GEOLOGICAL MODELING OF DAHOMEY AND LIBERIAN BASINS

A Thesis

by

HAKEEM BABATUNDE GBADAMOSI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Geophysics

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Approved by:

Chair of Committee,	Luc T. Ikelle
Committee Members,	Yuefeng Sun
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ABSTRACT

Geological Modeling of Dahomey and Liberian Basins.

(May 2009)

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Chair of Advisory Committee: Dr. Luc T. Ikelle

The objective of this thesis is to study two Basins of the Gulf of Guinea (GoG), namely the Dahomey and the Liberian Basins. These Basins are located in the northern part of the GoG, where oil and gas exploration has significantly increased in the last 10 years or so. We proposed geological descriptions of these two Basins. The key characteristics of the two models are the presence of channels and pinch-outs for depths of between 1 km and 2 km (these values are rescaled for our numerical purposes to 600-m and 700-m depths) and normal faults below 3 km (for our numerical purposes we use 1 km instead of 3 km). We showed that these models are consistent with the plate tectonics of the region, and the types of rocks and ages of rocks in these areas.

Furthermore, we numerically generated seismic data for these two models and depth-migrated them. We then interpreted the migrated images under the assumption that the geologies are unknown. The conclusions of our interpretations are that we can see clearly the fault systems in both models. However, our results suggest that seismic interpretations of the channels and pinch-outs associated with the geology of the

Dahomey and Liberian Basins will generally be difficult to identify. In these particular cases, we missed a number of channels and pinch-outs in our interpretations. The limited resolution of seismic images is the key reason for this misinterpretation.

DEDICATION

This thesis is dedicated to the Almighty God and my beloved family.

ACKNOWLEDGEMENTS

I want to express my profound appreciation to my advisor and committee chair Dr. Luc T. Ikelle. I will always be grateful for his guidance, patience and commitment to the successful completion of this work. It has been a great honor and privilege to have worked under his supervision. I would also like to thank my committee members, Dr. Yuefeng Sun and Dr. Daulat Mamora for their suggestions and valuable time.

My appreciation also goes to former and current Center for Automated Signal Processing (CASP) members especially Ioan, Jenny and Alexi for their technical support and friendship as well as the sponsors of CASP projects for providing the resources needed to accomplish this work. I would like to express my gratitude to my wife Adeola for her sacrifice and support. I will also like to thank my parents Alhaji and Mrs. Gbadamosi for my up-bringing and their unflinching support. Above all, I give thanks to God for His Mercies.

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CHAPTER I

INTRODUCTION

The main focus of this thesis is to propose 2D geological models of the offshore Dahomey and Liberian Basins in the Gulf of Guinea (GoG). These Basins are parts of the passive margin that developed from the opening of southern Atlantic Ocean in the Late Jurassic to Early Cretaceous as a result of the motion of South American and African plates (Emery et al., 1975 and Dumestre, 1985). The motivation for studying these Basins is to improve the understanding of potential petroleum reservoir units within these segments of the GoG.

We have divided this introductory chapter into four sections. In the first section, we briefly define the geology of the GoG, including the definition that we have adopted for this thesis. In the second section, we will describe the major transform fault zones, as they play a key role in the construction of the geological models of the Liberian and Dahomey Basins in the next chapters. In the third section, we will review the petroleum traps likely to be encountered in the GoG. In the final section, we describe in more detail the scope of this thesis.

This thesis follows the style of Geophysics.

A brief introduction to the Gulf of Guinea

In order to establish a good understanding of the petroleum systems of the two Basins which are focused in this thesis, we would like to briefly review the geology of the GoG. There are several definitions of the GoG in the literature; we have adopted here the definition of Emery et al., 1975. They defined the GoG as extending from Sierra Leone to Walvis ridge in Angola, to other definitions, such as that of Brownfield and Charpentier, 2007. These definitions cover the two Basins of interest. These Basins (Dahomey and Liberian Basins) have similar structural and stratigraphic characteristics, because they are wrench-modified Basins (Clifford, 1986) and the age range of the rocks is from Ordovician to Holocene (Kjemperud et al., 1992).

Using the Emery definition, we can partition the GoG into three major segments: upper, central and lower segments. These three segments are shown in Figure 1.1. The upper GoG extends from the Liberian to the Dahomey Basin (A more detailed illustration of the various Basins in this section is shown in Figure 1.2). The central part is mainly the Niger Delta (as shown in Figure 1.3) and the Lower part extends from Douala to Walvis ridge in Namibe Basin which is also referred to as the Aptian Salt Basin (as shown in Figure 1.4). Because we focus on the Liberian and Dahomey Basins, let us expand more on the geology of the upper part.

The upper Gulf of Guinea Basin*

The tectonic evolution of the upper part of the GoG can be described in four stages which are captured in Figures 1.5a – d. This description is attributed to Mascle et al., 1988.

Stage 1: In the Early Cretaceous times, the opening of the central Atlantic resulted in a wide Basin bounded southeastward by the Demarara and western-Guinea margin. Rifting in the equatorial Atlantic was initiated contemporaneously with the early opening of the South Atlantic. Between Sierra Leone and the Ghana Ridge (on the African side) and northern Brazil (on the south American side), small segments represent divergent rifting (off Sierra Leone – northern Liberia, off eastern Ivory Coast, off Benin and western Nigeria, and off the Brazilian conjugates of these areas), while large areas were subjected to transform rifting (northern Sierra Leone, southern Liberia, Ghana and the Brazilian conjugates of these areas). The future Demerara-Guinea marginal plateaus were also progressively subjected to this new rifting event.

Stage 2: In Aptian times, the progress of rifting resulted in the creation of small divergent Basins (off northern Liberia, eastern Ivory Coast, Benin and the Brazilian conjugates of these areas), which were characterized by a thinned continental crust in which very thick clastics were probably rapidly deposited and subsequently deformed

*Part of this chapter is reprinted with permission from "The shallow structures of the Guinea and Ivory Coast–Ghana transform margins-Their bearing on the equatorial Atlantic Mesozoic Evolution" by Mascle, J., Blarea, E., and Marinho, M., 1988, Tectonophysics, **155,** 193-209,© 1988 by Elsevier.

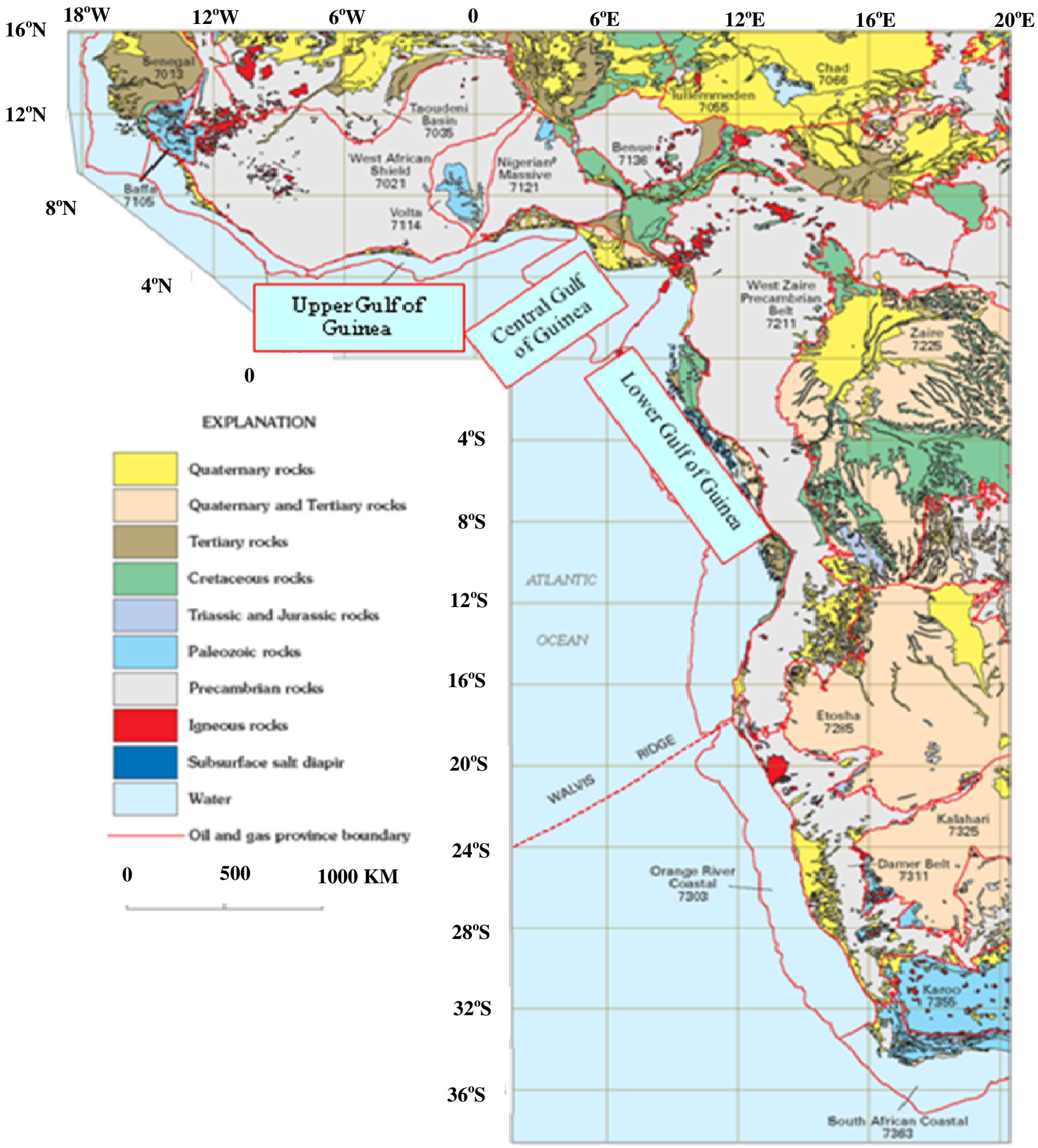


Figure 1.1: The distribution of the Basins and the geological map of the Gulf of Guinea. (Brownfield and Charpentier, 2007)

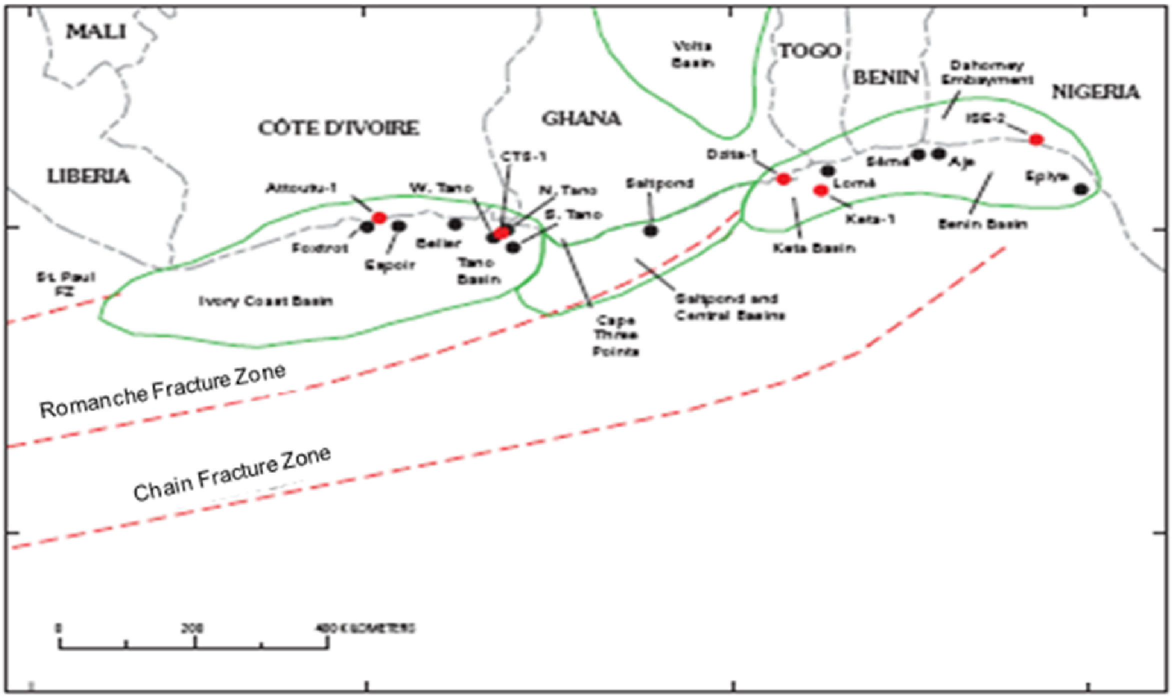


Figure 1.2: The distribution of the Basins in the upper segment of the Gulf of Guinea. (Brownfield and Charpentier, 2007)

along the main shear zones (northern Sierra Leone, southern Liberian, Ghana and the Brazilian conjugates). The Demerara-Guinea Jurassic margin was also affected and progressively split, giving rise to the structures of the southern Guinea slope.

Stage 3: By the Late Albian, the final contact between the continental crusts of Brazil and Africa was breached, allowing the formation of the progressive junction between small oceanic Basins (created between Sierra Leone and northern Liberia, Ivory Coast, Togo-Benin and Brazil), leading to the end of the synsedimentary deformation in these Basins.

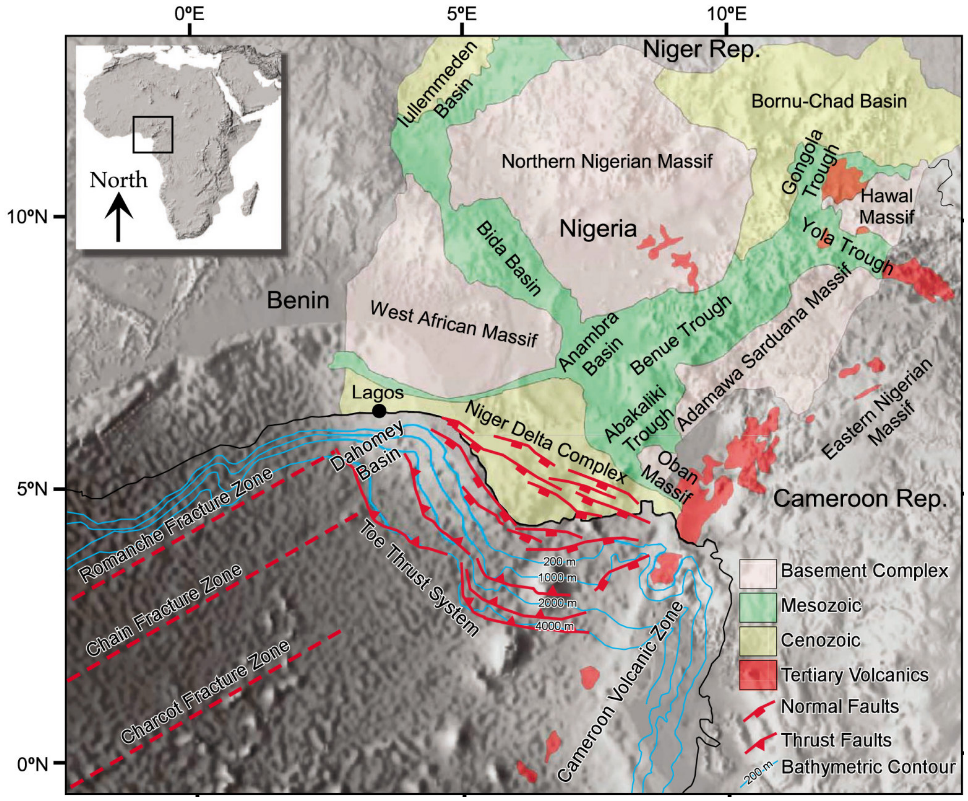


Figure 1.3: The location of the main structural domain of the Niger Delta from the onshore to the offshore depocenters. (Corredor et al., 2005)

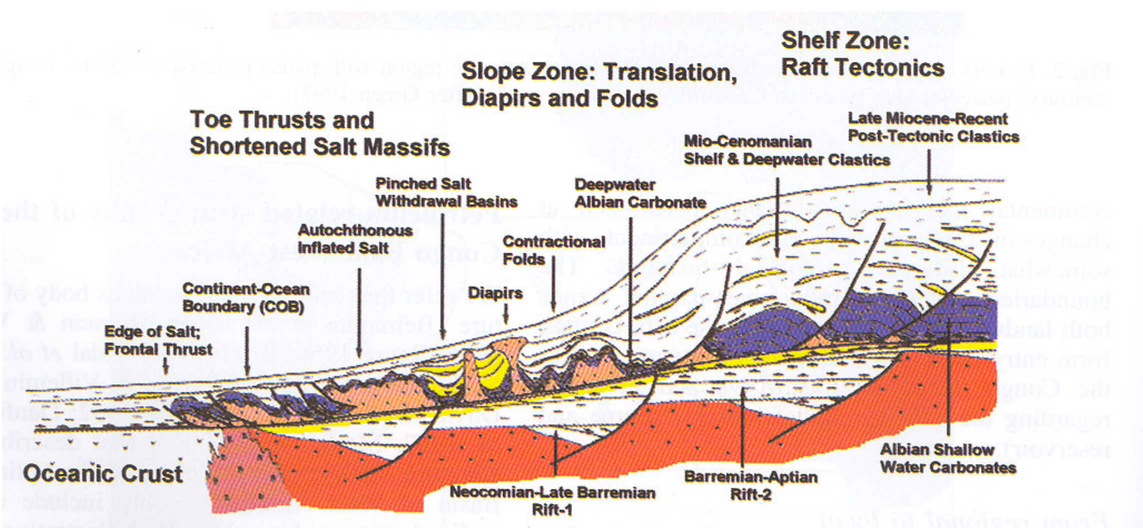


Figure 1.4: An illustration of the generalized geological profile of the Aptian Salt Basin showing the different tectonostratigraphic elements of the raft tectonics in the shelf zone to the toe-thrust in the ultra-deepwater of the lower Gulf of Guinea. (Arthur et al., 2003) (Used with permission from the Geological Society London)

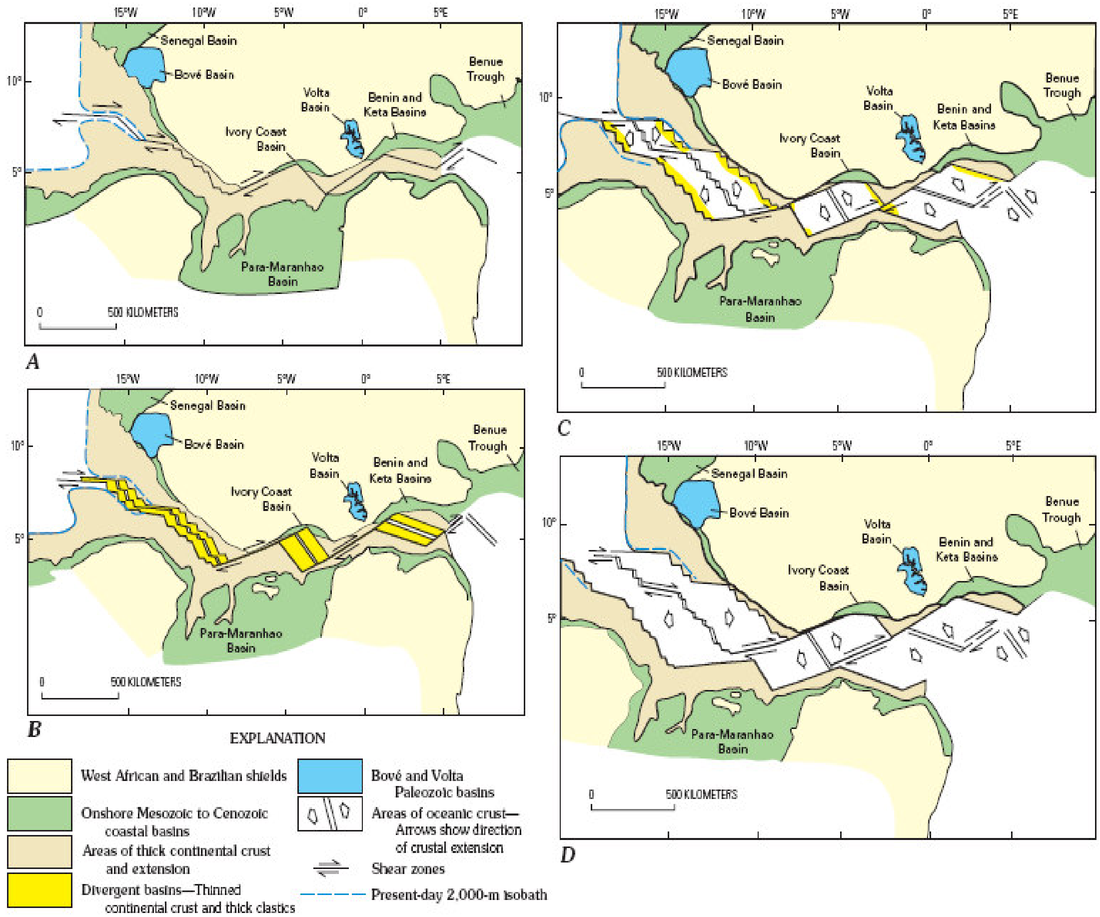


Figure 1.5a-d: Four schematic stages of the evolution of upper segment of the Gulf of Guinea. The Figures (A-D) show the major events during phase 1-4 (Lower Cretaceous, Aptian, Late-Albian and Turonian-Coniacian times respectively) of the evolution of the upper GoG. (Brownfield and Charpentier, 2007 and Mascle et al. 1989)

Stage 4: During the Late Cretaceous, in approximately Turonian – Coniacian times, the junction between the central Atlantic and south Atlantic oceanic Basins through the equatorial Atlantic was established. Prominent bathymetric highs such as the equatorial fracture zones and the ridge axis may however, still have formed structural dams, restricting deepwater exchanges between both oceans particularly from Liberia, Ghana and the Brazilian conjugates.

Transform fault zones in the upper part of Gulf of Guinea*

One of the important aspects of the upper part of GoG that is captured in our geological models is the presence of transform fault zones. In this section we would like to give the details of the major transform fault zones in the upper part of GoG. The result of this section will be used in the next two chapters. Early tectonic history of the upper part of GoG is different from the rest of central and lower parts. Basically, the upper part, as described in Figure 1.1, shows two important differences compared to the margin of the central GoG: (1) the influence of Transform tectonics (2) the absence of evaporites and halokinesis. Middle Jurassic volcanic rocks occur in the upper GoG province showing that tectonism started no later than the Mid Jurassic (Dumestre, 1985; Kjemperud et al., 1992).

Transform faulting was initiated between the African and South American continental plates in the Early Cretaceous time. This transform faulting has been largely studied by several authors (Blarez and Mascle, 1998, Haack et al., 2000, Chierici, 1996, MacGregor et al., 2003, Uchupi, 1989, Doust and Omatsola, 1990, Teisserenc and

*Part of this chapter is reprinted with permission from "Geology and total petroleum systems of the Gulf of Guinea" by Brownfield M.E, Charpentier R.R, 2007, U.S Geological Survey Bulletin 2207-C, 1-32, © 2007 by USGS.

Villemin 1990, Brown et al., 1995, Cameron et al., 1999, Mello and Katz 2000, Arthur et al., 2003). Today, it is well accepted that the upper GoG can be described with three major transform fault zones:

I Pre-transform (Precambrian to Triassic intracratonic rocks and Jurassic to Lower Cretaceous rocks)

II Syn-transform (Lower Cretaceous to Late Albian rocks)

III Post-transform (Cenomanian to Holocene)

The key reference for this discussion is Brownfield and Charpentier, 2007. Let us expand on each of the three major transforms.

Pre-transform stage

The Pre-transform rocks in the Benin and Dahomey embayment are represented by the lower part of the Ise formation (Dumestre, 1985; Elvsborg and Dalode, 1985; MacGregor et al., 2003). The Upper Jurassic to the Neocomian Ise formation, which is as much as 2,000 m thick, is composed of sandstones, shales and conglomerates deposited in fluvial and deltaic environments. Drilling has not reached the base of the formation, but seismics indicate that it directly overlies the basement rocks in the offshore part of the Benin Basin.

Syn-transform stage

Data on the age of volcanic intrusives associated with initial block faulting in Liberia, southern Sierra Leone, and Ghana indicate that faulting started no later than the Mid Jurassic and may be as old as the Early Jurassic (Dumestre, 1985; Kjemperud et al., 1992). Continental syn- transform rocks in the Ivory Coast Basin also show evidence that volcanic and fault activity may have started in the Early Jurassic. The orientation of the intrusives indicates that the initial fracturing and the graben formation were subparallel to the present coastline. Extensive block faulting and graben filling characterized the initial stage of tectonism, followed by transform or extensional faulting in the Gulf of Guinea.

The oldest Mesozoic syn-transform sedimentary rocks are continental Jurassic conglomerate and sandstone (Dumestre, 1985), with thicknesses as much as 2,000 m in the Ivory Coast Basin. A comparable sequence has not been penetrated by drilling in Ghana, indicating a period of non deposition and /or erosion in that area (Kjemperud et al., 1992). Drilling has not encountered rocks older than Jurassic in the Ivory Coast Basin. During the Neocomian, Aptian and probably Early and Middle Albian, more than 5,000 m (Chierici, 1996) of syn-transform sediments were deposited in continental to marginal marine environments in the Ivory Coast Basin. The oldest marginal marine strata are in the Upper Albian, and the lack of evaporites in the Lower Cretaceous section indicates that in the Gulf of Guinea province the syn-transform sediments were deposited in a humid equatorial climate.

Post – transform stage

The post-transform stage rocks in the Gulf of Guinea province consist predominantly of marine Cenomanian to Holocene sandstones, shales and minor carbonate rocks deposited in alternating regressions and transgressions (Dumestre, 1985; Chierici, 1996; Kjemperud et al., 1992; MacGregor et al., 2003) that resulted in several Late Cretaceous and Tertiary unconformities. In general, continental-margin tectonics of the province's post-transform stage was driven by thermal subsidence (Kjemperud et al., 1992).A marine transgression in the Ivory Coast Basin in the Early Cenomanian signaled the beginning of the post-transform stage, resulting in the deposition of limestone on fault-block crests and of organic-rich black shale and turbidites in the grabens (Dumestre, 1985; Chierici, 1996).

Paleontological evidence indicates restricted water circulation and low oxygen content. Following this transgression, a Middle Cenomanian regression and uplift resulted in the erosion of the Upper Albian to lower Cenomanian sequence in the eastern part of the Ivory Coast Basin. During the regression, more than 3,000 m of Middle and Upper-Cenomanian sediments were deposited in the central and western parts of the Basin, as evidenced by strata encountered in the Attoutu-1 well in the northwestern part of the Basin (Chierici, 1996). In the Turonian time, a major transgression took place that established the first communication between Atlantic and Tethyan waters. Paleontological analysis indicates that restricted water circulation and low oxygen content continued through the Turonian. Mainly marine shale, with some sandstone, characterizes the overlying Coniacian to Santonian interval.

Hydrocarbon reservoirs, traps and seals

The reservoir rocks present in the upper GoG can be classified, according to their age, into five major groups within the three main transform sections (Brownfield and Charpentier, 2007) as follows: Devonian-Carboniferous sandstone (pre-transform), Lower Cretaceous sandstone (syn-transform), Upper and Mid Albian sandstones (syn-transform), Cenomanian (post-transform and Tertiary sandstones (post-transform). Devonian-Carboniferous rocks are the oldest sandstone reservoirs identified within the upper GoG. The type-section of these units is present in the Saltpond field in Ghana. The depositional environments for the Devonian and carboniferous sandstones are shallow restricted marine and fluvial environments, respectively.

The Lower Cretaceous sandstone of fluvial to deltaic depositional environments has been delineated on the seismic data within the syn-transform sequence of the offshore Dahomey Basin. Similar sandstone reservoir types have also been encountered within the Ivorian Basin with a thickness of about 5,000 m. The depositional environment in the Ivory Coast area is continental to marginal marine (Chierici, 1996). This type of sandstone reservoir is also expected within the Keta and Tano Basins.

The Upper Albian sandstone present in Espoir and Belier fields in the Ivory Coast, Tano and Keta Basins represents the late syn-transform reservoir unit. The depositional environments vary from the lacustrine, fluvial to fluvial deltaic, marginal marine to marine and sub-marine fans. The marginal marine to marine sandstone units in the Ivorian Basin have the best petrophysical qualities (porosity of 25 percent and a permeability of hundreds of millidarcies). They are laterally discontinuous and exhibit variable petrophysical properties over short distances (Kjemperud et al., 1992, MacGregor et al., 2003). The Mid Albian sandstones in the Ivorian Basin have poorer petrophysical properties, unlike the Upper Albian, and their depositional environment is fluvial to continental. In the Dahomey Basin, the Mid Albian reservoir sandstones represent the only marine sediments within the syn-transform sequence.

The Cenomanian is noted for the development of a steep-shelf along the continental margin of the upper GoG. This steep configuration makes the continental shelf more susceptible to a series of low stands which aided in the deposition of detached sandstone units, ponded turbidites and clastic fans of potential reservoir properties within the slope margin areas. The Tertiary reservoir sandstones are composed of slope deposits within the shales and the most likely zone where this can be prospective will be the deeper-water section of the Dahomey Basin (Elvsborg and Dalode, 1985, MacGregor et al., 2003).

Four main trap types have been generally delineated within the upper GoG, as follows: fault-block traps, anticlinal traps, erosional channel-fill traps and ponded turbidite traps. The fault-block traps host most of the hydrocarbon accumulations within the upper part of syn-transform section in shallow to moderate water-depth areas of the Espoir and Tano fields. In the offshore-continental slope areas, they occur along the Romanche fracture zones in the Ivorian Basin.

The presence of untested anticlinal traps along the fault terminations of the major fracture zones in the offshore Dahomey, Keta and Ivorian Basins was delineated on the seismic data by MacGregor et al., 2003. However, the anticlinal trap has been successfully proven to hold hydrocarbon in the Tano and the eastern part of the Ivorian Basins. The erosional channel fills are proven traps within the offshore Dahomey in the Aje field. Most of the yet-to-be-drilled erosional channel traps are mostly associated with the regional Oligocene unconformity present from Benin to the Ivorian deepwater sections.

The ponded turbidites have been delineated within both the pre-transform and syn-transform sequence. In the syn-transform sequence, they lie directly above the Upper-Albian unconformity (western Ivorian Basin) and are mostly trapped against the existing fault. In the post-transform sequence, they occur as isolated sandstone bodies that are present in the Ivorian, Keta and Dahomey Basins. The carbonate traps are mostly associated with the Late-Albian unconformities which are represented by high amplitude reflections on the seismic data (Kjemperud et al., 1992, MacGregor et al., 2003). Other unproven stratigraphic traps are mounded sandstones and channel-fill sandstones encased within Cenomanian source rocks in the post-transform section of the GoG. Sealing is provided by the shale intercalations and up-dip faults in the syn-transform sequence, whereas the seals for the post-transform reservoirs are provided by only the shales.

The remaining part of this thesis is composed of three chapters. In chapter II, we propose a geological model of the Dahomey Basin using information obtained from published works. Finite- difference modeling will then be used to generate data. The resulting seismic data were depth-migrated and structurally interpreted. The algorithms used for seismic modeling and migration were obtained from the Center for Automated Signal Processing (CASP). We repeated the process of building a geological model, generating data and interpreting them for the Liberian Basin in chapter III. In chapter IV, we draw some conclusions.

CHAPTER II

GEOLOGICAL MODELING OF THE DAHOMEY BASIN

Introduction

In this chapter a 2D geological model that is composed of the major sedimentary features in the Dahomey Basin will be proposed. The geological model will be built based on lithostratigraphic column, regional chronostratigraphic section, cross-section, photographs from outcrops and other published studies from the Basin. The synthetic data for this geological model will be obtained using finite-difference modeling (FDM). The resulting shot gathers will be depth migrated and interpreted.

Dahomey Basin is an integral part of the upper GoG located between southwestern part of Nigeria (as shown in Figure 2.1a and b) to southeastern part of Ghana (Burke et al., 1972, and Okosun, 1989). It is bounded by the romanche fracture zone on the southeastern axis of Ghana and the chain fracture zone on the southwestern axis of Nigeria (Jones and Hockey, 1964). The evolution of the Basin could be grouped into three earlier-mentioned transform stages i.e., the pre-transform, syn-transform and post-transform phases. These zones have had a significant influence on the overall petroleum systems of the Basin.

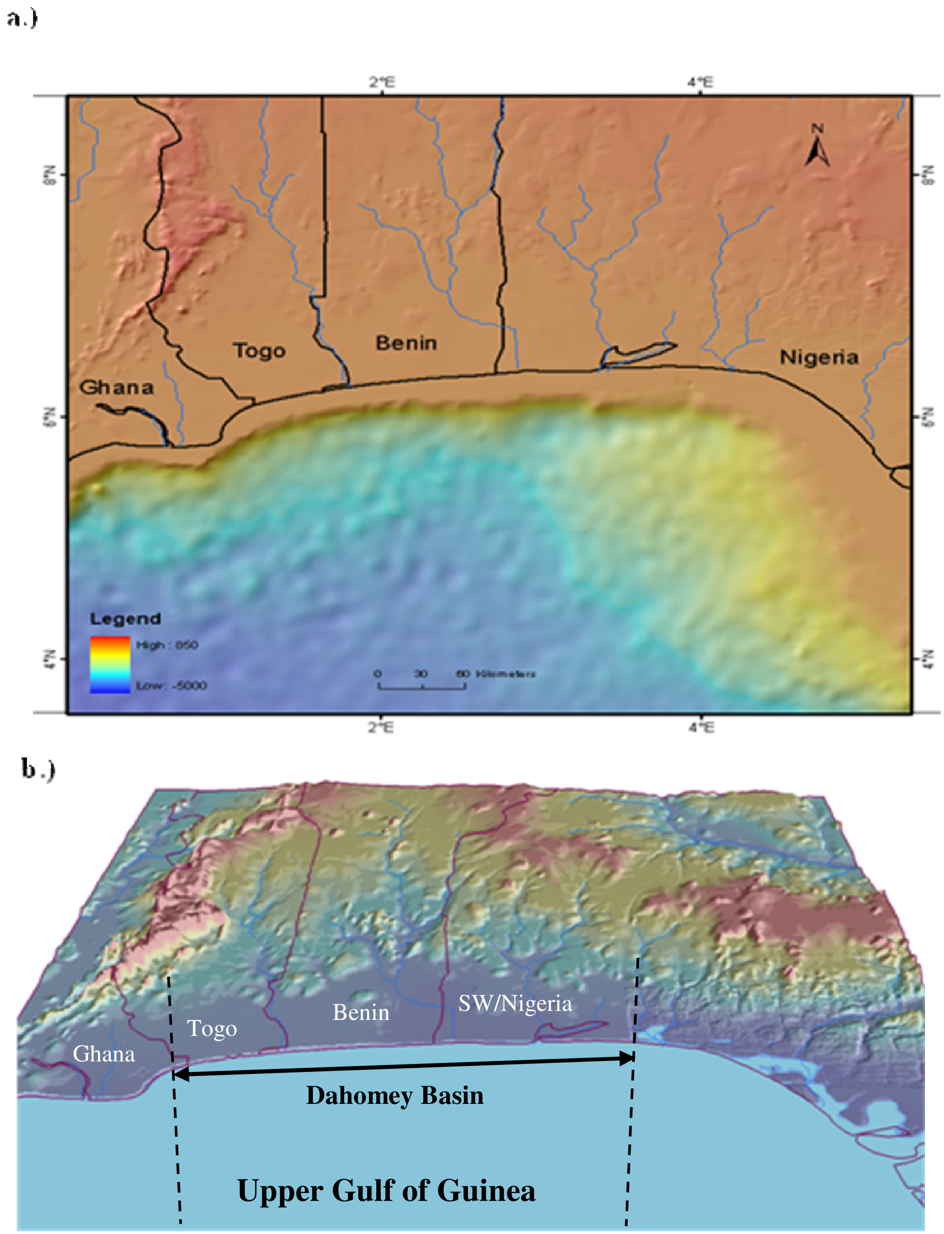


Figure 2.1: (a) A schematic map showing the location and bathymetry of offshore Dahomey Basin. (b) shows the physiographic features and the boundary of both onshore and offshore Dahomey Basin in the Gulf of Guinea. (National Geophysical Data Center, 2008)

The discovered fields from this Basin include Aje (southwestern Nigeria), Seme (Benin) and Lome (Togo). The syn-transform section is the main reservoir unit for Lome field, while the early post-transform unit is responsible for the hydrocarbon production in both the Seme and Aje fields. The reservoir rocks are made up of turbidites, channel fills and detached sandstones. The trap types are both stratigraphic and structural. The shale intercalations and up-dip sealing faults provide the seals for the emplaced hydrocarbons.

Construction of a geological model for the Dahomey Basin

The objective of this section is to build a 2D geological model that is representative of the tectonic sequences, facies associations, primary sedimentary structures and other depositional structures that are characteristic of the Dahomey Basin. The modeling involved integration of published studies by Elvsborg and Dalode, 1985, MacGregor et al., 2003, Brownfield and Charpentier, 2007; an outcrop study by Olabode, 2006; other earlier publications. The lithostratigraphic columns, regional chronostratigraphic correlations, schematic cross-sections, photographs taken from the surface outcrop of the Cretaceous Abeokuta group and generalized geological sections provided by these authors guided the construction of the geological model.

Elvsborg and Dalode, 1985, provided a detailed lithostratigraphic column and generalized cross-section based on the results of nine exploratory wells drilled and 2D seismic data. These results were modified by Brownfield and Charpentier, 2007.

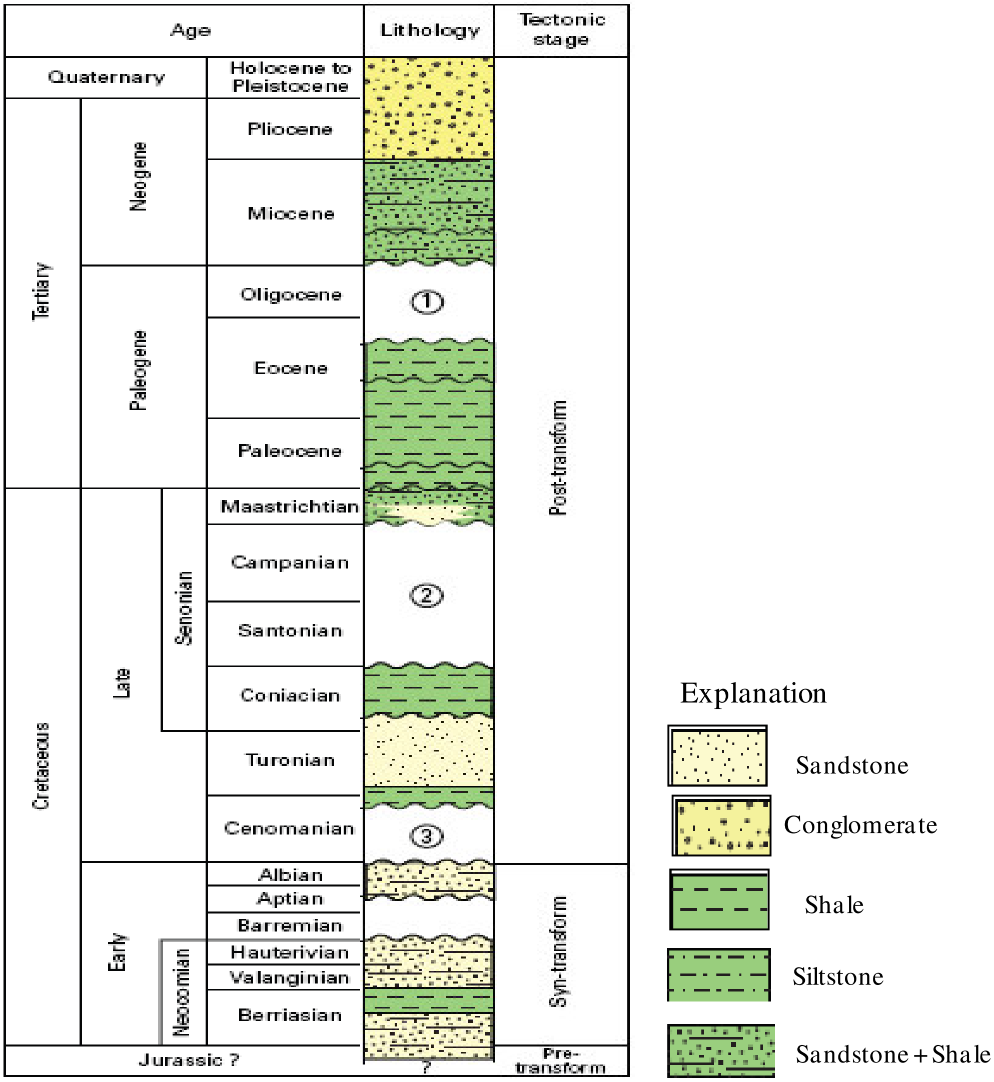


Figure 2.2: Stratigraphic column of the offshore Dahomey Basin. (Modified after Brownfield and Charpentier, 2007 and Elvsborg and Dalode, 1985). (Used with permission from the Oil and Gas Journal and United States Geological Survey)

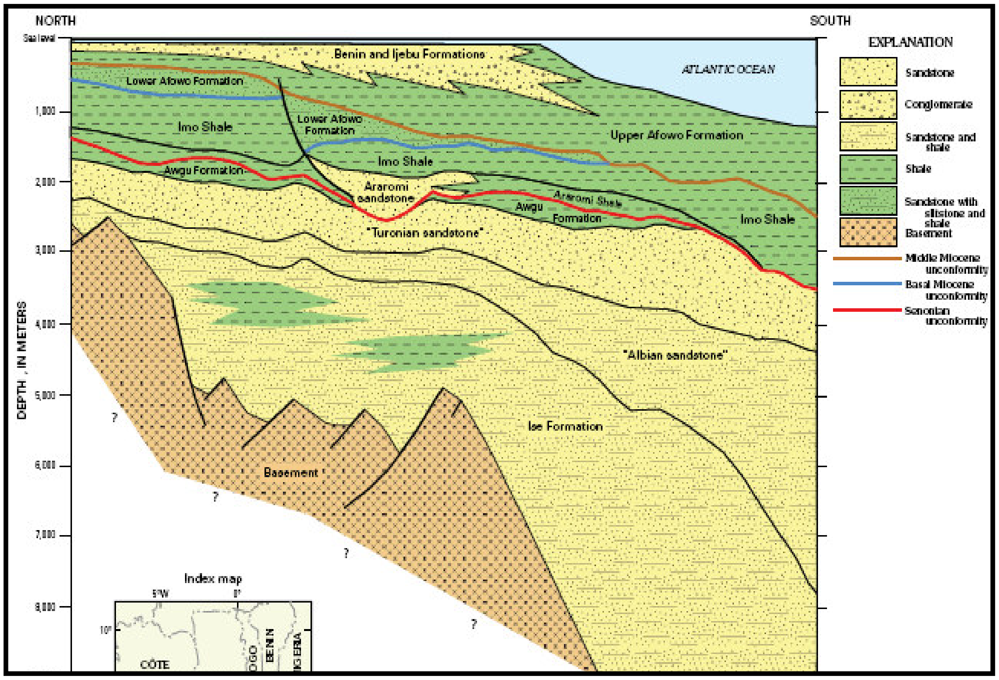


Figure 2.3: The cross-section of Dahomey Basin (Brownfield and Charpentier, 2007 and Elvsborg and Dalode, 1989). (Used with permission from the Oil and Gas Journal and United States Geological Survey)

The lithostratigraphic column (Figure 2.2) sub-divided the offshore Dahomey Basin into 18 geological units from the Jurassic age to the Holocene. These units are composed of sandstone, conglomerates, shales, siltstone and sandy-shales, with three major unconformities representing the Oligocene, Senonian and Albian.

The generalized geological section (Figure 2.3) provided a 2D configuration of the Basin with detailed facies associations in the younger section of the Basin. The characteristic horst and graben structures of the basement rocks were also shown to be dipping in the southern direction of the Basin. MacGregor et al., 2003 provided a regional correlation of reservoir and source rocks according to their age (Figure 2.4) from northeastern Brazil through Dahomey Basin. The Basin was subdivided into five major sequences namely, the pre-transform, syn-transform and post-transform I, II and III. The reservoir units in the Aje/Seme and Lome fields of the Dahomey Basin were correlated with those in the Ivorian, Tano and northeastern Brazilian Basins.

In addition, a detailed schematic cross-section of the play types within each of the Transform sections of the Dahomey Basin was generated (Figure 2.5). The cross-section provided more insight into structural and stratigraphic configurations for the offshore section of the Dahomey Basin. Most of the channels, pinch-outs, and anticlines were located in post-transform-I segment of the Basin. Three major source rocks, namely: Lacustrine Neocomian (pre-transform), Albian (syn-transform) and the Cenomanian-Turonian (post-transform-I) were delineated.

Olabode, 2006, performed a detailed outcrop study of the Cretaceous sandstones, otherwise referred to as the Abeokuta Group, which are comprised of the Araromi, Afowo and Ise formations (Omatsola and Adegoke, 1981, Okosun, 1989 and Adediran et al., 1991). The study involved the mapping of the different facies from surface outcrops and road-cuts in order to establish a depositional model for each of the sequences of Cretaceous Abeokuta group. This is the first reported attempt to correlate the offshore facies association and sedimentary structures with a surface outcrop of the type-sections of the Cretaceous Abeokuta group.

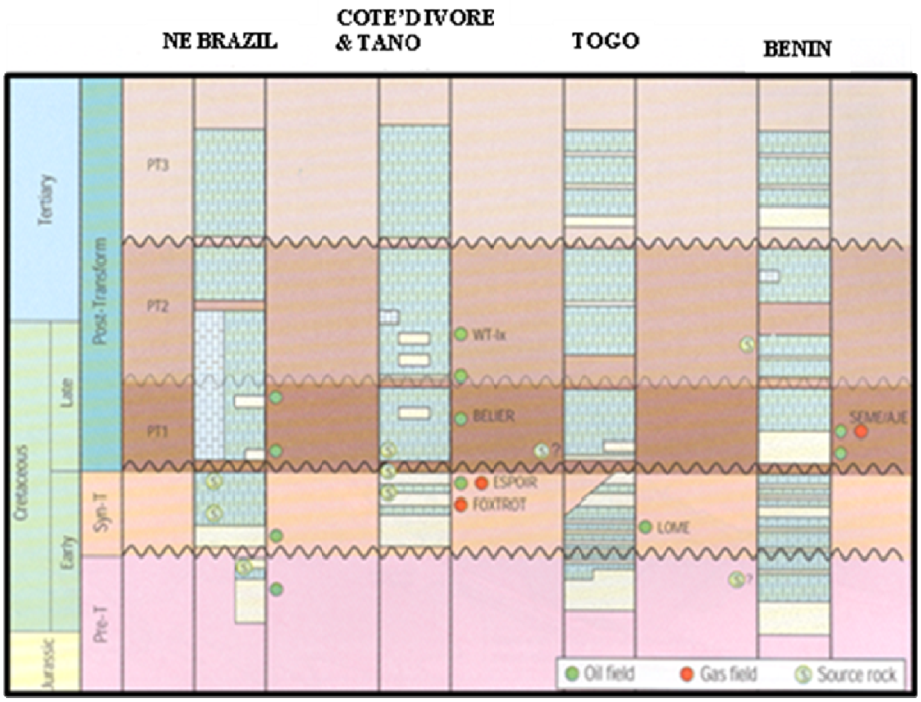


Figure 2.4: The regional correlation of the reservoir units and the transform boundaries from the upper Gulf of Guinea and northeastern Brazil. (MacGregor et al., 2003 (Used with permission from the Geological Society London)

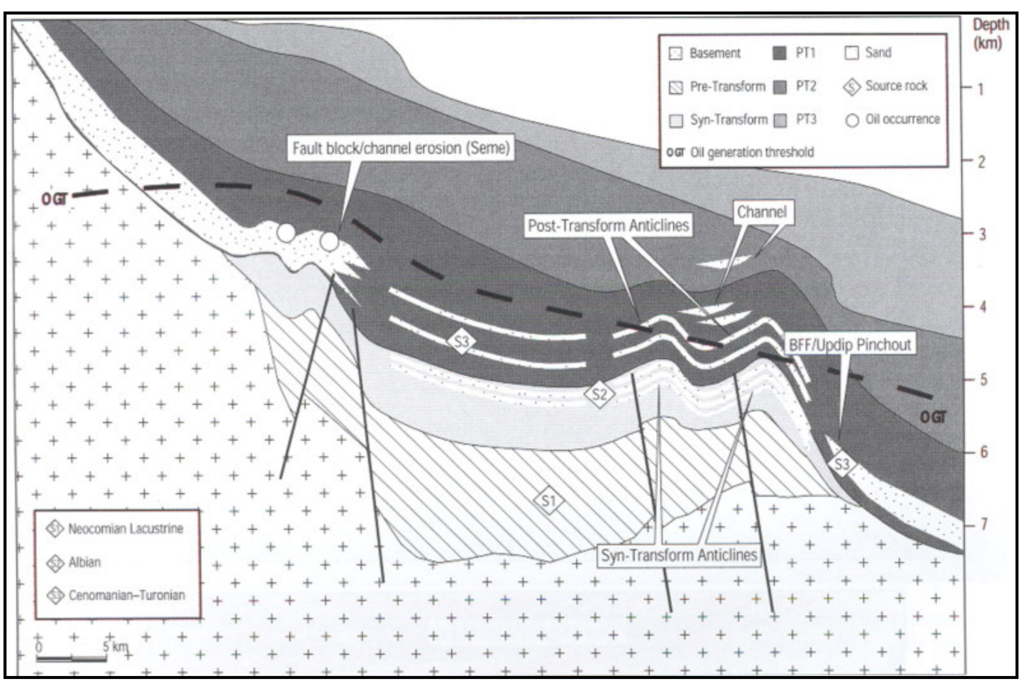


Figure 2.5: Schematic cross-section of Benin- Dahomey Basin according to MacGregor et al., 2003. (Used with permission from the Geological Society London)

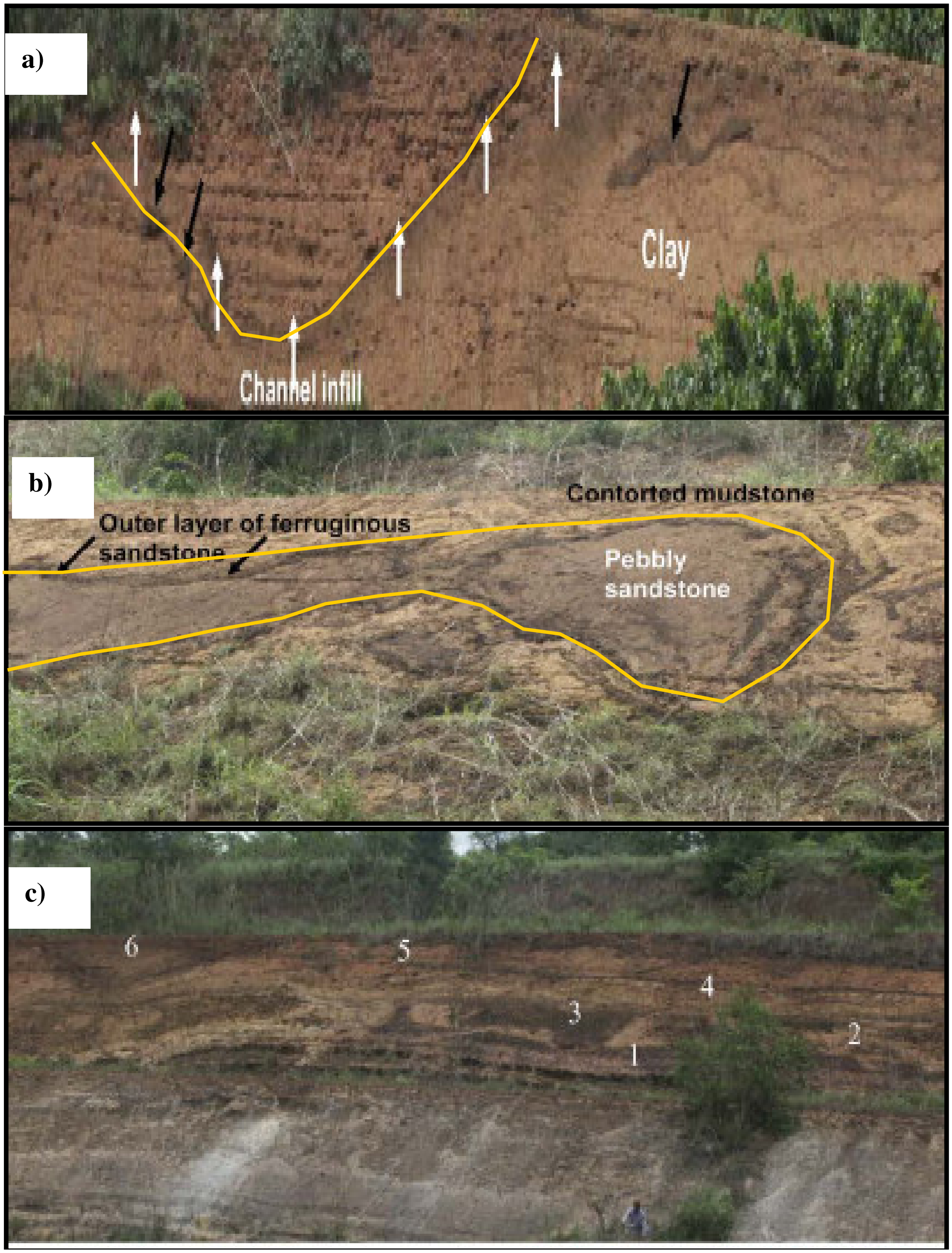


Figure 2.6a-c: The illustration of the outcrop of the Cretaceous sandstone in the Dahomey Basin. (a) Santonian Mastrichtian sandstone channel (b) Turonian (Afowo formation) sandstone encased within a thick deposit of mudstone. (c) Early Cretaceous (Ise formation) basal sandstone. (Olabode, 2006)

The results suggested that the basal part shown in Figure 2.6c is composed of cross-bedded sandstone, laminated sandstones and shale of distal lower shoreface to the upper slope environment of deposition. This sequence is referred to as the Ise formation (Omatsola and Adegoke, 1981). The post-transform I sequence is composed of poorly sorted pebbles, cobbles, turbidites, pinch-outs, channel complexes and other sedimentary facies of upper-slope depositional environment. The presence of these facies associations served as an effective stratigraphic trap for the hydrocarbon accumulation in the Basin. The Post-Transform II sequence, otherwise known as the Araromi sandstones (Omatsola and Adegoke, 1981), is predominantly composed of channel complexes, channel fills and other erosional "facies" that are consistent with an upper-slope environment of deposition.

Using results from the above-mentioned studies, 2D geological model of Offshore Dahomey Basin was constructed. The model was built with a dimension of 2.5km by 1.5km for computational efficiency, with 18 geological units to represent the major facies and the seawater. A simplified workflow of the key steps taken in creating the geological model is given in Figure 2.7. Each color in the geological model (Figure 2.8) represents a particular lithological unit. These lithostratigraphic units were defined within the five transform sections described earlier in the background geology. I used Figures 2.3 and 2.5 as a template for the 2D geometrical configuration in drawing the geological model shown in Figure 2.8. The details of the facies provided by Figure 2.3 in the upper section (predominantly shales and minor sandstone pinch-out directly below the seafloor) were replicated in my model in units 1-7 (0 - 430 m). However, I included a minor limestone (unit-4) in my model to show the reported (Omatsola and Adegoke, 1981) Paleocene Limestone (Ewekoro Formation). These lithologic units represent the sediments present within the post-transforms II and III.

From units 8-13 (between 430 m and 700 m in Figure 2.8), I used Figures 2.5 and 2.6a because they gave more details of the facies than Figure 2.5 for the post-transform-I segment. The channel-fills, thin beds, and pinch-outs shown in Figure 2.5 were included in my model (Figure 2.8). I drew two vertically stacked channels as units 9 and 13. Two additional detached sand-bodies in the up-dip and down-dip section were included in my geological model to indicate the extension of channel-sand bodies. The thin sandstone layer shown by unit-10, which indicates turbiditic sandstone, was taken from Figure 2.5.

In order to draw the configurations of units 14-17, I used Figures 2.3, 2.5 and 2.6c. The outcrop photograph showed laminated sandstones numbered 1 - 6 within the syn-transform. In my model, I only represented the major sandstones reported in the literature, but I followed the configuration shown in Figure 2.5. The basement structure in my model was taken from Figure 2.3. I included block faulting in the model to show the graben and horst structures that characterize the basement rocks in the pre-transform and syn-transform segments.

Key steps in building the geological model of Dahomey Basin

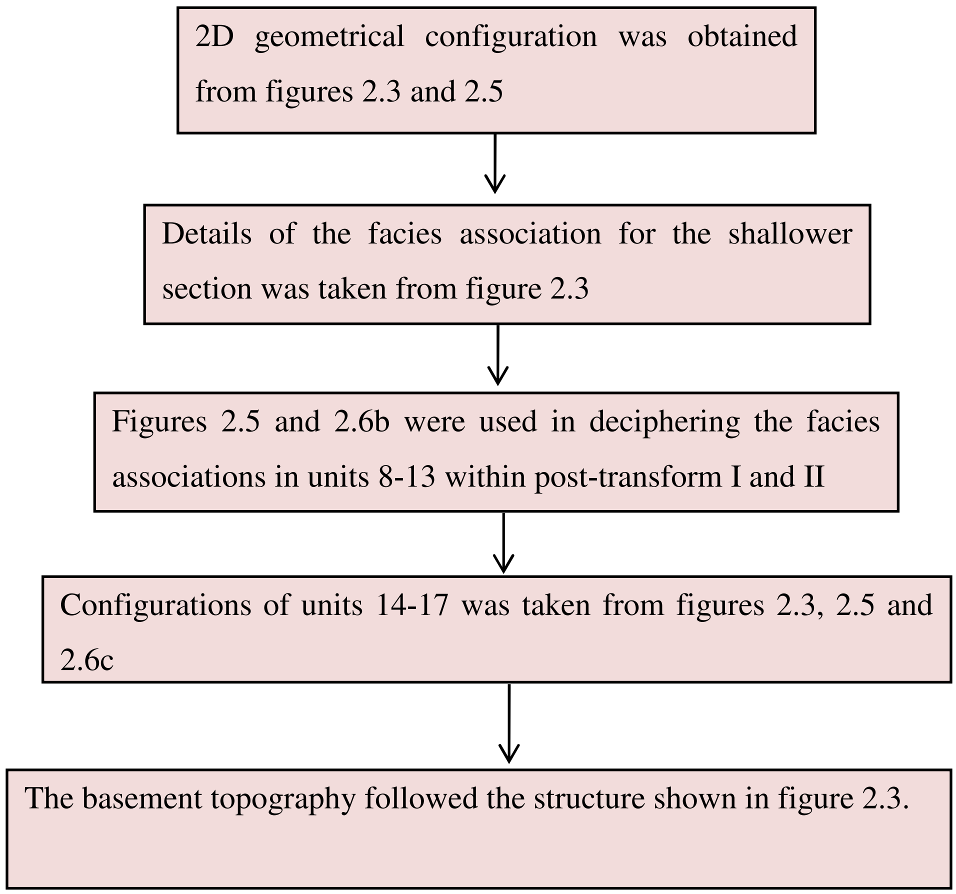


Figure 2.7: Simplified key-steps followed in the building of the geological model for the Dahomey Basin.

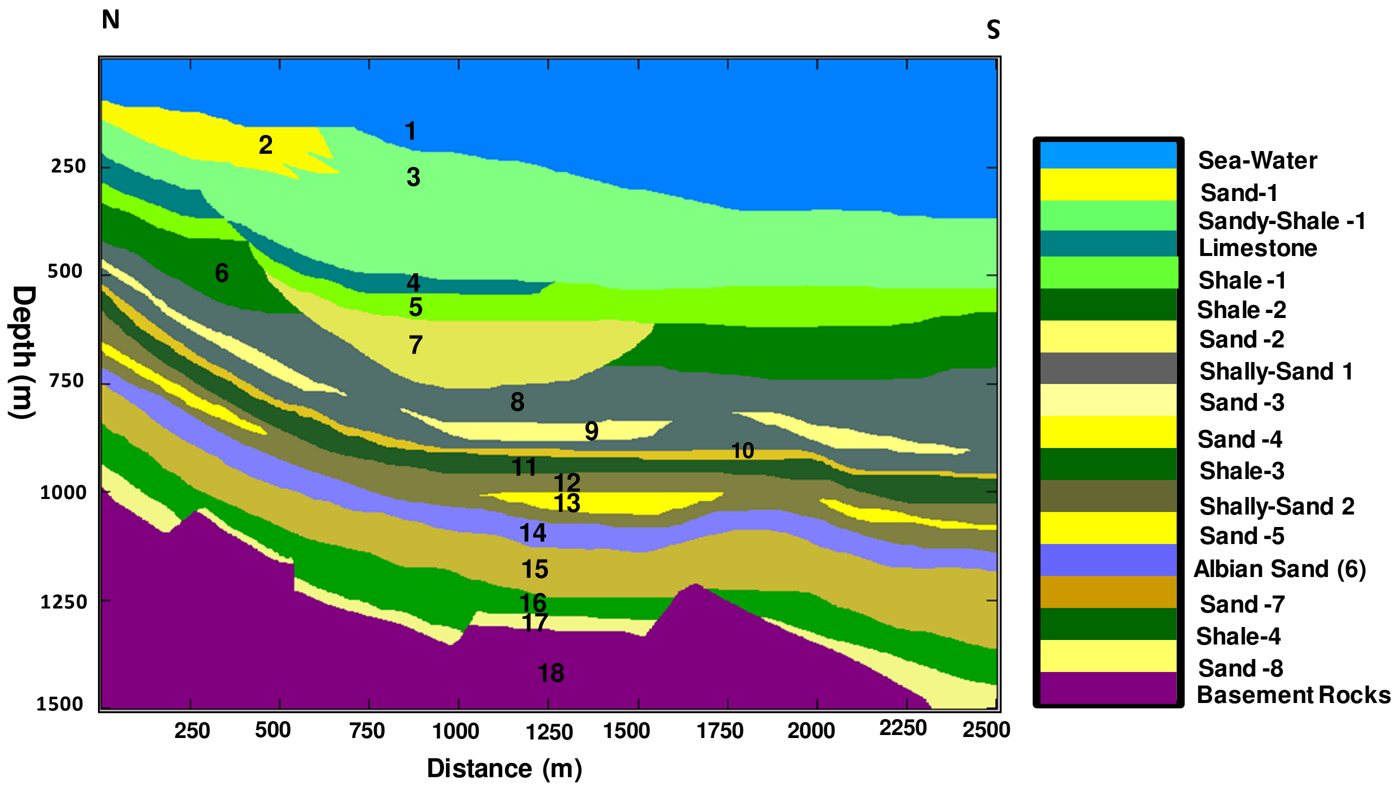


Figure 2.8: 2D geological model of the Dahomey Basin.

Seismic data simulation from the geological model

The geological model was used in the acoustic finite-difference modeling (FDM) algorithm obtained from CASP. The velocity and density values shown in Table 2.1 were assigned to the different layers. We generated 180 shot gathers with stationary receivers. The spacing between the shot gathers is 12.5 m. The same spacing was used for the receiver positions as shown in Figure 2.9. The first and last shot points and receivers were located at 125 m and 2362.5 m respectively. A sampling rate of 4 ms was used in recording the data, to a total record length of 2 s. Absorbing free-surface boundary condition was implemented in the code to prevent the generation of free-surface multiples and ghosts. The distributions of input parameters in the geological model were plotted in Figures 2.10 and 2.11 in order to order to convert the geological model into the physical models used in FDM. Figures 2.12 and 2.13 show the shot gathers at 425 m and 1237.5 m, respectively.

In order to remove direct waves from the shot gathers, a simulation was done using a geological model involving only water. Shot gathers with only direct waves were subsequently subtracted from shot gathers containing all the seismic events. The resulting seismic data were corrected for geometrical spreading before analyzing the various events present in the data. Also, for better understanding of the seismic events in these shot gathers, the simulation was carried out by successively revealing the deeper layers, so I was able to identify the reflection associated with say the top of unit-3, by subtracting the results of the corresponding step of the simulation from the previous one.

The approach described above was used in identifying the primary events from the major transform boundaries from the geological model. Figure 2.14 shows the primary reflection from the top of post-transform II. The major surfaces were delineated from the shot gather by the same technique for post-transform I, syn-transform and the top of the crystalline basement rocks, as shown in Figures 2.15 to 2.17. While this approach works very accurately in delineating continuous reflections from the model, it is, however, more challenging to delineate stratigraphic pinch-outs and other discontinuous sand bodies in the model.

In order to confirm the presence of all the geological units in the seismic model, the zero-offset gather was generated from the shot gathers. This shows the various seismic reflections in all the layers within the model (Figure 2.18). Some of the channels, sand pinch-outs and other stratigraphic features were more visible in the zero-offset gather. However, the presence of diffractions from the rough sea floor and sand pinch-outs, coupled with internal multiples and other numerical artifact reduces the quality of the image. In order to improve the image quality, the seismic data were depth-migrated (as shown in Figure 2.19) using the imaging algorithms obtained from CASP.

Table 2.1: A listing of compressional velocity and density values used in simulating the seismic data for the Dahomey Basin. (Well Leg 159 IODP database)

	Velocity (m/s)	Density (Kg/m3)	Facies	Transform Margin
1	1500	1000	Sea-water	
2	1657	1415	Sand-1	POST- Transform - 3
3	1830	1610	Sandy-Shale-1	
4	2057	1830	Limestone	
5	2184	2050	Shale-1	POST- Transform -2
6	2268	2282	Shale-2	
7	2560	2400	sand-2	
8	2436	2280	Shally-Sand-1	POST- Transform - 1
9	2500	2371	Sand-3	
10	2605	2450	Sand-4	
11	2647	2300	Shale-3	
12	2731	2350	Sandy-Shale-2	
13	2800	2650	Sand-5	
14	2940	2703	Albian sand(6)	SYN-Transform
15	2650	2550	Sandy-7	
16	2500	2335	Shale-4	
17	2700	2550	Sand-8	PRE- Transform
18	3000	2861	Basement Rocks	

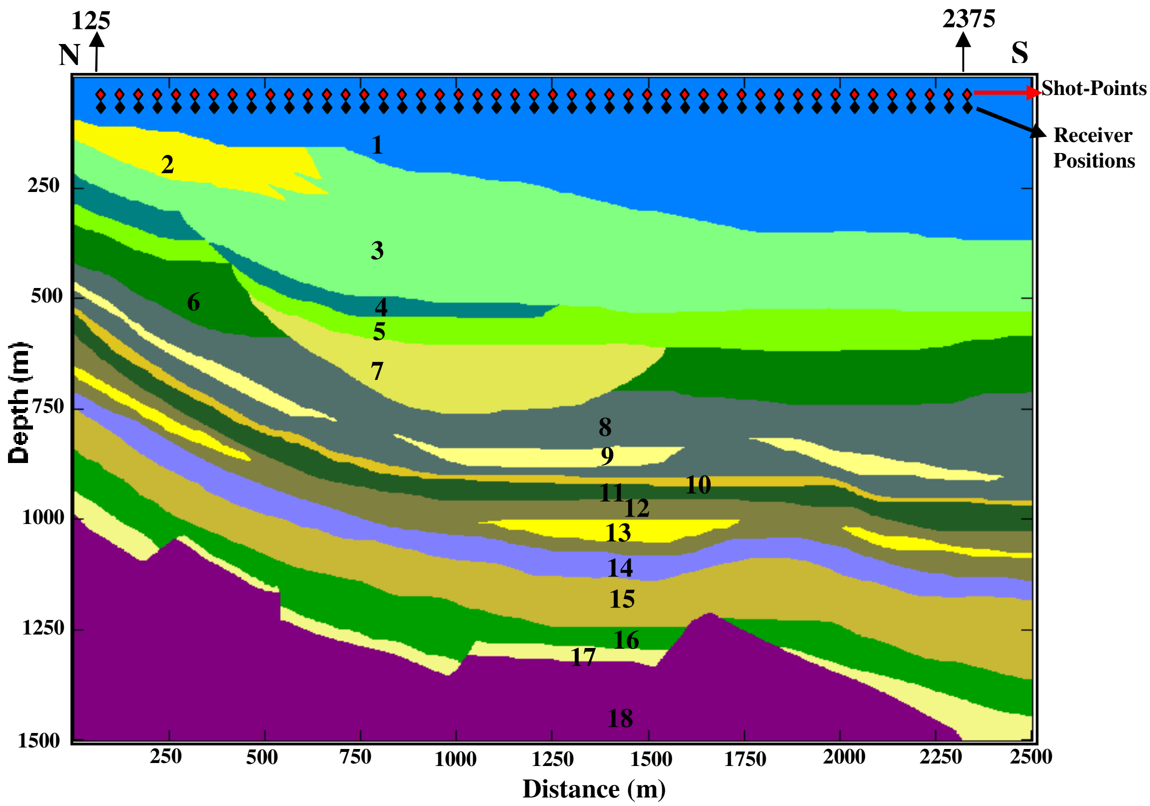


Figure 2.9: An illustration of the geometrical configuration of the shot-points and receiver positions used in the finite-difference modeling of the seismic data.

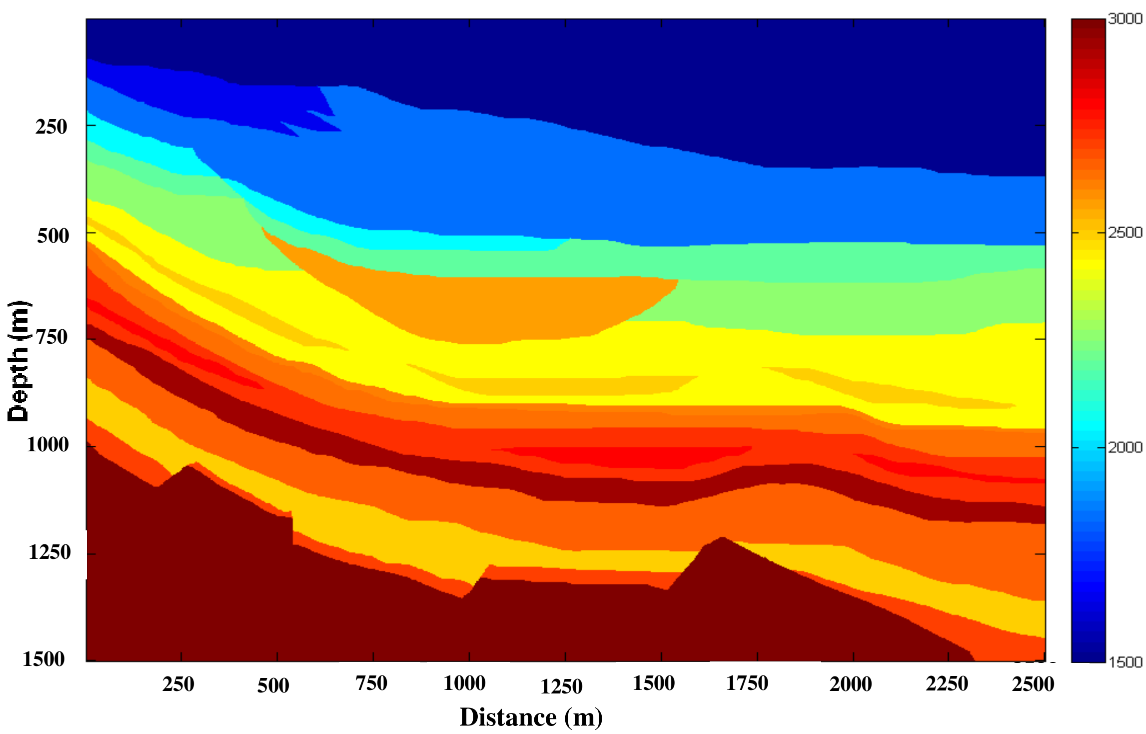


Figure 2.10: The distribution of the compressional velocity (m/s) values in the geological model for the Dahomey Basin.

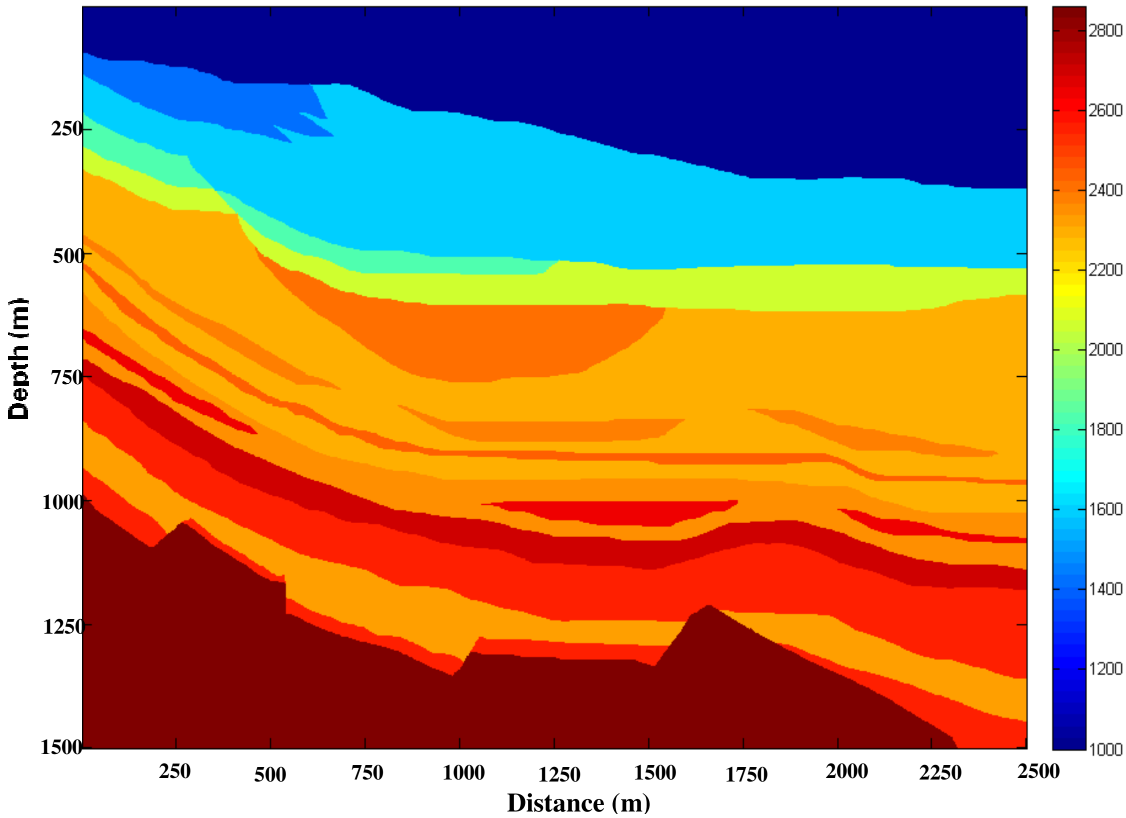


Figure 2.11: The distribution of the density (kg/m^3) values in the geological model for the Dahomey Basin.

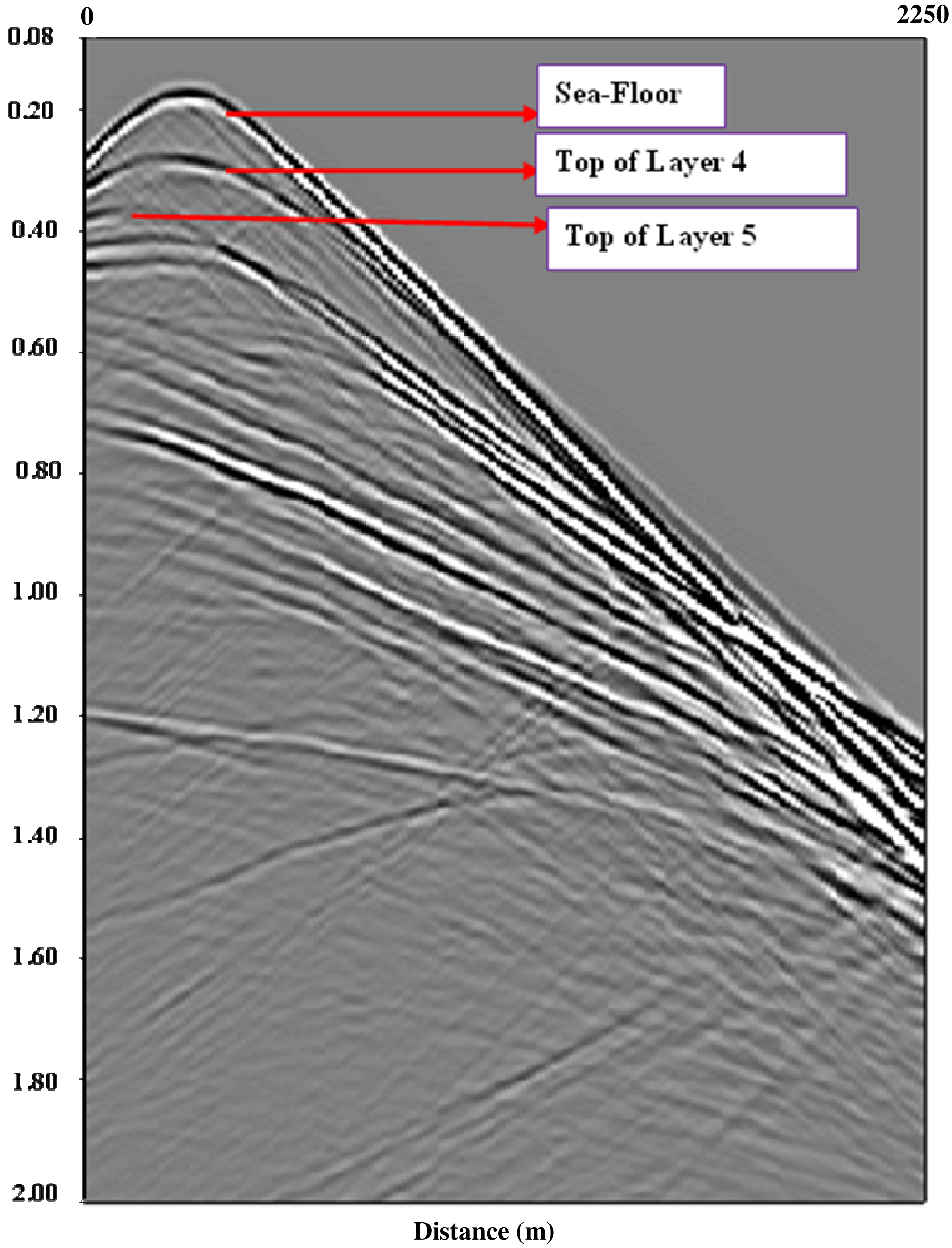


Figure 2.12: An illustration of the shot gather obtained at shot point 425 m from FDM simulation of the geological model for the Dahomey Basin.

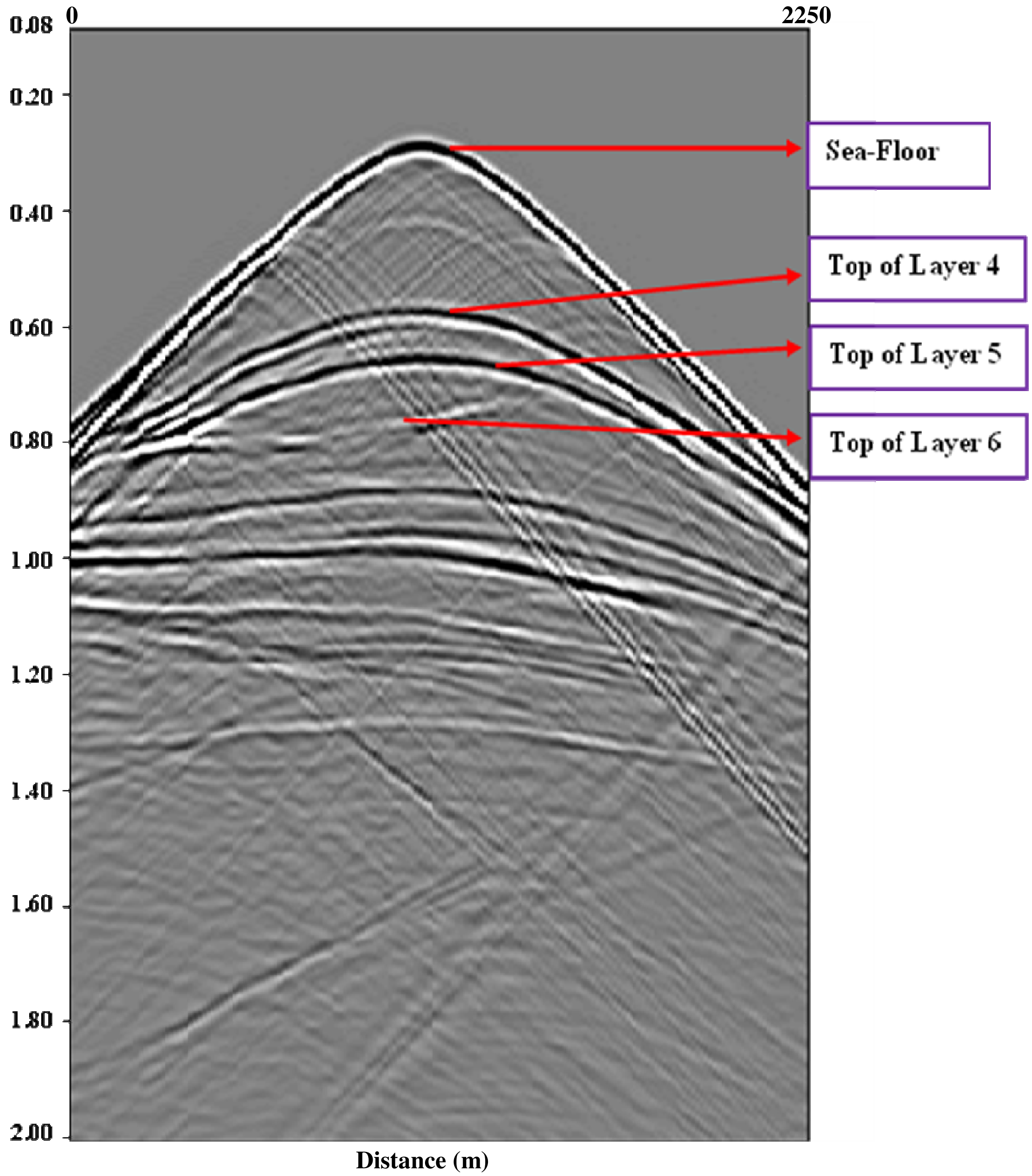


Figure 2.13: An illustration of the shot gather obtained at shot point 1237.5 m from FDM simulation of the geological model for the Dahomey Basin.

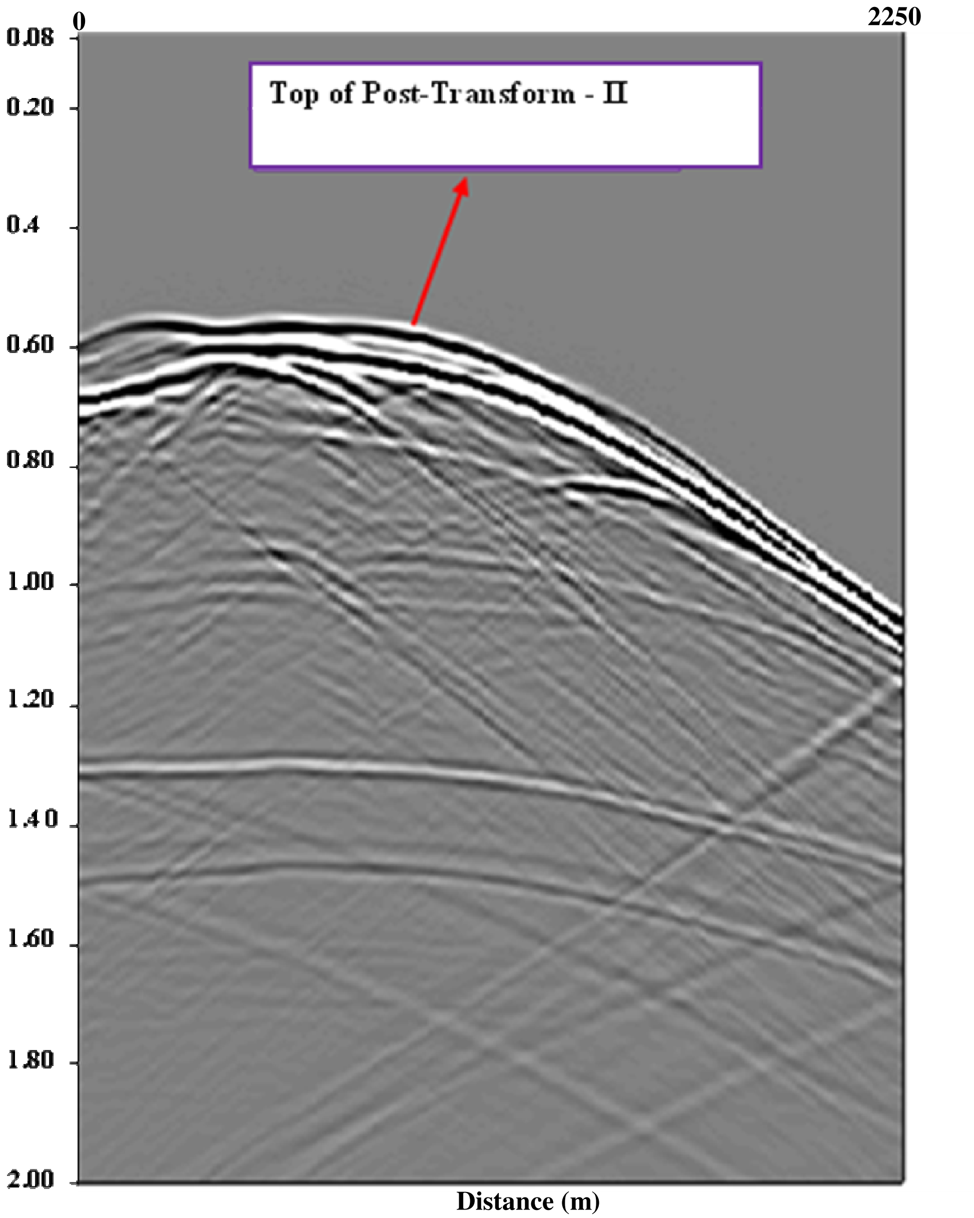


Figure 2.14: An illustration of the shot gather obtained at shot point 425 m showing the primary reflection from the top of layer 5 (post-transform-I1 boundary) of the geological model for the Dahomey Basin.

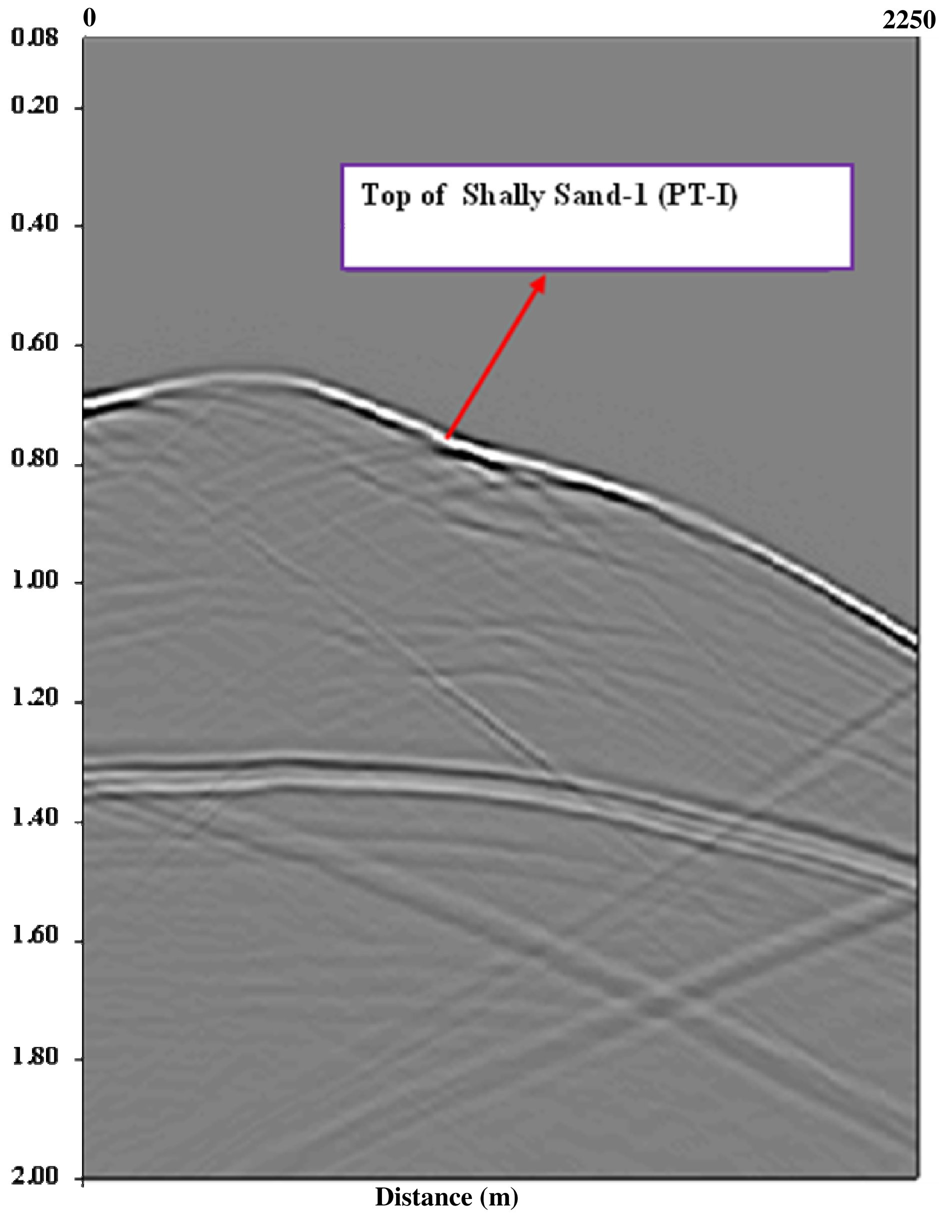


Figure 2.15: An illustration of the shot gather obtained at shot point 425 m showing the primary reflection from the top of layer 8 (post-transform-I boundary) of the geological model for the Dahomey Basin.

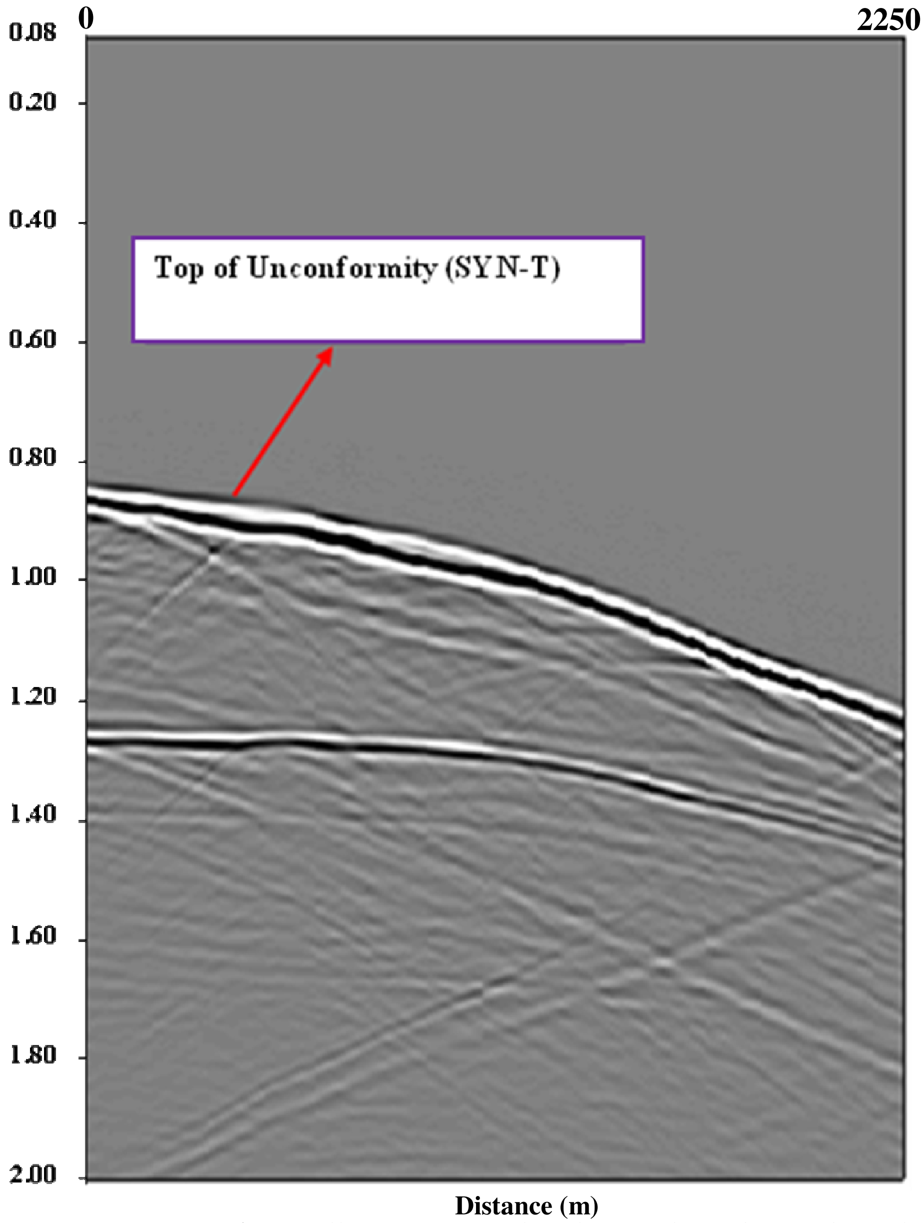


Figure 2.16: An illustration of the shot gather obtained at shot point 425 m showing the primary reflection from the top of unconformity surface at layer 14 (syn-transform boundary) of the geological model for the Dahomey Basin.

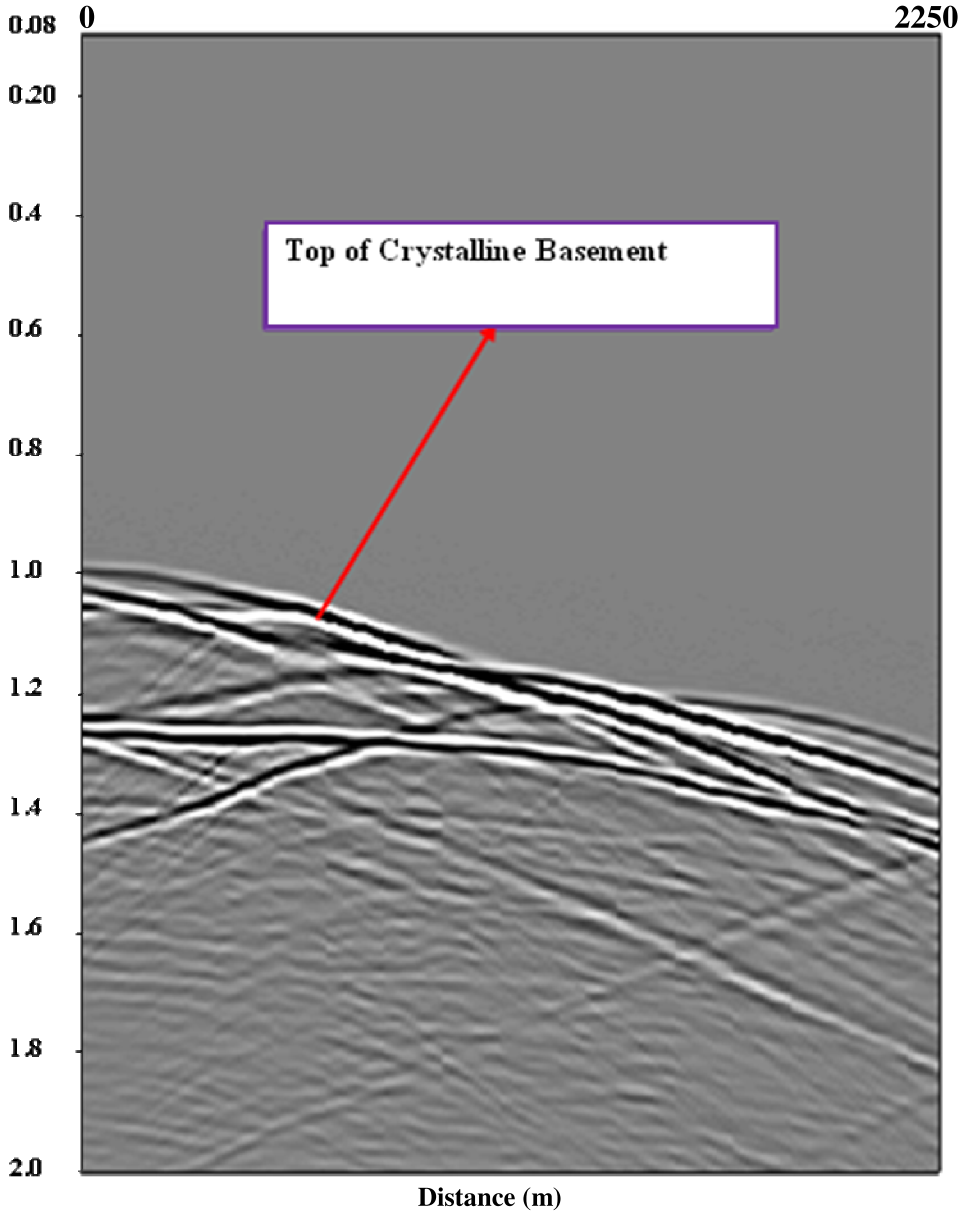


Figure 2.17: An illustration of the shot gather obtained at shot point 425 m showing the primary reflection from the top of layer 18 (basement complex rock) of the geological model for the Dahomey Basin.

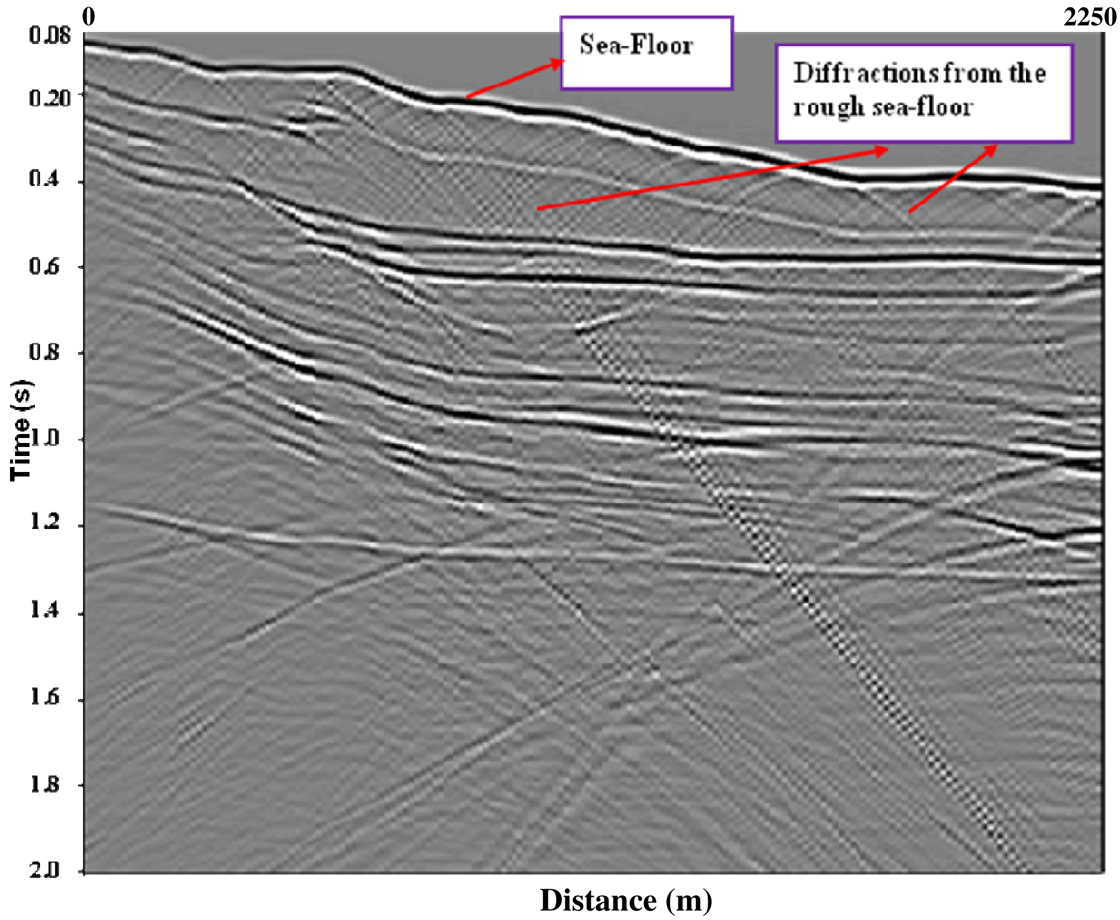


Figure 2.18: An illustration of the zero-offset shot gather obtained using 180 shot-points and receivers for the geological model of the Dahomey Basin.

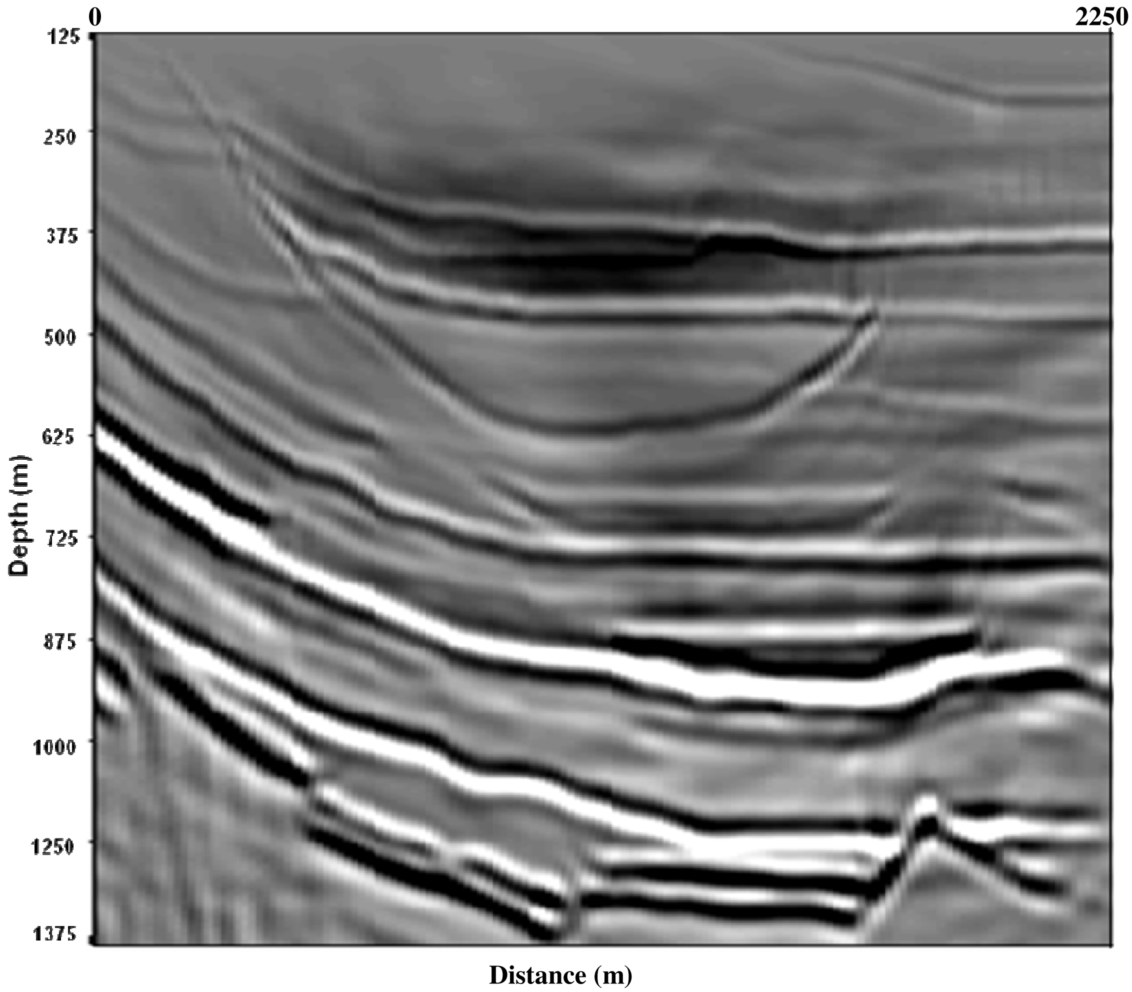


Figure 2.19: An illustration of the un-interpreted depth migrated seismic data from the shot gathers generated from the geological model for the Dahomey Basin.

Interpretation of the migrated seismic data

The interpretation of the 2D migrated seismic data generated from the geological model, involved structural interpretation of the seismic data as shown in Figure 2.20. The interpretation began with the mapping of all the faults present in the migrated image. A gravity driven slump-fault (F-1) was delineated in the shallower depth of the seismic section and it dips in the northwest to southeast direction. The remaining interpreted faults, F-2 to F-6, were restricted to the deeper depth of the Basin. Faults F-3 to F-4 dips in northeast to southwest direction and they have higher inclination angles than F-1 and F-2.

An interpretation was also carried out for the main reflections by tracking horizons with significant amplitude and continuity. Eleven horizons interpreted from the data were named H-1 to H-11. All the interpreted horizons generally dip towards the same direction. Horizon H-8 shows an anticlinal structure around the up-thrown side of fault F-3. Horizons H-10 could not be delineated between faults F-5 and F-6. From the displacement of the horizons around the basement faults, the type of fault could be determined as normal. For example, horizon H-10 between F-4 and F-5 represents the hanging wall of F-4 fault whereas the H-10 between F-4 and F-3 represents the footwall segment of F-4.

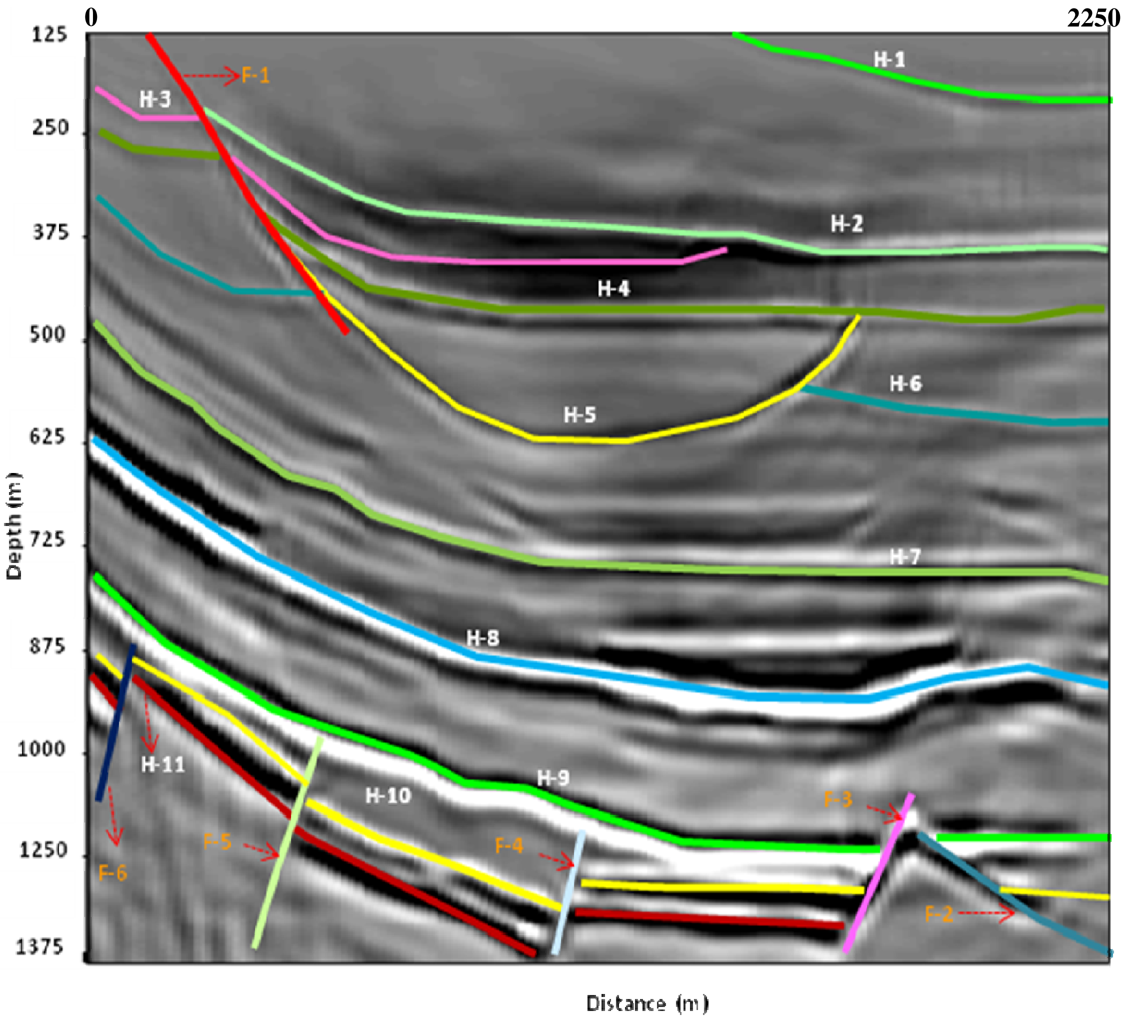


Figure 2.20: An illustration of the interpretation of the migrated seismic section with eleven horizons (H-1 to H-11) and six normal faults (F-1 to F-6) from the geological model for the Dahomey Basin.

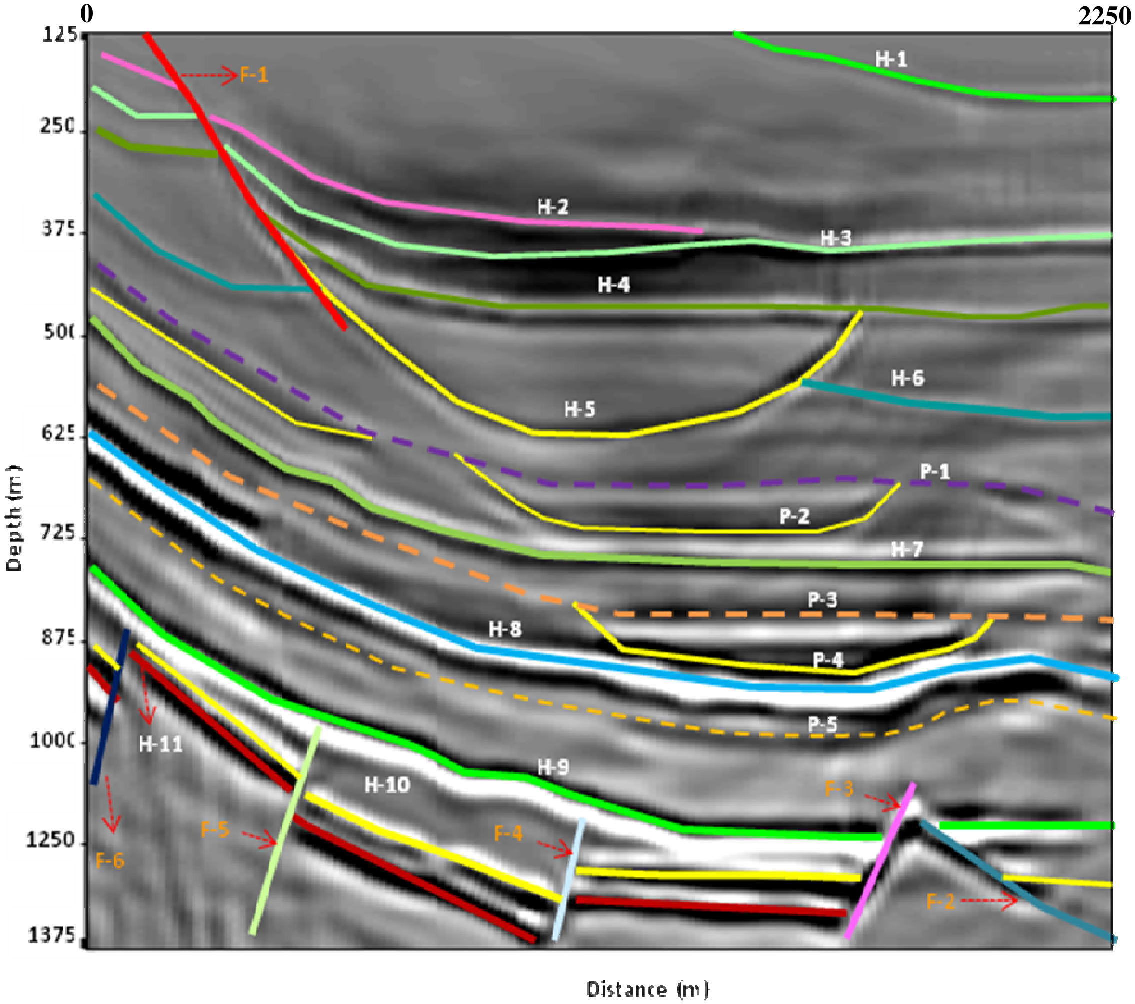


Figure 2.21: The result of the comparison between the interpretations in Figure 2.20 and the actual geological model for the Dahomey Basin.
Notice: The presence of five additional horizons named (P1 - P5). The dashed lines (P-1, P-3 and P-5) represent the horizons that were drawn across the image. P-2 and P-4 represent the base of the two isolated channels within the post-transform I sequence.

Discussion of the interpretation

On comparing the interpretation with geological model (Figure. 2.8), the interpreted horizons and faults could be related to the major layers. The transform boundaries in the geological model were interpreted as H-3, H-6, H-8 and H-9 horizons. The interpretation of the base of the Santonian to Mastrichtian channel was delineated by H-5. The unconformity surface that separates the syn-transform margin from the post-transform margin was marked by the H-8 horizon. The interval between H-8 and H-9 represents the Albian–Aptian sequence that is composed of sandstones with the characteristic syn-transform anticline. The interval between H-9 and H-11 are predominantly basal sandstone, shale and siltstone units of the Neocomian age. The basement (H-11) is characterized with horst and graben structures that resulted from the extensional faulting system.

However, the main objective of interpreting this data is to confirm whether all the layers represented in the geological model were also imaged in the migrated seismic section. On contrary, some of the layers were not delineated as shown in Figure 2.21. Horizons H-2 and H-3 in the interpretation should be switched with addition of an extra horizon on the up-thrown side of fault F-1. Horizons P1 to P-5 were used to represent those missed layers. P-1 and P-3 represent the tops of the second and third channels whereas; the basal parts were denoted by P-2 and P-5 respectively. These sand-rich vertically stacked channel systems within the post-transform I sequence are the exploration target in the Dahomey Basin. Horizon P-5 (denoted by dashed line) with weak reflection showed the top of Aptian sandstone.

Summary and conclusions

In this chapter, a 2D model of the geological units of the Dahomey Basin was built by using surface outcrop studies, information obtained from available well-log and other published works. The seismic data for this geological model were simulated using finite-difference modeling. The shot gathers were processed and depth-migrated to enhance the structural interpretation of the seismic data.

The interpretation showed the presence of six normal faults, F-1 to F-6, that are consistent with an extensional tectonic environment. Most of them are related to the development of horst and graben structures in the basement except for F-1 which is a gravity-driven slump fault (growth fault). Eleven horizons (H-1 to H-11) with significant amplitude and continuity were also interpreted for the various geological units in the model.

The base of the Santonian to Mastrichtian channel complex was interpreted and named H-5. This channel system shows an amalgamated channel complex representing at least two erosional phases. The remaining two isolated channel bodies were difficult to delineate because their reflections were laterally restricted and weak. It is noteworthy to emphasize that the values of the depth were chosen for computational efficiency. The actual depths of these geological units could be five times higher than the chosen values.

This approach to Basin modeling has facilitated a better understanding of the challenges involved in constructing geological models and seismic imaging of potential reservoirs in the Dahomey Basin.

CHAPTER III

GEOLOGICAL MODELING OF THE LIBERIAN BASIN

Introduction

The aim of this section is to propose a 2D geological model that shows the various geological units in the Liberian Basin. The model will be constructed based on the integration of chronostratigraphic framework and cross-section published by Bennett and Rusk, 2002. The synthetic seismic data for this geological model will be simulated using finite-difference modeling. The seismic data will be depth-migrated and structurally interpreted.

The Liberian Basin is located in offshore Liberia between Sierra Leone and the southern Liberian-Harper Basin (as shown in Figure 3.1). It is bounded on the southern margin by the St. Paul transform system and on the northern margin by the Sierra Leone transform system. Behrendt et al., 1974 conducted a study of the continental margin of Liberia using gravity and magnetic data. The study showed the presence of three fracture zones between the transform systems, which are referred to as the Monrovian, Buchanan and Greenville fracture zones.

Two major episodes of tectonics i.e., the rifting phase (Late Jurassic to Aptian) and the passive margin phase (Late Albian to Present) controlled the stratigraphic and structural architecture of the Basin. The rifting phase is equivalent to the pre- and syn-transform phases of the Dahomey Basin.

Figure 3.1: The location map of the Liberian Basin with the major fractured zones that are associated with the transform system. (University of Texas (UT) Library, 2008)

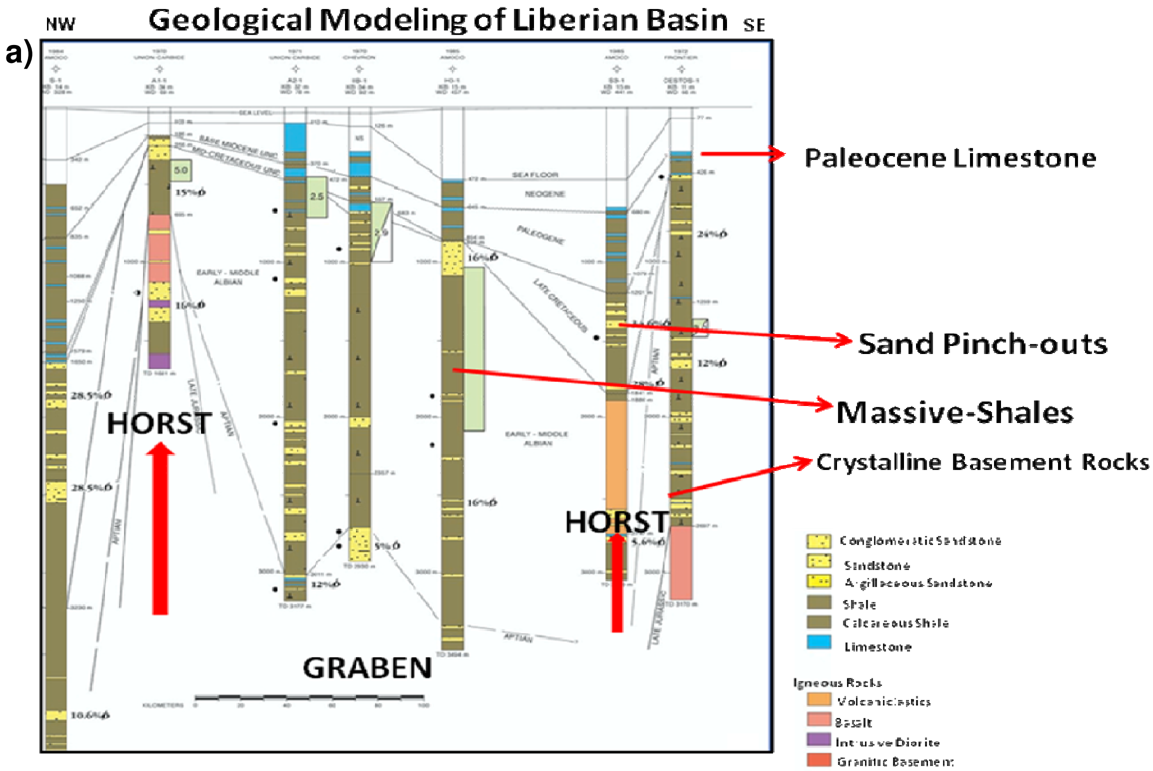
This phase is dominated by a series of basement-faulting, subsidence and the development of horsts, graben and half graben structures. The passive margin phase is associated with marine transgression and a shift in the shelf margin that led to the deepening of the fault blocks and deposition of marine sediments in the Basin.

The petroleum system of the Liberian Basin could be divided into five as follows; Aptian, Early to Mid Albian, Late Albian to Early Cenomanian, Late Cenomanian to Mastrichtian and Paloecene to Eocene. The three main source rocks are the lacustrine Aptian shales, the Aptian to Early Cenomanian shales and the Late

Cenomanian to Turonian shales. The reservoir rocks are Aptian to Early Cenomanian sandstones, Late Cretaceous carbonates and sandstones and the Paleogene sandstones and carbonates (Bennett and Rusk, 2002). The stratigraphic pinch-outs, slumps and debris flow features are restricted to the Early Tertiary and Late Cretaceous sections of the Basin (Brownfield and Charpentier, 2007). The major trapping mechanisms are the fault anticlines, unconformities, sand pinch-outs, drapes and rotated block faults (combination trap types). The sedimentation and Basin geometry were controlled by the closeness to the strike-slip fault along the St. Sierra Leone and St. Palmas at the northern and southern margins of the Basin, respectively (Bennett and Rusk, 2002).

Construction of a geological model for the Liberian Basin

The construction of the geological model of the Liberian Basin was based on the regional cross-section performed by Bennett and Rusk, 2002. Unlike the Dahomey Basin, which has been more extensively studied, there is no outcrop analog to complement the cross-section. Therefore, the model was built with the aim of representing the major geological units present in the Basin using the results of the study by Bennet and Rusk, 2002 (as shown in Figure 3.2a and 3.2b). Also, most of the volcanic intrusives (the Monrovia diabase) were restricted to the Paleozoic; hence they were combined with the crystalline basement rocks in the older segments of the Basin.



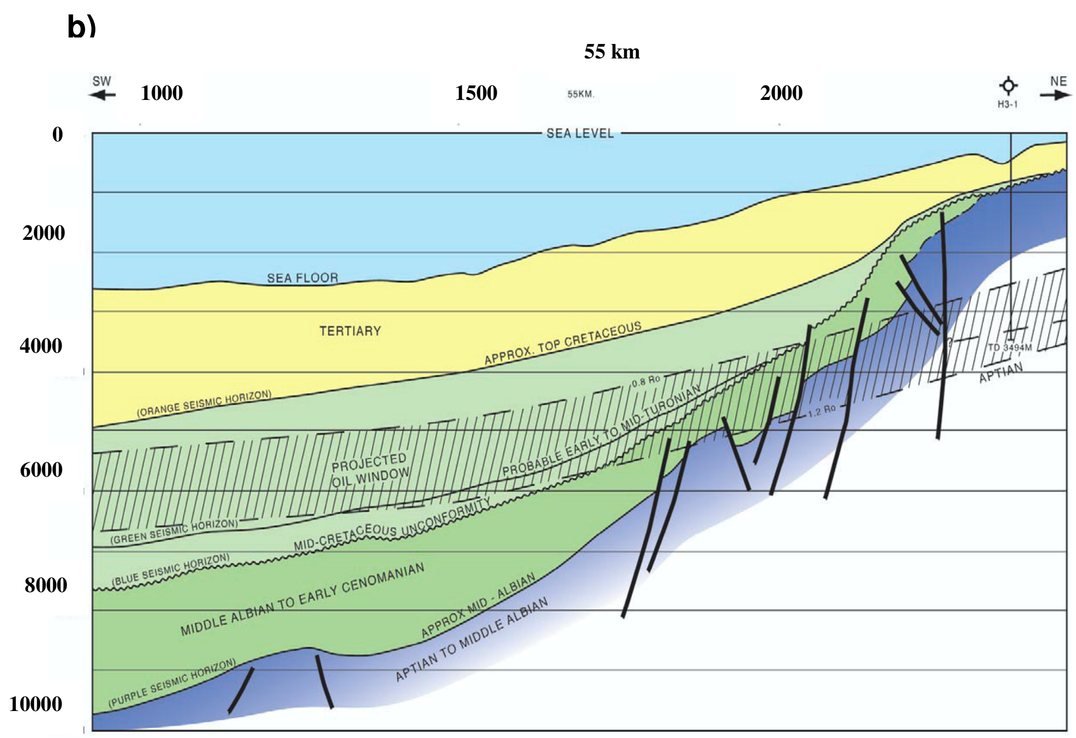


Figure 3.2: (a) The regional lithological correlation of the facies, (b) illustrates the chronostratigraphic framework of the projected oil window in the deepwater section of the Liberian Basin. (Bennett and Rusk, 2002)

The aim of this modeling is to capture the major structural configurations that have influenced the depositional pattern of the various facies within the Basin. The simplified key steps taken in building the geological model is shown in Figure 3.3. In order to understand the basement topography of the study area, the 2D chronostratigraphic framework and regional lithological section provided by Bennett and Rusk, 2002, gave a lead on the geological units within the Liberian Basin. The regional well-section was modified by eliminating the last two wells in the northwestern section (the Sierra Leone wells) and the last well on the southeastern segment (the onshore well) in order to show only the Liberian offshore wells. This cross-section (Figure 3.2a) aided in the determination of the facies association in the chronostratigraphic framework.

A 2D geological model (Figure 3.4) with a dimension of 2.5 km by 1.4 km was built according to the modified cross-section and Chronostratigraphic framework (Figures 3.2a and b) described above for the Liberian Basin. The first seven layers represent the Passive margin segment of the Basin while the last three units represent the rifting phase margin. Units-2 and 3 represent the Early Tertiary sequence below the seawater in which unit-3 is sandstone pinch-out from the Paleocene interval of limestone and shale represented by unit-2. The Mid to Late Cretaceous shales and sandstones were represented by units-4 and 5 respectively. This is equivalent to the prolific Turonian sandstone in the Dahomey Basin area.

Unit-6 represents the Early Cenomanian sandstone, which is a potential reservoir rock within the petroleum system in the Liberian Basin. Unit-7 represents the massive

Albian shale, which is a mature source rock interval within the Basin. The Aptian sandstone was represented by unit-8, whereas the pre-Aptian shale was represented by unit-9. The regional equivalence of unit-9 is the Neocomian-shale (pre-Aptian shale) in the adjoining Basins. This unit serves as a source rock for the pre-transform reservoir rocks. The last layer shows the combination of volcaniclastics, basalts, intrusive diorites and a granitic basement to form the crystalline basement complex rocks of the Paleozoic age. The basement structure shows the prevalence of deep extensional tectonics in form of normal faults.

Key-steps in building the geological model of Liberian Basin

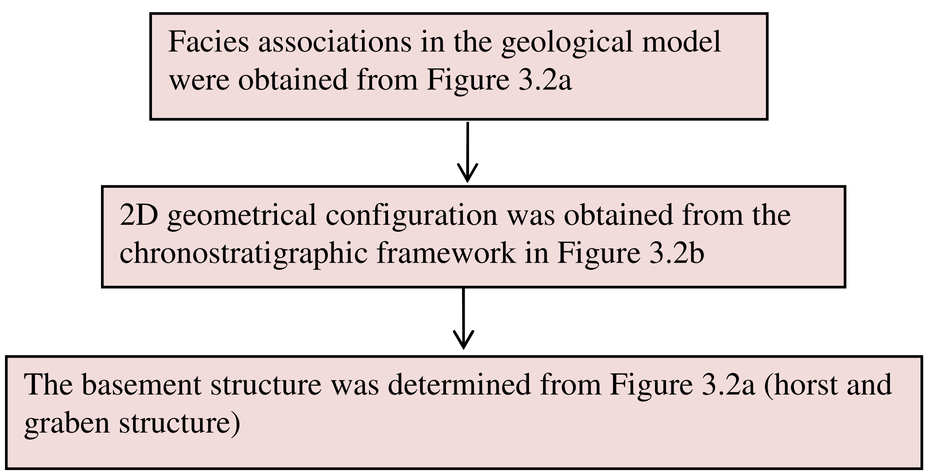


Figure.3.3: Simplified key-steps followed in building the geological model for the Liberian Basin.

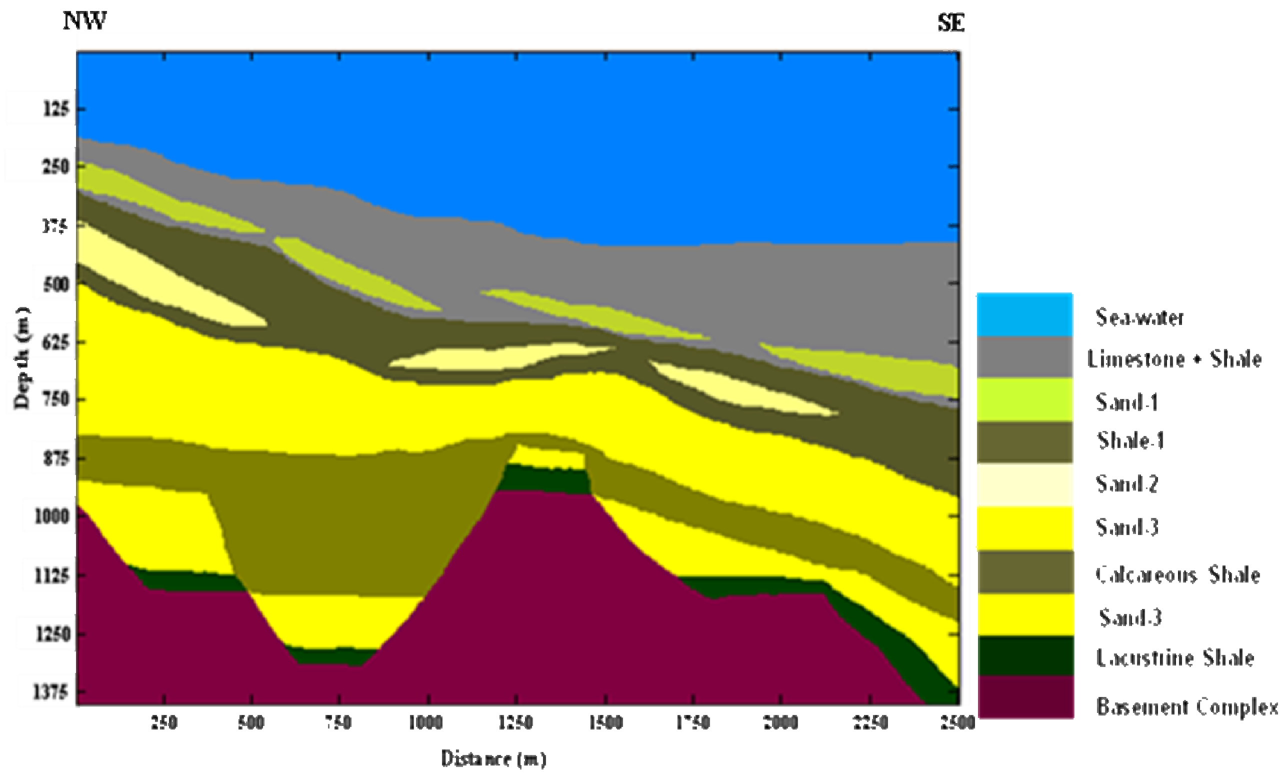


Figure 3.4: 2D geological model constructed for the Liberian Basin.

Table 3.1: A listing of compressional velocity and density values used in simulating the seismic data for the Liberian Basin. (Well Leg 159 IODP database)

	Velocity (m/s)	Density (kg/m3)	Facies	Tectonic Subdivision
1	1500	1000	Sea-Water	
2	1680	1321	Early Tertiary Limestone + Shale	Passive-Margin Phase
3	2203	1756	Early Tertiary Sandstone	
4	2480	1977	Late Cenomanian /Turonian Shale	
5	2600	2150	Turonian Sandstone	
6	2762	2280	Early Cenomanian Sandstone	
7	2605	2550	Albian - Shale	
8	2862	2650	Aptian - Sandstone	Rifting Phase
9	2500	2450	Pre - Aptian Shale	
10	3000	2850	Crystalline Basement Complex	

Seismic data simulation from the geological model

The simulation of the seismic data from the geological model followed the same configuration used in generating the data set for the Dahomey Basin as shown in Figure 3.5. The assigned compressional velocity and density values shown in Table 3.1 were used in the acoustic FDM algorithm obtained from CASP. The distributions of the input parameters in the geological model were plotted in Figures 3.6 and 3.7 in order to convert the geological model into the physical models used in FDM. The direct waves were also removed from the data to enhance the reflection from the primary events.

The next task after the FDM simulation was to identify the various primary reflections present in the data. Figures 3.8 and 3.9 showed the shot gather obtained from the first shot point (125 m) and 750 m. Apart from the sea floor, the identification of the exact primary reflection from the other units can be challenging. By creating sub model of the Basin and simulating the seismic data at shot-point 51 (750 m), the primary reflections from units-4 to 10 (Figures 3.10 to 15) were identified separately. The primary reflections from these seven units were correctly identified in the shot gather shown in Figure 3.16.

The relatively continuous geological units were easier to identify than the sand pinch-outs. In order to confirm the presence of all the geological units in the seismic model, the zero-offset gather was also generated from the shot gathers. The zero-offset gather shows the seismic events simulated from all the geological units present in the model (Figure 3.17). Unlike the Dahomey Basin, the shallower stratigraphic pinch-outs were difficult to delineate from the zero-offset gather because the interval between the basal part of the stratigraphic pinch-out and the underlying unit is too thin. Also the primary reflections from the basement were difficult to identify because of the interference from diffractions, edge-effects, internal multiples and other numerical artifacts present in the data. Therefore, in order to carry out a meaningful analysis, the seismic data were depth-migrated and the interpretation is discussed in the next section.

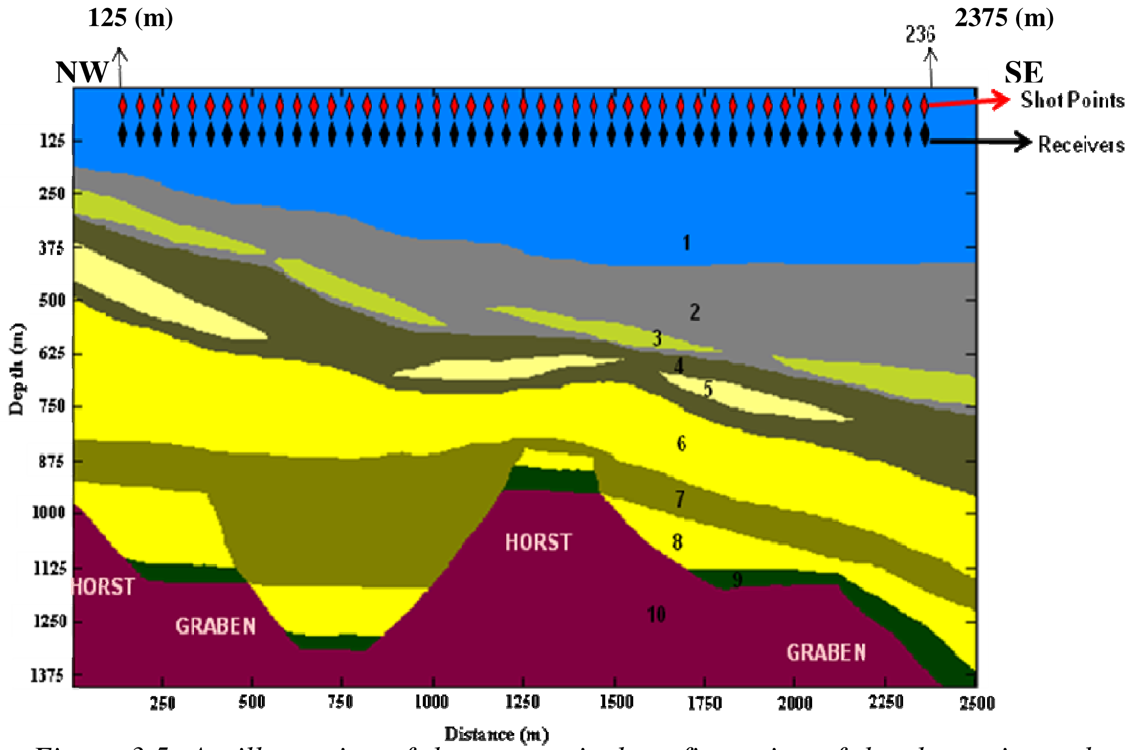


Figure 3.5: An illustration of the geometrical configuration of the shot-point and receiver positions used in the finite-difference modeling of the seismic data from the geological model for the Liberian Basin. Notice that a total of 180 shot-points and receivers at 12.5m intervals were used in generating the data.

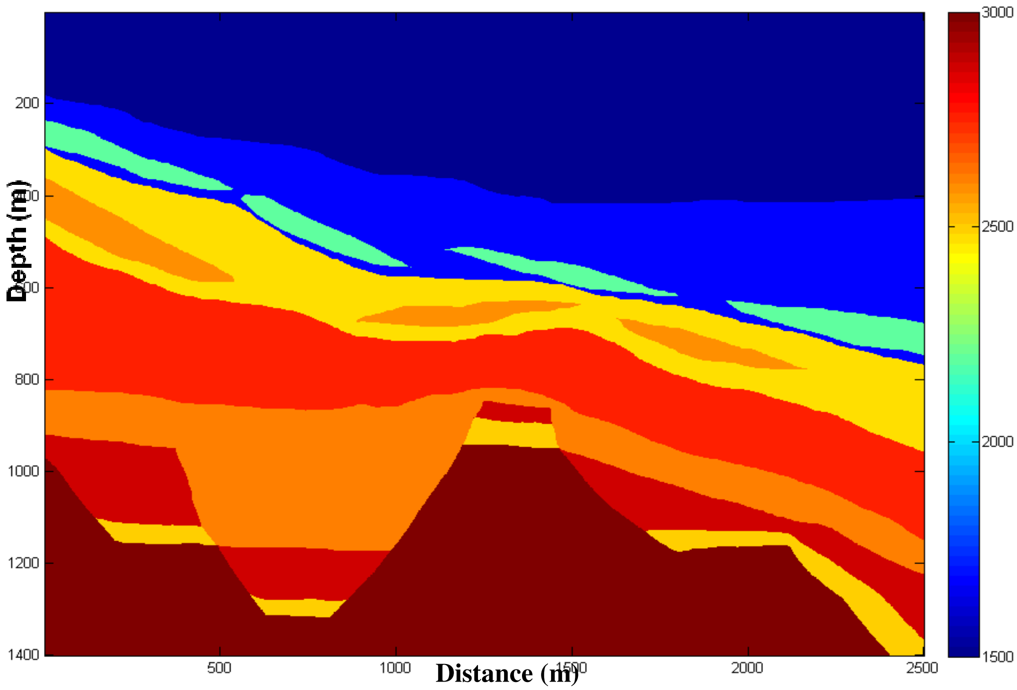


Figure 3.6: The distribution of the compressional velocity (m/s) values in the geological model for the Liberian Basin.

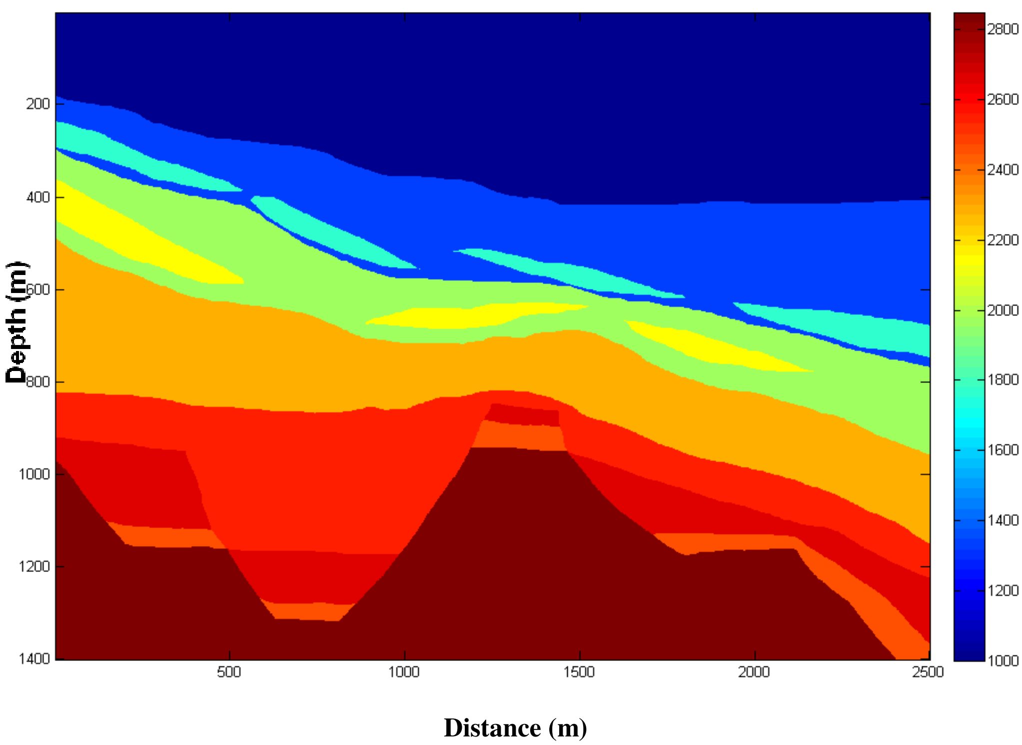


Figure 3.7: The distribution of the density (kg/m^3) values in the geological model for the Liberian Basin.

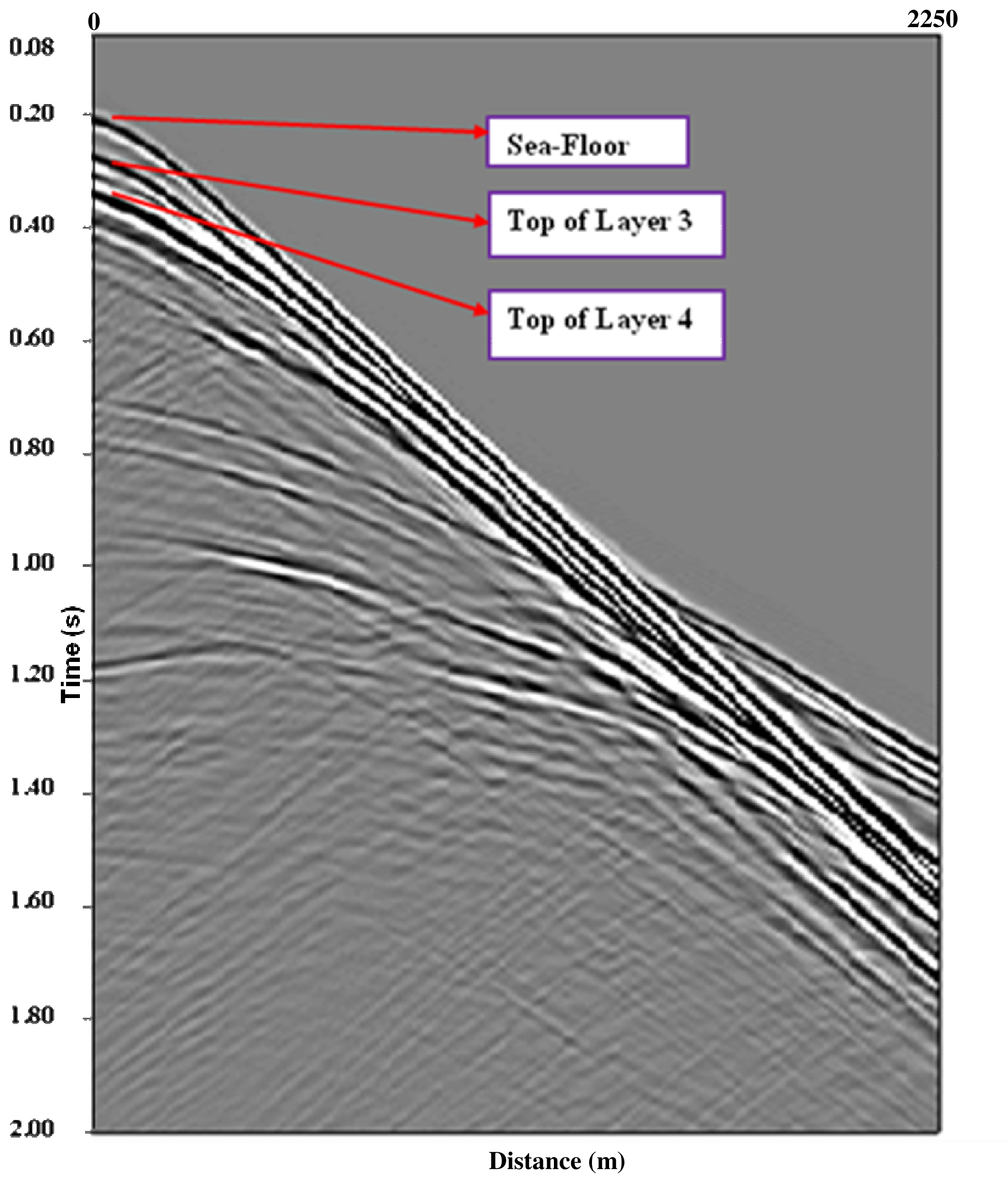


Figure 3.8: An illustration of the shot gather obtained at shot point 125 m from the FDM simulation of the geological model for the Liberian Basin.

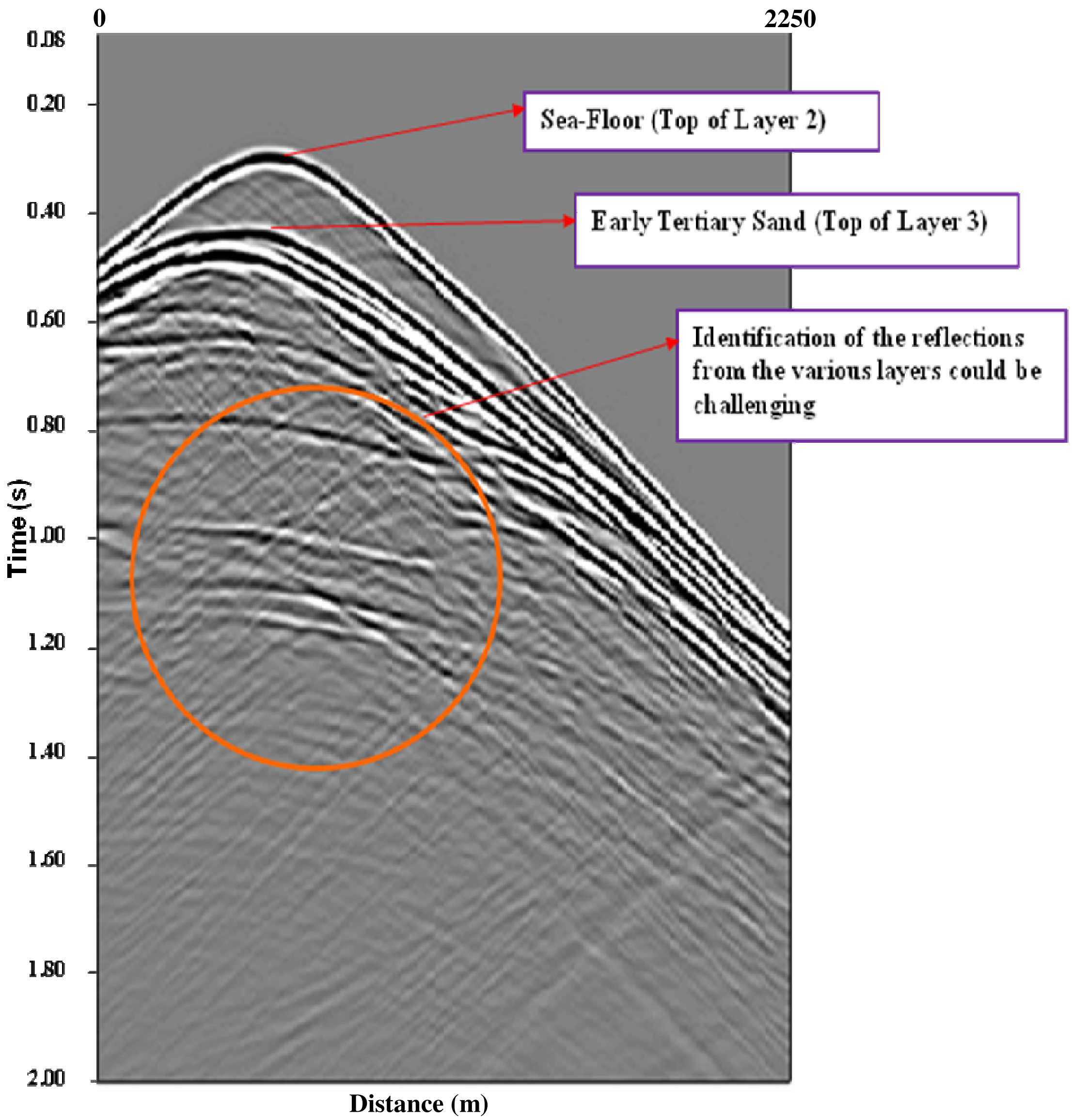


Figure 3.9: An illustration of the shot gather obtained at shot point 750 m from the FDM simulation of the geological model for the Liberian Basin. Notice the identification of the reflections from the various geological units can be challenging without generating the shot-gathers separately from different sub models.

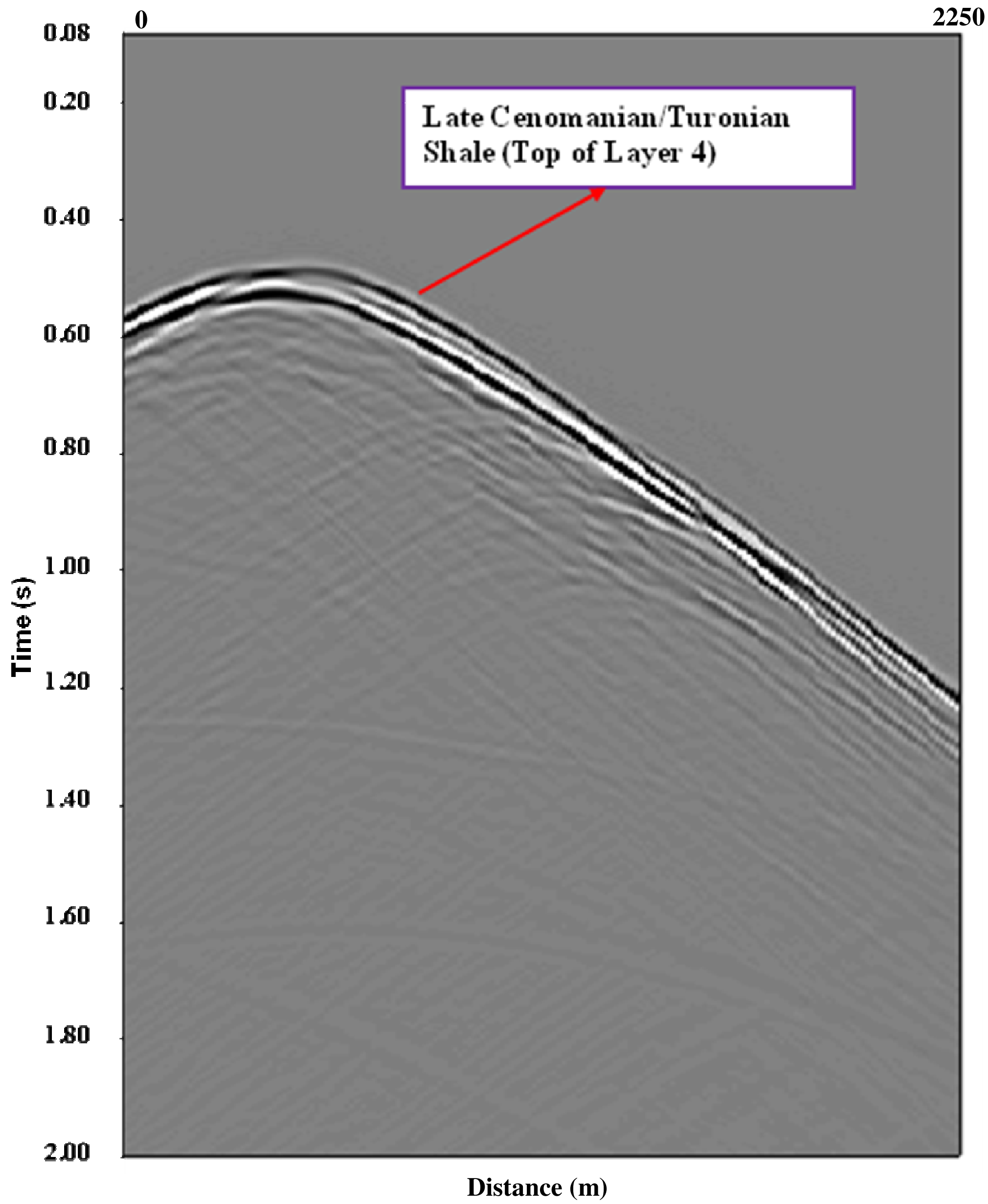


Figure 3.10: An illustration of the shot gather obtained at shot point 750 m showing the primary reflection from the top of layer 4 (Late Cenomanian/Turonian shale) of the geological model for the Liberian Basin.

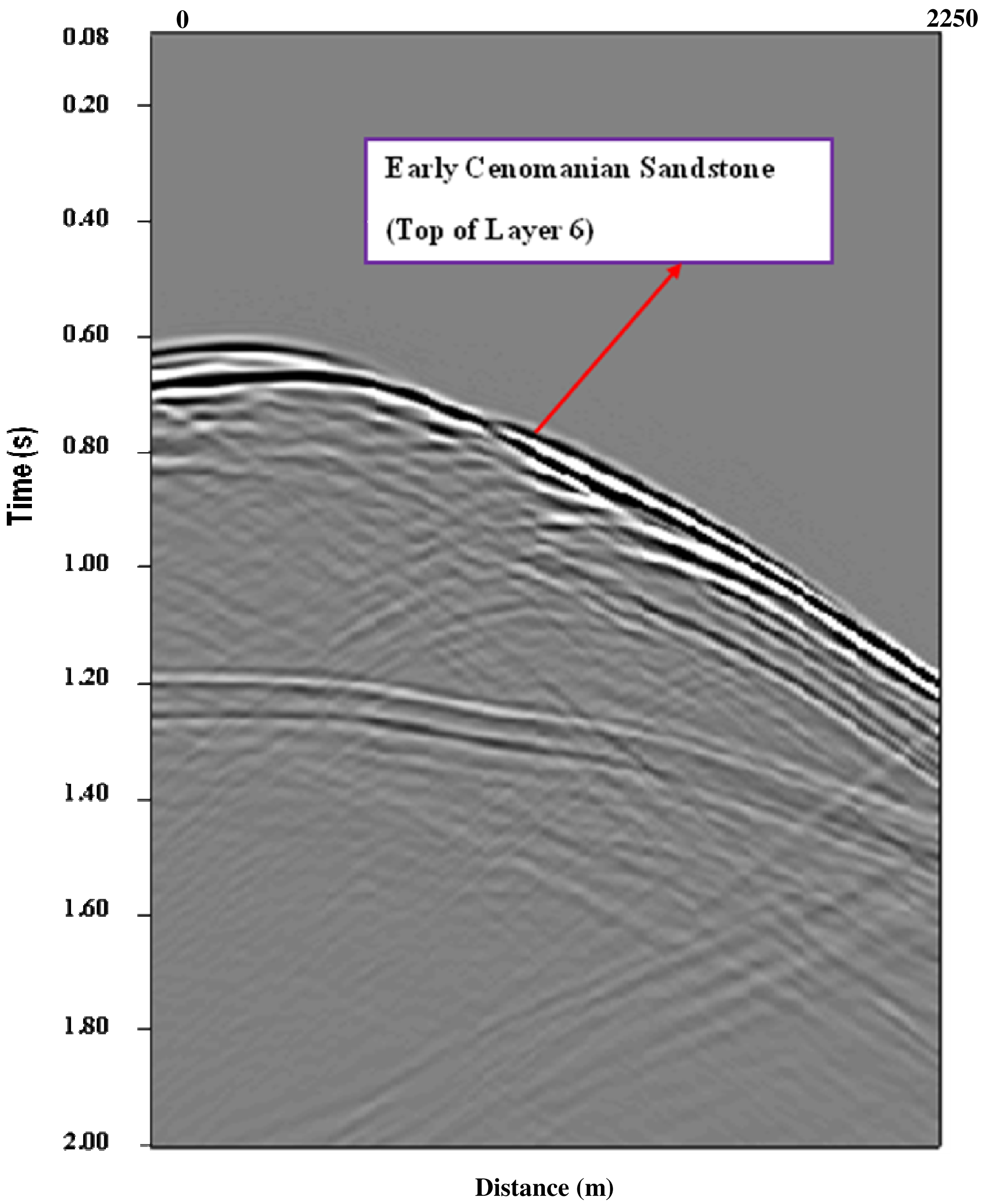


Figure 3.11: An illustration of the shot gather obtained at shot point 750 m showing the primary reflection from the top of layer 6 (Early Cenomanian sandstone) of the geological model for the Liberian Basin.

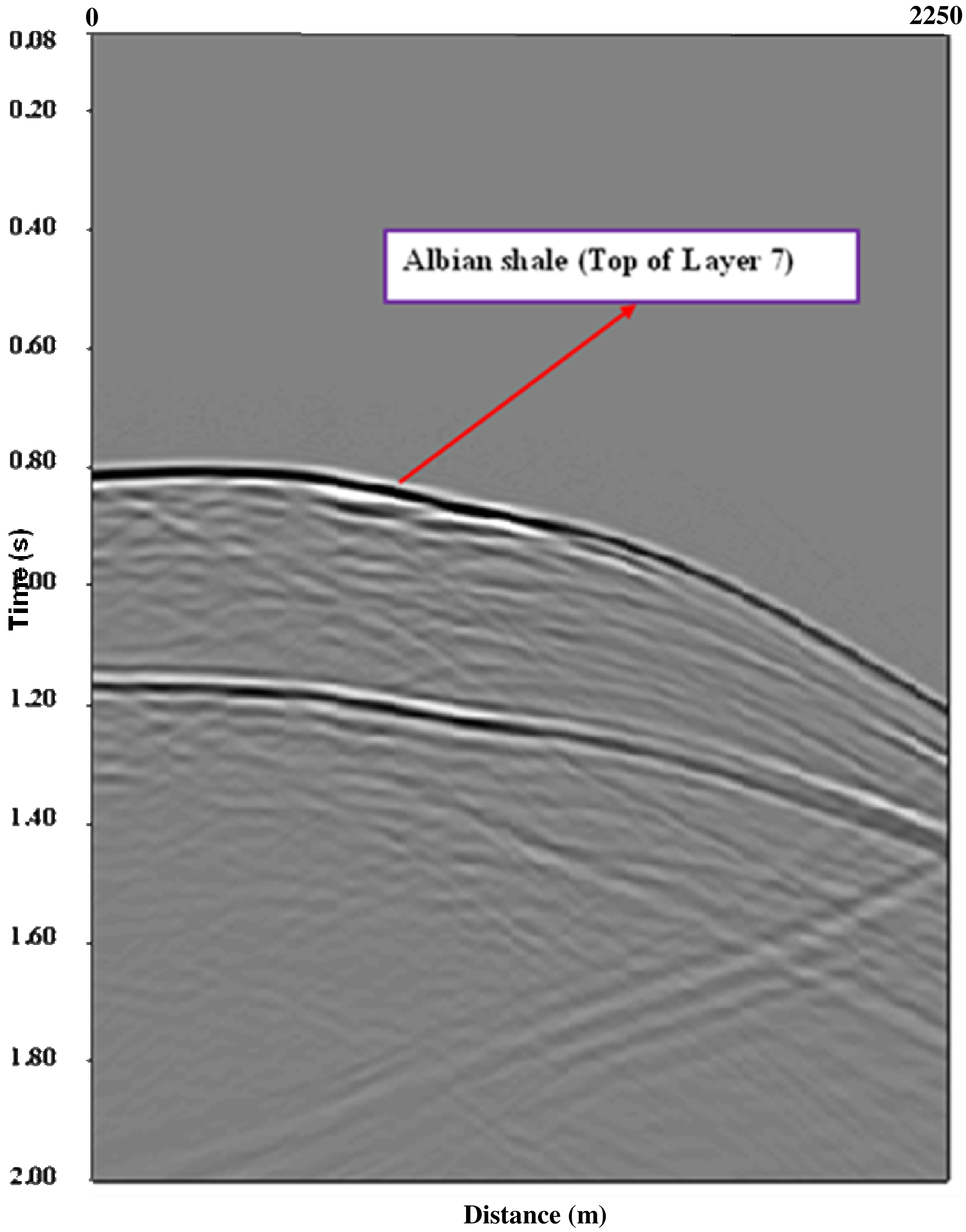


Figure 3.12: *An illustration of the shot gather obtained at shot point 750 m showing the primary reflection from the top of layer 7 (Albian shale) of the geological model for the Liberian Basin.*

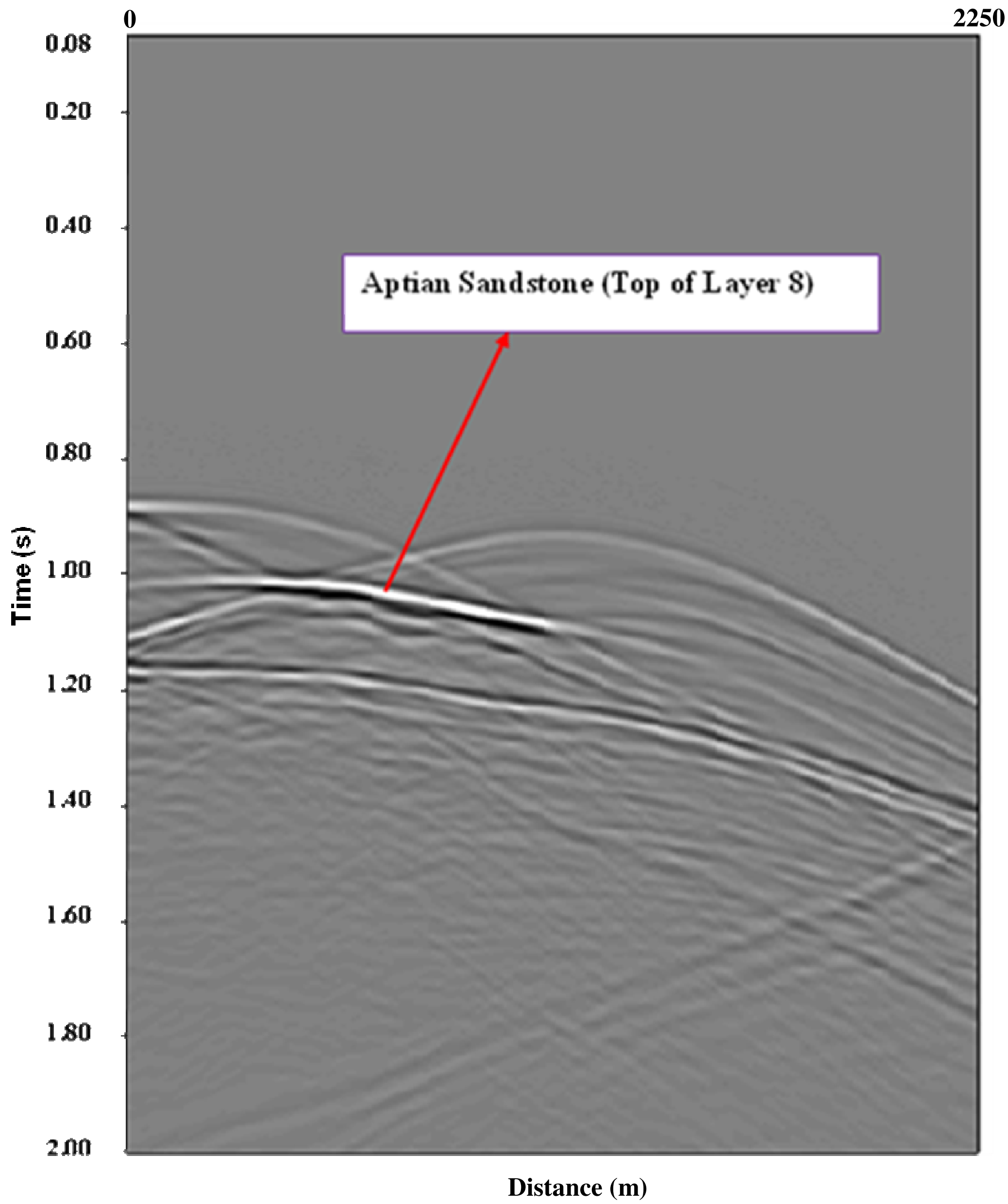


Figure 3.13: An illustration of the shot gather obtained at shot point 750 m showing the primary reflection from the top of layer 8 (Aptian sandstone) of the geological model for the Liberian Basin.

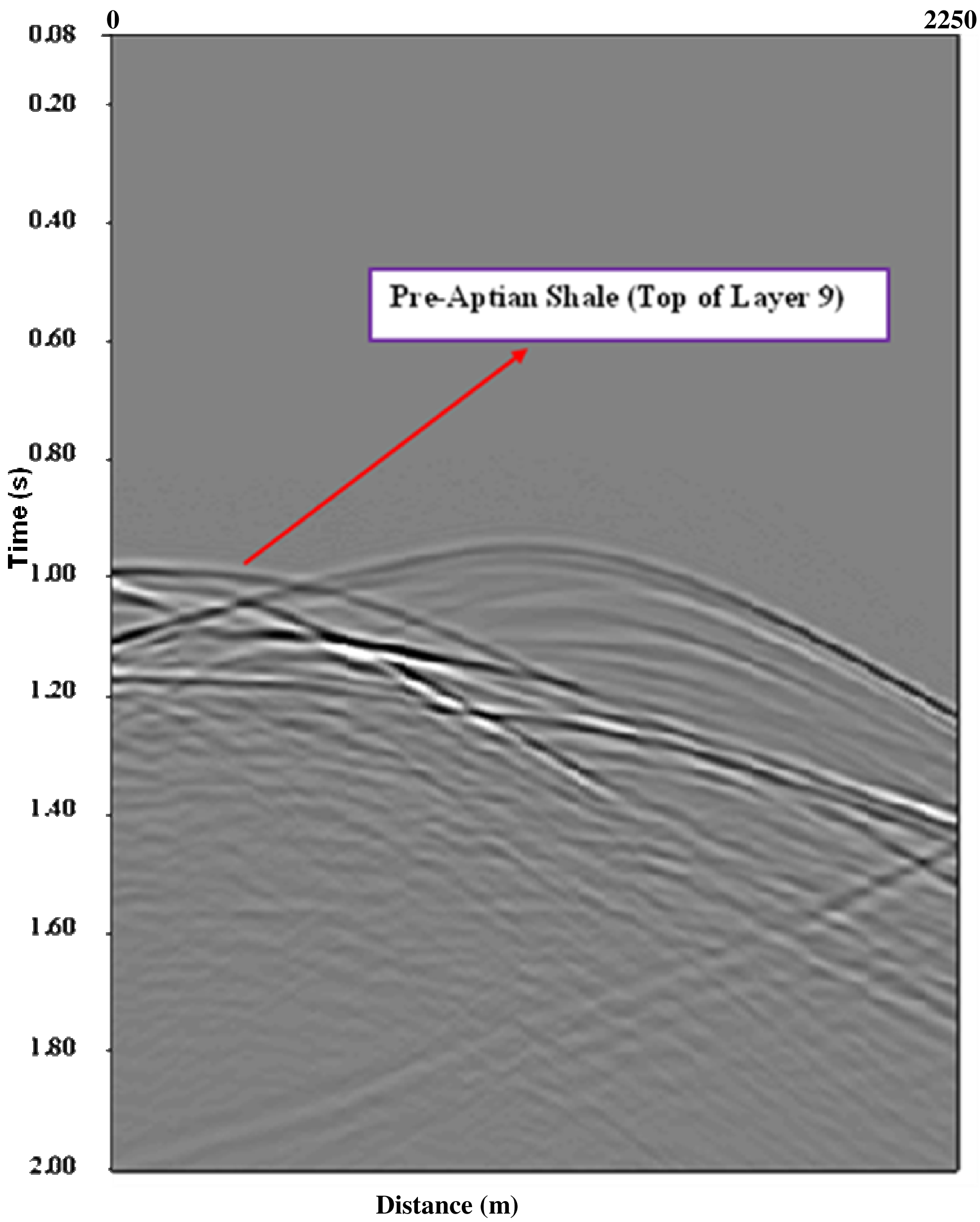


Figure 3.14: An illustration of the shot gather obtained at shot point 750 m showing the primary reflection from the top of layer 9 (pre-Aptian shale) of the geological model for the Liberian Basin.

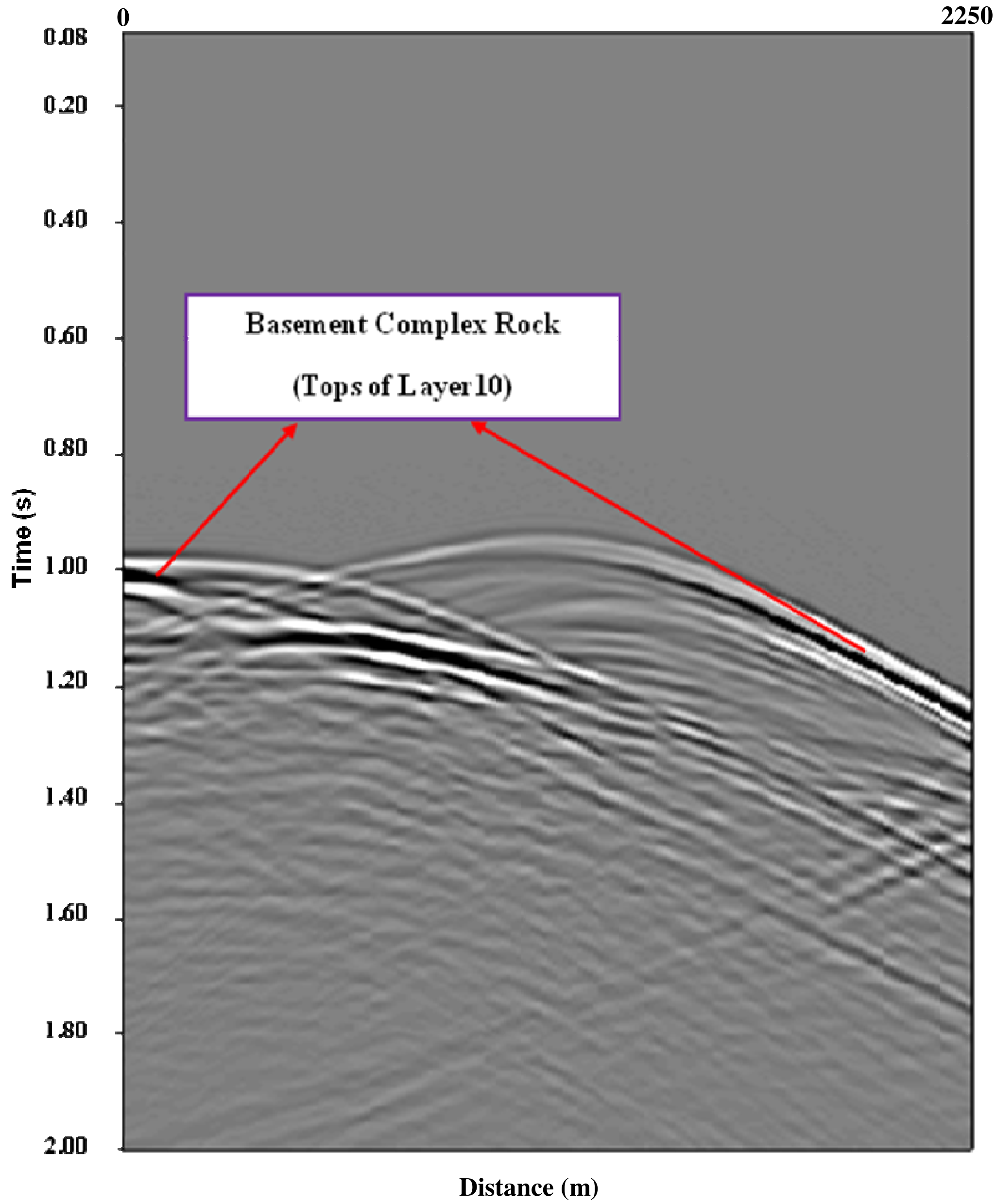


Figure 3.15: An illustration of the shot gather obtained at shot point 750 m showing the primary reflection from the top of layer 10 (basement complex rock) of the geological model for the Liberian Basin.

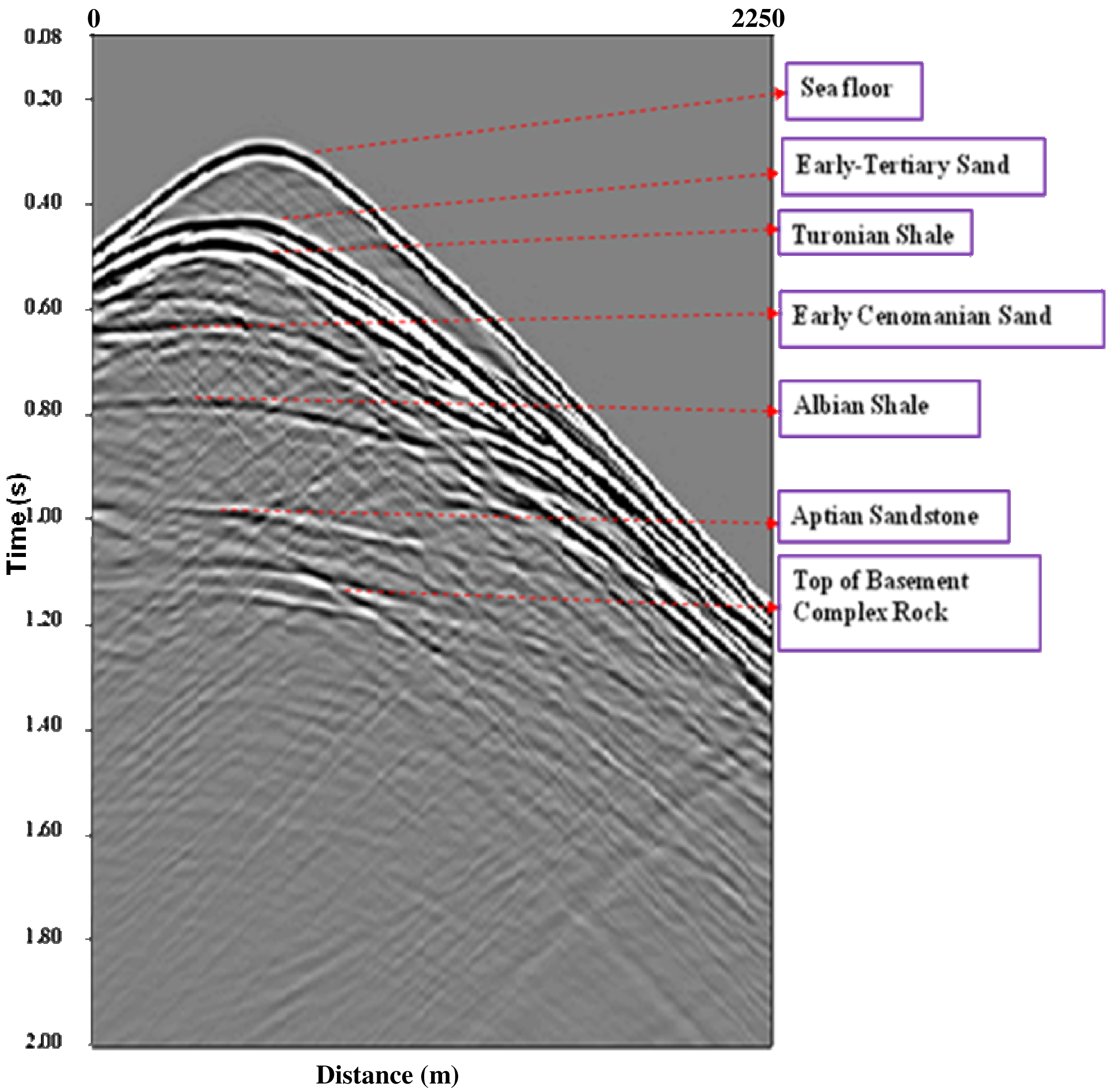


Figure 3.16: *An illustration of the shot gather obtained at shot point 750 m showing the primary reflections from all the surfaces of the layers within the geological model for the Liberian Basin. Notice the reflections from the tops of the shally intervals are weaker and more difficult to identify.*

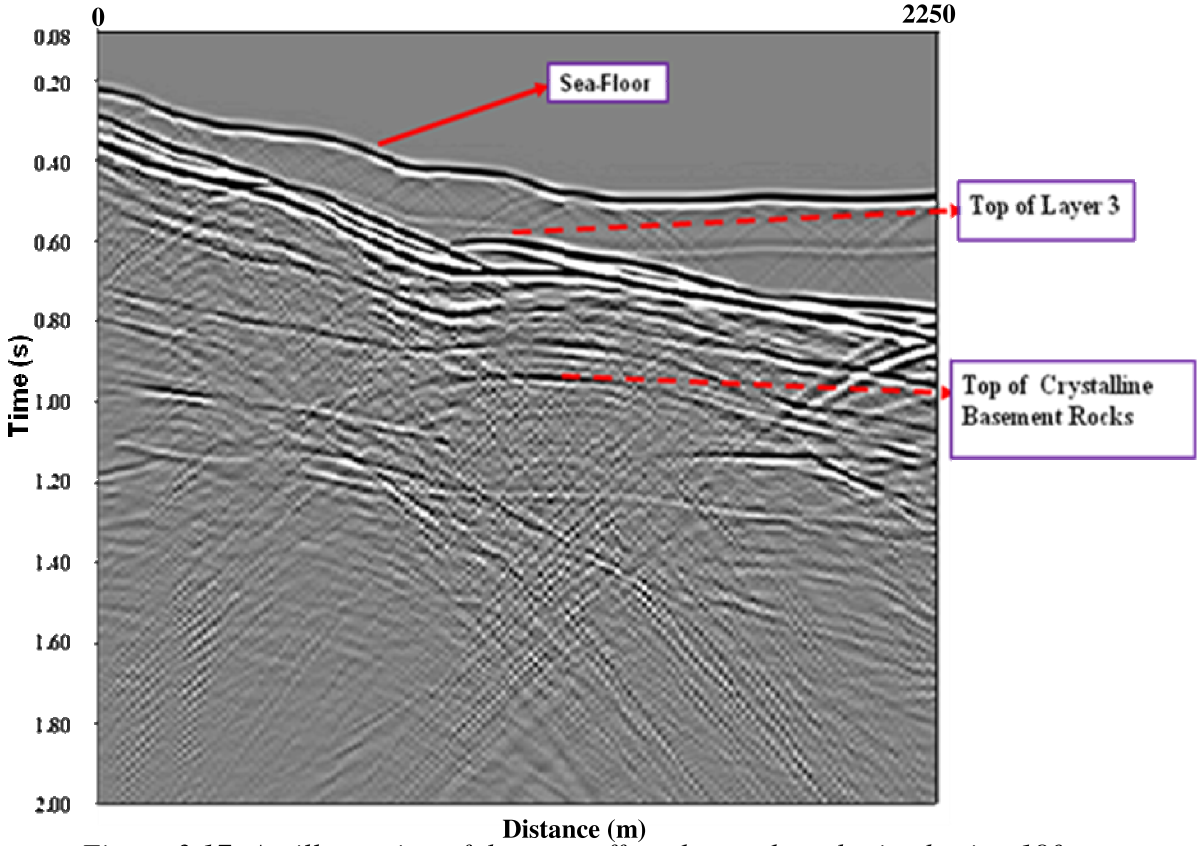


Figure 3.17: An illustration of the zero-offset shot gather obtained using 180 shot-points and receivers for the geological model of the Liberian Basin. Notice the presence of events from diffractions from the rough sea floor, edge-effects, internal multiples and other numerical artifacts.

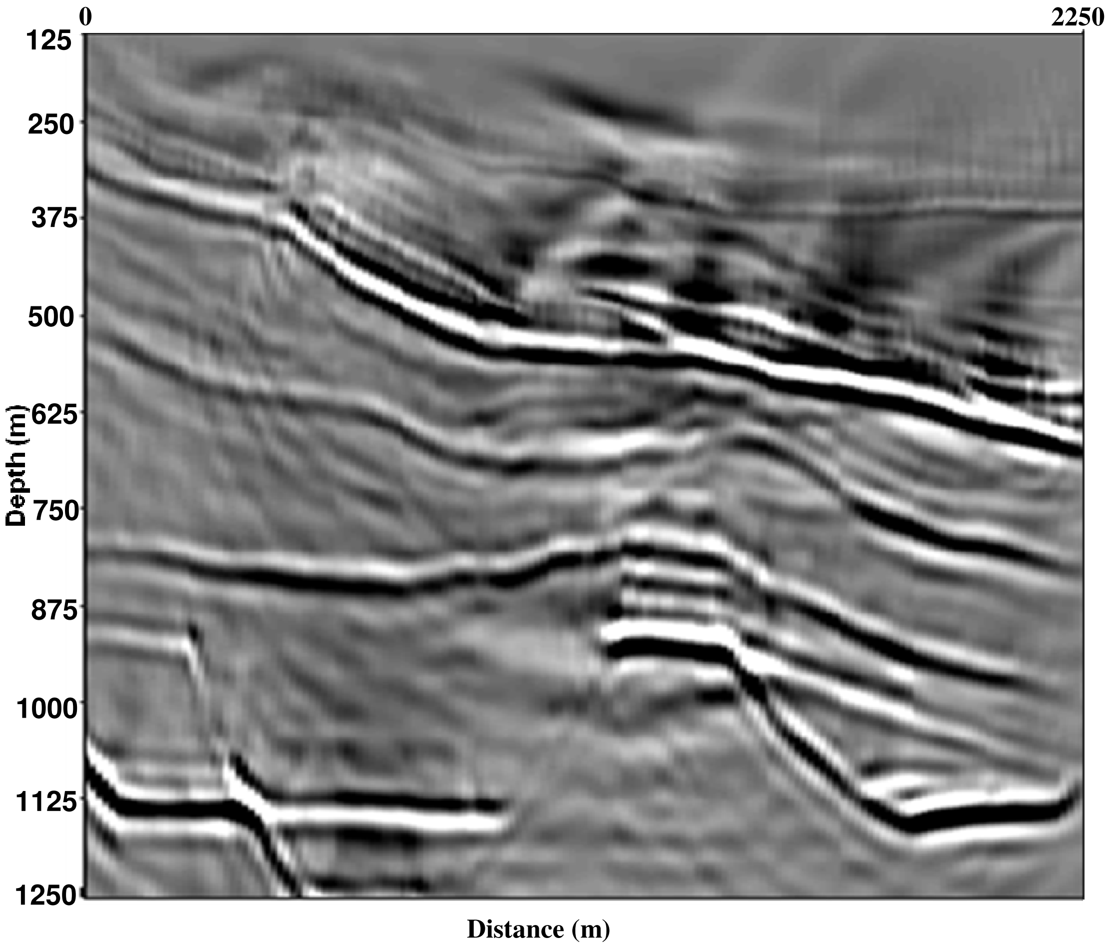


Figure 3.18: An illustration of the un-interpreted depth-migrated seismic data from the shot gathers generated from the geological model for the Liberian Basin.

Interpretation of the migrated seismic data

Interpretation of the migrated section from the shot gathers involved a structural interpretation of the reflection geometry as shown in Figure 3.19. Five faults named (F-1 to F-5) were delineated. All the faults were confined to the deeper section, but the associated anticlinal and synclinal structures still affected the shallower segments of the Basin. Except for fault F-3, all the faults dip towards northwest-southeast direction. The interpretation of the horizons involved tracking the reflection continuity across the seismic section. Seven horizons denoted by H-1 to H-7 were delineated in the migrated seismic section.

The geometrical configuration of the fault system and the mapped horizons reveals the structure of the basement topography. The anticlinal structures observed in horizons H-4 and H-5 were as a result of the up-thrown side of the basement faults F-2 and F-3. Also horizon H-7 could not be delineated on the hanging wall of fault F-4 and F-3 because its depth was not included in the migration. The shallowest horizons H-1 to H-5 generally dip towards the same direction.

Discussion of the interpretation

By comparing the interpreted horizons with the geological model, we can check whether all the layers were properly imaged in the migrated seismic section. Horizon H-1 shows the sea floor dipping in the northwest-southeast according to the cross-section shown in Figure 3.2a. The detached sand bodies were quite difficult to delineate because

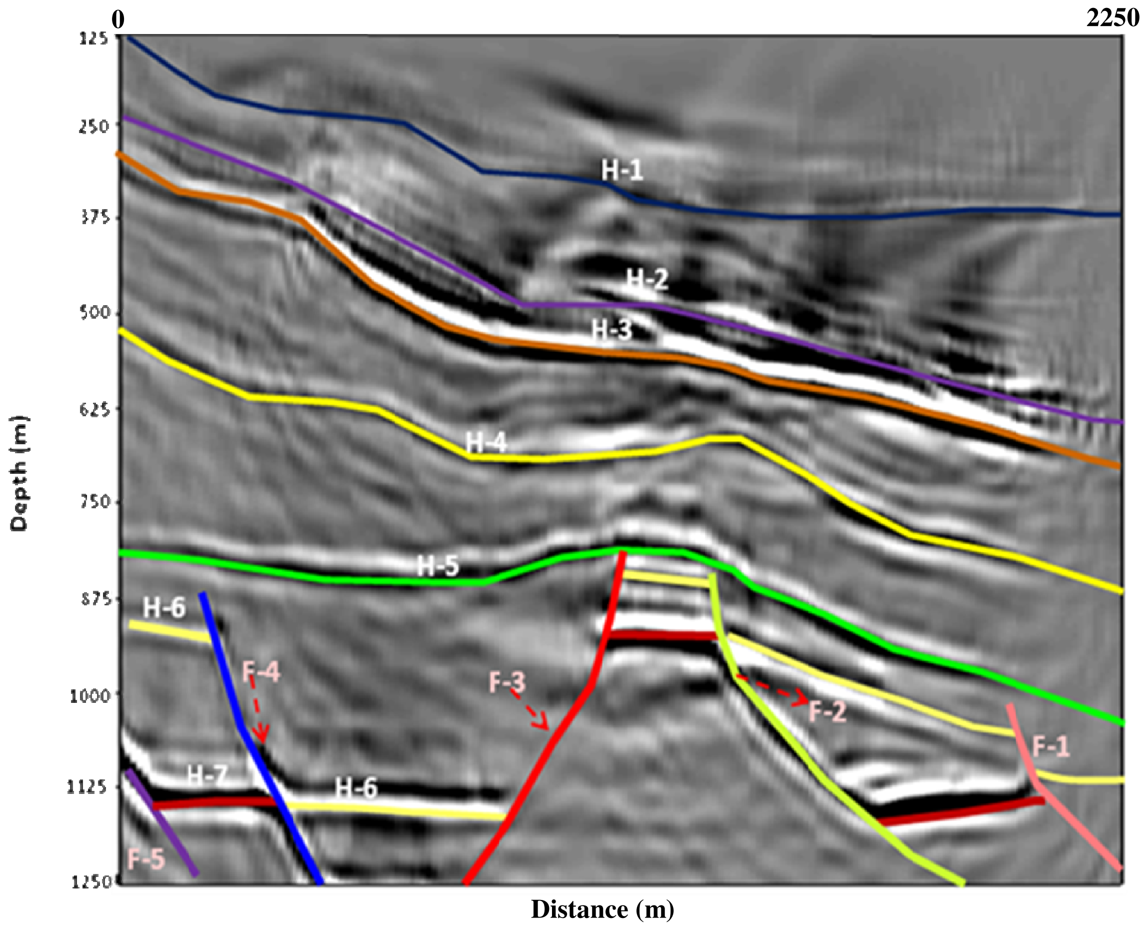


Figure 3.19: An illustration of the interpretation of the migrated seismic section with seven horizons (H-1 to H-7) and five normal faults (F-1 to F-5) from the geologic model for the Liberian Basin.

their reflections were weak and discontinuous across the seismic section. The Early Tertiary sandstone pinch-outs were interpreted as a continuous horizon with H-2. The Turonian sand bodies were completely missed out. These Late Cretaceous and Early Tertiary sand bodies are the main reservoir rocks in the deepwater areas of Liberian Basin. The top of Late Cenomanian shale was represented by H-3 whereas; H-4 represents the top of Turonian sandstones. The top of Albian shale was represented by H-5. The boundary between the passive margin and rifting phase was represented by horizon H-6.

In the interpretation above, some of the layers present in the geological model were not delineated. Figure 3.20 showed the comparison between the interpretation and the geological model. Four horizons namely; P-1, P-2, C-1 and C-2 were missed out in the interpretation. Horizon P-1 was represented with dashed lines because it was drawn across the seismic section to aid the mapping of the top of the detached sand bodies. Horizons C-1 and C-2 represent the base of these sandstone pinch-outs. Horizon P-2 represents the top of pre-Aptian shale that was also missed out in the interpretation in Figure 3.19.

All the interpreted faults are normal, which is consistent with the extensional tectonic regime described earlier for the Basin. Unlike the Dahomey Basin, no fault was delineated in the shallower segment (Tertiary unit) of the seismic data.

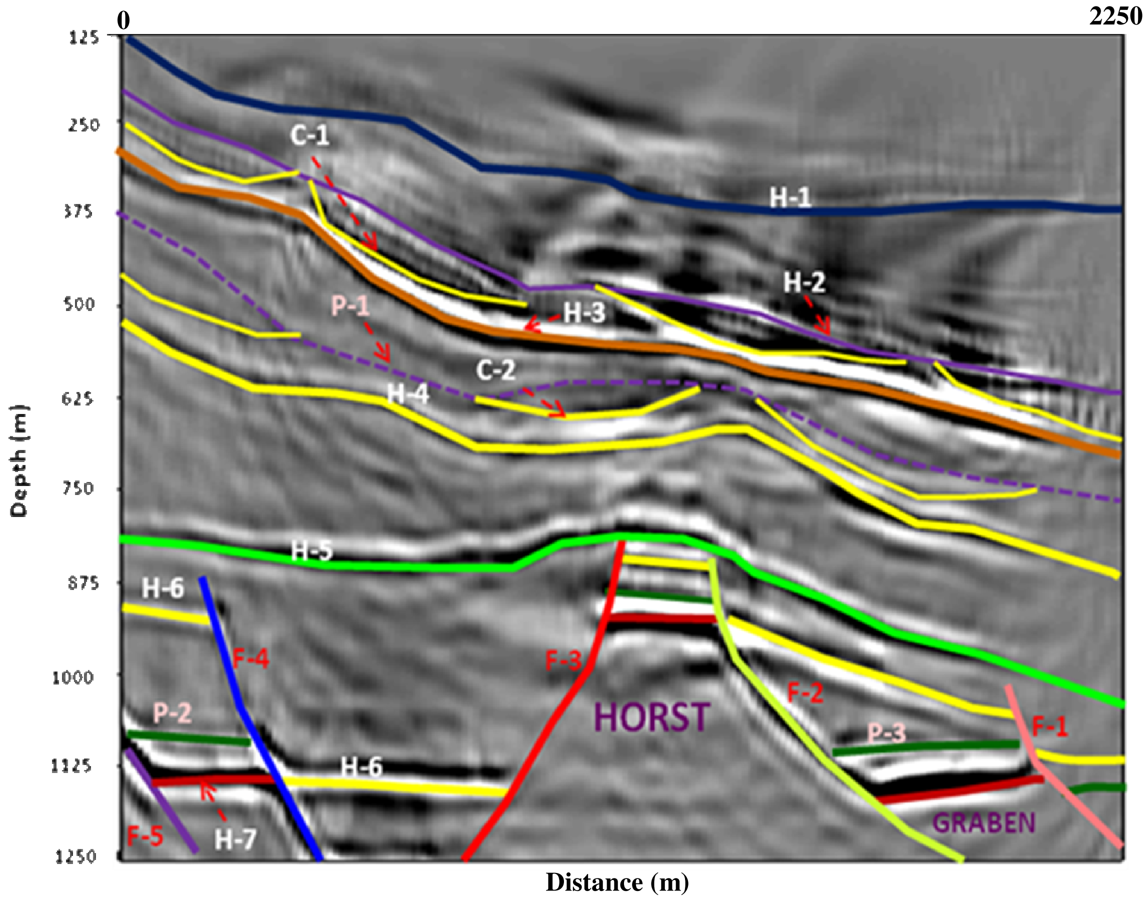


Figure 3.20: The result of the comparison between the interpretation in Figure 3.19 and the actual geological model for the Liberian Basin. Notice: The presence of four additional horizons named (P-1, P-2, C-1and C-2). The dashed line (P1) represents the horizon that was drawn across the image. C-1 and C-2 represent the base of the isolated sand bodies.

The reflections above the horst structures were more representative of the total number of reflections expected in the seismic section because the horizons were encountered at a shallower depth compared with the horizons above the graben structure.

Summary and conclusions

In this chapter, a 2D geological model was built from a published regional cross-section of the offshore segments of Liberian Basin. This model included major structural configuration of the geological units in Liberian Basin. The seismic data from the geological model were simulated using finite-difference modeling. The shot gathers were processed and depth-migrated to allow for a detailed interpretation of the seismic section.

The interpretation showed the presence of seven horizons (H-1 to H-7) and five basement-related extensional faults (F-1 to F-5) in the migrated seismic section. The slope-related isolated sand bodies within the Late Cretaceous could not be delineated in the interpretation because the reflections were weak and laterally discontinuous. These slope deposits were products of mass wasting, and the sediments occur in form of slumps, debrites, and rubbles which are related to gravity-controlled sedimentary features. The slope deposits represent the main reservoir targets in the Late Cretaceous and Early Tertiary section of the Basin particularly in the deeper water areas.

However, it is noteworthy to emphasize that the values of the depth used in the modeling were chosen only for computational efficiency. The actual depths could be seven times higher than the chosen values. This approach to modeling has provided further insight into understanding the reservoir potentials of the offshore Liberian Basin and some of the challenges associated with imaging and interpreting the potential reservoir units. This approach to reservoir modeling could be a useful template for future exploration in this segment of the GoG.

CHAPTER IV

SUMMARY AND CONCLUSIONS

This study involved the construction of geological models of two Basins (the Dahomey and Liberian) in the Gulf of Guinea. The central focus of this thesis was to provide a further understanding of the geological sequences and the challenges involved in properly imaging and interpreting the potential reservoir units for hydrocarbon exploration. These geological models were built using available information in the literature, well-log data, outcrop studies, regional cross-sections and schematic geological sections that show the geometrical relationships of the various units.

The seismic data for the geological models were simulated using finite-difference modeling. The resulting shot gathers were plotted and analyzed to show all the seismic events from the geological model. The seismic data were depth-migrated before performing a structural interpretation. The interpretation of the migrated seismic section showed that the basement tectonics had a significant impact on the general architecture of the two Basins.

In Dahomey Basin, the base of the amalgamated channel complex was delineated with H-5 but the two other isolated channel systems in the Mid to Late Cretaceous segment of the model could not be interpreted from the seismic data. The delineation of these channels was difficult because of the discontinuous reflections above the channels. A similar difficulty was faced in delineating the slope fills and other sandy pinch-outs in the Liberian Basin. Except for the gravity-related slump fault interpreted in the Dahomey Basin, almost all the faults were restricted to the older segments of both Basins. All the faults interpreted are normal, and are consistent with the extensional tectonic regime of the Basins.

Overall, despite the inherent ambiguities in the choice of velocity, density and depths assigned to each defined facies, this approach to the geological and seismic modeling of potential reservoir units could be a viable template for future exploration efforts in the GoG.

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