Int. j. adv. multidisc. res. stud. 2025; 5(3):1346-1354

Received: 27-04-2025
Accepted: 07-06-2025

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Unraveling the Sequence Stratigraphic Architecture of Ogbo Field, Niger-Delta Basin, Nigeria Using Well Logs and Biostratigraphic Proxies

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DOI: https://doi.org/10.62225/2583049X.2025.5.3.4456
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Abstract
Ogbo Field, one of the prolific hydrocarbon field in the Niger Delta basin was studied for the purpose of delineation of the environment of deposition of sediments and reconstruction of sequence stratigraphic framework within the field. Methodology employed in this study include well logs and biostratigraphic analyses. Two major lithologies were identified in the field and consist of sandstone and shale. Sediment depositional environments varied from marginal marine (deltaic) to shallow marine. Five depositional sequences (SEQ.1, SEQ.2, SEQ.3, SEQ.4 and SEQ.5) bounded by five sequence boundaries (SB) and six maximum flooding surfaces (MFS) were identified in the sequences. The SBs dated 13.1Ma, 12.1Ma, 10.6Ma, 10.35Ma and 8.5Ma while the MFSs dated 15Ma, 12.8Ma, 11.5Ma, 10.4Ma, 9.5Ma and 7.4 Ma. The sequences were grouped into highstand system tracts (HST), transgressive system tracts (HST) and lowstand system tracts (LST), indicating aggrading, retrograding and prograding stratal stacking patterns respectively. The sandy unit was characterized by TST while HST dominated the shale zone.

Keywords: Environment, Sequence, Boundaries, Well Logs, Biostratigraphy, System Tract

1. Introduction

Sequence stratigraphy, a recent field in stratigraphy has been defined in many ways as; the study of rock relationships within a time-stratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities (Posamentier, 1988; Van wagoner, 1990) [28, 40]. Galloway (1989) [13] defined it as analysis of repetitive genetically related depositional units bounded in part by surfaces of non-deposition, whereas according to Catuneanu (2006) [4], it is the analysis of the sedimentary response to changes in base level and the depositional trends that emerge from the interplay of accommodation and sedimentation.

Sequence stratigraphy is a stratigraphic approach that allows the identification of packages of strata that were deposited during similar conditions of accommodation change in relation to sediment supply and the key stratigraphic surface that bound them (Davies, 2019) [7]. Sequence stratigraphy supports the contention that the sedimentary record of earth's crust is the product of uniform and common physical processes that interact with sediments as they accumulate (Catuneanu, 2011). Thus, it is a very useful tool in developing a correlation framework within a sedimentary basin (Embrey, 2009) [11] on both local and regional scale. Sequence stratigraphic techniques permit the integration of a range of desperate geologic data set (e.g seismic, well logs, outcrop, biostratigraphy, geochemical e.t.c) (Catuneau, 2006; Catuuneau, 2009; Davies, 2019) [4, 5, 7]. Thus, it is an effective tool in evaluating reservoirs system continuity and trend of deposition as well as in the prediction of reservoir system source (Van wagoner et.al, 1990) [40]. The concept of sequence stratigraphy has been successfully applied to petroleum exploration in the world.

Niger Delta Basin is the seventh most prolific petroleum province in the world with average oil production of about 1.8 Million barrels per day (Doust and Omatsola, 1990) [9]. Nwajide (2022) described it as one of the major hydrocarbon provinces of the world, with ultimate recovery presently estimated at close to 40 million barrels, with gas estimation of over 40 trillion cubic feet reserves. Tuttle *et al*. (1999) [39] gave a gas estimate of over 93 trillion cubic feet. Niger Delta has been defined as the Cenozoic gross off flap clastic succession that form part of the western African geosyncline which spread out into the cooling and subsiding oceanic crust generated as African and south American Lithospheric plates separated (Whiteman, 1982; Wright, 1985; Nwajide, 2013) [41, 42, 22]. For a better understanding of the offshore sedimentary basin of Niger Delta, the application of sequence stratigraphy will help to enhance the geographic control and correlation of world pattern of sea level changes (Payton, 1977) [24]. This method facilitates the identification of major progradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation. High resolution biostratigraphic data will be integrated with well logs and seismic data in this research to unravel the internal stratal architecture of ogbo field, Niger Delta Basin. Niger Delta porous and permeable sediments have the enabling condition for generation of hydrocarbon with its complex structures like faults, and diaprism, which makes it an enabling environment for hydrocarbon to be trapped and generated, be it primary generation or secondary recovery of hydrocarbon which migrates into these traps (Mitchium, 1997). Thus, sequence stratigraphy is required in other to delineate these structural complications and enhance the production and secondary recovery of hydrocarbon in the field.

Niger delta is characterized by complex depositional environments such as fluvial, deltaic and marine which can complicate the identification of boundaries and system tracts.. High frequency parasequences which are composed of laterally and vertically continuous shale and sandstones that have laterally and vertically variable reservoir quality and continuity can have major effect on reservoir performance. Stratigraphic causes of poor recovery through improved understanding of internal stratal architecture can lead to new well recompletion and enhance exploitation in such fields. Hence, Ogbo field which is no longer producing commercially viable petroleum need sequence stratigraphic investigation to enhance its hydrocarbon recovery. In addressing these problems, an advanced modeling techniques and integrated approach that combine well logs and biostratigraphy approach is required to refine stratigraphic interpretation.

Geology of the study area

The Niger Delta Basin is characterized by a complex and extensive lithostratigraphy that reflects its geological history, including the deposition of sediments from various sources over millions of years. The lithostratigraphy of the Niger Delta Basin typically comprises several key lithostratigraphic units or formations, each with its own distinctive lithological characteristics. The stratigraphic sequence comprises of three broads subsurface lithostratigraphic units namely (from the oldest);

1. A basal marine shale unit -The Akata Formation (Paleocene) is typically the basal lithostratigraphic unit in the lithostratigraphy of the Niger Delta. It consists of predominantly shale and mudstone and serves as the primary source rock for hydrocarbons.
2. A crustal marine sequence of alternating sand and shales – (the Agbada Formation) (Eocene). This formation overlies the Akata Formation and consists of a diverse range of lithologies. It includes sandstones, shales, siltstones, and conglomerates. Within the Agbada Formation, reservoir-quality sandstones are often found, making it a critical unit for hydrocarbon exploration
3. A continental shallow marine sand sequence The Benin Formation (Oligocene). This Formation is typically the uppermost unit in the Niger Delta lithostratigraphy. It is primarily composed of unconsolidated and poorly sorted sands. The Benin Formation often forms the uppermost cap rock for hydrocarbon reservoirs in the underlying Agbada Formation.

The Akata Formation

The Akata Formation is Paleocene in age. It primarily consists of shale and mudstone deposits. It is characterized by organic-rich, fine-grained sediments (Doust, & Omatsola, (1990) [9]. The formation is believed to have been deposited in a deep marine environment during periods of sea-level rise and in anoxic condition (Reijers, 1997). It represents a transition from deltaic and shallow marine conditions to deeper offshore settings. The Akata Formation is rich in organic material, making it a source rock for hydrocarbons in the Niger Delta. This formation is estimated to be up to 7,000 meters thick. The thickness of the Akata Formation can vary across different parts of the Niger Delta Basin.

The Agbada Formation

The Agbada Formation is characterized by a diverse range of lithologies, including sandstones, shales, siltstones, and conglomerates. Sandstone intervals are particularly important as hydrocarbon reservoirs. Sandstone beds within the Agbada Formation often exhibit good reservoir properties, making them highly sought after for hydrocarbon exploration and production. The thickness of the Agbada Formation can vary significantly across different parts of the Niger Delta Basin. (Reijers, 1997) The Agbada Formation is of great significance to the petroleum industry, as it contains reservoir-quality sandstones that host substantial hydrocarbon reserves in the Niger Delta. It is estimated to be 13,000 feet thick (Doust and Omatsola, 1989) [8].

The Benin Formation

The Benin Formation consists of unconsolidated and poorly sorted sands. It is predominantly composed of sandstones with some interbedded shales and siltstones. The Benin Formation is often recognized as the uppermost cap rock for hydrocarbon reservoirs in the underlying Agbada Formation. The Benin Formation plays a critical role in hydrocarbon exploration, particularly as a cap rock, and is an essential part of the lithostratigraphy in the Niger Delta. It is estimated to be up to 2,000 meters thick (Short and Stauble, 1967) [36].

These subsurface lithostratigraphic units are complemented with their outcropping surface equivalents which includes; The facies of the Ameki Group conformably overlie the Imo Formation and contains three stratigraphic components: The Ameki Formation, the Nanka Formation and the Nsugbe Formation (Fig 1), which pinch out in both westwards and eastwards (Nwajide, 1980, 2013 [22]). The Imo Formation is the mappable equivalents of the Akata Formation and the Ameki Group and Ogwashi Formation are the mappable equivalents of the Agbada Formation of the subsurface stratigraphic units of the Niger delta (Short and Stauble, 1967) [36] (Fig 1). The Imo Formation is the oldest stratigraphic unit in the outcropping part of the Niger Delta Basin (Short and Stauble, 1967 [36]; Petters, 1991) and is composed of blue-grey shales with sand lenses, marl and fossiliferous limestones (Reyment 1965; Short and Stauble, 1967; Nwajide, 2013) [33, 36, 22]. The Ameki Formation is estimated to range from 1200 – 1500 m thick, and comprises mainly of sands, minor silt with thin shelly limestone and calcareous clay intercalations (Reyment, 1965; Nwajide, 2013) [33, 22]. The Nanka Formation is estimated at 305 m thickness, is mainly sands and minor calcareous clay/mud with heterolith (Nwajide, 1980, 2013 [22]; Ekwenye *et al.*, 2014 [10]). The Nsugbe Formation is predominantly sands with some conglomerate bands, estimated to be about 100 m thick (Nwajide, 2013) [22]. The Ogwashi Formation comprises alternating coarse sands, silts, and clays with thin to thick lignite seams (Kogbe, 1976; Nwajide, 2013 [22]).

The Benin Formation: The Benin Formation which is the youngest stratigraphic unit of the Niger Delta Basin (Short and Stauble, 1967) [36] The Benin Formation exists in both outcrops and the subsurface (Fig 2) and occupies an extensive area of southern Nigeria (Reyment, 1965; Short and Stauble, 1967; Nwajide, 2013) [33, 36, 22]. The stratigraphic succession of the Niger Delta is presented as Fig 2.

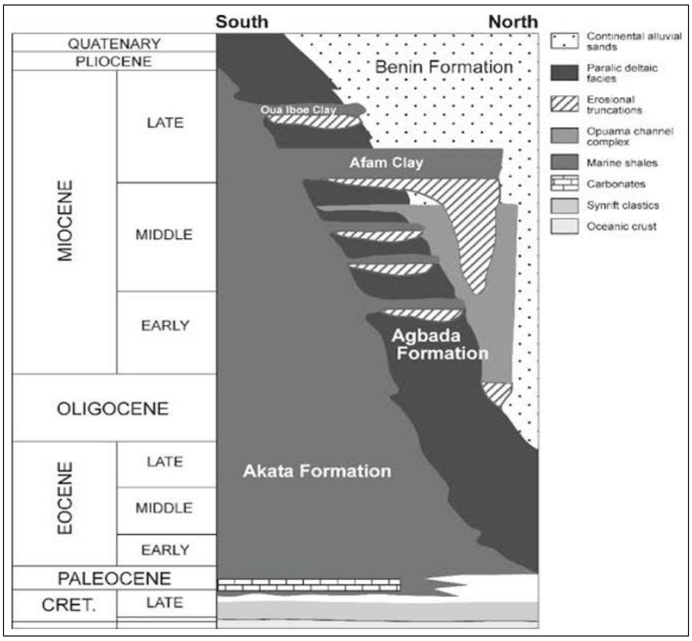


Fig 1: The regional Stratigraphic column of the Niger Delta Basin shows the three major units in the Delta (Akata, Agbada, and Benin formations) (Doust and Omatsola 1990) [9].

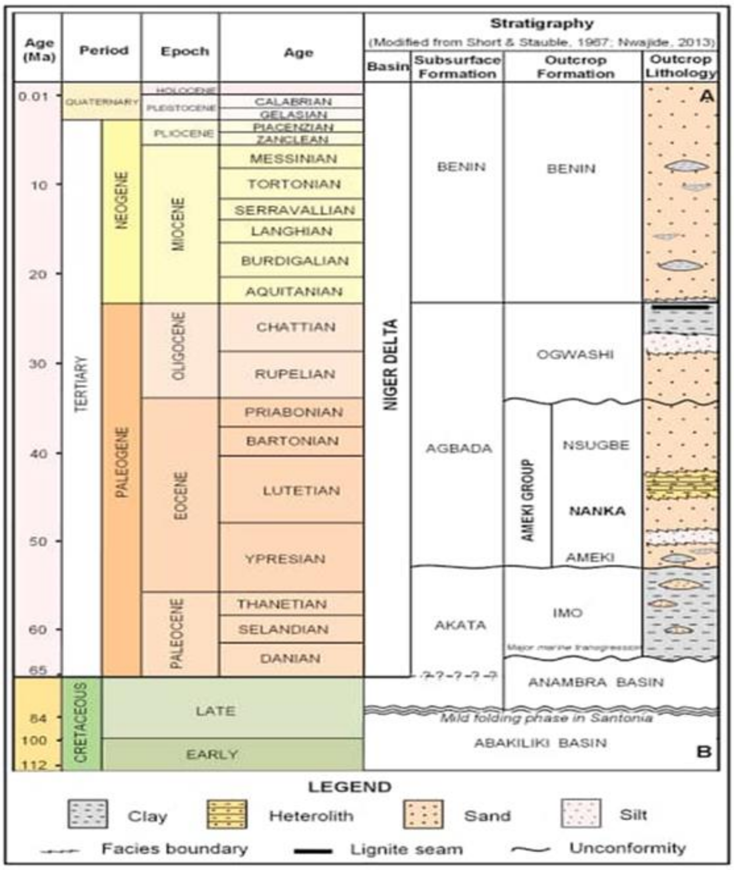


Fig 2: Stratigraphic Succession of Niger Delta Basin (redrawn and modified from Short and Stauble, 1967 [36]; Nwajide, 2005)

2. Materials and Method

Materials/ Data Set

The data set for this study was made available by Shell Petroleum Development Company (SPDC), Port Harcourt, Nigeria. The data consists fifteen wells with full log suites, check shot data for eleven wells and biostratigraphic data for one well (Table 1). The biostratigraphic data is shown in Table 2.

Well data

Fifteen (15) wells were used in this study to integrate seismic and well-log data. The well data that were used in this study include full well-log suites (including gamma ray, resistivity, sonic, density and neutron), check shots data for five wells, and biostratigraphic data for two wells (Table 1). Biostratigraphic data includes the foraminiferal and palynological zones extracted from side-wall samples and ditch-cuttings which were depth calibrated with corresponding well logs. The population and diversity peaks of the benthic and planktonic foraminifera were used for age calibration and paleobathymetric interpretation (Table 2).

Table 1: Display of well data showing available log suites for the wells

Well Name	Surface X	Surface Y	MD (FT)	Elevation (ft)	GR (API)	ILD (Ohm-m)	DT (µs/ft)	RHOB (g/cm3)	NPHI (ft/ft)	Checkshot	Biostrat
Ogbo-1	434726.49	98143.24	11400.00	47.90	Y	Y	Y	Y	Y	Y	Y
Ogbo-3	433451.38	98840.47	12060.00	43.64	Y	Y	Y	Y	Y	Y	N
Ogbo-6	434949.60	96804.05	11910.00	46.59	Y	Y	N	N	Y	Y	N
Ogbo-7	435573.15	98522.97	11970.00	44.95	Y	Y	N	N	Y	N	N
Ogbo-10	435609.32	96209.51	12000.00	36.16	Y	Y	N	N	Y	Y	N
Ogbo-12	436805.81	96636.02	12000.00	33.79	Y	Y	Y	N	N	Y	N
Ogbo-15	433147.54	95720.77	11950.00	38.29	Y	Y	Y	Y	N	Y	N
Ogbo-19	435396.36	99170.46	12100.00	41.00	Y	Y	Y	Y	N	Y	N
Ogbo-24	431257.40	96216.07	11880.00	36.91	Y	Y	Y	Y	Y	Y	N
Ogbo-25	434848.55	95806.92	12050.00	40.04	Y	Y	Y	N	Y	N	N
Ogbo-30	436413.26	95704.25	12310.00	36.68	Y	Y	N	N	N	Y	N
Ogbo-31	434608.46	99740.05	8344.00	39.80	Y	Y	N	N	N	Y	N
Ogbo-33	438293.95	97960.32	12490.00	36.81	Y	Y	N	Y	Y	N	N
Ogbo-34	437765.51	96618.36	12143.00	36.42	Y	Y	Y	Y	N	N	N
Ogbo-35	432567.79	99257.82	12284.00	35.86	Y	Y	Y	Y	Y	Y	N

Y = available, N = not available

GR (Gamma Ray log), DT (Sonic log), LLD & LLS (Resistivity logs), NPHI (Neutron log), RHOB (Density log).

Table 2: The biostratigraphic zonation for Ogbo-1 well

Well Name	Top Depth (ft)	Base Depth (ft)	Zone Type	Zone Code	Quality	Remarks
Ogbo-1	0	450				No Data
Ogbo-1	0	6070				No Data
Ogbo-1	500	5400				Barren
Ogbo-1	5600	7200	F	F9500/F9600		
Ogbo-1	6080	6100	P	P770	2	occurrence of 440
Ogbo-1	6179	7800	P	P750	1	t.r.320
Ogbo-1	10000	10000	F	F9540	1	Bol.25 Uvigerina 5

Methodology

The sequence stratigraphy of the Ogbo Field, in Greater Ugheli Depobelt, Niger Delta Basin, Nigeria was interpreted with well logs and biostratigraphic data. Interpretation of the well logs was done using Schlumberger's Petrel interpretation software. The packages that were used included all available tools for well data interpretation.

Well Log Conditioning (Normalization)

Well logs are result of physical measurements of the earth properties taken within the confined space of a borehole. Sometimes, the measurements are subject to borehole irregularities and lapses of time between drilling and logging of the hole and this need to be corrected to have a quality data for efficient geological interpretation. The well log editing was carried out using LOG MATH in E-LOG program where various editing mechanism such as median filtering, depth shift splice, and block were applied to the well logs prior to data analysis. The idea is to obtain consistent and accurate logs from well to well.

The dispersion and median filtering corrections were applied to account for differences in frequencies between logging tools, surface seismic reflection data which minimize errors arising from wellbore washouts, casing points, mud filtrate invasion, gaps, missing data or insufficient log suites. The median Filtering corrections on the logs were carried out by simply creating or overwriting a log from an existing log by applying a median filter with a user defined operator length of n. It smoothens the logs and removes the high frequency noise.

However, in splice corrections, I created or overwrite a log by copying one existing log to another existing log. Therefore, before splicing, few precautions were undertaken and these include but not limited to environmental corrections, editing and compatibility of the units of the wellbeing spliced. It is also important to avoid auto splicing routines and use of generic log names common to spliced logs. In this study, we created a model that illustrates how we could overwrite a log by copying one existing log to another existing log.

Well-log Interpretation

Data used for the interpretation comprise gamma ray logs with counts measured on the horizontal scale from 0 to 150 calibrated in standard American Petroleum Institute (API). A baseline of 65 API was chosen to discriminate between sands and shales. The gamma ray facies cut off that will be applied in this study include 0 - 65 API representing sandstone facies, 65 – 75 API representing siltstone facies and >75 API representing shale facies. The approach adopted for the sequence stratigraphic analysis include the identification of important key stratigraphic surfaces was based on the integration of well logs, biostratigraphic (Foraminifera and Palynological) data and the Chronostratigraphic chart of the Niger Delta Basin updated by Shell Petroleum Development Company (SPDC). The stratigraphic surfaces comprising Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB) identified were used to subdivide the stratigraphic architecture of the field into 3rd Order Sequences using the Galloway (1989) [13] genetic sequence model (Fig 5). The stratigraphic surfaces were dated using the Niger Delta Basin Chronostratigraphic Chart. The stratigraphic surfaces were identified based on several criteria comprising the peak of fossil population and diversity, the pattern of stratal contact with the identified stratigraphic surfaces and their depositional stacking patterns (Fig 6). The individual interpretations for each well were correlated across all available wells to reveal the lateral variations of the lithologies, stratigraphic packages and depositional environments.

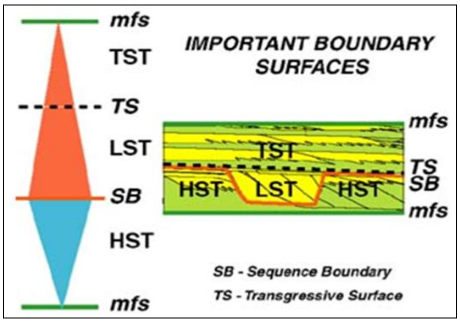


Fig 3: Illustration of the Galloway (1989) [13] genetic sequence model used in interpreting the stratigraphic sequence of the Ogbo 1 Field (Modified from Kendall, 2004). MFS = Maximum Flooding Surface, TST = Transgressive System Tract, HST = Highstand System Tract, LST = Lowstand System Tract

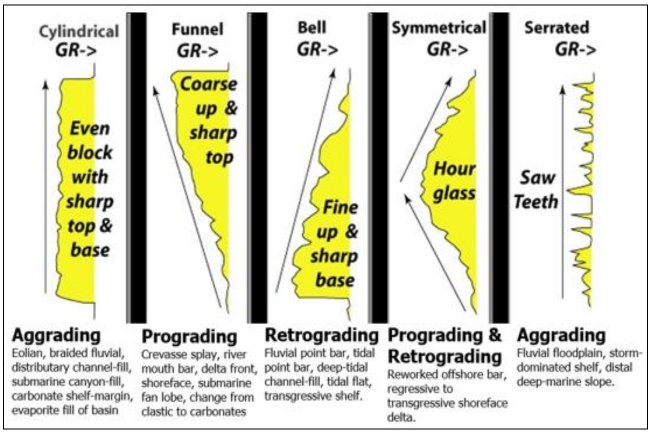


Fig 4: General gamma ray response to parasequence stacking patterns (Rider, 1990)

3. Results and Discussion

Data Enhancement

Fig. 5 and 6 show the uncorrected and corrected median frequency spike data respectively. Fig 5: Shows a sharp peak in frequency distribution and ununiform distribution of values such as radioactive values and this was denoted by thick signals. The spike was due to measurement noise, instrumental noise, thin shale beds and radioactive mineral deposits. Fig 6 shows the corrected median frequency spike which was done by filtering, smoothing, statistic adjustment and normalization to remove errors and also provide a more accurate representation of subsurface properties. The filtering and smoothing reduces the sudden and unrealistic spikes, the adjusting of data remove the outliers that causes unnatural peaks while normalization scales the resistivity values to a standard range to ensure consistency of the data. The corrected median frequency in Fig 6 have a lighter signals and smooth curve which shows that the spikes due to noise are removed and the peaks are now more accurate.

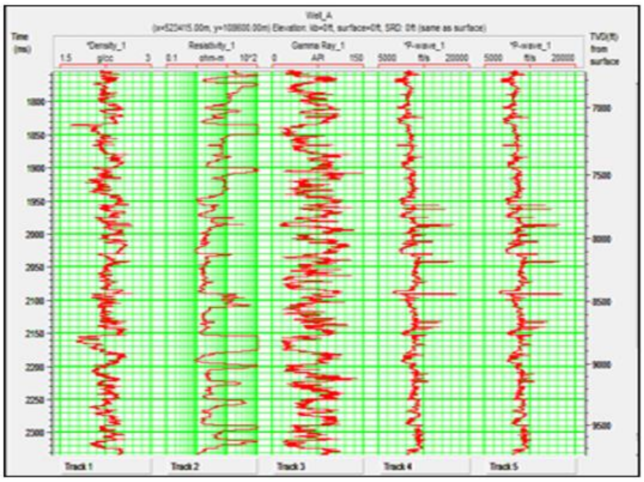


Fig 5: The Ogbo with high frequency spikes (uncorrected logs)

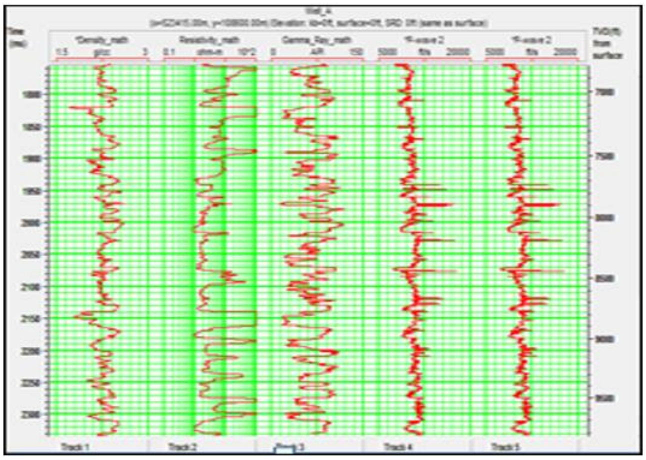


Fig 6: The Median corrected Ogbo with despiked frequency

The log to copy from was Resistivity log while log designated for repalcement was gamma ray log. The blue curve is the splice from the resistivity log while the interwined red and green curves are the overlay of the splice to gamma ray logs.

Reservoir Identification

The reservoir identification was carried out using geological and petrophysical methods. Different horizons were marked based on the well tops recognized from petrophysical analysis of well logs. The horizon tops and bases were identified using gamma-ray and resistivity logs which were also linked with other six wells. Two major lithologies identified are shale color coded with black and sandstone color coded with yellow. The results further revealed that each of the identified horizons (sand unit) spreads over the field with varying thicknesses. However, some horizons occurring at greater depth than their adjacent unit which is possibly an evidence of faulting. The sand layers were observed to decrease with depth along with a corresponding increase in shale layers at the base. The resistivity logs which reveals the presence of hydrocarbons were used to identify the hydrocarbon bearing sands. Furthermore, nine major sand bodies (1,2,3,4,5,6,7, 8 and 9) were identified and correlated across all the eight wells in the field. Three bigger reservoir sands were selected for the purpose of this study.

Fig, 12 presents the varying Lithologies, parasequence, systems tract and sequence analysis of the study area.

The results revealed five major sequence boundaries (SEO.1, SEO.2, SEO.3, SEO.4, and SEO.5), with each sequence showing distinctive maximum flooding surface (MFS). The key bounding surfaces identified in the study area are the MFS and SB with their corresponding depths. The Niger Delta Chronostratigraphic chart aided in this identification and is also used in dating the key surfaces. The MFSs are categorized by dense and widespread mudstone components identified by high gamma-ray value and lowest resistivity readings. The biostratigraphic interpretation was focused on the identification of major faunal abundance and diversity peaks, which coincide with maximum flooding surfaces, while faunal abundance and diversity minima correspond to sequence boundaries. The recognized sequence boundaries were considered by significant sand unit and low gamma ray value (Fig 8). It is the interval separating the overlying shallow microfacies from underlying deep-water facies with minimal biofacies abundance and diversity. The bounded sequences revealed a retrograding, aggrading and prograding character. The interpreted hydrocarbon bearing reservoirs occur within the sands of the transgressive system tract. while high stand system tracts dominate in the shale zones.

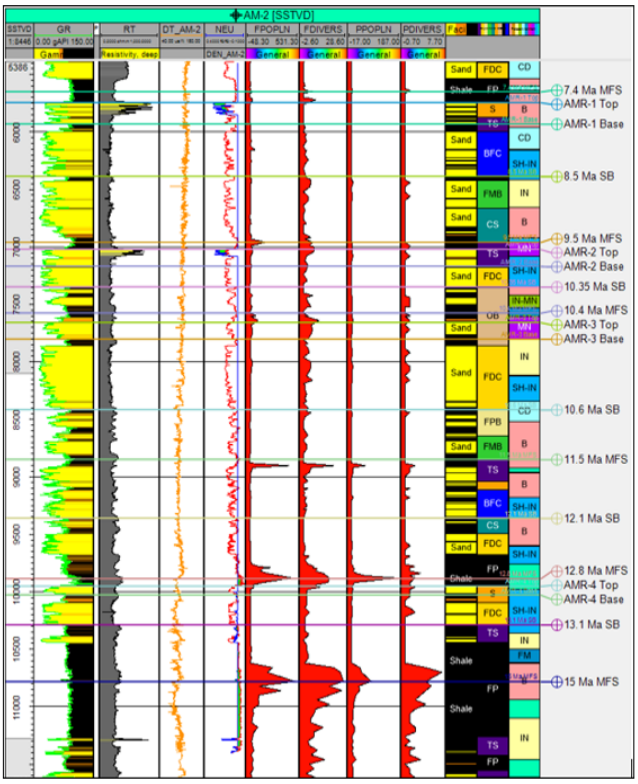


Fig 7: Presents Lithofacies and Well-Log Sequence Stratigraphic Analysis

Stratigraphic Analysis and Correlation

Five depositional sequences were identified across the correlated wells which were further divided into para-sequences and their associated systems tracts, namely Highstand systems tract (HST), Lowstand system tracts and Transgressive systems tract (TST). TST often assume a position of middle systems tract in an ideal depositional sequence which develops as a result of an increase in the rate of sea-level rise. In this system tract, retrogradational Parasequence dominates and this occurs at depth intervals: 11379ff – 10860ft, 10000ft – 9500ft, 8850-8000ft, 8500ft-70500ft.

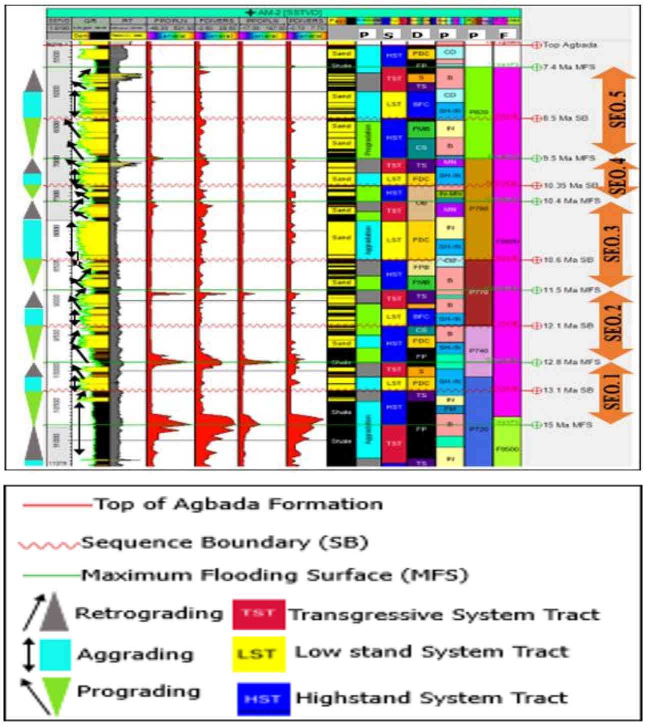


Fig 8: Lithology, Parasequence, systems tract and sequence analysis of Ogbo

On the other hand, the highstand systems tract (HST) represents the uppermost unit of a depositional sequence according to Mitchum *et al.*, 1993. It is characterized by early gradational to later progradational Para sequence sets. In the studied well, HST occurs at the depth intervals of 10750ft-10250ft, 9750ft-9250ft, 8750ft-8250ft, 7750ft-7250ft and 5780ft-5250ft. The highstand and transgressive systems tracts recognized in the studied well suggest that the wells are updipping wells. Each systems tract was deposited at a predictable position in an interpreted base level cycle caused by eustacy and has recognizable signature on well logs. The Lowstand systems tract (LST) which also occurs at the interval of 1025ft-1050ft, 9250ft-9050ft, 8250ft-8050ft, 7250ft-7050ft and 6250ft-6000ft includes deposits that accumulate after the onset of relative sea level rise which lies directly on the upper surface of the falling stage systems tract and is capped by the transgressive surface formed when the sediments onlap onto the shelf margin. The Five depositional sequences (SQ1-SQ5) were demarcated with six maximum flooding surfaces and five sequence boundaries. The depositional sequence 1 starts at the depth interval of 11379ff-10250ft with total thickness of 1129ft. The interval is bounded by SB 15ma and SB 13.1ma which falls within the 3rd order cycle based on the identification of the unit boundaries. Here, the interval of the transgressive systems track shows a retrogradational parasequence pattern consisting dominantly of pelagic shale with some transgressive sand sediments and terminate at maximum abundance and diversity of foraminiferal assemblages called the maximum flooding surface (MFS) at depth of 10750ft dated 15ma. The overlying HST interval consist of shale unit at the base and progressively into a progradational stacking pattern with sand increasing upwards to terminate at the base of cylindrical log shape marking the sequence boundary at 10750ft ft. dated 13.1 Ma. Fig 10 showed the detailed behavior of the sediments and their potential depositional environments. In depositional Sequence 2, the interval falls between SB 13.1 and SB 12.1 Ma which is of the 3rd order cycle based on the identification of the unit boundaries. The depositional sequence showed three distinct system tracts with low stand system tract at the base.

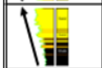
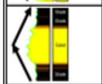
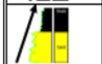
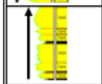
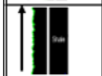
GR Log Shape and Facies	Description	Interpreted Depositional Environment	Paleobathymetry
	Retrograding: bell shape, finning upward sequence with serrated pattern.	Transgressive shelf (TS)	Shallow Neritic - Bathyal
	Prograding: funnel shape, coarsening upward sequences with serrated pattern	Crevasse splay and shoreface (CS & S)	Inner Neritic
	Aggrading: blocky shape, abrupt top and base sequences	Fluvial distributary channel (FDC)	Shallow Inner Neritic
	Prograding & Retrograding: symmetrical shape, coarsening upward changing to finning upward sequence	Offshore bar (OB)	Middle Neritic - Bathyal
	Retrograding: bell shape, finning upward sequence with clean pattern.	Fluvial point bar (FPB)	Coastal Deltaic
	Aggrading: blocky shape, abrupt top and base sequences with serrated pattern with sand/shale intercalation	Braided fluvial channel (BFC)	Coastal Deltaic – Shallow Inner Neritic
	Aggrading: serrated shape	Fluvial floodplain (FP)	Fluvio Marine - Bathyal
	Prograding: funnel shape, coarsening upward sequences with clean pattern	Fluvial mouth bar (FMB)	Inner Neritic - Bathyal

Fig 9: Detailed chart showing behavior of the sediments and their potential depositional environments

With a starting depth interval of 10250ft and the end depth interval of 1050ft. This was followed by the overlying TST interval (1050ft-9900Ft) a middle system track of both type 1 and type 2 sequences which consists of the deposits accumulated from the onset of coastal transgression until the time of maximum transgression of the coast, just prior to renewed regression. The sequence terminates at the 12.8ma MFS which formed the base of the overlying HST interval (9900ft). The HST consist of sand and shale intercalations with sand increasing upwards to terminate at base of cylindrical log shape marking the sequence boundary at the depth interval of 9500ft dated 12.1ma.

Similarly, in depositional Sequence 3 (9300ft-8400ft), the deposition episode starts at the depth of 9300ft and ends at 8400ft with total thickness of about 400ft. like depositional Sequence 2, the results showed three distinct system tracts with low stand system tract at the base (9400ft-9300) followed by the overlying TST interval (9050ft-8800ft) which terminates at 11.5ma MFS. The interval of the transgressive systems track starts with a progradational stacking pattern that finally shows a retrogradational parasequence pattern consisting dominantly of pelagic shale. This was also capped by High Stand System tract (HST) (8800ft-8300Ft) that terminate at depth interval of 8300Ft that dated 10.6ma at sequence boundary. Generally, the HST occur during the late stage of base level rise especially when the rate of sea level rise drops below the sedimentation rate. As shown in the depositional sequences so far, they bounded by maximum flooding surface at the base and composite surface at the top. In depositional Sequence 4, the sequence episode of deposition starts at depth of 7300ft and terminates at depth interval of 6400ft. The interval falls between SB 10.35ma and SB 8.1ma which is of the 3rd order cycle based on the identification of the unit boundaries. After the interval of Low Stand system tract at the base, the interval of the transgressive systems track starts witha progradational stacking pattern that terminate at the maximum flooding surface of 9.5ma. This was capped with High Stand System Tract (HST) interval that terminate at 8.5ma SB with a progradational stacking pattern consist of sand and shale intercalations with sand increasing upwards.

In the depositional sequence 5, the sediment deposit episode at depth interval of 8400ft and terminate at 5270ft. This interval falls between 8.5ma SB and undefined point with low stand system tract at the base. This is the youngest depositional sequence. The interval of the transgressive systems track is capped by the maximum flooding surface at 5600 ft. dated 7.5 Ma. The overlying HST interval (5600ft. - 5270 ft.) is capped by the top of Agbada.

However, to have more regional view, we present a regional correlation of the stratigraphic sequence along depositional dip and petroleum system elements distribution across the study area along depositional dip. In stratigraphic correlation, the results establish the age of sedimentary strata in different geographical areas in the study area by analyzing their stratigraphic relationship. In this, we create a chronological profile of an entire geologic time period by piecing together information from widely separated rock outcrops which continually exhibit the tempo spatial facies variations within third-order depositional sequences.

Depositional Environments

The faunal distribution deposits found in the shale sediments is as a result of maximum flooding surfaces which suggested the paleoenvironment of deposition to be a marine environment characterized by deep water sedimentation due to gravitational flows and high deposition of turbidity currents. However, in the other hand, the sand sediments bounded by sequence boundaries indicate a deltaic environment of deposition which is as a result of depositional process of fluvial and distributary channels (Fig 9).

Age of the Sequence

Using the Niger Delta Basin chronostratigraphic chart, the interpreted sequences range in age from Middle Miocene to Late Miocene (15 Ma - 7.4 Ma).

Petroleum System Elements

The petroleum system elements distribution across the study area along depositional dip, will determine the regions that have the right conditions to produce hydrocarbon. The results present the schematic cross section showing the source rocks (shale) that generate hydrocarbons as indicated in grey color with 50% abundance, the reservoir (sand) that stores the hydrocarbon as indicated in yellow color with 50% abundance, growth faults and rollover anticlines which serves as traps and shows the geometric arrangement of reservoir. The Shale seal rocks that allow hydrocarbon to accumulate and primary and secondary migration through faults and fractures. The prospect of finding an accumulation of natural gas or oil in an area depends on satisfactory coefficient of the above factors in the subsurface.

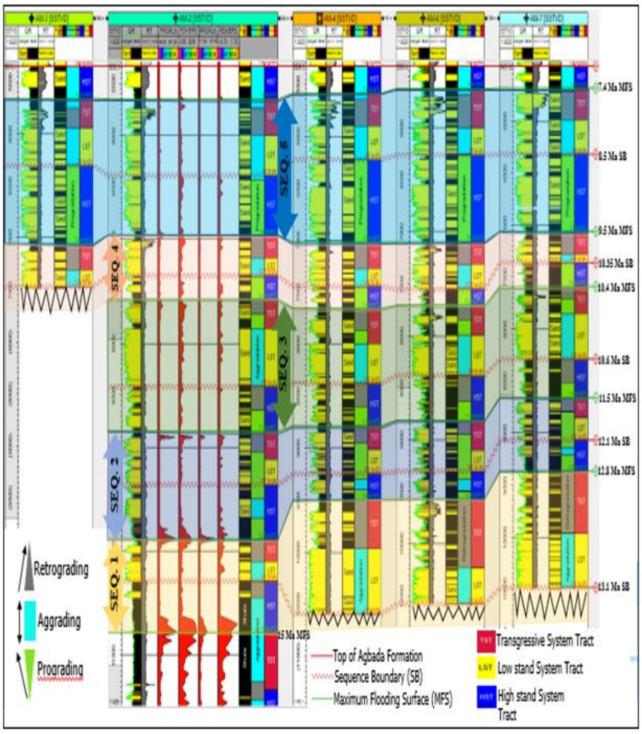


Fig 10: Regional correlation of the stratigraphic sequence along depositional dip

4. Conclusion

This work provides a comprehensive framework for understanding sequence stratigraphy,reservoir distribution and hydrocarbon migration pathway using this combined approach of well log and biostratigraphic data. Ogbo field is influenced by relative sea-level changes and sediment supply. Five sequence boundaries (SEO.1,SEO.2,SEO.3,SEO.4 and SEO.5) were identified with each sequence showing distinctive maximum flooding surface (MFS). The MFSs are categorized by dense and widespread mudstone components identified by high gamma-ray and lowest resistivity reading. The bounded sequences revealed a retrograding, aggrading and programming character. The interpreted hydrocarbon reservoirs occur within the sands of the transgressive system tract while the high stand system tracts dominate in the shale zone. The biostratigraphic result shows the faunal distribution in Ogbo field which coincide with the maximum flooding surfaces and diversity minima correspond to sequence boundaries. Wiith Niger Delta chronostratigraphic chart, the age of the field was identified to be Miocene in age.

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