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SEISMIC STRATIGRAPHIC AND STRUCTURAL CHARACTERIZATION OF XY-1 (TOMBOY) FIELD, OFFSHORE WESTERN NIGER DELTA, NIGERIA

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ABSTRACT

The focal aim of the study is to map the structures in the study area using seismic characterization methodology. Key stratal terminations such as onlaps, toplaps and erosional unconformities (or truncations) were recognized. Nine surface boundaries, namely: four maximum flooding surfaces and five sequence boundaries were detected as peaks and troughs of the seismic onsets, respectively. The maximum flooding surfaces and the sequence boundaries depths were converted to time in milliseconds using check shot data. The converted time represents two-way travel time. Accordingly, the wireline logs were effectively tied to the seismic lines for better stratigraphic interpretation. The structural style of the field is characterized by two systems of antithetic and growth faults. On the seismic lines, shale structures were recognized as zones of chaotic or transparent seismic reflections. The overall geometry of the reflectors is parallel or sub-parallel. On the seismic lines, chaotic reflectors were identified to be associated with small-scale gravity faulting resulting in debris flow. The sandstone-prone facies have greater seismic amplitude values than the shale-dominated units. The seismic expression of such lithology change may have resulted from the juxtaposition of low amplitude and moderately continuous seismic facies (shale-prone) on high-amplitude and variable continuity seismic facies (sand-prone). The identified structural and stratigraphic traps, the reservoir blocks and the depositional environments are useful input to the petroleum system of the area.

Keywords: *Stratigraphic, Structural Seismic Characterization, Seismic Stratigraphy, XY-1 Field*

INTRODUCTION

The area of study is located in the Tomboy field of the offshore western Niger Delta area of Nigeria (Figs. 1 and 2). The Niger Delta is situated in the Gulf of Guinea on the west coast of Central Africa. Niger Delta lies between latitudes 4° and 6° N and longitudes 3° and 9° E in the south-south geo-political region of Nigeria (Ojo *et al.,* 2009). The Cenozoic Niger Delta is situated at the intersection of the Benue Trough and the South Atlantic Ocean where a triple junction developed during the separation of South America and Africa in the Late Jurassic (Whiteman, 1982). The main aim of this study is to map the structures in the study area using seismic characterization methodology. Key stratal terminations such as onlaps, toplaps and erosional unconformities (or truncations) were mapped and integrated with log and biostratigraphic data to establish the candidate surface boundaries in the study area.

Reflection seismology is compartmentalized into acquisition, processing and interpretation. Seismic stratigraphy deals with interpretation (Andrew, 2013). According to McGraw-Hill Science and Technology Encyclopedia (2013), seismic stratigraphy is pronounced (′sīz•mik strə′tig•rə•fē) and defined as a branch of stratigraphy in which sediments and sedimentary rocks are interpreted in a geometrical context from seismic reflectors. On the other hand, it is defined as a technique used to determine the nature of sedimentary rocks or their stratigraphic characterization by the analysis of seismic data (Wiktionary, 2013; Vail, 2013).

Primary seismic reflections are generated by physical surfaces in the rocks, consisting mainly of stratal surfaces and unconformities with velocities-density contrasts of the bedding planes rather than lithostratigraphic boundaries (Vail, 2013; Ramsayer, 1979; Juhlin, 2008). Andrew (2013) classified seismic stratigraphy into three principal categories, namely: (i) seismic-sequence analysis, (ii) seismic-facies analysis and (iii) reflection-character analysis. Firstly, in seismic-sequence analysis, there is need to separate out the time-depositional units based on detecting the unconformities or changes in seismic patterns as they are shown by angularity (McGraw-Hill Science and Technology Encyclopedia, 2013; Andrew, 2013). Angularity below an unconformity may be produced by erosion at an angle across the former bedding surfaces or by toplap (offlap) and angularity above an unconformity may be produced by onlap or downlap, the latter distinction being based on geometry. The unconformities are then followed along reflections from the points where they cannot be so identified, advantage being taken of the fact that the unconformity reflection is often relatively strong. The procedure often followed is to mark angularities in reflections by small arrows before drawing in the boundaries. Secondly, **Seismic-facies** units are three-dimensional and many of the conclusions from them are based on their three-dimensional shape. The appearance on seismic lines in the dip and strike directions is often very different. For example, a fan-shaped unit might show a progradational pattern in the dip direction and discontinuous, overlapping arcuate reflections in the strike direction. Thirdly, **Reflection-character** analysis may be based on information from boreholes which suggests that a particular interval may change nearby in a manner which increases its likelihood to contain hydrocarbon accumulations. Lateral changes in the wave shape of individual reflection events may suggest where the stratigraphic changes or hydrocarbon accumulations may be located McGraw-Hill Science and Technology Encyclopedia (2013). Finally, according to Okosun (2013), stratigraphy is the description and classification of all rock bodies forming the earth's crust into distinctive and mappable units on the basis of their inherent properties or attributes, distributions, relationship and succession in space and time.

GEOLOGICAL SETTING

Three main formations have been recognized in the subsurface of the Niger Delta (Esan, 2002; Short and Staüble, 1967; Weber and Daukoru, 1975; Avbovbo, 1978; Knox and Omatsola, 1989; Tutle *et al.,* 1999). These are the Akata, Agbada, and Benin Formations. These formations were deposited in marine, transitional and continental environments, respectively; together they form a thick, overall progradational passive-margin wedge (Esan, 2002).
The Akata Formation is Paleocene to Pliocene in age and it is the basal unit composed mainly of marine shales believed to be the main source rock within the basin. The Agbada Formation is made up of alternating sandstone, siltstone and shale sequences that constitute the petroleum reservoirs of the basin. Agbada Formation is Eocene to Quaternary in age (Figs. 3 and 4). On the other hand, the Benin Formation is Oligocene to Recent in age and it is mainly made up of non-marine fine to coarse-grained sands with a few mudstone and shaly intercalations (Esan, 2002).

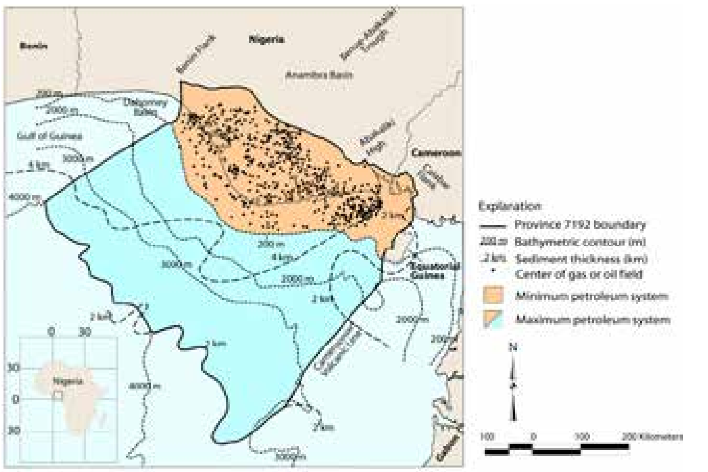

Fig. 1. Location Map of the Study Area (Source: Tutle *et al.,* 1999)

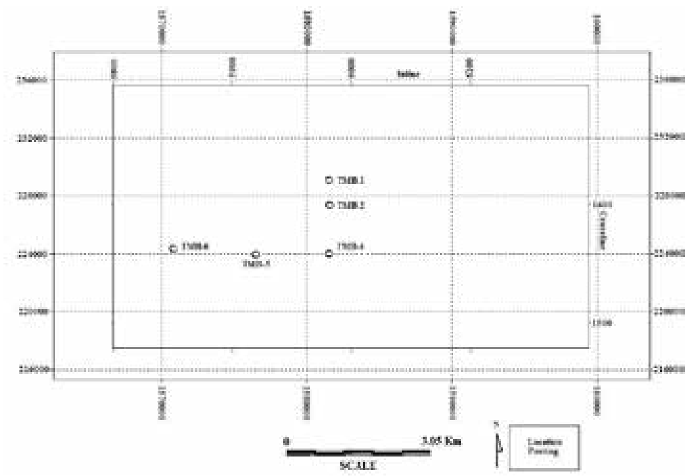

Fig. 2. Seismic Survey Base Map of Study Area showing Locations of Five Wells
and the Seismic In-line and Cross-line Sections

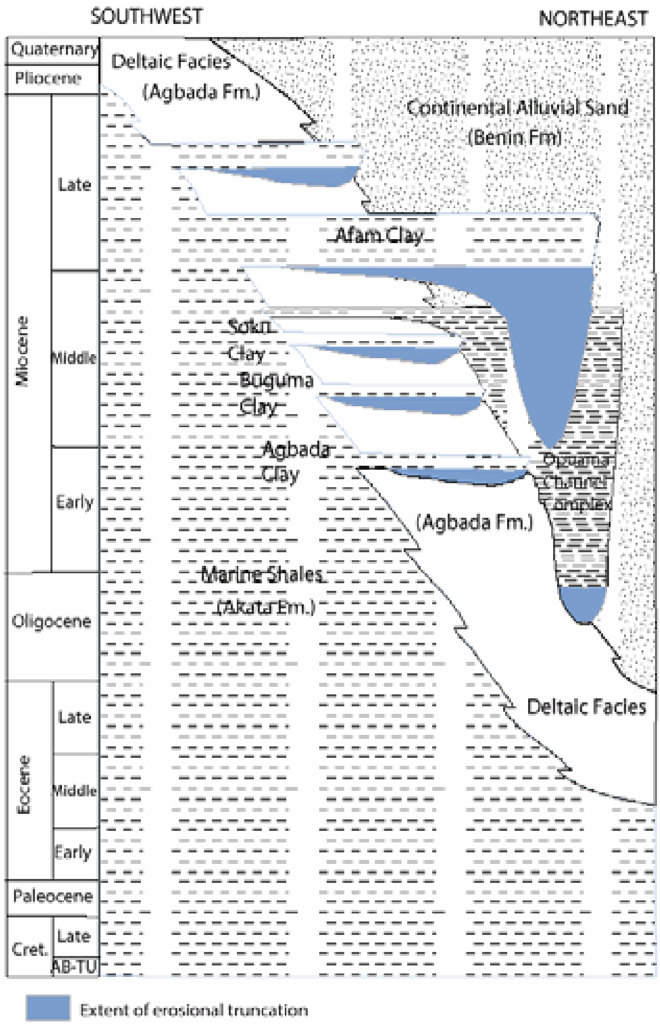

Fig. 3. Stratigraphic column showing the three formations of the Niger Delta (after Tuttle *et al.*, 1999; modified from Doust and Omatsola, 1990)

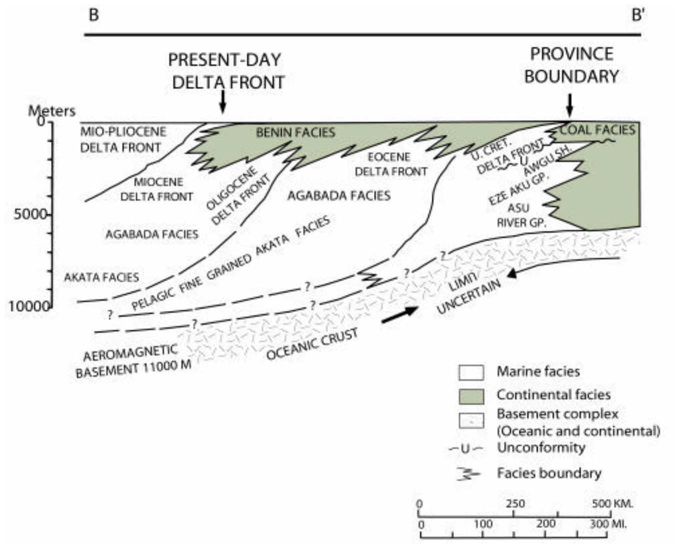

Fig. 4. Southwest-northeast (B-B') cross-section through the Niger Delta (modified from Whiteman, 1982)

MATERIALS AND METHODS

The materials for the study are seismic section, well logs, base map and check shot data for five wells in the study area. The five wells are named TMB-1, TMB-2, TMB-4, TMB-5 and TMB-6 where TMB is an abbreviation for Tomboy. The wells are drilled to the depths of 3,782.57 m (TMB-1), 3,791.71 m (TMB-2), 3,489.96 m (TMB-4), 3,535.68 m (TMB-5) and 3,962.40 m (TMB-6). All the data were loaded on Landmark Workstation. The database was created on the Geographix Discovery R2007.1 platform (Windows) version. The study was performed using SeisVision 3Dimensional (3D) seismic characterization modules. The parameters of the projection system used on the Geographix Discovery are Coordinate System Type of Transverse Mercator, Geographical Coordinate System using Nigeria Minna (DMA REG MOL); Greenwich Datum Prime Meridian and Minna Spheroid after Clarke 1880 Zone. The cross-line (strike) and the in-line (dip) and the above mentioned data set were provided by ChevronTexaco Nigeria Limited. The in-line (dip) ranged from 5,800 to 6,200 and the cross-line (strike) ranged from 1,480 to 1,700 covering a total area of 71.33 km2 and the line space of 2.51 km (Fig. 2). The 3D seismic volume data were supplied in SEG-Y format, while the well log data were given in LAS format. Seismic and structural characterization along the dip and strike sections of the Tomboy field was undertaken in this study with a view to identify and correlate the surface boundaries along the seismic transect from one well to another. The following method and workflow plan was adopted: loading of seismic and well data, review of seismic and log data after loading, integration of biostratigraphic data and their calibration with seismic data, identification of candidate sequence boundaries, and the posting of the dominant faults on the transect. The time-depth relationship was determined using the check shot data available for XY-1-1 well (Fig. 5). The two-way time (TWT) is given in milliseconds (msec.) on the x-axis, while the true vertical well depth is given on the y-axis in feet (and the conversion value is 1 foot equals 0.304804 metre). The depositional environments were interpreted using the characteristic patterns and curves of the gamma ray and resistivity logs in line with the published charts of Busch (1975) and Schlumberger (1985) (Figs. 6 and 7).

Fig. 5. The Plot of Check Shot Chart for TMB-1 Well (Conversion: 1 foot = 0.3048 metre)

RESULTS AND DISCUSSION

The condensed sections are generally the most easily recognized and dated regional correlatable surfaces. The maximum flooding surface (MFS) is a clay-rich major condensed interval formed by slow deposition of sediments. This condensed section represents the deepest water facies with a significant increase in fossils diversity/abundance and abundance of authigenic minerals (glauconite and phosphates) (van Wagoner *et al.*, 1990; Adegoke, 2002). The gamma ray log provides a measure of sediment type, with curve deflection to the right indicating increase in clay content (Asquith and Gibson, 1999). MFS's can be interpreted from gamma-ray log as "spikes" associated with uranium concentrations in condensed sections.

Using biostratigraphic data, concentration and dilution cycles are very important. In general terms, concentration cycles represent zones where large numbers of microfauna and flora are condensed over short intervals, and they are often associated with maximum flooding surfaces (MFS's). On the other hand, dilution cycles are often associated with sequence boundaries (Snedden and Sarg, 2008).

The high resolution chronostratigraphic framework used in the seismic characterization is mostly MFS's and SB's that have been assigned their absolute ages. Stacking patterns seen on logs (and outcrops sections) are often indicative of key stratigraphic surfaces. For example, the change from retrogradational to progradational stacking often is associated with a maximum flooding surface, which can be checked in both seismic and biostratigraphic data. Log motif characterization of systems tracts is particularly well defined Mitchum *et al.,* 1993). Stacking patterns, log curve shape, vertical trends in sand content, and relationship to over- and underlying surfaces are keys to identifying the systems tracts. However, integration with seismic and other data is critical to validating these interpretations (Snedden and Sarg, 2008). Nine surface boundaries, namely: four maximum flooding surfaces and five sequence boundaries were defined as peaks and troughs of seismic onsets, respectively (Table 1).

The maximum flooding surfaces (MFS's) and the sequence boundaries (SB's) depths were converted to time in milliseconds using the check shot data provided by ChevronTexaco Nigeria Limited (Fig. 5). Consequently, the wireline logs were effectively tied to the seismic lines for better seismic stratigraphic characterization. The converted time representing the two way travel time in relationship to the seismic stratigraphic characterization are given in Tables 3-7. Careful assessment of the events recognized using the biostratigraphic age dates of samples from the wells constrained by seismic and wireline logs data indicated that 9.5 Ma, 10.4 Ma, 11.5 Ma and 12.8 Ma MFS's constituted reliable chronostratigraphic surfaces for the correlation of the sequences within the wells in the study area. Key stratal terminations such as onlaps, toplaps and erosional unconformities (or truncations) were recognized. The maximum flooding surfaces (MFS's) coincided with the seismic peaks, while the sequence boundaries (SB's) tallied with the seismic troughs (Table 1).

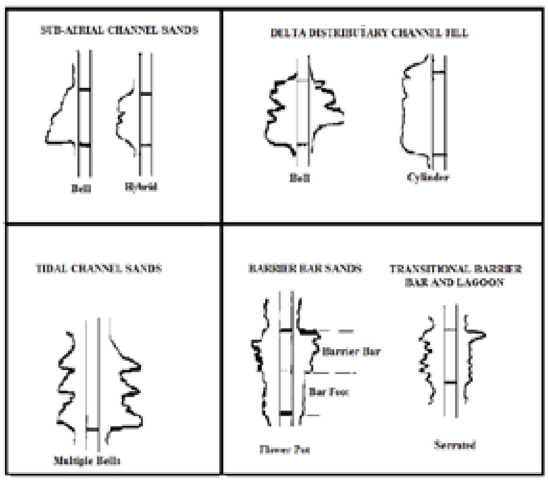

Fig. 6. Gamma Ray and Resistivity Log Patterns Indicative of Depositional Environments (Source: Busch, 1975)

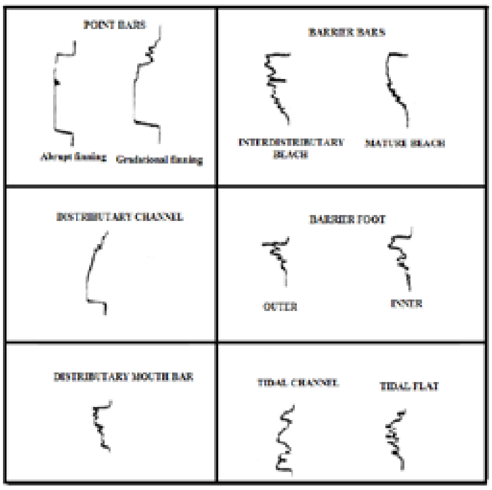

Fig. 7. Gamma Ray Log Stacking Patterns Defining Deltaic Depositional Environments (Source: Schlumberger, 1985)

Table 1. Surface Boundaries (MFS'S & SB'S)

MFS (Ma)	SB (Ma)	NO. OF WELLS	SEISMIC ONSET
	8.5	2	Trough
9.5		2	Peak
	10.35	5	Trough
10.4		5	peak
	10.6	5	Trough
11.5		5	Peak
	12.1	5	trough
12.8		4	Peak
	13.1	1	trough

Structural characterization was done on the Tomboy field wells to map the structures, principally the fault patterns. A geologic section based on the line drawn on the seismic characterization illustrates the structural style observed in the study area (Figs. 8 - 11). Time horizons constrained by well data and absolute ages indicated Middle and Late Miocene. The structural style of the field is characterized by two systems of antithetic and growth faults. On the seismic lines, shale structures were recognized as zones of chaotic or transparent seismic reflections areas. The 3D seismic volume data is of good quality, but below 3.5 seconds TWT the seismic lines are very chaotic and of very poor quality and therefore, the characterization of such deeper horizons are uncertain.

The relative distance between the up-thrown sector and the down-thrown sector of a fault is referred to as its throw. The direction of throw is dominantly westward. The faults (F1, F2, F3, F4 and F5) indicated that the faults are down-thrown. The Faults (F6 and F7) basically are the up-thrown faults. TMB-1, TMB-4 and TMB-6 wells are situated in the down-thrown arms, having been affected by F6 and F7 faults thus leading to the loss of some horizon blocks from them. The F1 is observed to be southwest trending fault, while F2 and F3 have western trending pattern; F4 trends west to east direction, F5 has nortwestern trend and F6 and F7 trend in northeastern direction (Table 2). TMB-2 and TMB-5 wells are situated in the up-thrown sector in relationship to fault (F2), while TMB-6 well is located on the fault (F6). The wells were correlated based on the relationships in the MFS's and the SB's. Because some of the horizon blocks were interpreted to have been faulted out, it may be inferred that growth faults principally controlled the sequence architecture of the study area (Figs. 8 - 11).

Table 2. Directions of Fault Patterns in the Tomboy Field

NAME OF FAULTS	DIRECTION OF FAULT PATTERN
F1	Southwest trend
F2 and F3	Western trend
F4	West to East
F5	Northwest
F6 and F7	Northeast

Table 3. XY-1-1 Well Strike Section 1,620

DEPTH (M)	TIME (SECONDS)	SEISMIC STATIGRAPHIC INTERPRETATION	AGE
1,527.05 – 2,420.11	< 2.10	PGC	
2,420.11	2.10	HST	8.5Ma SB
2,431.39	2.14	TST	9.5Ma MFS
2,471.32	2.20	TOP PGC	
2,855.06	2.35	HST	
2,882.80	2.40	TST	10.35Ma SB
2,908.71	2.45	TOP PGC	10.4Ma MFS
3,157.12	2.60	HST	10.6Ma SB
3,218.08	2.65	TST	11.5Ma MFS
3,386.94	2.72	HST	12.1Ma SB
3,404.92	2.74	TST	12.8Ma MFS
3,441.80	2.85	HST	13.1Ma SB

*PGC: Prograding Complex; TST: Transgressive System Tract; HST: High stand System Tract

Table 4. XY-1--2 Well Strike Section 1,600

DEPTH (M)	TIME (SECONDS)	SEISMIC STATIGRAPHIC INTERPRETATION	AGE
1,527.05 – 2,268.93	< 2.0	*PGC	
2,268.93	2.0	HST	8.5 Ma SB
2,431.39	2.1	TST	9.5 Ma MFS
2,639.57	2.25	HST	10.35 Ma SB
2,731.62	2.3	TST	10.4 Ma MFS
3,046.17	2.5	HST	10.6 Ma SB
3,150.41	2.58	TST	11.5 Ma MFS
3,313.48	2.7	HST	12.1 Ma SB
3,446.37	2.8	TST	12.8 Ma MFS

Table 5. XY-1--4 Well Dip Line 5,980

DEPTH (M)	TIME (SECONDS)	SEISMIC STATIGRAPHIC INTERPRETATION	AGE
731.52 – 2,273.81	< 2.0	PGC	
2,273.81	2.0	HST	10.35Ma SB
2,433.22	2.15	TST	10.4Ma MFS
2,728.27	2.35	TOP PGC	
3,157.42	2.60	HST	10.6Ma SB
3,218.99	2.65	TST	11.5Ma MFS
3,404.62	2.75	HST	12.1Ma SB

Table 6. Tomboy-5 Well Dip Line 5,920

DEPTH (M)	TIME (SECONDS)	SEISMIC STATIGRAPHIC INTERPRETATION	AGE
1,219.20 – 2,417.98	< 2.12	PGC	
2,417.98	2.12	HST	10.35Ma SB
2,443.89	2.18	TST	10.4Ma MFS
2,581.35	2.25	TOP PGC	
2,909.93	2.32	HST	10.6Ma SB
2,933.10	2.4	TST	11.5Ma MFS
2,957.47	2.50	TOP PGC	
3,387.24	2.75	HST	12.1Ma SB
3,466.80	2.85	TST	12.8Ma MFS

Table 7. XY-1--6 Well Strike Section 1,560

DEPTH (M)	TIME (SECONDS)	SEISMIC STATIGRAPHIC INTERPRETATION	AGE
1,222.25 – 2,948.33	< 2.52	PGC	
2,948.33	2.52	HST	10.35Ma SB
3,258.01	2.60	TST	10.4Ma MFS
3,317.44	2.65	PGC	
3,592.37	2.75	HST	10.6Ma SB
3,622.55	2.80	TST	11.5Ma MFS
12,615	2.85	HST	12.1Ma SB
3,907.23	3.0	TST	12.1Ma MFS

An unconformity is defined as the period of non-deposition or erosional surfaces in a sedimentary sequence (van Wagoner *et al.,* 1990; Emery and Myers, 1997). An unconformity can easily be inferred from seismic data. The sequence boundary is recognized by the erosional truncation of the underlying strata and by the onlaps of overlying strata of the next sequence (Snedden and Sarg, 2008) (Figs. 8 - 11). In the Tomboy field, five unconformities were recognized in the wells. The stratigraphic succession is generally represented by nearly concordant, moderately bright amplitude reflectors and only subtle erosional features representing a limited incision were observed.

Maximum flooding surfaces correspond to the most transgressive stratigraphic architecture and mark the limits between genetically related sedimentary units. According to Snedden and Sarg (2008), regionally continuous, parallel, uniformly high amplitude reflectors in seismic data can be interpreted as candidate MFS's. In the study area, four maximum flooding surfaces were identified and traced on the seismic sections. The downlap surfaces were recognized to mark the maximum flooding surfaces that change from retrogradational to progradational parasequence sets (Snedden and Sarg, 2008).

Seismic facies are packages of reflectors with a set of seismic characteristics differing from adjacent units (in similarity to the definition of a formation), seismic facies must be distinguishable from adjacent units and mappable on earth's surface) (Snedden and Sarg, 2008). Conventional and qualitative seismic facies characterization of stratigraphic features such as turbiditic facies (downlap, mounds) and lithology or fluid content were tentatively carried out. In this study, the overall geometry of the reflectors is parallel or sub-parallel. On the seismic lines, chaotic reflectors were identified to be associated with small-scale gravity faulting resulting in debris flow. The sandstone-prone facies have greater seismic amplitude values than the shale-dominated packages. The seismic expression of such lithology change may have resulted from the juxtaposition of low amplitude and moderately continuous seismic facies (shale prone) on high-amplitude and variable continuity seismic facies (sand-prone).

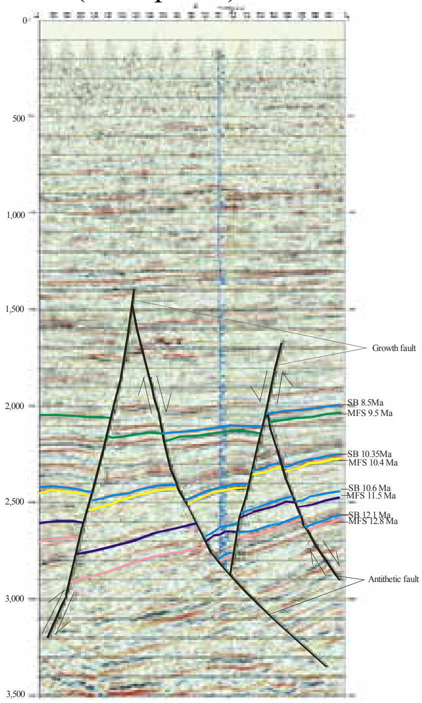

Fig. 8. Interpreted seismic section showing transect along in-line (dip) 5,980 section
Scale: vertical: 100 msec.; horizontal: 10 dip lines

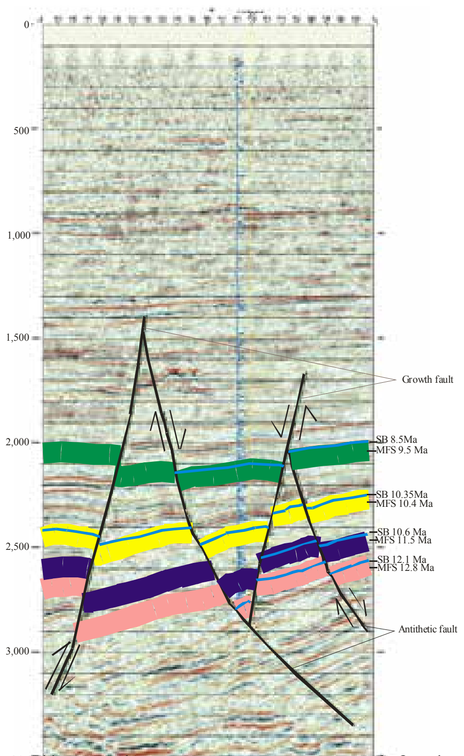

Fig. 9. Collapsed crest structures and fault styles and throw along in-line (dip) 5,980 section
Scale: vertical: 100 msec.; horizontal: 10 strike lines

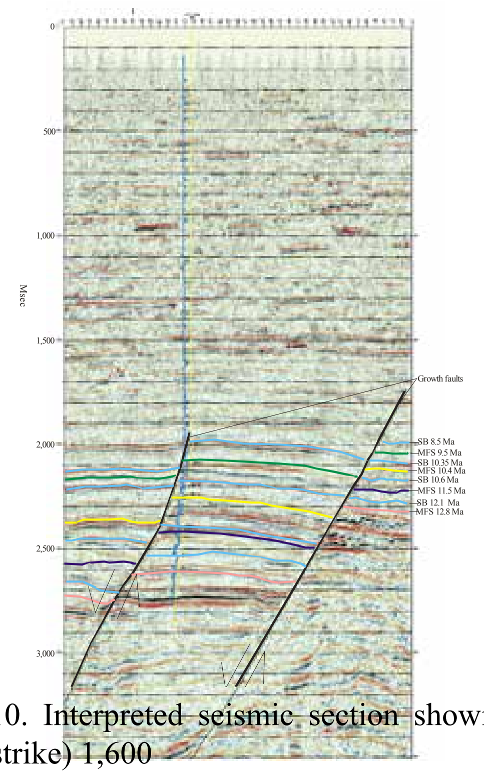

Fig. 10. Interpreted seismic section showing cross-line (strike) 1,600
Scale: vertical: 100 msec.; horizontal: 10 strike lines

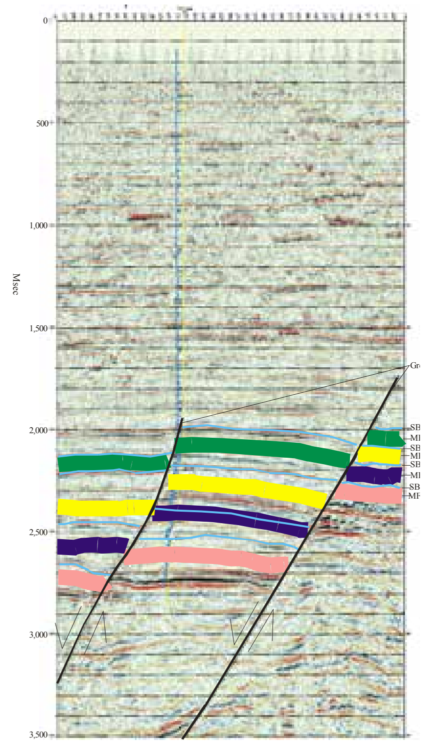

Fig. 11. Structures with growth faults along cross-line (strike) 1,600
Scale: vertical: 100 msec.; horizontal: 10 strike lines

From the seismic interpretation, it was detected that the sequence architecture was strongly controlled by extensional gravity-induced growth faulting. Though the influence of the Niger Delta regional tectonism on the local structural control was not differentiated;

however, it may be inferred that the following two factors may have affected the depositional sequences: differential subsidence, which in turn provided the variation in accommodation and shales with local withdrawal which may have provided areas of high subsidence.

The main traps are both structural and stratigraphic. Structural traps include rollover folds, tilted fault blocks, fault closure and horsts. Stratigraphic traps include pinch outs, sand deposit in the down-thrown blocks and up-thrown blocks, in-filled channels and debris flow deposits. Stratigraphic facies changes and pinch-outs in growth structure provide hydrocarbon traps; and may, therefore, provide exploration and development opportunities (Shaw *et al.,* 2004). Biostratigraphic data (Obaje, 2011) integrated with gamma ray and resistivity log characteristic curves were used to interpret the paleo-depositional environments of the study area. The defined depositional environments in stratigraphically ascending order are Prodelta shales, channel sands, tidal/distributary channel sands, barrier bar sands and upper shoreface deposits. The sands are mostly interbeded by shales/mudstones (Tables 8 - 12).

Table 8. The Environment of Deposition of XY-1-1 Well interpreted using the Well Log Signatures

DEPTH (M)	DEPOSITIONAL ENVIRONMENT
1,527.05 – 2,268.93	Upper shoreface
2,268.93 – 2,404.57	Inter-distributary channel overlain by shallow marine shales
2,404.57 – 2,868.47	Distributary channel sands overlain by shallow marine shales
2,868.47 – 3,150.41	Barrier bar sand deposits overlain by marginal marine shales
3,150.41 – 3,313.48	Inter-distributary channel overlain by shallow marine shales
3,313.48 – 3,446.68	Channel sands with occasional shallow marine shales
3,446.68 – 3,779.52	Pro-delta shales

Table 9. The Environment of Deposition of XY-1-2 Well interpreted using the Well Log Signatures

DEPTH (M)	DEPOSITIONAL ENVIRONMENT
1,828.80 – 2,268.93	Upper shoreface
2,268.93 – 2,404.57	Inter-distributary channel overlain by shallow marine shales
2,404.57 – 2,868.47	Distributary channel sands overlain by shallow marine shales
2,868.47 – 3,151.33	Barrier bar sand deposits overlain by marginal marine shales
3,151.33 – 3,313.48	Inter-distributary channel sand overlain by shallow marine shales
3,313.48 – 3,446.68	Channel sands with occasional shallow marine shales
3,446.68 – 3,791.71	Pro-delta shales

Table 10. The Environment of Deposition of XY-1-4 Well interpreted using the Well Log Signatures

DEPTH (M)	DEPOSITIONAL ENVIRONMENT
731.52 – 2,274.42	Upper shoreface
2,274.42 – 2,417.98	Lower shoreface
2,417.98 – 2,552.40	Tidal channel sands overlain by shallow marine shales
2,552.40 – 2,728.57	Inter-distributary channel sands
2,728.57 – 3,065.37	Distributary channel sands
3,065.37 – 3,270.20	Channel sands overlain by shallow marine shales
3,270.20 – 3,493.01	Pro-delta shales overlain by lower shoreface sands

Table 11. The Environment of Deposition of XY-1-5 Well interpreted using the Well Log Signatures

DEPTH (M)	DEPOSITIONAL ENVIRONMENT
1,219.20 – 2,274.42	Upper shoreface
2,274.42 – 2,417.98	Lower shoreface
2,417.98 – 2,581.35	Tidal channel overlain by shallow marine shales
2,581.35 – 2,909.93	Distributary channel sands with shale/ mudstone interbeds
2,909.93 – 3,270.20	Channel sands overlain by shallow marine shales
3,270.20 – 3,535.68	Marine shales overlain by tidal channel sands.

Table 12. The Environment of Deposition of XY-1-6 Well interpreted using the Well Log Signature

DEPTH (M)	DEPOSITIONAL ENVIRONMENT
2,133.60 – 2,656.94	Upper shoreface
2,656.94 – 2,947.72	Channel sands overlain by shallow marine shales/siltstones
2,947.72 – 3,134.26	Tidal channel sands with occasional shales interbeds
3,134.26 – 3,317.44	Distributary channel sands with shale/mudstone interbeds
3,317.44 – 3,592.68	Distributary channel sands
3,592.68 – 3,962.40	Lower shoreface overlain by prodelta muds/shales

The logs analytical data indicated the presence of two lithostratigraphic units in the XY-1 field, viz: the paralic Agbada and the continental Benin Formations, respectively, that are recognized in the Niger Delta area (Short and Staüble, 1967; Whiteman, 1982). The Agbada Formation, as shown in the wells, is typically a sequence of sandstones alternating with shales/mudstones, with sands predominating up-section. On the other hand, the Benin Formation is dominantly made up of non-marine (fluviatile) fine to coarse-grained sands with a few mudstone and shaly intercalations (Esan, 2002).

The thickness of the Agbada and Benin Formations varied widely in the five wells studied. The Agbada Formation is predominantly shale/ mudstone sequence alternating with variably, thickly bedded channel sandstones with coarsening upward and occasionally finning upward log signatures. The two recognized lithostratigraphic units and their thicknesses in the study area are shown in Table 13.

The ages of the five wells in the XY-1 Field range between Middle and Late Miocene based on the high resolution biostratigraphic data (Obaje and Okosun, 2013). All the MFS's and SB's fell within the Middle and Late Miocene interval and the five wells were adequately correlated (Table 14; Fig. 12).

Table 13. Lithostratigraphic Data of XY-1 Field

FORMATION	XY-1-1 DEPTH (M)	XY-1-2 DEPTH (M)	XY-1-4 DEPTH (M)	XY-1-5 DEPTH (M)	XY-1-6 DEPTH (M)
BENIN	1,527.05-2,268.93	1,527.05-2,282.95	731.52-2,273.81	1,219.20-2,417.98	1,222.25-2,948.33
AGBADA	2,268.93-3,779.52	2,282.95-3,791.71	2,273.81-3,489.96	2,417.98-3,535.68	2,948.33-3,962.40

Table 14. Chronostratigraphic Data of XY-1 Field

S/N	WELL NAME	DEPTH (M)	AGE
1.	XY-1-1	1,527.05-2,721.86	Late Miocene
		2,721.86-3,791.71	Middle Miocene
2.	XY-1-2	1,527.05-3,142.49	Late Miocene
		3,142.49-3,791.71	Middle Miocene
3.	XY-1-4	731.52-2,433.52	Late Miocene
		2,433.52-3,489.96	Middle Miocene
4.	XY-1-5	1,219.20-2,933.10	Late Miocene
		2,933.10-3,535.68	Middle Miocene
5.	XY-1-6	1,222.25-3,258.01	Late Miocene
		3,258.01-3,962.40	Middle Miocene

Table 15. Chronostratigraphic Horizons of XY-1 Field

MFS (Ma)	SB (Ma)	WELL NAME AND DEPTHS (M)				
		XY-1-1	XY-1-2	XY-1-4	XY-1-5	XY-1-6
	8.5	2,268.93	2,420.11	-	-	-
9.5		2,431.39	2,431.39	-	-	-
	10.35	2,639.57	2,855.06	2,273.81	2,417.98	2,948.33
10.4		2,731.31	2,882.80	2,433.22	2,443.89	3,258.01
	10.6	3,046.17	3,157.12	3,157.42	2,909.93	3,592.37
11.5		3,150.41	3,218.08	3,218.99	2,933.09	3,622.55
	12.1	3,313.48	3,386.94	3,404.62	3,387.24	3,845.05
12.8		3,446.37	3,404.92	-	3,466.80	3,907.23
	13.1	-	3,441.80	-	-	-

CONCLUSION

The direction of throw of the faults is dominantly westward. The faults (F1, F2, F3, F4 and F5) indicated that the faults are down-thrown. The Faults (F6 and F7) basically are the up-thrown faults. XY-1-1, XY-1-4 and XY-1-6 wells are situated in the down-thrown arms, having been affected by F6 and F7 faults thus leading to the loss of some horizon blocks from them. The F1 is observed to be southwest trending fault, while F2 and F3 have western trending pattern; F4 trends in west to east direction; F5 has nortwestern trend, while F6 and F7 trend in northeastern direction. XY-1-2 and XY-1-5 wells are situated in the up-thrown sector in relationship to fault (F2), while XY-1-6 well is located on the fault (F6). The wells were correlated based on the relationships in the MFS's and the SB's. Because some of the horizon blocks were interpreted to have been faulted out; it may be inferred that growth faults principally controlled the sequence architecture in the study area. The main traps are both structural and stratigraphic. Structural traps include rollover folds, tilted fault blocks, fault closure and horsts. Stratigraphic traps include pinch outs, sand deposit in the fault down-thrown blocks and up-thrown blocks, in-filled channels, debris flow deposits and shale/clays infilling and sealing of the fault planes. Stratigraphic facies changes and pinch-outs in growth structure provide hydrocarbon traps; and may, therefore, provide exploration and development opportunities in the XY-1 field and other areas of the Niger Delta. In this study, the overall geometry of the reflectors is parallel or sub-parallel. On the seismic lines, chaotic reflectors were identified to be associated with small-scale gravity faulting resulting in debris flow. The sandstone-prone facies have greater seismic amplitude values than the shale-dominated packages. The seismic expression of such lithology change may have resulted from the juxtaposition of low amplitude and moderately continuous seismic facies (shale prone) on high-amplitude and variable continuity seismic facies (sand-prone). Five unconformities were recognized in the wells of the study area. The stratigraphic succession is generally represented by nearly concordant, moderately bright amplitude reflectors and only subtle erosional features representing a limited incision were observed. On the other hand, downlap surfaces were traced on the seismic sections to mark four recognized candidate maximum flooding surfaces which were established using wireline logs and biostratigraphic data. Using integrated data set from wireline logs and biostratigraphy, five depositional environments recognized in stratigraphically ascending order are prodelta shales, channel sands, tidal and distributary channels sands, barrier sands and shoreface deposits.

It is recommended that structural map of the sub-surface horizons should be produced for further study of the area.

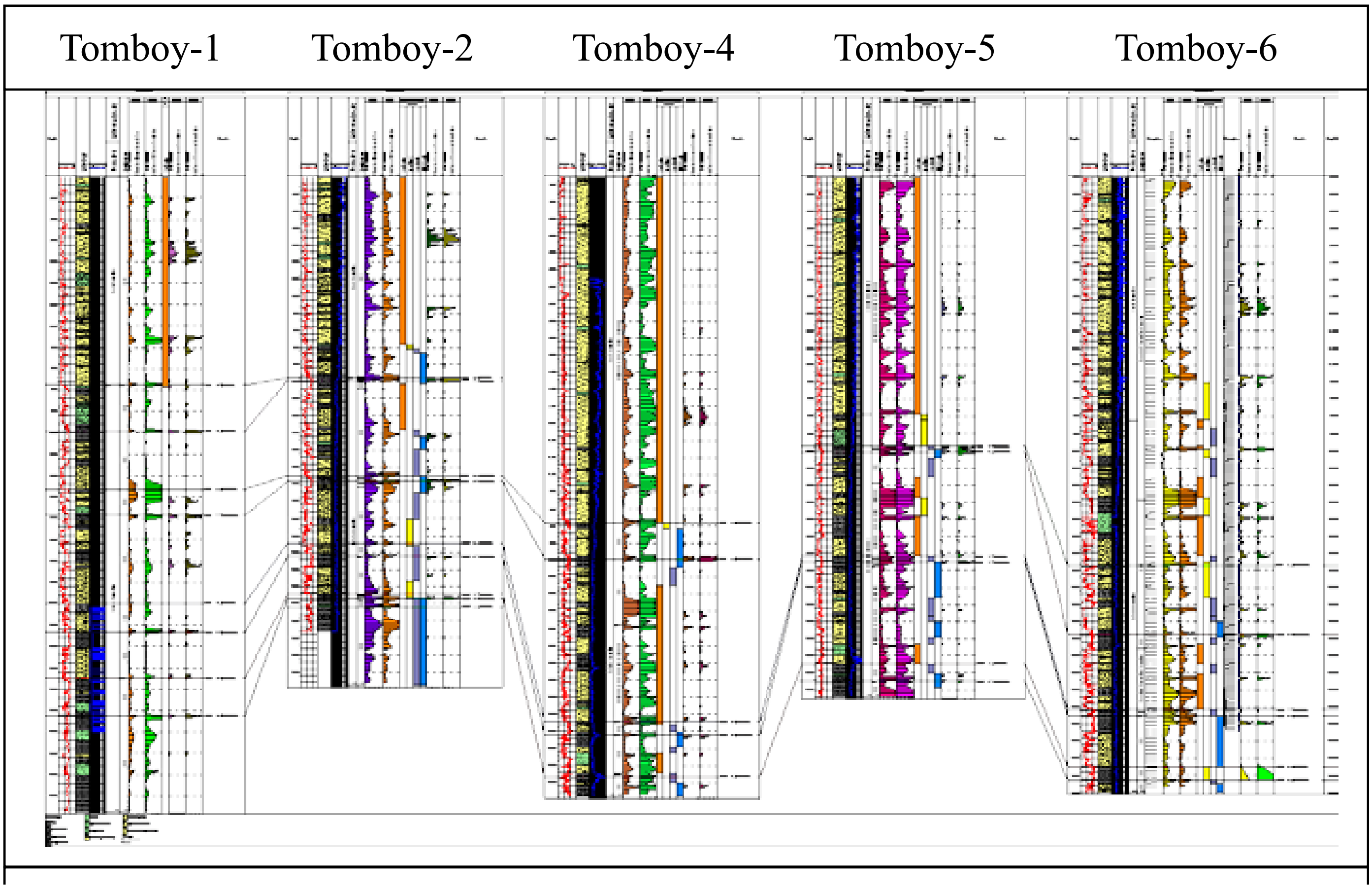

Fig. 12. Correlation Chart of Five Wells in Tomboy Field (Source: Obaje, 2011)

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