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CHAPTER I  

INTRODUCTION

The Niger Delta Basin, situated at the apex of the Gulf of Guinea along the West African coast is one of the most prolific hydrocarbon habitats in the world. The basin, which is estimated to cover about 75,000 square kilometers with a sediment thickness of 10 kilometers, is estimated to contain 21 billion barrels of oil, 800 million barrels of condensate and 110 trillion cubic feet of gas. At current rates of production, present proven reserves will last 30 years.

As the Niger Delta becomes a mature petroleum province, it has increasingly become necessary to understand the interplay between sedimentation and structure in order to adequately predict trap and reservoir development for successful hydrocarbon exploration and therefore increase the reserve base. Understanding of the trap and reservoir is also needed to be able to produce the existing fields and discoveries in a cost-efficient way.

The aim of this study is to interpret structural trap and stratigraphic architecture over the western Niger Delta and to demonstrate the effect the structural development of the Niger Delta has on sediment deposition. These interpretations will enhance the ability to predict reservoir quality, architecture and spatial distribution.

The approach employed in this study involves the building of a robust and consistent 3-D fault framework by interpreting a regular grid of high-resolution 3-D seismic data. This is followed by sequence stratigraphic analysis, utilizing seismic expression, wire log, and biostratigraphic data to subdivide the stratigraphic section into time equivalent, genetically-
related, sediment packages called sequences (Vail, Mitchum & Thompson, 1977). The sequences were then sub-divided into their constituent depositional environments called system tracts. Isopachs of the mapped sequences were analyzed for sediment thickness variation within the various fault blocks. There is a high rate of subsidence in the western Niger delta due to sediment loading and active growth faulting. These growth faults provide accommodation space and therefore focus sedimentation into tectonically active depositional centers called "depocenters." The position of the shelf edge therefore remains stable for a long period of time. This results in the aggradation of thick sediments within the megastructures adjacent to the active main structure building fault (msbf). The Niger delta depositional model suggested by McHargue, Diedjomahor, Arowolo, Hobbet, and Onyia (1993) and modified from the Exxon model (Vail et al., 1997) for passive margins, aptly illustrates the overall depositional profile of the western Niger delta. Seaward of the shelf edge sedimentation is predominantly pro-deltaic mud and thin turbidite sands. Mapping and correlating the sequences across the study area demonstrates that the timing of fault movement has played a major role in sediment accumulation and trap partitioning.

**Area of Study**

The area of this study is located offshore on the continental shelf of the western portion of the Niger Delta, Nigeria (Figure 1) which is presently being explored for its hydrocarbon potential. It is located between the shoreline and a water depth of 200 meters and covers approximately 400 square kilometers.
Data

The database used for this study includes a high-fold, migrated 3-D seismic volume acquired in 1987, a suite of gamma ray wireline well logs and biostratigraphic data (palynomorphs, nanofossils and foraminifera). These data have been used to interpret sequence stratigraphic boundaries. The 3-D seismic data were also used to interpret the structural framework for the area. The data were collected using a network of hydrophones, which transmit data via radio link to a central receiving equipment onboard a ship. The energy source is an airgun array consisting of 12 guns. The guns have a total capacity of 930 cubic inches of air at a pressure of 4,500 psi. At a speed of 4 knots (2 meters per second), the guns are synchronized to fire every 25m. The shot line spacing is 25 meters while the cross line spacing is 50 meters.
The well log data were employed in subdividing the sequences into constituent depositional environments while the biostratigraphic data base provided the basis for assigning ages to the sequences.

**Objective of Study**

The objectives of this study include:

1. Interpret and map time correlative sequences and their associated sediments and the partitioning of the sedimentary section into depositional packages.

2. Define a structural framework, identify the major structural trends and demonstrate the predominant structural style and nature of fault linkage and fault termination for the study area.

3. Examine the effect of structural development on sediment deposition and distribution and hence the ability to predict reservoir development.

4. Develop a depositional model consistent with the established structural and stratigraphic interpretation in the western Niger delta.
CHAPTER II

GEOLOGIC SETTING

The Niger delta, situated on the Gulf of Guinea on the coast of West Africa is built out into the Atlantic Ocean at the mouth of the Niger-Benue river system. The catchment area of the delta encompasses more than a million square kilometers of predominantly savannah-covered lowlands (Doust & Omatso, 1989). The delta is confined in a structural trough containing sediments of Upper Cretaceous and Tertiary age and bounded by the Benin Hinge zone along the Ilesha spur to the west and the Onitsha High to the north and the Abakaliki High and the Oban Massif to the east (Figure 2).

The Niger River system, which drains the West Africa subcontinent, funneled huge volumes of sediment into the structural depression beginning in late Cretaceous time. These Niger Delta sediments have filled the trough and prograded across the narrow continental shelf beyond the continental margin over oceanic crust.

Structure

The pre-Tertiary tectonic framework made up of the Ilesha spur to the west and the Oban massif to the east (Figure 2) controlled the direction of progradation of the deltaic sediments. These tectonic structural elements appear to have no influence on the Tertiary deformation style. The Tertiary Niger delta is dominated by a complex system of sub-
parallel, arcuate, listric normal growth faults as well as a system of antithetic and counter-regional faults and shale diapirs. At any one time, sediment loading in the area of delta front and pro-delta causes compression and dewatering of underlying pro-delta ductile clays. These clays are then extruded towards the basin resulting in the formation of a major structure-building fault on the proximal side of the newly formed depocenter. As the underlying pro-delta clays are extruded beyond the main area of sediment loading, they rise up as mud diapirs, creating an arcuate series of basins parallel to the paleocoastline. The proximal face of this mud diapir is termed a counter-regional fault. The series of basins
formed between the structure building and the counter-regional faults are called “megastructures” (Doust & Omatsola, 1989; Weber, 1987).

High subsidence within these trends results in the aggradation of thick packages of sediments that are considerably older than the sediments and associated structures of the next seaward trend.

Growth faults provide accommodation space and focus sedimentation into these tectonically active megastructures. The megastructures are linked in a direction perpendicular to the sedimentation direction at the time of formation to form structural trends that contain sediments of the same age.

Stratigraphy

The Niger Delta is a regressive sequence of clastic sediments formed in a series of offlap cycles. Deep wells in the basin have documented a tripartite lithostratigraphic succession in which the regressive sequence is demonstrated (Doust & Omatsola, 1989). The Delta has followed the same pattern of sedimentation and progradation throughout its period of growth. The three lithostratigraphic units have been identified and referred to as the Akata, Agbada and Benin Formations from the oldest to the youngest (Short & Stauble, 1967).

The Akata Formation is composed mainly of thick marine shales with interbedded siltstones and thin sands believed to be turbiditic in origin. Although no well has penetrated the entire Akata shale in the heart of the delta, it is believed that this sequence could be as thick as 7000m in the central portion of the delta where sediment thickness is estimated to be about 12000km. They are known as the Imo shales where they crop out in the northeastern
part of the delta and offshore, they are expressed as shale diapirs. They range in age from Eocene in the north to Mio-Pliocene in the south.

The Akata Formation grades into the overlying Agbada Formation, which is an interbedded sand shale sequence of shallow-marine and fluvial sand, silt and clay that formed the paralic facies of the delta. This sequence which typifies the characteristics deltaic cyclic process was formed in a series of progradational and retrogradational cycles. This cyclic process is largely responsible for the alternating reservoir and seal rock that has made this unit the hydrocarbon-prospective sequence in the Niger Delta. The sediments were deposited in a wide range of delta front, shore face and fluvio-deltaic environment. The Agbada Formation ranges in age from Eocene to Pleistocene and has a thickness of up to 3000m.

The uppermost unit known as the Benin formation comprises marginal marine to continental sandstones deposited in alluvial or upper coastal environment. This unit has been suggested to be Oligocene to Recent in age though the lack of fauna has made direct dating impossible.

It should be mentioned that the boundary between these three units is gradational and is only characterized by changes in sand-shale ratio as one moves from the base of the mega-sequence to its top.
CHAPTER III

STRUCTURAL INTERPRETATION

The study area has been mapped in order to establish a consistent regional fault framework. This mapping was performed using a standard workflow for building a 3-D structural framework from 3-D seismic data volume developed by the Chevron Petroleum Technology Company (CPTC) Structural Geology Team. All seismic interpretation was performed using a Landmark seismic interpretation platform (SEISWORKS) at CPTC facility in San Ramon, California.

Methods and Concepts

The workflow involves eight critical steps, which are documented with examples as shown below.

Step 1: A coherency seismic (Figure 3) volume was generated from the standard amplitude volume. In this study, the Chevron Enhancement & Detection of Geologic Events (EDGE) coherency technique was used. The technique involves the processing of a seismic amplitude volume using a trace to trace subtraction method to detect amplitude differences. Faults generally cause amplitude changes between neighboring traces and consequently appear dark on EDGE sections while undisturbed strata is light. EDGE therefore enhances the seismic data to highlight structural information more quickly and accurately. EDGE also help in the detection of stratigraphic features such as channels.
Figure 3. An EDGE (coherency) time seismic volume showing faults.

**Step 2:** A regular fault interpretation grid of 4 lines by 16 traces (100m by 100m) was established. Also a consistent fault-naming convention was developed. In this project, all major structure-building faults are prefixed with Msbf. Synthetic faults to the major faults are prefixed Isf while antithetic faults are prefixed Iaf.

**Step 3:** Interpreted faults on dip section (Figure 4) using both amplitude and EDGE 3-D seismic volume on the established grid spacing.
Figure 4. Transverse time seismic section showing fault interpretation.

Step 4: Faults were checked for consistency on vertical strike sections (Figure 5) and arbitrary lines (traverses). Interpretation was also performed on these sections in order to account for faults that splay or curve from their dominant strike direction.

Step 5: Faults were interpreted and checked for consistency on EDGE timeslices (Figures 6 and 7). Timeslices are the only view in which strike and dip are truly represented. EDGE timeslices therefore provide a powerful tool for structural interpretation. It must be noted, however, that amplitude timeslices can be misleading. A major advantage of EDGE timeslices over amplitude timeslices is the ability of the interpreter to instantly recognize the geometry of the fault network. Also, faults can be accurately located, which enables the fault
Figure 5. Longitudinal time seismic section showing fault interpretation.

model to be built more quickly. EDGE timeslices help to correlate and limit the extent of faults at each level of refinement.

Step 6: Fault plane contour maps (Figure 8) were generated to help check the geometric consistency of fault interpretation in map view. Composite fault plane maps for the selected time interval show the structural linkage in three dimensions.

Step 7: A final quality control of the fault interpretation was performed in a 3-D viewer (Figure 9). The Chevron Geologic Object Computer Aided Design (GOCAD) software package (version 1.5, 2000) was used for this process.
Figure 6. A 1300 milliseconds EDGE timeslice without interpretation.

**Step 8:** A 3-D fault framework was built using GOCAD. Interpreted faults vectors were imported into the GOCAD program for the purpose of validating the geometric consistency of the faults and building a 3D model that supports the structural interpretation.

### Structural Framework

The workflow led to the building of a consistent and robust 3-D fault framework from the 3-D seismic volume (Figure 10). Sixteen major structure-building faults (Msbf) were identified and mapped. These faults strike in the predominant NW – SE direction and dip towards the basin. In addition, 34 minor synthetic faults and 13 minor antithetic faults were
also identified and mapped. Most of these minor faults have the same NW – SE strikes as the structure-building faults. However, these faults change their strike direction to a N – S orientation as they tip out.

In the study area, the major structure-building faults form four structural trends (Figure 11). These structural trends are Ewan-Kito, Meta-Tapa-Delta, Meren-Tapa West and Meren West-Ofu. Each trend is bounded by a set of linked major structure-building faults (Msbf) and contains sediments of the same age. The structural relationship between each fault, the manner of fault linkage and termination within the study area is very well
Figure 8. Fault plane map between 1200-1800 milliseconds of main structure-building faults. Demonstrated with this 3-D model. In addition, the spatial relationship between the four trends can also be clearly seen.

**Deformation Style and Fault Linkages**

Interpretation of faults in the study area revealed a distinct faulting pattern consisting of large normal faults. These faults are mostly southwest-dipping, listric growth faults with a
Figure 9. A 3-D view of major structure-building fault vectors.

cuspate outline in map view (Figure 11). The major structure-building faults (Msbf) link together to form trends. Intra-structure synthetic and antithetic faults show en-echelon patterns. Structural culmination, typically 4-way closures, occur in the hanging walls to most of the major faults.

A characteristic rhombohedral shape is observed for each fault block. This observed fault block shapes could be explained by uniform rheologic behavior of sediments in the western Niger delta.
In the study area, there are two dominant mechanisms by which faults are linked. These are:

**Accommodation Zones.** These are belts of overlapping fault terminations that can separate either systems of uniformly dipping normal faults or adjacent domains of oppositely dipping normal faults parallel, perpendicular or oblique to the extension direction. Both
synthetic and antithetic accommodation zones can be observed in the study area especially in the Eko-Meta-Tapa-Delta trend. Linkage through accommodation zones tends to produce a soft-fault link whereby strain is redistributed through transfer from one fault to another without physical connection between the faults involved in the strain transfer process. An example of this type of linkage is the Tapa structure-building fault (Msbf 2a) which tips out in an accommodation zone that separates it from the delta structure building (Msbf 2b). This
relationship is also observed as the Meren structure building fault tips out towards Tapa-West (Figure 12).

**Fault Capture.** This is the coalescence or joining of two independent faults to form a single fault leading to the redistribution of strain. As normal faults propagate in the sediments, they propagate towards each other until the tip of one fault reaches the other, capturing the other fault. After capture, the two faults become one fault eliminating movement on the shortcutted segments (former fault tips). The process of fault capture results in a *hard-fault linkage* where the resultant fault after capture behaves as a single fault.
The progressive propagation of a fault leading to capture can be represented diagrammatically as stage 1, Stage 2, and Stage 3 (Figure 13). These 3 stages can be seen clearly in seismic time slices, as well as in trace lines, from the study area.

![Figure 13. A conceptual model for the progressive evolution of fault capture.](image)

The fault capture mechanism accounts for the along strike variation on varied history of very large normal faults. Recognition of this mechanism allows for the kinematic reconstruction of movement along the faults and the need to correlate across these trends at their tip points.

Most of the structural trends identified in the study area are created through this process. A good example is the Meren-Tapa West trend where there are a series of fault
capture to link faults Msbf3A, Msbf3B and Msbf3C (Figure 11). It appears that the Delta major structure-building fault (Msbf 2B) is propagating towards the Tapa major structure-building fault (Msbf 2A). Deeper in the section it appears that Msbf 2B is very close to connecting to Msbf 2A and only a little more motion on these faults would be necessary to link the two faults. An example of two faults that have linked is the Msbf 3A – Msbf 3B – Msbf 3C system. In map view, (Figure 13) these three faults form one continuous, fairly linear fault trace. In the study area the structural trends are bounded by a series of faults that are hard linked to one another.

As a result of these two types of fault linkages, faults in the study area form a linked system where movement along one set of faults leads to a general movement and redistribution of strain across all faults. This movement on the faults provides relative accommodation space during fault movement and has a profound effect on the distribution of sediments and reservoir rock.
CHAPTER IV

SEQUENCE STRATIGRAPHIC INTERPRETATION

Sequence stratigraphy is an approach to stratigraphic correlation that emphasizes regional unconformities as the basis for subdividing sediments into time-equivalent packages called sequences. A “sequence” is defined as genetically related strata (deposits) bounded by surfaces of erosion or non-deposition and their correlative conformities (Van Wagoner, Mitchum, Campion & Rahamanian, 1987). Sequences are classified by the duration of the events controlling the creation and destruction of space available for sediment accumulation, i.e. tectonic subsidence and/or eustasy. Duval, Cramez, and Vail (1998) classified sequences into four orders of cyclicity and global correlation; 1\textsuperscript{st} order (> 50 ma) continental encroachment cycles controlled by tectono-eustasy, 2\textsuperscript{nd} order cycles (3 – 50 ma) caused by changes in subsidence rate, 3\textsuperscript{rd} order cycles (0.5 – 3 ma) controlled by glacio-eustasy and 4\textsuperscript{th} and higher order cycles which are related to autocyclic processes. Each sequence therefore represents sedimentation during a cycle of relative sea-level change from fall, through rise and back to fall. The sequences described in this work are 3\textsuperscript{rd} order sequences which have duration of half a million to three million years.

In the Niger Delta, identifying sequences and their composite depositional environments (system tracts) provides the basis for correlating, interpreting and predicting lithologies. Using a combination of 3-D seismic and gamma ray well log data in an integrated approach, five sequence boundaries (SB100, SB200, SB300, SB400, and SB500) were identified and mapped in the study area. The mapped sequences were then set in a
chronostratigraphic framework by integrating biostratigraphic data and then correlated to the Cenozoic Cycle Chart by Haq, Hardenbol, and Vail (1988). This helps to facilitate regional correlation across the main structural trends, provides paleobathymetry at the time of deposition of the sequence and therefore constrains the interpretation of the environment of deposition.

**Identifying Sequences**

Most 3rd order sequences in the Niger delta are marked by the presence of a prominent erosion channel near the paleo-shelf edge and are therefore easily identifiable on seismic data. Identifying sequence boundaries in areas where channels are not present is often difficult on seismic and in such cases the boundaries can be identified from a combination of the seismic attributes with well log signature and biostratigraphic data.

**Recognizing Sequence Boundaries from Seismic Data**

On the 3-D seismic data, a combination of the following criteria was used to identify sequence boundaries.

**Truncation:** This is an expression of abrupt termination of underlying seismic reflection by a sequence boundary as shown in (Figure 14). This is the most common and easily recognizable criterion in the Niger delta. Truncations are caused by a drop in sea level and therefore represent sequence boundaries.

**Onlap:** This is a geometric relationship between the sequence boundary and seismic strata sitting above it (Figure 15). It is commonly used in combination with truncation, as the presence of onlap by itself may not suggest the presence of a sequence boundary.
Figure 14. Seismic example of truncation, onlap and attribute discordance on SB200 sequence boundary.

**Dip Discordance:** Sequence boundary usually separates reflections with different amounts and orientations of dips. Seismic reflection dips tend to be steeper above sequence boundaries than those beneath the boundaries (Figure 16). This relationship can also occur around low-angle structures.

**Attribute Discordance:** Seismic reflection attributes such as amplitude and continuity vary across sequence boundaries and can therefore be used to identify these boundaries. Figure 14 shows parallel to sub-parallel seismic reflections beneath the SB1 sequence boundary in contrast to a chaotic reflection pattern above the same boundary. In Figure 14, the boundary separates panels of high- and low-amplitude seismic reflections.
Recognizing Sequence Boundaries from Well Log Data

In combination with the various seismic criteria discussed above, the gamma-ray well log pattern was used to identify sequence boundaries. The ability to identify sequence boundaries from well log signatures is dependent upon the succession of system tracts. Since a complete succession of system tracts is not to be expected within a sequence at any one location, biostratigraphic data are used to provide an idea of the relative position along the depositional profile. The study area is essentially composed of neritic sediments; thus sequence boundaries may be identified from the following features.

Base of thick shale: There is a predominance of shale-filled submarine canyons due to shelf failure relative sea-level fall in the western Niger delta. The base of these canyons in
Figure 16. Seismic example of dip discordance across SB500 sequence boundary.

an otherwise sandy environment can easily be identified in the wire-line logs (Figure 17). In Figures 17 and 18, left pointing arrows depict coarsening up sediment packages while right pointing arrows depict fining up sediment packages.

**Base of sandy intervals:** Away from the shale filled canyons the first sediments deposited on the sequence boundary in this shelf environment are prograding sandstone units. Therefore the base of up-wards coarsening sands are likely sequence boundaries (Figure 18).
Description of Sequences

The five mapped sequences in the study area are as described below.

**Sequence SB100 to SB200 (3.8 – 4.2 Ma.)**

This sequence bounded by SB100 at the top and SB200 at the base was deposited over a period of 0.5 My. The SB100 sequence boundary (Figure 19) has no major submarine
canyon associated with it. It is identified based on log pattern and biostatigraphic data. The SB200 sequence boundary is associated with a fairly large submarine canyon that is evidenced on seismic in the Delta field area of the Eko-Meta-Oloye-Tapa-Delta structural trend (Figure 20). The canyon is straight, running from northeast to southwest across the entire study area. There are several tributaries that feed the main canyon from Kito, Meji and
Figure 19. Time structure map of SB100 (3.8 Ma.) sequence boundary.

Meren fields respectively. The sequence is thickest in area where the SB200 submarine canyon is present due to the presence of the canyon fill.

**Sequence SB 200 to SB300 (4.2 – 5.5 Ma.)**

Sediments within this sequence were deposited over a period of 1.2 Ma and have great thickness variation because of the erosional nature of its bounding surface. The SB300 sequence boundary has fairly widespread submarine canyon formation that is evidenced on seismic in the vicinity of the Delta field area of the Eko-Meta-Oloye-Tapa-Delta trend.
Figure 20. Time structure map of SB200 (4.2 Ma.) sequence boundary.

(Figure 21). This submarine canyon system continues into the Ofu area of the Meren West-Ofu trend and therefore provides the basis for correlation across the faults. In the central portion of the study area, this sequence has been completely removed by erosion by the SB200 boundary.
Figure 21. Time structure map of SB300 (5.5 Ma.) sequence boundary.

**Sequence SB 300 – SB 400 (5.5 – 6.3 Ma.)**

This sequence deposited over a period of 1.0 Ma. is bounded at the base by a fairly conformable SB 400 boundary. The SB400 sequence boundary has no submarine canyon associated with it that is evidenced on seismic (Figure 22). This sequence was therefore identified and mapped on the basis of log pattern and biostratigraphic data. Across most of the study area this sequence is comparatively thin and has its thickest occurrence in the Meren west – Ofu trend.
Figure 22. Time structure map of SB400 (6.3 Ma.) sequence boundary.

Sequence SB 400 – SB 500 (6.3 – 8.2 Ma.)

This sequence is bounded at the base by SB500 sequence boundary, which has no submarine canyon, associated with it (Figure 23). This sequence was therefore identified and mapped on the basis of log pattern and fossil abundance. Although sediments in this sequence were deposited over a period of 1.0 million years, it is comparatively thin across the entire study area. The sequence is however thinnest in the Ewan – Kito trend and increase in thickness to a maximum in the Meren west – Ofu trend.
Sequence SB 500 – SB 600 (8.2 – 10.5 Ma.)

The basal boundary (SB 600) of this sequence is marked by the presence of a large submarine canyon system in the vicinity of Tapa in the Meta – Tapa – Delta trend. The sequence is therefore very thick in this area because it includes the fill of the underlying submarine canyon. The sequence is however thickest in the Meren west – Ofu trend in the vicinity of Ofu.
Sediment Distribution within Sequences

A sequence can be subdivided into system tracts, which are linked contemporaneous depositional units genetically linked by processes and environment (Fisher & McGowen, 1967). It consists of Lowstand, Transgressive and Highstand system tracts that changes predictably through time in response to relative sea level fluctuation. Figure 24 shows the sediment records in response to relative sea-level variation in the study area.

During relative sea-level drop the highstand shelf is subjected to erosion and sediment by-pass and sediment deposition is displaced towards the basin. There is general slope instability resulting in formation of submarine canyons. These canyons extend by head-wards erosion across the shelf and are filled with clays slumping from the previous muddy highstand shelf (Figure 25).
Figure 24. Relative sea level variation and associated system tracts in the study area.
Figure 25. A cross section showing the sediment records in response to relative sea-level variation in the study area
CHAPTER V

DISCUSSION AND SUMMARY

In order to document the influence of the faulting on sediment distribution, 5 transverse and 3 longitudinal sections were established across the study area (Figure 26). 3-D seismic data from the Niger River Delta have allowed the study of propagation and development of normal faults in the delta. Normal faults are accommodating sedimentation and hence are driven by it. An analysis of thickness variation within each mapped chronostratigraphic unit (sequence) shows that the fault displacements correlate to the distribution of sediments and reservoir facies in the study area.

Mapped sequences in the study area are relatively thick and this is indicative of high rates of subsidence and sedimentation. The high rate of subsidence is created by active fault movement and sediment supply from the Niger River which drains the West Africa sub-region is adequate to fill the accommodation space created by these faults in the study area. Continuous sedimentation faithfully records fault movements. Sedimentation itself drives the movement of faults, as the faults serve to level topographic highs, which are gravitationally unstable.

Sediment Response to Growth Faulting

It is observed in the study area that the chronostratigraphic units increase in thickness from one structural trend to the other in the direction of the basin (Figures 27, 28, 29, 30 and 31). In the north, however, the presence of submarine canyons in some chronostratigraphic
units provides local thickness variations (Figures 28 and 29). There is stratigraphic thickness variation along dip direction from one major structure-building fault to the other.

The basinward thickening results from greater accommodation space created as fault blocks move down at the same time as rapid sedimentation. So thicker sedimentary sections are deposited on the down-thrown fault blocks and record the movement history of the faults. Interpreted time seismic sections and depth cross sections that illustrate this observation are shown in Figures 27 through 31.

On all of the cross sections the stippled chronostratigraphic unit represent sediments deposited between sequence boundaries SB 400 and SB 500, representing sediments deposited from 8.2 Ma to 6.3 Ma.
Figure 27. Transverse profile A-A’ through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 28. Transverse profile B-B’ through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 29. Transverse profile C-C’ through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 30. Transverse profile D-D’ through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 31. Transverse profile E-E' through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 27 from the NW part of the study area illustrates the thickness variation and therefore the differences in the timing of fault movement from one trend to the other. The Ewan-Kito trend, which is represented by the EW-1 well on the right-hand section of the cross section, the SB400-SB500 interval (marker interval) is relatively thin and shows little thickness variation. As shown in the MT-2 and MN-1 wells, in the center part of the cross section, the marker interval is thicker than in the Ewan-Kito trend.

This indicates that relatively more accommodation space was present due to greater fault movement on the Meta-Tapa-Delta trend-bounding fault than the Ewan-Kito trend during this time period. The Meren-Tapa West trend is represented by the MR-4 well, in the left part of the cross section, where the marker interval is thicker than in the Meta-Tapa-Delta trend. This indicates that relatively more accommodation space was present due to greater fault movement on the Meren-Tapa West trend-bounding fault than the Meta-Tapa-Delta trend during this time period.

The Meren West-Ofu trend is represented by the MR-73 well, in the left part of the cross section, where the marker interval is thicker than in the Meren-Tapa West trend. This indicates that relatively more accommodation space was present due to greater fault movement on the Meren West-Ofu trend-bounding fault than the Meren-Tapa trend for this time period.

This relationship shows the direct control of the fault on the creation of accommodation space and therefore the distribution of the sediments. The basinward trends (Meren West-Ofu and Meren-Tapa West) show more subsidence than the landward trends (Ewan-Kito and Meta-Tapa-Delta).
This same relationship of basinward thickening across trend-bounding faults and their control on sediment distribution is also illustrated in Figures 28 and 29. The Meren-Tapa West trend-bounding fault is decreasing in displacement towards the southeast (Figure 30). Cross section D-D' illustrates small thickness variation in the marker interval between the Meta-Tapa-Delta trend (well TP-3) and the Meren-Tapa West trend (TW-1). The decrease in displacement results in a decrease in accommodation space between the two trends and therefore relatively small thickness change in the marker interval.

Figure 31 show that the Meren-Tapa West trend-bounding fault is no longer present in the south-east portion of the study area. The result is that only three trends are present in that area (basinwards, Ewan-Kito, Meta-Tapa-Delta and Meren West-Ofu trends). The control of the trend bounding faults on the creation of accommodation space and therefore sediment distribution observed in the three remaining trends is the same as in other parts of the study area towards the northwest.

**Sediment Variation Along Faults Parallel to Depositional Profile**

The thickness variation along strike, within each structural trend, is illustrated in Figures 32 (Meta-Tapa-Delta), 33 (Meren-Tapa West) and 34 (Meren West-Ofu). These figures show that the thickness variation within each trend is relatively small compared to that between trends. However, the gross sediment thickness for each depositional sequence, including the marker interval, thins laterally from the center of the each fault towards the tips. This thickness relationship is another evidence of structural control on sediment deposition and distribution. This thickness relationship with greater thickness at the center
Figure 32. Longitudinal profile X-X’ through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 33. Longitudinal profile Y-Y' through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
Figure 34. Longitudinal profile Z-Z' through the study area. (a) Interpreted time seismic section (b) Depth section showing faults, gamma-ray well logs and sequence boundaries.
during each sequence interval indicates that fault grew from the center towards the fault tip. (Walsh & Watterson, 1988).

**Reservoir Distribution within Structural Trend**

The structural architecture also controls the facies distribution including reservoir distribution and quality just as it controls sediment thickness. The movement along these major structure-building faults preferentially localizes reservoir quality rocks proximal to the faults through sediment ponding (Figures 35 and 36). These illustrations are an isopach map of the G-1 sand (Figure 35) and a dip profile (Figure 36) through four wells in the Meren field area of the Meren-Tapa West trend. The thickest part of the G-1 reservoir is immediately adjacent to the structure building fault. This is due to the rotation of the hanging wall that produces the greatest amount of accommodation space near the fault at the time of reservoir deposition. The movement on the fault also controls the quality of the reservoir. Coarser sand materials that are better reservoir are ponded proximal to the controlling fault. Reservoir quality deteriorates on the hanging wall away from the structure building fault (Figure 36). The structure-building faults also control reservoir quality in the strike direction (Figure 37). The G-1 reservoir quality improves toward the center of the controlling fault. This effect is due to the creation of maximum accommodation space near the center of the fault. Maximum sand development due to ponding occurs at this point, in topographic lows resulting from maximum displacement on the fault plane.

The control of reservoir distribution and quality by the bounding fault in the Meren-Tapa West trend is also demonstrated along the same fault just to the southeast of the area.
Figure 35. Isopach map of G-1 reservoir in the Meren Trend.

described above (Figures 38 and 39). In the southeast, the thickness and reservoir quality of the G-1/G-2 sand increase towards the center of the structure-building fault.

Sediment thickness pattern observed in the two Meren blocks indicate "capture" of displacement on one bounding fault by another. The thickness pattern at the G-1/G-2 interval indicates separate movement on the controlling faults. However, the thickness pattern at the D-04 interval in the two fault blocks shows uniform thickness (Figures 37 and 39). This is indicative of the two fault blocks moving together on a common hanging wall at this time.
Figure 36. Dip profile through the Meren Trend showing reservoir distribution away from the major structure-building fault.
Figure 37. Strike profile 1 through the Meren Trend showing reservoir distribution along the major structure-building fault.
Figure 38. Isopach map of G-1 reservoir in the Meren Trend.
Figure 39. Strike profile 2 through the Meren Trend showing reservoir distribution along the major structure building fault.
CHAPTER VI

CONCLUSIONS

The Tertiary western Niger delta is dominated by growth faulting associated with progading siliciclastic underlain by a predominantly shaley and overpressured Akata Formation. These faults are initiated and propagated through gravity-driven sediment loading. The faults therefore form a linked system to create structural trends. The temporal pattern of movement of these faults is documented in the sedimentation record. Throws across faults have been established in the study area and the timing of fault movement has been determined relative to the sequence boundaries.

Most of the sequence boundaries established in the study area have major submarine canyons associated with them and are relatively very thick. This is interpreted to be due to high subsidence and sedimentation rates. The progradation of the delta in the study area seems to be in major pulses controlled by high frequency fluctuations of the relative sea level. This is expressed as a package of upward-coarsening reservoir sands each having a thickness of up to 500 feet.

In the western Niger delta, depositional patterns and reservoir distribution are strongly affected by growth faults, which provide accommodation space. The faults focus sedimentation into tectonically active structural trends bounded by major structure-building faults. This causes the position of the shelf edge to remain stable for a long period of time resulting in the aggradation of thick sediments within the structural trend.
Sedimentation in turn causes loading resulting in complex patterns of fault movement and subsidence across the area. These complex movement and subsidence patterns play a direct and important role in the distribution of syntectonic sediments and reservoir rock facies. In general each chronostratigraphic unit increases in thickness from one structural trend to the other in the direction of the basin. Within each structural trend, however, there is reduction in chronostratigraphic unit thickness away from the controlling trend-bounding fault in the direction of the next younger trend. Associated with this overall thickening of sequences across each structural trend is a proportional increase in reservoir rock thickness and quality. This observed pattern demonstrates the profound control the faults have on sediment and reservoir distribution in the western Niger delta.
REFERENCES


ABSTRACT
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The effect of the structural development of western Niger Delta basin on sediment and reservoir distribution was examined using a high-fold, migrated 3-D seismic volume, a suite of gamma ray wire-line well logs and biostratigraphic data sets. The approach employed in this study involved the building of a 3-D fault framework from the seismic data followed by the building of a chronostratigraphic framework through a sequence stratigraphic analysis of the Middle Miocene to the Lower Pliocene sediments.

The area of this study is located offshore on the continental shelf of the western portion of the Niger Delta, Nigeria, which is presently being explored for its hydrocarbon potential. It is located between the shoreline and a water depth of 200 meters and covers approximately 400 square kilometers.

The structural framework of the study area revealed a distinct faulting pattern consisting of large normal faults. These faults are mostly south-dipping, listric growth faults with a cuspate outline. The major faults are linked together to form trends through the process of fault capture while smaller synthetic and antithetic faults show en-echelon patterns. These faults form a linked system whose temporal pattern of movement is documented in the sedimentary record. Structural culmination, typically four-way closures, occurs in the hanging walls to most of the major faults. A chronostratigraphic framework was established by interpreting and mapping time correlative sequences and their associated sediments. Most of the time correlative surfaces were observed to have major submarine canyons associated with them.
A strong structural effect is observed on sediment and reservoir deposition and distribution. Depositional pattern, sediments and reservoir distribution was affected by the growth faults, which provide accommodation space. There is an overall thickening of each sequence basin-wards across the structural trends. Within each structural trend there is also a decrease in reservoir rock thickness and net-to-gross ratio from one structure-building fault towards the next younger one. This structural control on sedimentation is also observed within each trend along strike with net-to-gross decreasing towards fault tips. Also, associated with this thickness reduction is the deterioration of reservoir quality rock in the same direction.

This knowledge can therefore be use to predict reservoir development in oil and gas exploration and exploitation.