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Sequence Stratigraphic Interpretation of Gabo Field, Onshore Niger Delta, Nigeria

Belema F. Jamabo[1], Godwin J. Udom[2], Godwin O. Emujakporue[3], Monday U. Udoh[4]

[1](World Bank Centre of Excellence for Oil Field Research, University of Port Harcourt, Port Harcourt.
Email: belemaj@gmail.com)

[2](Department of Geology, University of Port Harcourt, Port Harcourt.
Email: godwin.udom@uniport.edu.ng)

[3](Department of Physics, University of Port Harcourt, Port Harcourt.
Email: owin20009@yahoo.com)

[4](Pioneer-Alfa Petroleum Ltd, Benin City, Edo State
Email: monday.udofia@pioneeralfa.com)

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Abstract:

The sequence stratigraphic interpretation of Gabo Field located in the Central Swamp depobelt area of the Niger Delta Basin has been carried out. Well logs and biostratigraphic datasets integration helped in the identification of five major maximum flooding surfaces (MFS_1, MFS_2, MFS_3, MFS_4, MFS_5) recognized between the intervals of 2423-2084ft with an age range from 20.7Ma -15.0Ma. Conversely, five sequence boundaries (SB_1, SB_2, SB_3, SB_4, SB_5) were identified based on intervals that experience reduction in faunal abundance. Their ages are between 21.8Ma and 15.5Ma. Four depositional cycles (sequences) comprising of transgressive systems tracts (TST) and highstand systems tracts were also identified. The sequences depict that the sediments within this well were deposited within a Coastal- Outer Neritic paleo-water depth. A combination of the coarsenng upward reservoir sands of the highstand systems tract (HST) and the retrogradational shale units of the transgressive systems tracts form good stratigraphic traps for hydrocarbon exploration and production.

Keywords **—Sequence Stratigraphy, Systems tracts, Depositional sequences, Maximum flooding surfaces, Sequence boundaries.**

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I. INTRODUCTION

The Niger Delta hydrocarbon bearing fields are characterized by multiple heterogenous reservoirs stacked over intervals of 10,000ft thickness. Therefore, the ability to understand the chemical and physical properties of the earth is essential for detailed study of the subsurface and its constituents especially hydrocarbon.

Sequence Stratigraphic analyzes the sedimentary response to changes in base level and the depositional trends that emerge from the interplay of sedimentation and accommodation {1}. Sequence stratigraphic interpretation can be used to develop more accurate surfaces for mapping and correlating facies; predict reservoir, source and sealing facies; identify stratigraphic traps; and project reservoir trends into areas with limited data. It provides a framework for the elements of any depositional setting, facilitating paleographic reconstruction and the prediction of facies and lithologies away from control points. The main tool used in sequence stratigraphic interpretation is the stacking pattern of strata and the key surfaces that bound successions which are defined by different stratal stacking patterns. A sequence stratigraphic framework consists of three different types of stratigraphic unit, namely sequences, systems tracts and parasequences. Each type of this unit is defined by specific stratal stacking patterns and bounding surfaces. Unlike the analytical stratigraphic methods of lithostratigraphy and biostratigraphy that involve subdivision as objectively free of interpretation as possible, sequence stratigraphy is a genetically-based analytical approach to stratigraphic interpretation that of necessity involves conceptual depositional models.

Sequence stratigraphy has been applied in several sedimentary basins of the world, leading to the discovery and recovery of more hydrocarbaon reserves. In the North Central of Mexico, this technique improved reservoir development and Management strategies, provided insight into basin fill history and contributed to the ongoing exploration success in the basin {2}. Sequence stratigraphy is an integrated tool in reservoir studies that can utilize analyse from well logs and seismic inputs as well as biostratigraphic datasets. The objectives of the study are to carry out sequence stratigraphic interpretation of well. However, logs and other key parameters will be used in order to establish correlation of reservoir horizons and its hydrocarbon potential implication within the study area. The research also involves the determination of environment of deposition, delineation Maximum Flooding Surfaces and their respective boundary of sequences from the available well log motifs.

II. MATERIALS AND METHODS

The data set for this research was provided by Total Exploration and Production Nigeria limited (Total E&P) through the approval from the Nigerian Upstream Regulatory Commission (NUPRC). The materials (Table 1) used for this research consist of suite of well logs, biostratigraphy data (microzones and biofacies), well header and well deviation data. The suite of well log signatures comprises of gamma ray (GR), spontaneous potential (SP), resistivity and density logs respectively. The software used for the interpretation and modelling includes Schlumberger petrel (2014 version), Microsoft word (2016 version), Microsoft PowerPoint (2016 version) and Coral Draw (2016 version).

i. Well logs

Well logs are basically series of recorded geophysical parameters of penetrated geologic formations during and after drilling of a wellbore at various depths in real time. These enables well loggers to articulate real time wells reports of stratigraphic sections based on the available information, problems encountered during drilling as well as initiating profound solutions and techniques in managing and tackling issues related to the identified reservoirs for effective productions of hydrocarbon. There are several types of well logs recorded during the drilling of wells as well as after the wells have been drilled and probably cased, these well logs include; Gamma ray logs (GR), Density logs (RHOB), Neutron logs, Porosity logs, Sonic logs, Volume Shale logs (Vsh), Permeability logs, Fluid saturation logs, Resistivity log (R), Natural Gamma ray spectroscopy logs, Spontaneous potential (SP), Calliper logs, Micro resistivity logs, Production logging and Cement bond log, etc.

Table 1 DATA INVENTORY

S/N	TYPE OF DATA	FORMAT	REMARKS
1	Well Header	ASCII	**Available**
2	Deviation Data	ASCII	**Available**
3	Well Logs	LAS/ASCII	**Available**
4	Reservoir Tops and Bases	ASCII	**Available**
5	Microzonation	MS Excel	**Available**
	Biofacies data		**Available**
	Biostratigraphic Report	MS Word	**Not Available**

ii. Biostratigraphic datasets

Biostratigraphic datasets contain intrinsic details of fossils aboudance and diversity; and can be used to establish relative ages of rock and correlate successions of sedimentary rocks within and between depositional basins. Widely used fossil groups include brachiopods, conodonts, dinoflagellate cysts, foraminifera, graptolites, nannofossil, spores and pollen and trilobites. Species extinctions, often referred to as "tops," are used as horizons of correlation. The first and last down-hole (FDO & LDO) of faunal occurrence in a well section is the datum most commonly used. The inception, or lowest occurrence of a species or lineage, is a reliable datum only in core or outcrop samples because caving is virtually unavoidable in cutting samples; however, it can help refine the stratigraphy. The overlap of species extinctions and inceptions allows the development of range of zones, which can be correlated from site to site. Correlation of tops is the most rapid and economical biostratigraphic technique and is the one most commonly used. Zonal schemes based on several different fossil groups can be used in parallel, and the zones can be calibrated to the absolute geological timescale using tie points to rocks which have been radio-isotopically dated.

A. Study Area

Gabo field is an Onshore Nigeria Oil field. The study area (Fig. 1) is located between Latitude 4^0 31' E – 4^0 35' E and Longitude 5^0 25' N – 5^0 26' N, consisting of six (6) wells designated as Gabo-4, Gabo-12, Gabo-13, Gabo-20, Gabo 30 and Gabo-57 (Fig 2). The structure is a rollover anticline limited northward by the Gabo fault. The reservoir is made up of several layers. Deposits are interpreted as Miocene in age, and are made up of siliciclastic deltaic sediments.

Fig 1: Map Showing the location of Gabo Field in the Central Swamp Depobelt, Niger Delta.

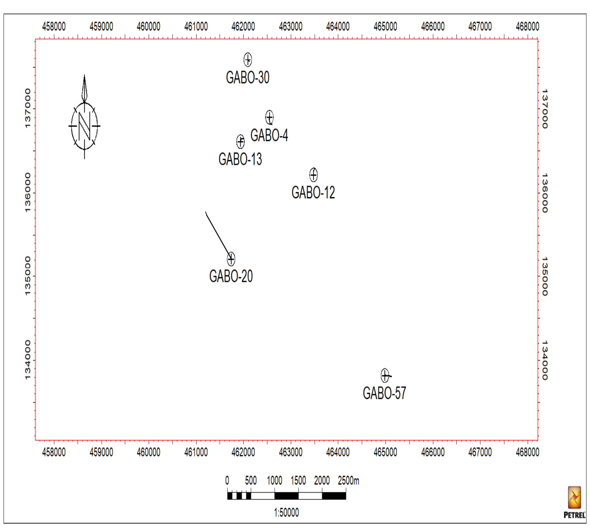


Fig. 2: Base Map of the location

B. Research Workflow

The research design used for this study is shown in Fig. 3. Various analysis and interpretations were applied to the well logs and biostratigraphic datasets used for the study.

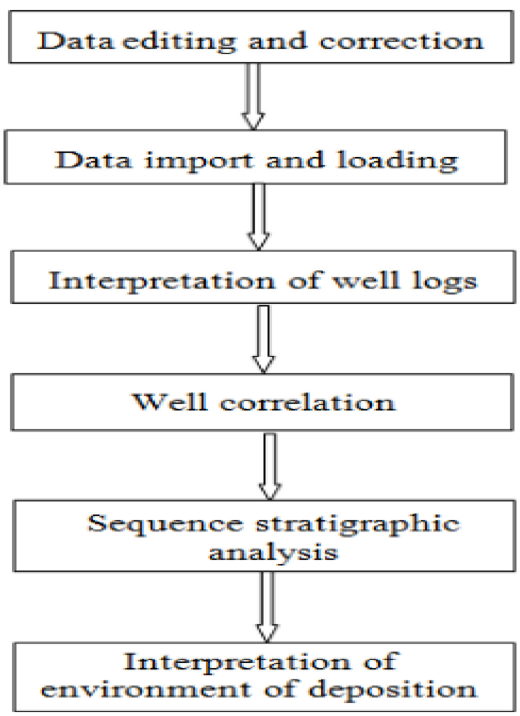


Fig.3: Research Workflow

C. Data Importation

The given datasets used in this research study was imported into Petrel software. The geographical location of the field was first imputed, followed by the well header which was matched with the appropriate file type. The various log signatures were imported and were matched with the various well heads before the well deviation data were imported.

D. Quality Control of Dataset

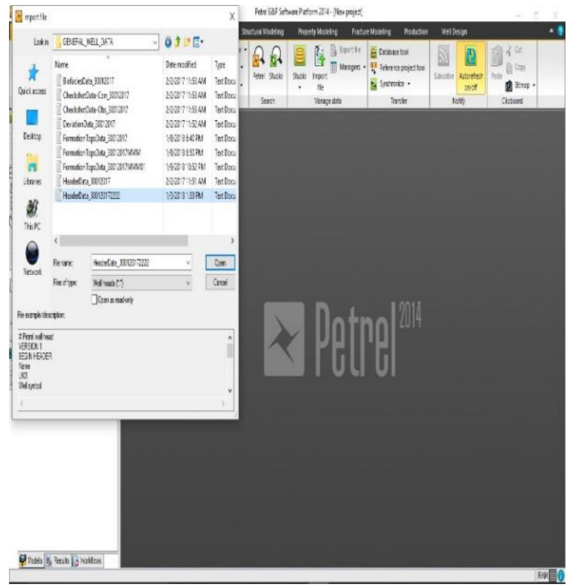
Quality control is very key in inspecting the quality of datasets that will be used for this research as well as the appropriate methodology designed to achieve the required results from the research. Quality control takes inventories of available datasets and materials for the research as well as the present conditions for research (availability of research laboratory, equipment, workstation, electricity, research funds and research time frame) and scale them appropriately to know if the research is worth undergoing or not. Quality control also creates room for the improvement of the quality of the datasets, materials as well as methods in achieving the required objectives of the research. The unwanted datasets were filtered out in order to improve the quality of the datasets.

i. Quality Control of Well Data

The quality control was applied to the well headers, well deviation data, microzonation/biofacies and the well log motifs.

ii. Quality Control on Well Header

The well headers and deviations were provided for six (6) wells. Well Header data which has a digital file format (fig. 4) was the first well data to be imported in the analytical Petrel software for this research. The well header usually contains information about the well pipes (drilled boreholes) as well as the heading of individual wells, which includes well names, well coordinates, universal well identifier (UWI), well total depths (TD) and well symbols. Quality control on the well Header was carried out by analyzing the raw information in the data and processing them into data that would be recognizable by Petrel. This was achieved by filtering out the unwanted information, formats and making various necessary corrections in other to make the Well Header recognizable for Petrel to display. The numbers of wells available for the research was known after Quality control of Well Header.



iii. Quality Control on Well Logs

The well logs were available for six (6) wells. Well logs with a digital file format were the next well data imported into Petrel after the Quality control on well header and well deviation was completed. The well logs contain all well information that are needed for any form of analysis. Quality control on the well logs helps to select the preferred well logs that are relevant to the research. Quality control was carried out on well logs for this research to know the number of wells containing the required well logs and also to check if the well logs are measured with their appropriate units and scales (for example, Gamma ray log is measured in American Petroleum Institute (API) units and scaled 0-150 API Units).

E. Determination of Lithology

Gamma ray log was utilized for lithology identification. A gamma ray log cut off value of 75API was chosen after proper visual examination of log signatures. High gamma ray values between 75-150 API units were classified as shale intervals. On the other hand, intervals with low gamma ray values that fall below 70 API units were considered sand and silt units. In Niger Delta, the sand units are regarded as the reservoir units because shale is not porous and permeable enough to host, retain and release fluid.

However, according to reference {3}, radioactive sources are observed in most sedimentary rocks especially within the siliciclastic deposits. In siliciclastic depositional settings, each lithological deposit emits varying amounts of gamma ray (GR) that contains basic gamma radiation elements of potassium 40, thorium and uranium and depending on the rate of emission; the lithologies of individual penetrated formation could be inferred. The analysis of gamma ray log is very key in understanding not just lithologies containing radioactive isotopes but could also be used to infer grain size distribution of reservoir sands as well as how they were transported and deposited. Reference {4} suggested that radioactive sources occur in varying compositions which are dependent on the depositional environment and for this reason; the gamma ray logs could be used in the absence of 3D seismic data and cores to interpret subsurface sedimentary facies. Reference {5} highlighted that interpretation of gamma ray logs could be achieved based on the type of gamma ray motifs (well log curves) displayed by the log as each type of gamma ray log motifs has a unique characteristic that could describe the shaliness of a formation (amount of shale content) and other lithologies, the grain size distributions of the formation as well as inferring the environment of deposition especially when incorporated with other logs such as mud logs, spontaneous potential logs (SP logs), sonic logs, etc., during analysis.

F.Stratigraphic Development and Biostratigraphic Interpretation

The biostratigraphic zonation datasets from Gabo-12 well was provided as type-log for this study and was employed for the interpretation of the sequence stratigraphic framework delineation of the field. Gabo-12 well, therefore served as the reference well as seen in Fig. 5. Datasets from this well helped in the establishment of the delineated ages, zones and sequence stratigraphic framework by comparing it with the Cenozoic Niger Delta Chronostratigraphic chart (Fig. 6). Foraminiferal data input derived from the reference well was used principally for the interpretation of the paleoenvironment, sequence stratigraphy and their respective depositional systems. Foraminiferal micropaleontological zones adopted in this interpretation showed the penetration of N5 - N11 {6} which is equivalent to the Shell zonation scheme of F9300 - F9500 zones and coinciding with the Aquitanian - Burgundianstages (21.8Ma MFS – 15.0Ma MFS). These datum were delineated utilizing the available biofacies and carried into this study. However, observed palynological subzones from the reference well point saw the penetration of P620 - P730 zones.Additional inferences drawn from the given wireline log motifs and sedimentological attribute inputs was tied with the biofacies for the detailed sequence stratigraphic framework delineation of the field.

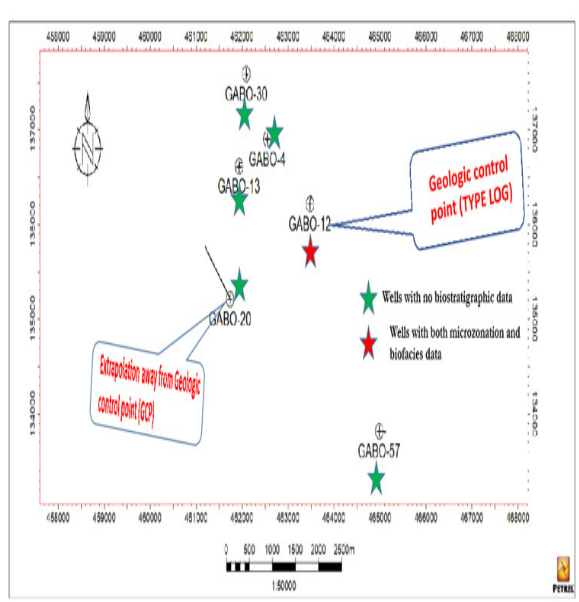


Fig 5: Reference wells with microzonation and biofacies data sets used for sequence stratigraphic interpretation

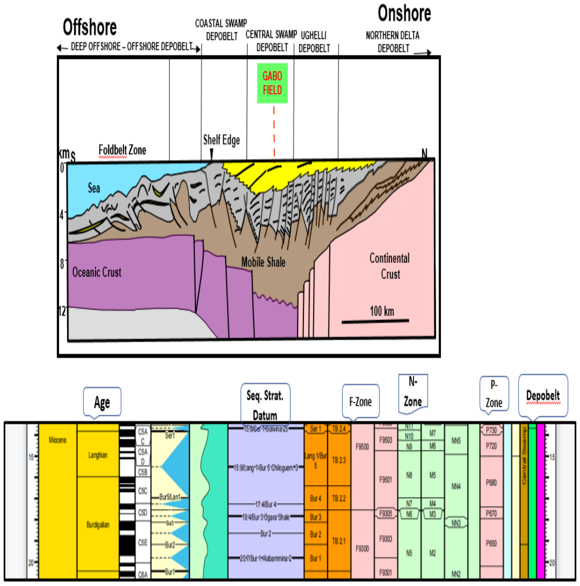


Fig 6: Showing a section of the Niger Delta Cenozoic Chronostratrigraphic Chart. SPDC (2010)

i. Key Stratigraphic Surfaces

The major sequence stratigraphic surfaces recognized in this research are the Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB). These surfaces were used to subdivide the stratigraphic units into their third order depositional sequences. Maximum Flooding Surfaces were identified at depths with high abundance of fauna deposition. These depths also corresponding with the shaliest parts of the section, high gamma ray values, low resistivity values and a wide separation of neutron and density logs. Whereas, the sequence boundary corresponds on where there is low fauna deposition, high resistivity readings. The sequence boundary is a surface that is starved of sedimentation, controlled by erosion and marked with significant hiatus.

ii. Delineation of Systems Tract and Stacking Pattern

Systems tracts are connections of concurrent depositional systems. Each individual system tract is defined based on their contained parasequences, stacking arrangements and positions within the sequence {8}. Parasequences may generate a shift in sedimentation either in landwards retogradational manner or in a basinward progradational manner. There are three systems tracts, which are:

1. The Highstand Systems Tracts (HST): This sand body displays a coarsening upward trend and it downlaps on the Maximum Flooding Surface.
2. The Transgressive Systems Tracts (TST): Transgressive Systems Tract can be recognized by its position in a sequence and stacking pattern. It occurs between the Maximum Flooding Surface the Transgressive Surface. On well log it shows a fining upward trend of increasing water depth, a retrogradational parasequence stacking.
3. The Lowstand Systems Tracts (TST): The Lowstand Systems Tract is made up of three sub depositional units; the prograding wedge complex, slope fan and the basin floor fans. The unit forms a prograding to aggradational stacking pattern.

Paleobathymetric interpretation which principally shows the peak of the respective candidate surfaces (on the basis of rise and fall in sea levels) were observed as retrogradational (finning upward sequence pattern) and progradational/aggradational parasequence sets (shoaling-upward stratal units) from the gamma ray wireline log motifs. The observed and depicted rise in relative sea water level in the Transgressive systems tract (TST) terminated at the Maximum Flooding Surface (MFS) while the regressive phase (HST) culminated at the Sequence Boundary (SB) commonly typified by a type 1 sequence boundary.

In carrying out the sequence stratigrap

III. RESULTS AND DISCUSSION

A. Identified Lithology

shale deposition contained within the formation because of its abundance in radioactive minerals. Sands show log signatures deflecting to the left while shales show log signatures deflecting to the right. The yellow colour indicates sand, while the black represents shale.

Resistivity logs are measured in ohms/meters and records the resistance of the rock fluid unit. Permeable and porous rocks with high resistivity are interpreted to contain hydrocarbon which increases resistivity, while shales are interpreted as compacted low resistivity rocks.

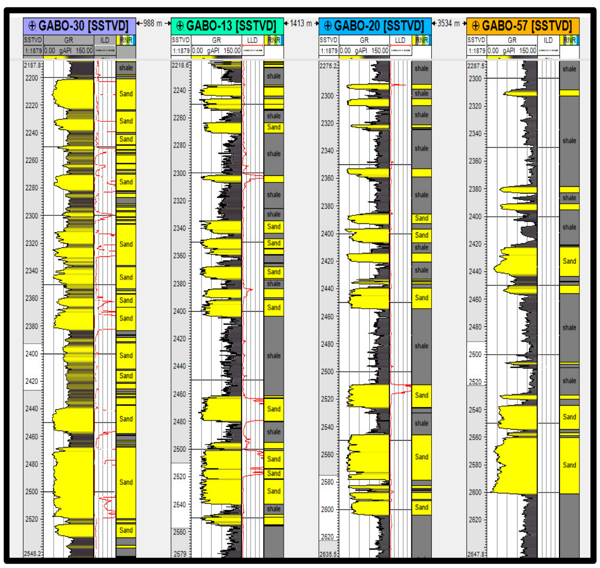


Fig 7: Sand- Shale Lithologic Logs

B. Stratigraphic Development and Biostratigraphic Interpretation

Two major sequence stratigraphic surfaces were identified. They include; the Maximum Flooding Surfaces (MFS) and the sequenceboundary (SB). The qualitative examination of the gamm depicted rise in relative sea water level in the Transgressive systems tract (TST) terminated at the Maximum Flooding Surface (MFS) while the regressive phase (HST) culminated at the Sequence Boundary (SB) commonly typified by a type 1 sequence boundary.

The stratigraphic development of the wells in this study suggested the penetration of Agbada Formation as observed from the paralic development of sand and shale (with silt intercalations) sediments.

The inference drawn from the results of the interpreted biozonation showed that the reference well penetrated sediments not older than Early - Middle Miocene age within the delineated reservoir tops.

i. Maximum Flooding Surface (MFS)

A qualitative study was carried out with the objective of establishing the sequence stratigraphic framework for the field. This involves subdividing the geologic section into chronostratigraphic correletable horizons, determination of ages, and understanding the sequence stratigraphic framework of all sequences penetrated by the well. Five MFSs (MFS_1, MFS_2, MFS_3, MFS_4, MFS_5) and their corresponding depths (2423ft, 2355ft, 2192ft, 2133ft, 2084ft) were delineated and correlated across the field (Fig 8a and 8b). From the oldest to the youngest, the observed maximum flooding surfaces were conspicuously described. The oldest MFS is the 20.7Ma. It was dated using the Alabammina marker. It occurs within the P730 biozone. The 19.4Ma MFS was dated using the Ogara shale marker. The next identified MFS was the 17.4Ma. the 15.9Ma and the 15.0Ma corresponds with the Chilogumem-3 and Bolivina-25. The biostratigraphic markers utilized for zonation are shown in Table 2.

Table 2 STRATIGRAPHIC DATUM

Shale (MFS)	Age (Ma)	Epoch/Stage
Bolivina 25	15.0	Middle Miocene/Burdigalian
Chilogumem-3	15.9	Middle Miocene/Burdigalian
Unmamed	17.4	Middle Miocene/Burdigalian
Ogara Shale	19.4	Early Miocene/Aquitanian
Alabammina	20.7	Miocene/Aquitanian

ii. Sequence Boundary (SB)

The lithologic attributes were integrated with wireline log motifs (gamma ray and ILD) for paleoenvironmental deductions. Paleoenvironmental interpretations are based on wireline log responses and lithologic characteristics of sediments. Sequence stratigraphic analysis based on the integration of lithologic characteristics of the sediments and wireline log motifs aided the recognition of five (5) sequence boundaries marked asSB_1, SB_2, SB_3, SB_4 and SB_5. Their ages and corresponding depths are: 21.8Ma at 2551ft, 20.4Ma at 2400ft, 17.7Ma at 2252ft, 16.7Ma at 2159ft and 15.5Ma at 2111ft**.**

iii. Field-Wide Horizon and Datum Correlation

Detailed correlation of the horizons in Gabo field was carried out using six (6) wells with the aid of relevant normalized petrophysical logs and other parameters. The correlation was achieved with the integration of biostratigraphic/biofacies and sequence stratigraphic bio-event datasets. The Biostratigraphic datasets comprises of foraminiferal and palynological microzones (F and P zones) derived from Gabo-12 well. This reference well (Gabo-12) information aided in the establishment of their respective datum and paleo-water depth interpretations. The correlation of the horizons was carried out first with the reservoir tops and bottoms and afterwards the key candidate markers (MFSs and SBs). Having established the sequence stratigraphic framework across these wells in the field, it was then possible to extend the sequence stratigraphic markers to all the other wells in the field with high degree of confidence. This shows a good sequence stratigraphic architecture to be carried out thereby allowing individual flooding surfaces and reservoirs correlation across the entire block

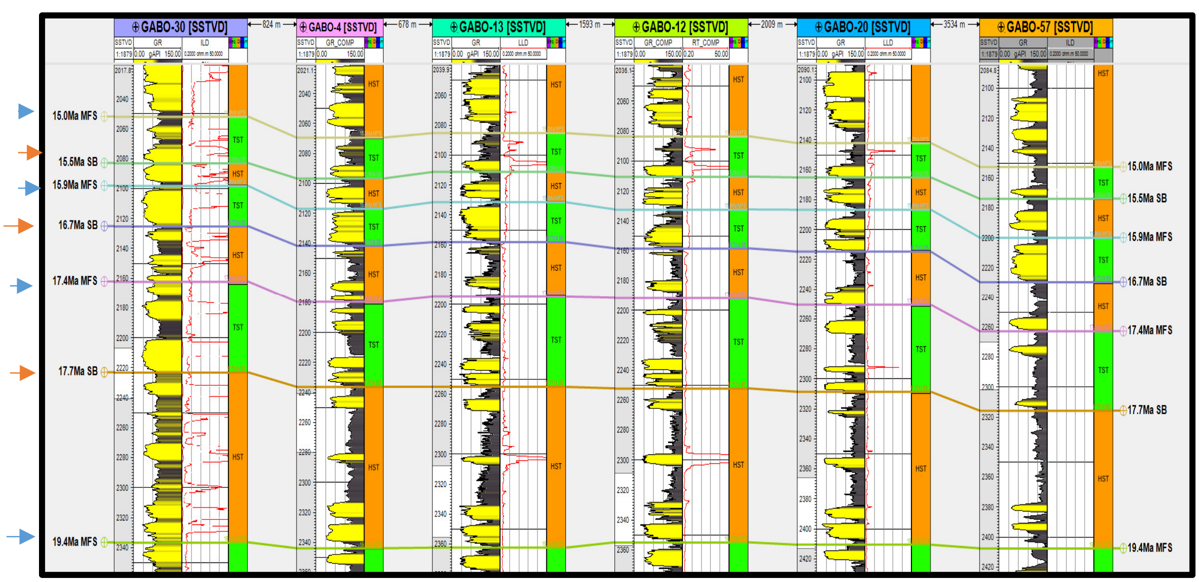
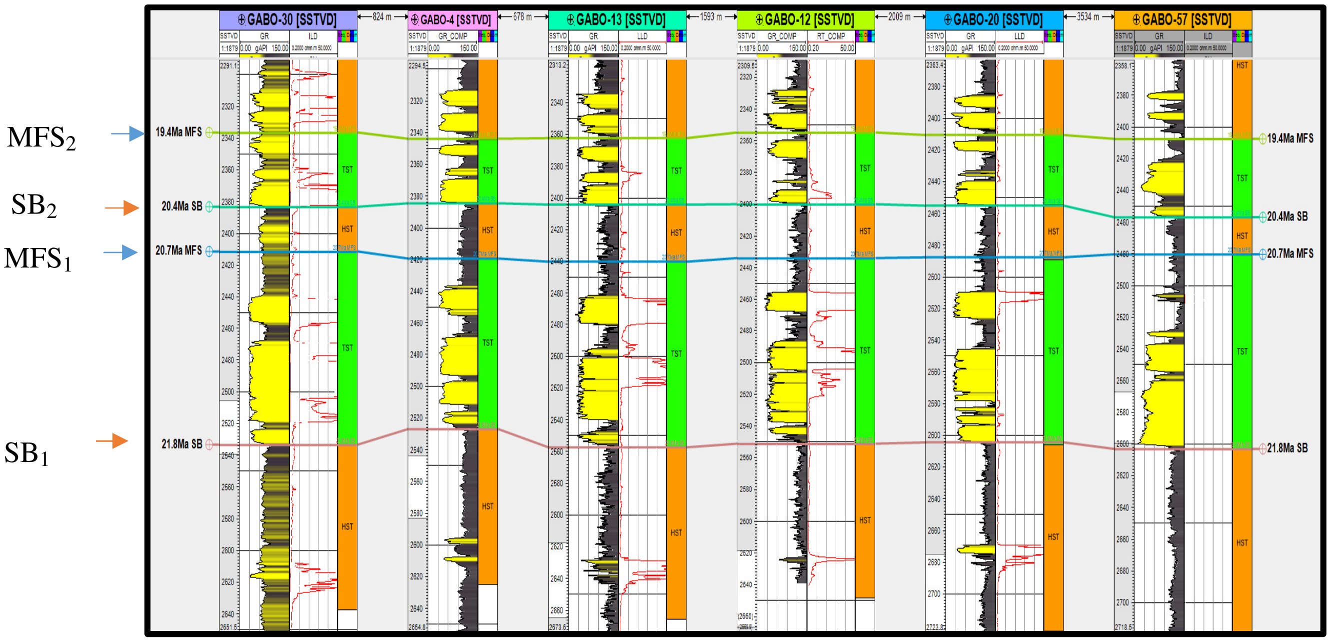


Fig 8a: Gabo Field Sequence Stratigraphic Framework 1/2



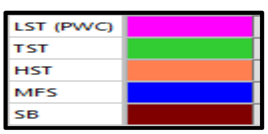


Fig 8b: Gabo Field Sequence Stratigraphic Framework

iv. System Tracts

Two system tracts were carefully identified and accurately correlated across the field of study. They are the highstand system tract and the transgressive system tract. The average percentage thickness of the system tracts varies across the wells such that Transgressive system tract (TST) accounts for 40% of the system tracts and the highstand system tracts (HST) accounts for 60% of the system tract. Table 3 shows all the delineated maximum flooding Surfaces (MFSs), sequence boundaries (SBs) and systems tracts as well as their corresponding depths

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DEPTH INTERVAL (ft)	SYSTEMS TRACT	KEY SURFACES

2084 - 1999	HST	-
2084	-	MFS (15.0Ma)
2111 - 2084	TST	-
2111	-	SB (15.5Ma)
2133 - 2111	HST	-
2133	-	MFS (15.9Ma)
2159 – 2133	TST	-
2159	-	SB (16.7Ma)
2192– 2159	HST	-
2192	-	MFS (17.4Ma)
2252 – 2192	TST	-
2252	-	SB (17.7Ma)
2355 – 2252	HST	-
2355	-	MFS (19.4Ma)
2400- 2355	TST	-
2400	-	SB (20.4Ma)
2423 – 2400	HST	-
2423	-	MFS (20.7Ma)
	TST	-
	-	SB (21.8Ma)
	HST	-

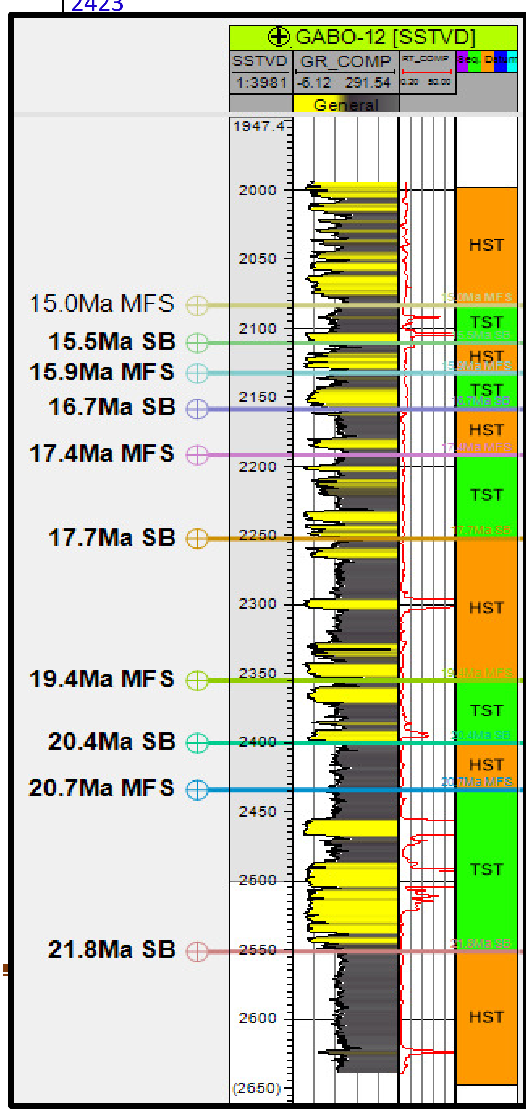

Table 3 Delineated Datum Surfaces From Gabo-12 Well.

v. Depositional Sequences

Galloway's sequences (GQ1, GQ2, GQ3, and GQ4) were observed in the research area based on the system tracts. This study focused on the Galloway's interpretation of sequences. (Fig 9)

Reference {9} defined a depositional sequence as the interv

four

(4)

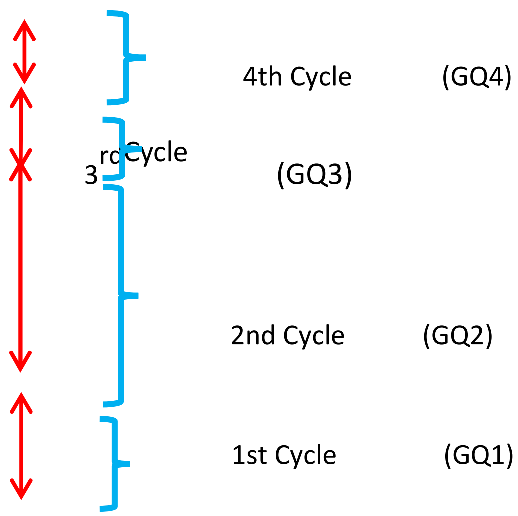

Fig 9: Gabo Depositional Cycles

Details of the depostional sequences are below:

Sequence 1 (GQ1)

This is the oldest sequence delineated and it lies between the 20.7Ma MFS at the lower level and 19.4Ma MFS at the upper level. The sequence ranges from 2355ft- 2423ft, with a thickness of about 68ft. This sequence comprises of the highstand system tract and transgressive system tract. The Highstand systems tract initiated the commencement of the deposition within this unit, however the progradational/retrogradational log pattern of this unit experienced deposition of sand bodies with intermixed shale deposits within the intervals. The occurrences of channel with minor shoreface sands and predominant shale deposits within the section indicated the effect of the subtle and gradual fall in sea water level within this unit. Deposition within this interval culminated at the 21.8Ma SB.

The transgressive phase within the 20.7Ma MFS (**Alabammina-2 shale**) datum was observed within this phase. This stratigraphic datum unveiled a somewhat good sand body representing a channel and admixture of minor shoreface deposits which shows a coarsening upward sequence pattern with intermittent deposition of finning upward sediments. However, this sequence witnessed an overall thinning and finning trend towards the top of this section. All the wells saw this datum considering their respective stratigraphic positioning and interval depth penetrations.

The Highstand systems tract overlying the transgressive phase initiated the commencement of the regressive phase of deposition within this unit. The sediments terminated at its peak and is dated 20.4MaSB. Deposition within this interval probably suggests a prograding/forestepping stacking sequence pattern with overall coarsening and thickening of the sand interval as observed on the gamma ray log signatures. These sediments exhibited a progradational - retrogradational sediments with low occurrences of shale towards the top wells. The sand predomination typified a low sea level regime as depicted from the low abundance and diversity of fauna occurrences within the reference well. The associated environments encountered within this unit includes upper to lower shoreface sands; channel facies predominate with interplay of shale deposits.

Sequence 2 (GQ2)

This sequence spans from the 17.7Ma MFS to the 19.4Ma MFS. The sequence ranges from 2192ft -2355ft, with a thickness of about 163ft. This sequence comprises of highstand system tract and transgressive system tract. Above the highstand systems tract, overlaid the transgressive systems tract with progradational and retrogradational upward sequence patterns deposits are observed in the wells and is dated 19.4Ma MFS (**Ogara Shale Shale**). The deepening bathymetric settings exhibited in these wells within this section showed interplay of shale and sand counterpart occurrences. Channel facies predominates within this setting with occurrences of upper and lower shoreface sands with heterolithic sediments deposited within the Inner to Middle Neritic paleo-water realms. All the wells within this study field attested this datum.

The Highstand systems tract overlying the transgressive phase initiated the commencement of the deposition within this unit, however this unit experienced deposition of sand bodies with intermixed shale deposits within the intervals of the wells in the field and is dated 17.7Ma SB. Sediment deposition within this environment suggest a prograding stacking pattern with overall coarsening and thickening of the sand interval. These sediments are characterized by progradational to blocky, sometimes with minor multi-storey channels. The associated environments encountered within this unit include upper to lower shoreface sands; channel deposits predominate with incursion of shale deposited within the coastal deltaic - Shallow lnner Neritic setting with lateral continuous sand.

Sequence 3 (GQ3)

This is from the 15.9Ma MFS to the 17.7Ma MFS. This sequence ranges from 2133ft -2192ft, with a thickness of about 59ft. The sequence comprises of highstand system tract and transgressive system tract. On the other hand, inference from the type well showed that the 17.4MaMa MFS (**Unmamed Shale***)* datum occurred at the peak of this transgressive phase. The wells that saw the datum were believed to have been deposited during a relative sea level rise with overall finning upward sequence pattern and terminated at their respective marked maximum flooding surface peak. The associated facies within this environment are channels, minor lower to upper shoreface/delta front sands and channel heterolithics with alternating shale deposits. The encountered peak within this unit represents an avalanched setting of the sediments deposition which occurred within this depositional episode. Distributary channels are the dominant facies categories found within this unit with shale enveloping the distributary channel. All the wells saw this datum.

A renewed regressive phase emerged suggesting a progradational (forestepping) with aggradational setting coupled with overall coarsening upward patterns with thickening of sandstone interval within this zone. These sequences are predominantly shoaling upward sediments with the deposition of channel sands admixture minor shale and lower shoreface sediments depicting a low regime depositional setting for these sediments. The minor marine shale witnessed within the sand deposits may probably act as baffle within this section. The maximum regressive surface terminated this Highstand systems tract and is dated 16.7Ma SB. However, within the Gabo field all the wells in their respective field penetrated this datum.

Sequence 4 (GQ4)

This is the youngest MFS which spans from 15.0Ma to 15.9Ma. This sequence ranges from 2084ft -2133ft, with a thickness of about49ft. This sequence comprises of highstand system tract and transgressive system tract. The culminated peak of the underlying Highstand system tract marked the top of the Transgressive systems tract and this occur in all the wells. However, the top of the overlying transgressive episode terminates this system tract and is dated 15.9Ma MFS (***Chilogumem-3* Shale Maker**). This section witnessed a relative rise in sea level with progressively finning and coarsening upward sequence pattern of sediments deposition. This setting becomes deepening upward with predominant deposition of channel, upper/lower shoreface sands, channel heterolithics and shale deposits. This transgressive phase suggests sediments deposited in a predominantly Inner-Middle Neritic paleo-water setting.

A regressive phase was witnessed to have initiated the underlying transgressive systems tract above and terminated this phase marking the peak of this regression phase and coincided with the surface datum and is dated 15.5Ma SB. The facies encountered within this litho-unit include channel, lower to upper shoreface sands, bar complexes and shale deposits. The subsequent overlying transgressive phase is heralded by the presence of marine shales with a gradual deepening of the environment. This systems tract unveiled a good sand body representing a channel deposit which shows a coarsening upward pattern. However, this sequence witnessed an overall thinning and finning trend towards the top of this section and indicated a gradual rise in sea water level. This transgressive phase suggests sediments deposited in a Middle - Outer neritic paleo-water depths and terminates at the 15.0Ma MFS datum.

A renewed regressive phase emerged suggesting a progradational (forestepping) with aggradational setting coupled with overall coarsening upward patterns with thickening of sandstone interval within this zone. These sequences are shoaling upward sequences with the deposition of channel sands with minor shale and lower shoreface sediment deposits depicting a low regime depositional setting for these sediments. The maximum regressive surface terminated this highstand systems tract was not encountered.

IV. SUMMARY

Detailed sequence stratigraphic well datum correlation was carried out utilizing the generated stratigraphic datum from Gabo-12 well. All the candidate surfaces (MFSs and SBs) delineated in

Gabo-12 well were conspicuously dated based on their chronologically significant occurrences of foraminiferal (planktic and benthic) bio-events as well as correlation to the third order cycles chart {11}. The understanding of the respective key datum in this study was achieved based on the observed foraminiferal biozonation and biofacies information. Inference drawn from all the key sequence candidate markers derived from the type-log well was carried across by extrapolation to the rest of the wells in this study within the horizons of reservoirs of interest.

In the sequence stratigraphic analysis, five maximum flooding surfaces (MFSs) and five sequence boundaries (SBs) were identified. Genetic stratigraphic sequence (Galloway, 1989) was interpreted in the Gabo field and was divided into systems tracts. This was then correlated with other wells of the study area corresponding with palynological and foraminiferal zones which simply implied that the section being studied was deposited through early Miocene to Middle Miocene. The genetic sequence in this study was divided into transgressive system tracts (TST) and highstand system tracts (HST) respectively. Sequence stratigraphic framework interpretation and erection of Gabo wells revealed the delineation of 21.8 Ma MFS – 15.0 Ma MFS datum from the type-log well. Inference from similar logs character exhibition is drawn from the same and adjoining wells located in the adjacent block which shows the penetration of the same datum. This datum falls within a Coastal – Outer Neritic paleoenvironment

V. CONCLUSION

Sequence stratigraphic delineation unveiled four (4) genetic cycles; 21.8Ma SB - 15.0Ma MFS datum. However, a prograding system is observed within this wells which conformed with the Niger Delta basin depositional geologic history The transgressive systems tract (TST) was made of retrograding shale and sand units. The highstand system tract was made of prograding sands with decreasing shale volume upwards.

Biostratigraphic deduction points to Early - Middle Miocene age.

A sequence stratigraphic framework/datum was generated with the integration of microzonations and biofacies from the well that had this biostratigraphic datasets and extrapolated across the other wells within the field. The environment of deposition was deciphered; the sediments were deposited within Coastal deltaic – Outer Neritic paleo-depths depicting shelf-edge depositional environments.A combination of the reservoir sands of the highstand systems tract (HST) and the shale units of the transgressive systems tracts form good stratigraphic traps for hydrocarbon exploration and production

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