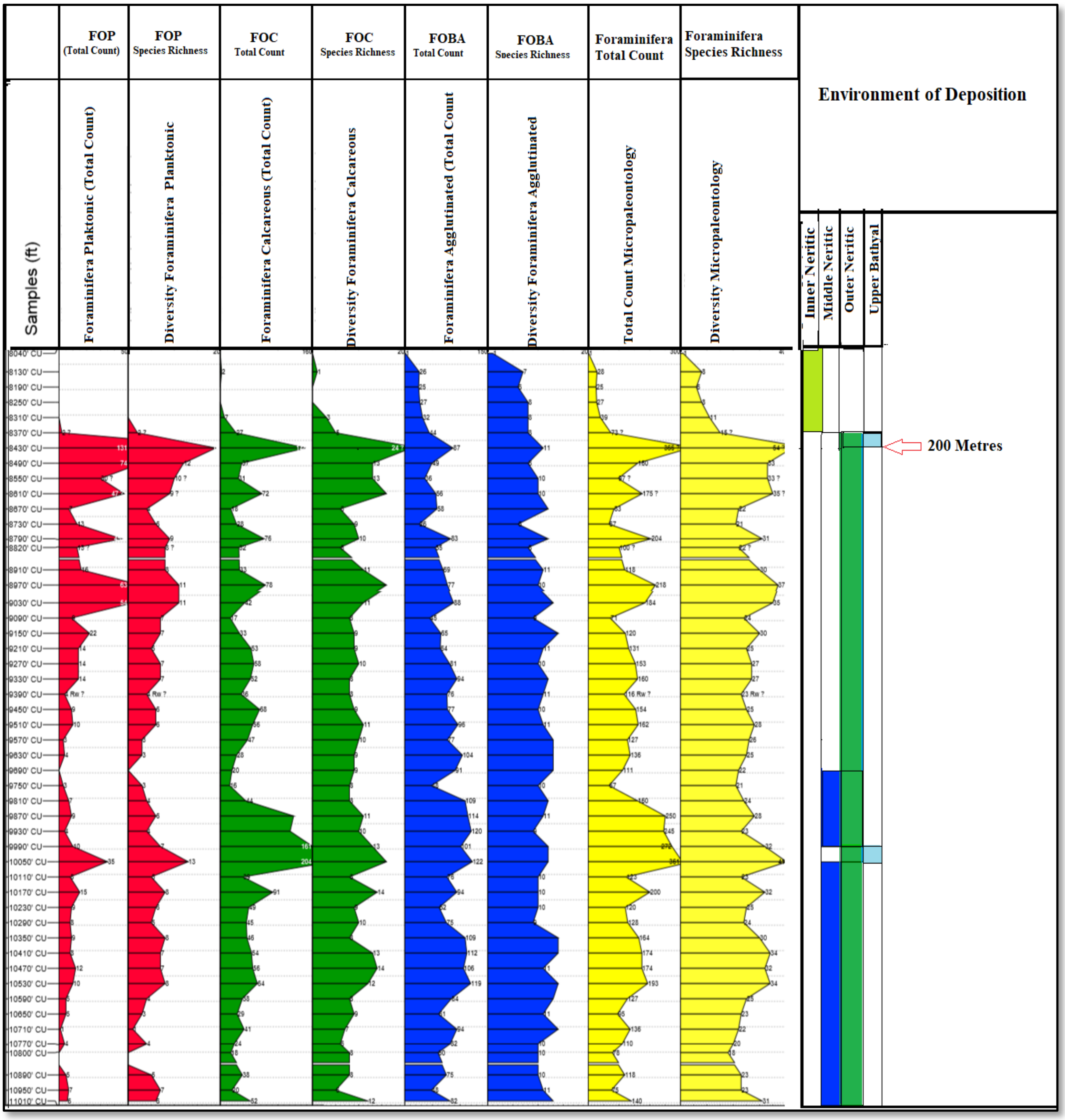

Figure 4: Abundance and diversity charts and paleoenvironmental interpretation of well X-1

Interval 10,050 to 11,010ft: Middle Neritic - Outer Neritic setting

The foraminiferal species within this studied interval is characterized by few foraminiferal species. The interval recorded common *Lenticulina inornata, Siphouvigerina auberiana attenuata, Florilus costiferum, Trifarina angulosa, Ammonia beccarii, Heterolepa pseudoungeriana, Epistominella pacifica, Marginulina costata, Bolivina beyrichi, Cassidulina norcrossi, Cassidulina neocarinata, Karreriella siphonella, Ammodiscus glabratus, Valvulina flexilis, Eggerella scabra, Saccammina complanata and Poritextularia panamensis.* The percentage planktic/benthic ratio (%FOP/FOB) ranges from 0.7 to 10.3%, while the percentage calcareous benthic (%FOBC) ranges from 22.64 to 49.19%. The above foraminiferal association supports proximal/distal Middle Neritic to Outer Neritic setting interpreted for this zone.

4. Conclusion

Six paleo-ecological zones calibrated based on the both qualitative (predominance of foraminifera species and families at depth) and quantitative analysis (abundance and diversity ratiosand percentages) were recognized. The paleoenvironment ranges from inner neritic, middle and outer neritic to upper bathyal setting.

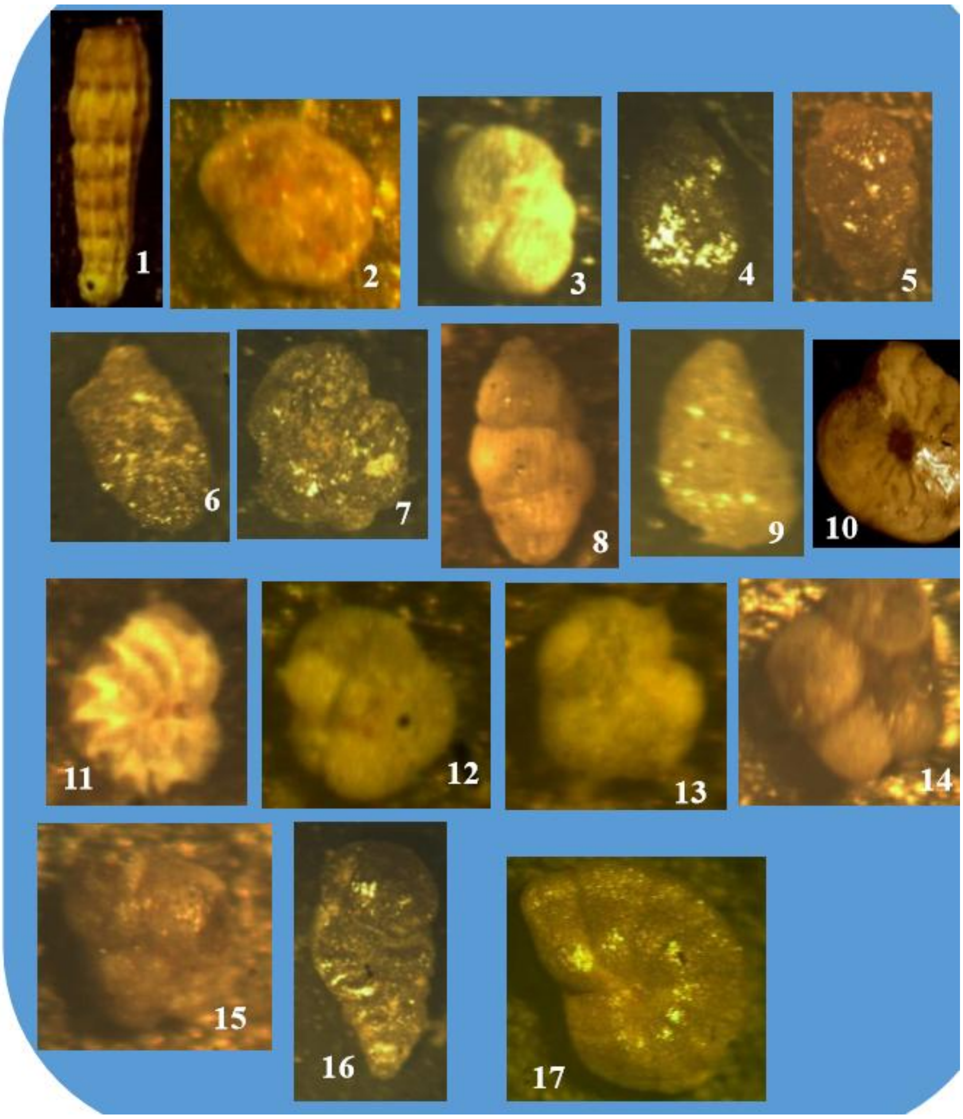

Plate 1:

1. *Marginulina costata* 2. *Haplophragmoides compressa* 3. *Globigerina nepenthes* 4. *Cyclammina minima* 5. *Eggerella scabra* 6. *Ammobaculites strathearnensis* 7. *Haplophragmoides narivaensis* 8. *Uvigerina subperegrina* 9. *Ammobaculites agglutinans* 10. *Amphistegina lessonii* 11. *Florilus costiferum* 12. *Globorotalia acostaensis* 13. *Globorotalia acostaensis* 14. *Globorotalia obesa* 15. *Globorotalia obesa* 16. *Valvulina flexilis* 17. *Cyclammina cancellata*

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