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SEDIMENTOLOGICAL, BIOSTRATIGRAPHIC AND WIRELINE LOG ANALYSIS OF ELE-1 WELL, NIGER DELTA BASIN, NIGERIA

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ABSTRACT

ELE-1 Oil Well samples were subjected to sedimentological, biostratigrapic and Wireline log analyses for well-based characterisation. One hundred (100) ditch cutting samples were analysed for sedimentological characteristics and a lithologic section was produced based on the results of the analysis. ELE-1 Well ranged from 160ft (48.77m) to 12580ft (3,834.38m) with a total thickness of 12420 ft (3,785.62m) ranging from depths of 160 ft – 12580 ft. The lithologic section showed that it was mainly sandstone from 160 ft to 8380 ft (2,554.22). Shale was encountered at 8380 ft and alternated with sandstone till 9920 ft. A thick section of shale was displayed from 9920ft to 12580 ft. The well had four (4) Maximum Flooding Surfaces (MFSs) and three Sequence Boundaries (SBs). They were picked and dated as P870/P830 (5.0Ma MFS), P870/P830 (5.6Ma SB), P870/P830 (6.0 Ma MFS), P870/P830 (6.7Ma SB), P830/P870 (7.4Ma MFS), P820/P788 (8.5Ma SB), P820/P788 (9.5Ma MFS). The sequence stratigraphic surfaces enable the Third (3rd) order sequence stratigraphic characterization, which can achieve a detailed reservoir prediction

Keywords: Sedimentology, Biostratigraphic analyses, Wireline Log, Well-based characterisation, Sequence Stratigraphy

INTRODUCTION

Positioned in the eastern Gulf of Guinea, the Niger Delta Basin is one of the world's most abundant petroleum basins. The Niger Delta is located in Nigeria's South-South geopolitical zone, between latitudes 4°N and 7°N and longitudes 3°E and 9°E. The Cenozic Niger Delta is located where the South Atlantic Ocean and the Benue Trough meet, a triple junction formed in the late Jurassic period when the African and South American plates separated (Obaje, 2009). One of the sedimentary basins created by the rift faulting of Nigeria's Precambrian rock is the Niger Delta Basin. The delta is made up of pieces of the extended African continental crust and Tertiary marine and fluvial deposits that lie on top of oceanic crust (Bilotti and Shaw, 2005).

Since commercial oil was discovered in the Oloibiri-1 well in 1956, the Niger Delta has been a significant hydrocarbon producing area in Nigeria, the focus of intense exploration and exploitation activity since the early 1960s (Reijers *et al.*, 1996). Thus, to explore and utilise the hydrocarbon resources of the delta, one must have a thorough grasp of its lithostratigraphy, biostratigraphy, sedimentology, and palaeoenvironment.

Study Area

Geological Setting

The study well "ELE-1 Well" is located in the Coastal Swamp Depobelt of the Niger Delta Basin (Figure 1).

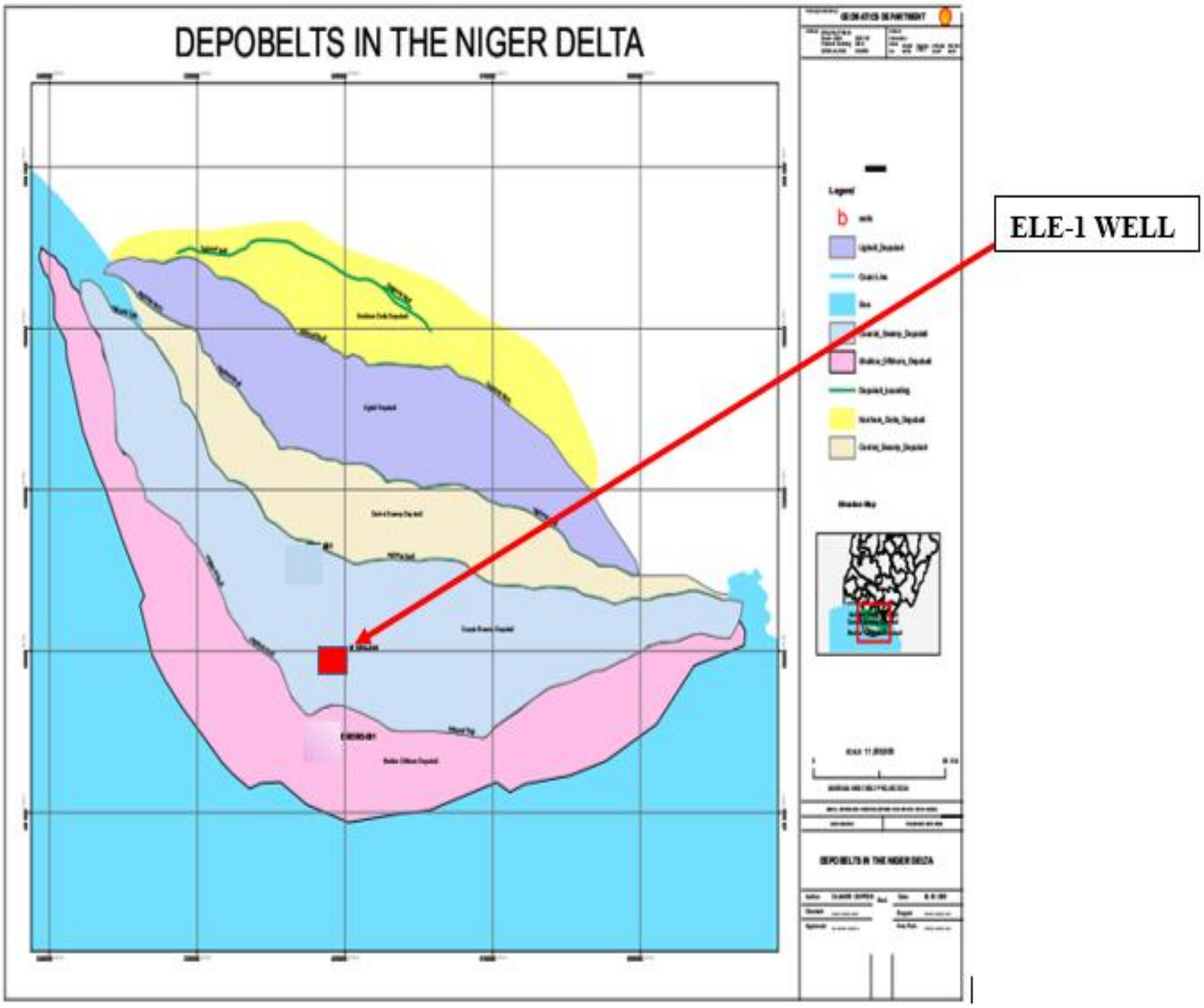

Figure 1: Location of Study Area – Coastal Swamp Depobelt - (in red) insert in the Regional Niger Depobelts. (Modified from SPDC Creations 2008)

Regional Niger Delta Development.

The Niger Delta Basin is located on the continental margin of the Gulf of Guinea in equatorial West Africa (Figure 2). The Delta originated at the location of a triple junction of rifts connected to the Southern Atlantic opening, which occurred between the Late Jurassic and Early Cretaceous periods. In the Eocene, the Delta proper started to form and fill with sediment. Beginning in the Eocene, the Delta proceeded southwestward, creating depobelts, which symbolised the most dynamic areas of the Delta throughout its evolution (Doust and Omatsola, 1990). The Niger Delta Basin may be further classified into three formations (Figure 3): The Agbada Formation (Eocene to Recent), the Benin Formation (Oligocene- Recent), and the Pro-delta shales of the Akata Formation (Palaeocene to Recent). It is a sizable, constructive wave-dominated delta with an arcuate sediment wedge in cross-section.

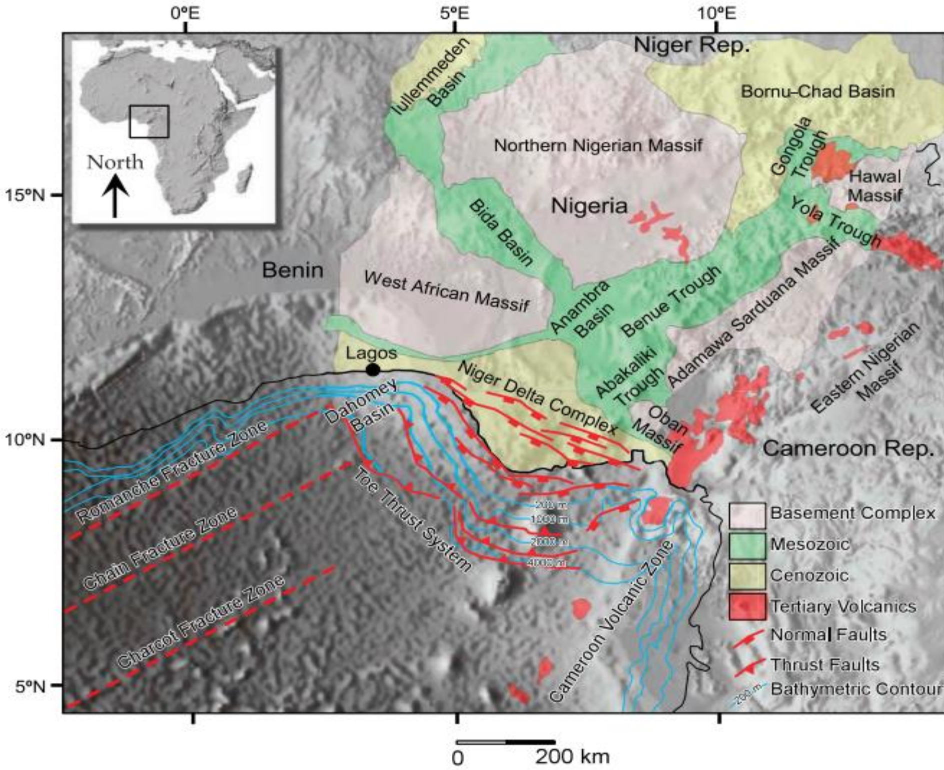

Figure 2: Location of the Niger Delta region showing the main sedimentary basins and tectonic features. The delta is bounded by the Cameroon volcanic zone, the Dahomey Basin, and the 4,000-m (13,100-ft) bathymetric contour (After Onuoha,1999).

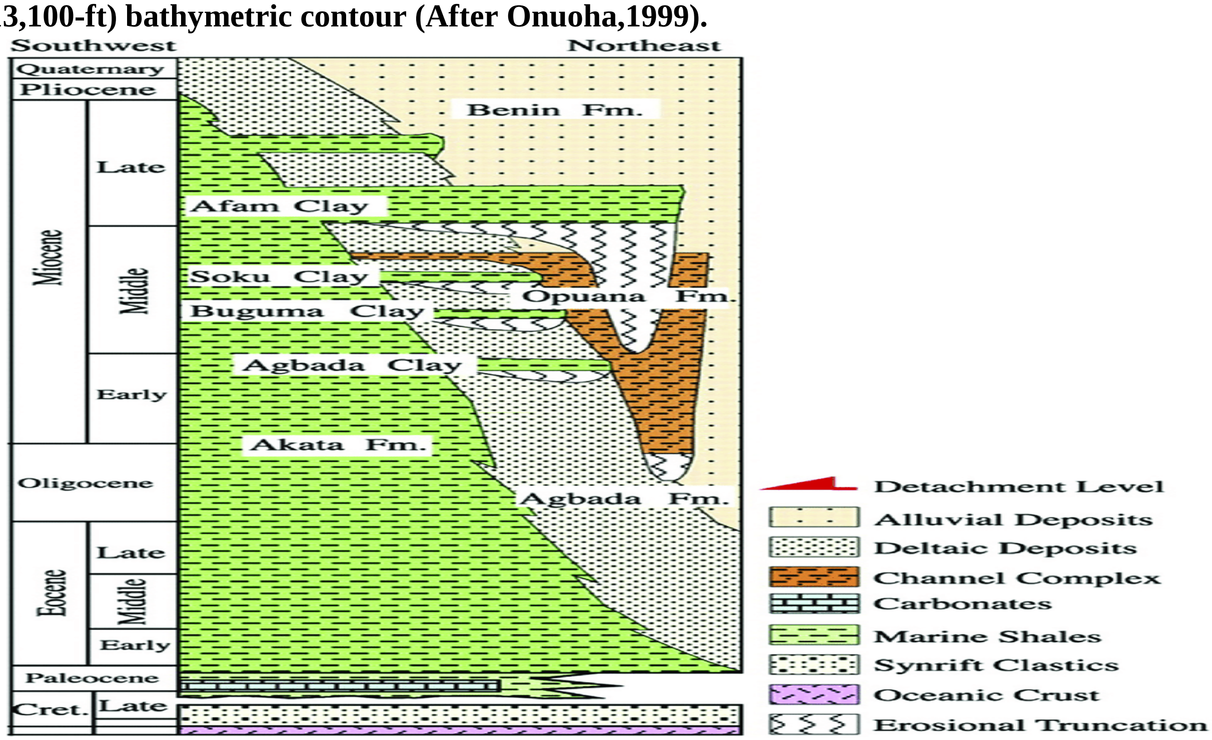

Figure 3: Stratigraphic column showing the 3 formations of the Niger Delta (Doust and Omatsola. 1990)

The Akata Formation was deposited in the Paleocene. The primary constituents of the Akata Formation, the base unit of the Cenozoic delta complex, are marine shales (a probable source rock), turbidite sands (a possible reservoir in deep water), and trace quantities of silts and clay (Figure 2). Sediments are formed because the high energy delta progressed into deep water; the approximate range of thickness is 0-6000 metres (Fatoke *et al.*, 2010), (Schlumberger, 1985). Because of its constant shale growth, the shale is often dark grey, although it can also be silty or sandy in certain areas and include thin sandstone lenses, particularly in the upper section of the formation (Short and Stauble, 1967). This Formation originated during lowstands, when clays and terrestrial organic materials were carried to deep water regions with low oxygen levels and energy levels (Michele *et al.,* 1990).

The Agbada Formation was deposited in the Eocene. Shale diapirs were created as a result, pressing the underlying shale (Akata Formation) onto them. According to Nwachukwu and Odjegba (2001), the Agbada Formation (Figure 2) is a paralic sequence of alternating sandstones and shales deposited on a shoreline's landward side. The sandstone reservoirs of the Agbada Formation are responsible for the Niger Delta's oil and gas production. The formation is made up of an alternating series of delta-front sandstones and shales, with a paralic siliciclastic origin that is over 3700 metres thick and originates in a distributary channel and deltaic plain. The sandstones have fine grains, are clear, calcareous, glauconitic, and occasionally shelly. The silty shales have a medium to dark grey colour and include local glauconite. It is composed of a lower shale level that is thicker than the upper than the upper sandy unit and an upper mostly sandy unit with small shale intercalations.

A higher rate of deposition in the delta front is indicated by the formation's dense microfauna near the base, which decreases upward. The coarse grains and poor sorting are signs of a fluviatile origin. This series is associated with sedimentary growth faulting and contains hydrocarbon reserves. The top rock is composed of shale beds, whereas the main hydrocarbon deposits are found in the sand layers.

The Benin Formation was then created throughout the Oligocene and continues to be deposited now. The Benin Formation (Figure 2) extends southward past the present seashore and across the Niger Delta from west to east. It is mostly composed of massive, very porous, freshwater-bearing sandstones with thin, shale-like interbeds that are assumed to have originated from braided streams. In terms of minerals, the sandstones are mostly composed of quartz and potash feldspar, with trace quantities of plagioclase. With shale intercalations, more than 90% of it is sandstone. It has a range of grain sizes, from coarse to fine, is gravelly in some areas, is poorly sorted, sub-angular to well-rounded, and has pieces of wood and lignite streaks throughout. Because to its tectonic structure, the basin is divided into a few distinct zones. Because of the thicker crust, the ocean floor has an extensional zone. Within the deepwater portion of the basin, there are two zones: one for transition and the other for contraction. (Fatoke and others, 2010).

The geology of southern Nigeria and southwest Cameroon defines the onshore area of the Niger Delta Province. Stable mega-tectonic frameworks flank the Niger Delta Basin. These include the Calabar and Benin flanks along the delta's eastern and northwest borders, respectively. The delta's northern limit is indicated by the Anambra Basin and Abakaliki. The Niger Delta Basin is bordered to the south by the Gulf of Guinea. Situated between latitudes 4^o and 7^oN and longitudes 3^o and 9^oE, it is the oil province of Nigeria (Whiteman, 1982).

The whole sedimentary prism, spanning 140,000 km^3 (75,000 km^3), is made up of an overall regressive clastic sequence that reaches a maximum thickness of 9,000–12,000 metres. Its stratigraphic thickness is approximately 12 km (Evamy *et al.*, 1978).

The study involved three phases of analyses viz: sedimentological analysis, biostratigraphic data interpretation and Wireline Log analysis.

MATERIALS AND METHODS

Table 1: ELE-1 Well Sample Inventory

S/N	DEPTH	**S/N**	DEPTH	**S/N**	DEPTH	**S/N**	DEPTH	**S/N**	DEPTH
1	160	21	2660	41	5160	61	7660	81	10160
2	280	22	2780	42	5280	62	7780	82	10280
3	400	23	2920	43	5400	63	7900	83	10400
4	520	24	3020	44	5520	64	8020	84	10520
5	640	25	3140	45	5640	65	8140	85	10640
6	760	26	3260	46	5760	66	8260	86	10760
7	880	27	3350	47	5880	67	8380	87	10880
8	1000	28	3500	48	6000	68	8500	88	11000
9	1120	29	3620	49	6120	69	8620	89	11120
10	1240	30	3740	50	6240	70	8740	90	11240
11	1360	31	3860	51	6360	71	8860	91	11360
12	1480	32	3980	52	6480	72	8980	92	11480
13	1600	33	4100	53	6600	73	9100	93	11600
14	1720	34	4220	54	6720	74	9220	94	11720
15	1840	35	4340	55	6840	75	9340	95	11840
16	1940	36	4500	56	6980	76	9480	96	11980
17	2100	37	4620	57	7120	77	9620	97	12120
18	2240	38	4760	58	7260	78	9760	98	12260
19	2380	39	4900	59	7400	79	9900	99	12380
20	2540	40	5040	60	7540	80	10040	100	12580

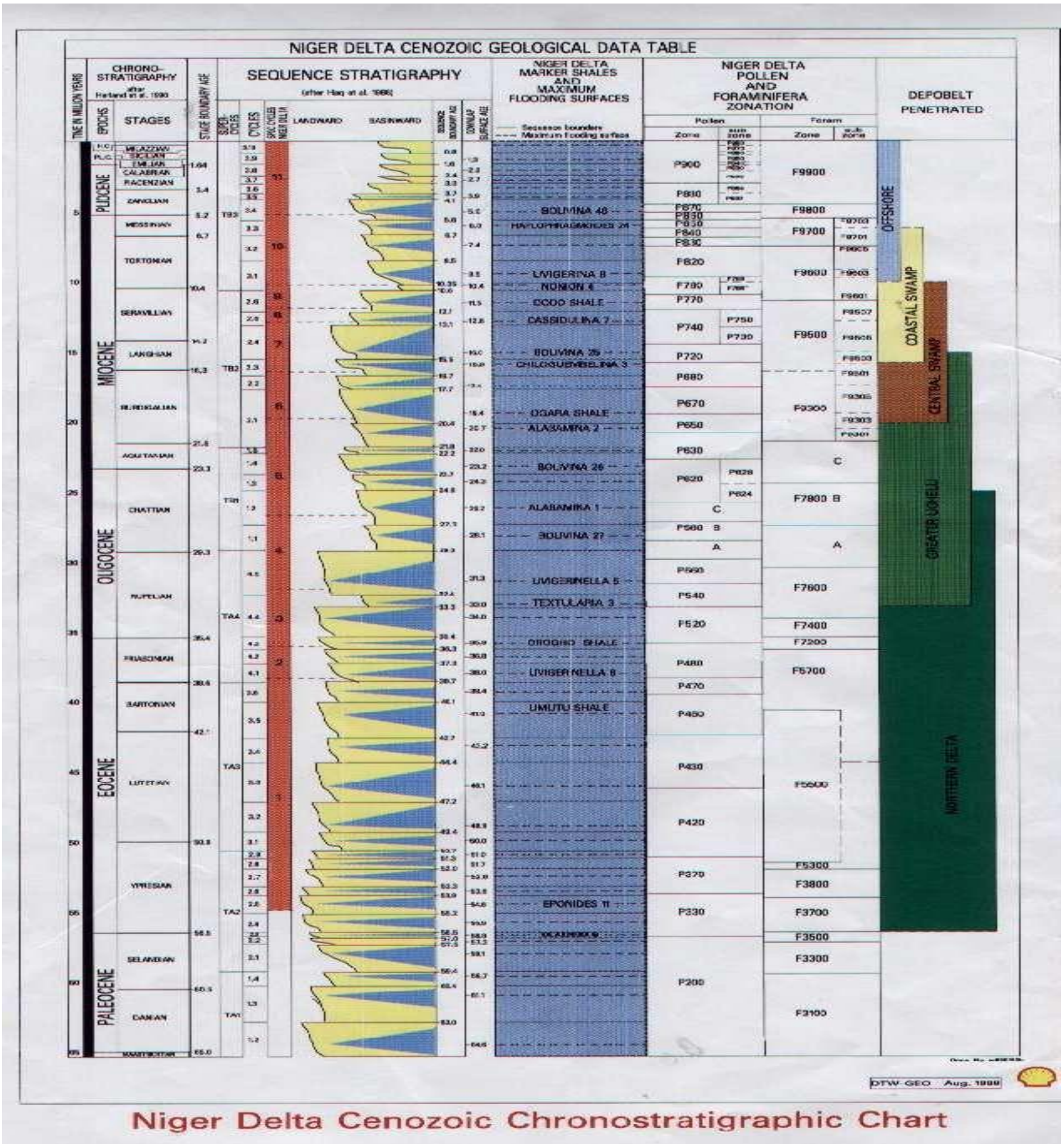

Figure 3: The SPDC Niger Delta Cenozoic Chronostratigraphic Chart (SPDC, 1988)

a. Sedimentological Analysis

The sedimentological analysis of the well samples involved washing the samples initially with water to remove the contamination of the drilling mud, since the drilling mud used was water based mud. After that, the washed samples were dried in pans placed on hot plates. After the drying, the samples were viewed and analyzed with the aid of a microscope for sedimentological description of the samples with particular focus on sediment texture, sorting and lithologic type.

b. Wireline Log Analysis

The Wireline logs used were the Caliper Log, Gamma Ray Log and the Spontaneous Potential

(SP) Log. These logs are sensitive to sediment variance and therefore can delineate between sand and shale lithologies

c. Biostratigraphic Interpretation

Biostratigraphy is a powerful tool for constraining the ages of stratigraphic sequences. When integrated with wireline logs, it becomes very useful to locate sequence boundaries (SB) and condensed sections Maximum Flooding Surface (MFS).

RESULT

Sedimentological Analysis

The sedimentological analysis of ELE–1 Well was carried out using one hundred (100)) ditch cutting samples (Table 1) and samples description was done with the production of a resultant lithologic section (Table 2).

Table 2: Sedimentary Description of ELE-1 (Coastal Swamp Depobelt) Well Samples

S/N	DTH	%SST	%SHL	%SLTS	LITHOLOGIC DESCRIPTION	ACCESSORY MINERALS	S/N
1	160	50	50	0	Heterolic, light gray, very fine, well sorted, angular		1
2	280	99	<1	<1	Sandstone, whitish, fine-coarse, poorly sorted, angular	Siderite particles	2
3	400	99	<1	<1	Sandstone, whitish, coarse, moderately sorted, angular	Siderite particles	3
4	520	98	1	1	Sandstone, whitish, fine-medium, well sorted, sub-angular	Carbon particles	4
5	640	99	<1	<1	Sandstone, colourless, medium, well sorted, angular		5
6	760	100	0	0	Sandstone, whitish, medium, well sorted, angular		6
7	880	100	0	0	Sandstone, whitish, medium, well sorted, angular		7
8	1000	100	0	0	Sandstone, whitish, coarse, moderately sorted, angular		8
9	1120	99	<1	0	Sandstone, whitish, fine, well sorted, angular		9
10	1240	99	<1	<1	Sandstone, whitish, fine, well sorted, angular		10
11	1360	99	<1	<1	Sandstone, colourless, fine, moderately sorted, angular	Siderite particles	11
12	1480	99	0	1	Sandstone, brownish, fine, moderately sorted, angular		12
13	1600	99	0	<1	Sandstone, colourless, medium, well sorted, angular		13
14	1720	99	<1	<1	Sandstone, colourless, medium, well sorted, angular	Micaceous flakes	14
15	1840	100	0	0	Sandstone, whitish, fine, moderately sorted, angular	Carbon particles, ferruginized sst	15
16	1940	99	<1	<1	Sandstone, whitish, fine-coarse, poorly sorted, angular	Ferruginized sst	16
17	2100	99	0	<1	Sandstone, whitish, fine-coarse, moderately sorted, angular	Carbon partcicles	17
18	2240	99	0	<1	Sandstone, whitish, medium, moderately sorted, angular	Coal	18
19	2380	99	0	<1	Sandstone, whitish, medium-coarse, moderately sorted, angular		19
20	2540	99	0	<1	Sandstone, whitish, medium-coarse, moderately sorted, angular		20

21	2660	99	<1	<1	Sandstone, whitish, medium-coarse, well sorted, angular		21
22	2780	98	<1	<1	Sandstone, whitish, medium-coarse, poorly sorted, angular	Coal	22
23	2920	99	<1	0	Sandstone, gray, fine-coarse, moderately sorted, angular	Few coal input	23
24	3020	100	0	0	Sandstone, colourless, medium, moderately sorted, angular		24
25	3140	99	<1	<1	Sandstone, colourless, fine, moderately sorted, angular	Ferruginized sst, coal	25
26	3260	98	1	1	Sandstone, colourless, coarse, moderately sorted, angular	Ferruginized sst, coal	26
27	3360	99	0	<1	Sandstone, whitish, fine-coarse, poorly sorted, angular	Coal	27
28	3500	99	<1	<1	Sandstone, whitish, medium, well sorted, angular		28
29	3620	99	<1	<1	Sandstone, whitish, medium-coarse, well sorted, angular		29
30	3740	99	<1	<1	Sandstone, whitish, medium-coarse, well sorted, angular		30
31	3860	98	1	1	Sandstone, whitish, very fine-medium, well sorted, angular		31
32	3980	99	<1	<1	Sandstone, whitish, very fine, well sorted, sub-rounded		32
33	4100	99	<1	<1	Sandstone, whitish, medium, well sorted, sub-rounded		33
34	4220	99	0	0	Sandstone, dark, medium, angular	Much carbonaceous	34
35	4340	99	<1	<1	Sandstone, whitish, very fine-medium, well sorted, angular	Coal	35
36	4500	99	<1	0	Sandstone, whitish, very fine-coarse, poorly sorted, angular	Carbonaceous particles	36
37	4620	99	<1	<1	Sandstone, whitish, coarse, very well sorted, angular		37
38	4760	99	<1	0	Sandstone, whitish, fine, moderately sorted, sub-rounded		38
39	4900	99	<1	<1	Sandstone, whitish, medium-coarse, well sorted, angular		39
40	5040	98	<1	2	Sandstone, gray, fine-coarse, moderately sorted, sub-angular		40
41	5160	99	<1	0	Sandstone, colourless, medium, well sorted, angular		41
42	5280	99	<1	0	Sandstone, colourless, fine-medium, moderately sorted, sub-angular		42
43	5400	99	0	<1	Sandstone, colourless, fine-medium, moderately sorted, sub-angular		43
44	5520	99	<1	<1	Sandstone, whitish, very fine-medium, well sorted, sub-angular		44
45	5640	98	2	0	Sandstone, colourless, fine-coarse, poorly sorted, angular		45
46	5760	99	<1	0	Sandstone, gray, coarse, well sorted, angular		46
47	5880	99	0	<1	Sandstone, whitish, medium, well sorted, angular		47
48	6000	99	<1	<1	Sandstone, whitish, fine-coarse, poorly sorted, angular		48

49	6120	99	<1	<1	Sandstone, whitish, fine-coarse, moderately sorted, angular	Ferruginized sst	49
50	6240	92	8	<1	Shaly sandstone, gray, very fine-medium, well sorted, angular		50
51	6360	99	<1	<1	Sandstone, gray, very fine-medium, moderately sorted, angular		51
52	6480	99	<1	<1	Sandstone, gray, fine-medium, moderately sorted, angular		52
53	6600	99	0	<1	Sandstone, colourless, fine, well sorted, angular	Ferruginized sst	53
54	6720	99	<1	<1	Sandstone, gray, fine, well sorted, angular		54
55	6840	98	1	1	Sandstone, whitish, very fine-medium, well sorted, angular		55
56	6980	70	30	0	Shaly sandstone, brownish, very fine-medium, well sorted, angular		56
57	7120	80	20	0	Shaly sandstone, colourless, very fine-medium, well sorted, angular		57
58	7260	90	10	0	Shaly sandstone, colourless, fine, moderately sorted, sub-angular		58
59	7400	90	10	0	Shaly sandstone, colourless, very fine-medium, well sorted, angular		59
60	7540	80	20	0	Shaly sandstone, colourless, very fine-medium, well sorted, angular		60
61	7660	95	5	0	Sandstone, colourless, fine-medium, poorly sorted, angular	Coal, ferruginized sst	61
62	7780	80	20	0	Shaly sandstone, colourless, very fine, well sorted, angular		62
63	7900	95	5	0	Sandstone, colourless, very fine, well sorted, angular	Carbonaceous particles	63
64	8020	40	20	40	Heterolic, brownish, very fine, poorly sorted, angular	Ferruginized sst	64
65	8140	90	5	5	Sandstone, whitish, very fine, very well sorted, angular	Ferruginized sst	65
66	8260	50	50	0	Heterolic, brownish, very fine, poorly sorted, angular		66
67	8380	20	80	0	Sandy shale, dark gray		67
68	8500	1	99	0	Shale, dark gray		68
69	8620	90	9	1	Shaly sandstone, colourless, very fine, very well sorted, sub-angular		69
70	8740	80	20	0	Shaly sandstone, colourless, very fine, very well sorted, sub-angular		70
71	8860	1	95	4	Shale, dark gray		71
72	8980	2	98	0	Shale, dark gray		72
73	9100	80	20	0	Shaly sandstone, colourless, fine-coarse, poorly sorted, angular		73
74	9220	10	90	0	Shale, dark gray		74
75	9340	10	90	0	Shale, dark gray		75
76	9480	30	70	0	Shale, dark gray		76
77	9620	5	95	0	Shale, dark gray		77

78	9760	49	50	1	Heterolic, gray, very fine sst, very well sorted, sub-angular	78
79	9920	1	99	0	Shale, dark gray	79
80	10040	1	99	0	Shale, dark gray	80
81	10160	1	98	1	Shale, dark gray	81
82	10280	1	99	0	Shale, dark gray	82
83	10400	<1	99	<1	Shale, dark gray	83
84	10520	<1	99	<1	Shale, dark gray	84
85	10640	1	99	0	Shale, dark gray	85
86	10760	<1	99	0	Shale, dark gray	86
87	10880	<1	99	<1	Shale, dark gray	87
88	11000	1	99	0	Shale, dark gray	88
89	11120	2	97	1	Shale, dark gray	89
90	11240	1	98	<1	Shale, dark gray	90
91	11360	<1	99	<1	Shale, dark gray	91
92	11480	1	99	<1	Shale, dark gray	92
93	11600	1	99	0	Shale, dark gray	93
94	11720	<1	99	<1	Shale, dark gray	94
95	11840	<1	99	0	Shale, dark gray	95
96	11980	<1	99	0	Shale, dark gray	96
97	12120	2	98	0	Shale, dark gray	97
98	12260	2	98	0	Shale, dark gray	98
99	12380	<1	99	<1	Shale, dark gray	99
100	12580	5	95	0	Shale, dark gray	100

Coding:

1 Coarse sand stone
2 Medium/fine sand stone
3 Very fine sand stone
4 Shaly sand stone
5 Heterolic lithology
6 Sandy Shale
7 Shale

DTH DEPTH
SST SAND STONE
SHL SHALE
SLTS SILT STONE
LITH LITHOLOGY

ELE-1 Well samples displayed a lithologic section that is generally sandy at the top and the basal parts having intercalations of sand and shale lithologies. The sands range from very fine to coarse grained. The overall lithologic section suggests a lateral shifts of depositional environment from shallow to deep water environment (Lucas and Omodolor, 2018)

Biostratigraphic and Wireline Interpretations

A broad biostratigraphic framework was developed for the well with the MFSs determined based on biofacies abundance data with the associated sequences boundaries mapped. Wireline logs were used in conjunction with the biofacies data. Using an already established data of MFSs and SBs in the Niger Delta Basin as Portrayed in the Niger Delta Cenozoic Geological Data Chart (Fig. 3), the relative F and P zones and biofacies data of ELE-1 Well enabled the delineation of the MFSs and SBs in the well.

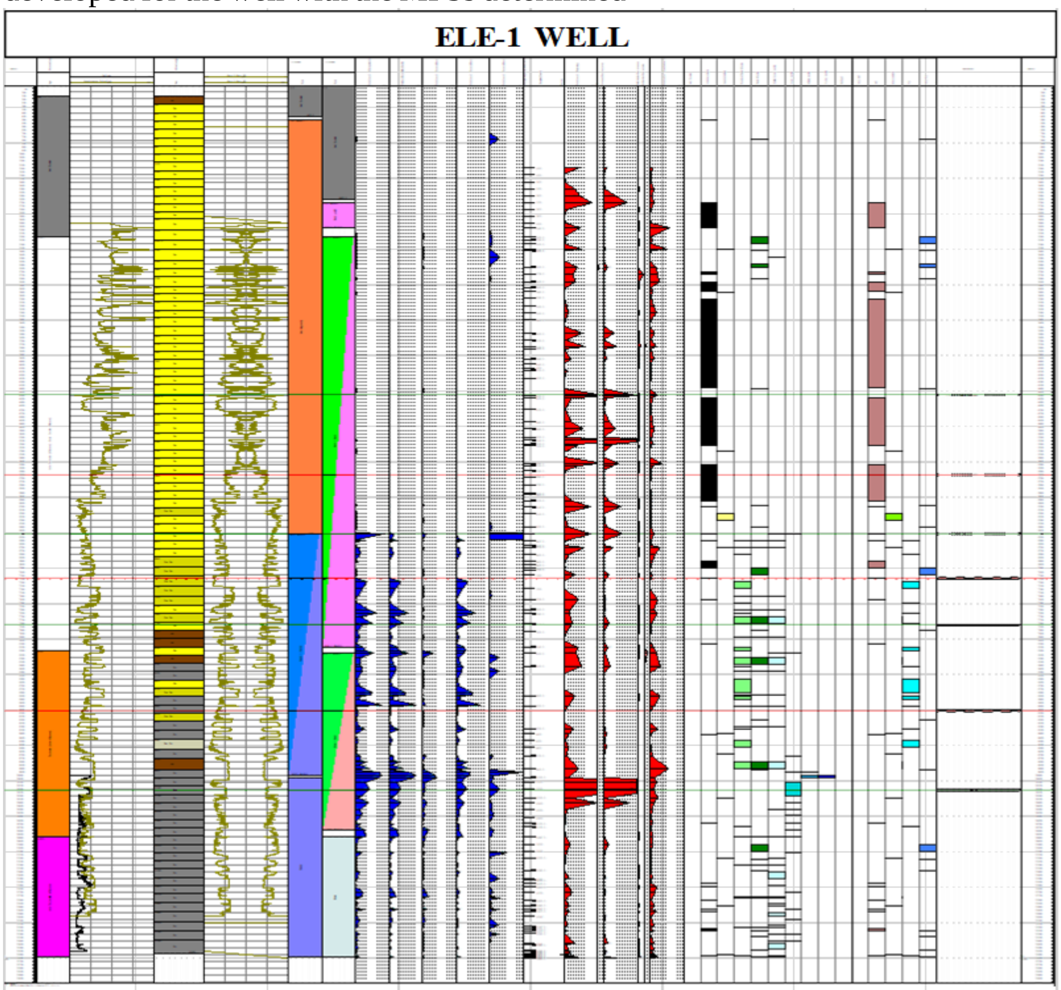

Figure 4: Stratabugs plot of ELE-1 Well composite interpretations. Showing the depth scale, wireline logs, interpreted lithologic section, F & P zones, biofacies abundance data and the stratigraphic surfaces (MFS & SB)

A broad biostratigraphic framework was developed for the ELE-1 Well with the MFSs determined based on biofacies abundance data with the associated sequence boundaries mapped. Wireline logs were used in conjunction with the biofacies data.

Using an already established data of Maximum Flooding Surfaces (MFSs) and Sequence Boundaries (SBs) in the Niger Delta as portrayed in the Niger Delta Cenozoic Chart, the relative F- and P- zones and biofacies data of ELE-1 Well resulted to the delineation of the MFSs and SBs in the well (Fig. 4).

The biofacies data for ELE-1 and the Spontaneous Potential (SP) log were imported into the StraraBugs software. Matching the biofacies data and wireline signatures against the Niger Delta Cenozoic Chronostratigraphic Chart, MFSs and SBs were determined.

The first MFS was picked at the depth of 4490ft. It was tied to the abundance peak of palynology data and substantiated by a landward deflection of the SP log. The MFS is attributed to the Bolivina 46 event at 5.0Ma. It occurs within the undifferentiated P870/P830 biozones.

The first SB was determined at depth of 5650ft based on absence of biofacies data, landward deflection of the SP log and matching it with the 5.6Ma SB of the Niger Delta Cenozoic chart. It also occurs within the undifferentiated P870/P830 biozones.

At the depth of 6500ft, the second MFS was picked based on the abundance peaks of both the foram and paly data. It was picked again within the P870/P830 biozones. The MFS was tied to the 6.0Ma Haplophragmoides 24 event of the Niger Delta Cenozoic Chart.

SB 6.7Ma was placed at the depth of 7150ft, as hinted by the low occurrence of microfossils and the landward shift of the SP log. This determination was matched against the Niger

Delta Cenozoic chart. It also occurs within the undifferentiated P870/P830 biozones.

The next stratigraphic surface, which is the 7.4Ma MFS was placed at depth of 7827ft. It also falls within the P870/P830 biozone. With the landward deflection of the SP log and absence of microfossils, the third sequence boundary was tied to the 8.5Ma. SB at 9063ft within the undifferentiated P820/P788 biozones. 9.5Ma Uvigerina 8 microfossils marked the fourth MFS in the well. It was defined at the depth of 10220ft. The wireline log signals show a thick condensed section. The biofacies data had high abundance counts at the depth and it fell within the undifferentiated P820/P788 biozones.

Based on the biostratigraphic data and sequence stratigraphic surfaces, ELE-1 is characterised by seven (7) lines of subdivision, depicting the alternating MFSs and SBs (Fig. 4).

CONCLUSION

This work has employed sedimentological analysis to produce lithologic section of ELE-1 Well; biostratigraphic interpretation was used to define the chronostratigraphic surfaces (Maximum Flooding Surfaces and Sequence Boundaries) which define the Third Order sequence. The litholgic sections give visual aspects of the well from shallow to deep water environments as the sediment type grades from sand to shaly lithologies. The biostratigraphic interpretation defined Maximum Flooding Surfaces and Sequence Boundaries based on microfossils abundance peaks and the signatures of the wireline logs, producing a characterization on chronostratigraphic lines of subdivision, which spells out the Third Order sequence. From the result, it is evident the tools used in this research for well based characterization are indispensable in detailed reservoir prediction in petroleum exploration.

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