ANALYSIS OF OIL EXPLORATION PLAYS IN ANZA BASIN FROM A TRAP-TYPE PERSPECTIVE

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DECLARATION

I hereby declare, that this dissertation is my original work and it has not been submitted for a degree in any other university or for any other award.

SIGNED ......Cheruiyot...................... DATE ......8th August, 2012.......

CHARITY CHERUIYOT

The dissertation has been submitted for examination with my knowledge as university supervisors

SIGNED .... DATE ....8/8/2012.......................

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ABSTRACT

The Anza basin is a sedimentary basin in North Eastern Kenya. The first wells in the Anza basin were drilled in 1976. Chevron and Esso drilled Anza-1 and Bahati-1 wells in the southern part of Anza Basin. Since then 11 wells have been drilled in the Anza Basin. There have been oil and gas shows in some of the wells.

This study employed play analysis which is a technique used for petroleum resource exploration and assessment. In play analysis a basin is divided into prospective resource areas called plays. In this study these prospective areas were divided into these prospective resource areas based on the trap types identified. The play is a useful analytical concept that allows the analysis to be sensitive to the physical processes involved in the entrapment of oil and gas and in the discovery of oil and gas accumulations.

The main objectives of this study were to delineate plays types based on trap types identified in the area, to determine the stratigraphy of the area and to identify and delineate structures within the area. This was done by the interpretation of seismic sections, refining well log information and by integrating information from interpreted seismic sections and final well log information so as to determine the stratigraphy of the area. ArcView GIS (Geographical Information Systems) and SMT (Seismic Micro Technology) Kingdom Suite were the main tools that were used in achieving the objectives of this study.

The trap types identified included both structural and stratigraphic traps with shale being the sealing rock and siltstone and sandstone as the major reservoir rocks. Several structures including faults, folds, unconformities and pinch-out were also identified and delineated. The stratigraphy of the area was also determined by refining the information that was available from the three wells (Ndovu-1, Duma-1 and Kaisut-1) that are in the study area.

ACKNOWLEDGEMENT

Very special thanks to God for the many blessings He has accorded me. I owe everything to Him.

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I am also indebted to my family for their moral support and to my classmates for they played a role in one way or another all through the course of my studies.

For all of you, thank you so much, God bless you.

DEDICATION

To my mother Rael Cheruiyot and to my brothers Japheth and Carson Cheruiyot - with love

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Oil exploration in Kenya began in the 1950's with the first well being drilled in 1960. The first wells in the Anza basin were drilled in 1976. Chevron and Esso drilled Anza-1 and Bahati-1 wells in the southern part of Anza Basin. Since then 11 wells have been drilled in the Anza Basin. Ndovu-1 well had gas shows in the Lower Cretaceous sands and oil shows in the Aptian sands. Sirius-1, Hothori-1 and Chalbi-1 wells had oil shows.

This study presents a useful concept that allows the analysis to be sensitive to the physical processes (trap, seal, and source and reservoir rocks) involved in the entrapment of oil and gas and in the discovery of oil and gas accumulations. This was done by delineating plays types based on trap geometries/types in the area, establishing the stratigraphy of the area so as to identify the potential trap, source, reservoir and seal rocks. Structures in this area were also identified and delineated.

1.2 PROBLEM STATEMENT

Petroleum resources are a key factor for sustainable development of the worlds economies, Kenya inclusive. To estimate the probability of discovery is an important part of prospect evaluation because of the degree of uncertainty involved in petroleum exploration. Geological risk assessment requires an evaluation of those geological factors that are critical to the discovery of recoverable quantities of hydrocarbons in a prospect area. One of the more popular techniques used for petroleum resource assessments is play analysis. In play analysis a basin is divided into prospective resource areas called plays. A fundamental assumption is that geologic characteristics are significantly correlated within the play but show substantially less correlation between plays (Miller, 1988). The underlying objective of play analysis is to "find undiscovered petroleum accumulations at a profit" (Magoon and Sanchez, 1995).

In this study the analysis will be done by delineating plays types based on trap geometries/types in the area. The stratigraphy of the area will also be investigated to establish the potential source, reservoir and seal rocks. This will be done by means of seismic interpretation of 2D seismic sections and well log data. Structures in this area will also be identified and delineated to give a better understanding of structure of the area. This study will present a useful concept that allows the analysis to be sensitive to the physical processes involved in the entrapment of oil and gas and in the discovery of oil and gas accumulations. Thus, if all these physical processes are present within the play area, the play probably will contain accumulations of oil or gas or both; however, if one or more of the significant geologic characteristics is missing or unfavorable, all the prospects within the play probably will be unsuccessful.

1.3 THE STUDY AREA

1.3.1 LOCATION

The area under investigation (figure 1.1) is in North Eastern Kenya. It is a NW-SE trending Jurassic-Cretaceous rift system which extends across Central Africa (CAR) and also trends along the prolific Mesozoic play of southern Sudan (Muglad Basin) where the petroleum system is proven and productive. This basin is over 580km long and 150km wide and is filled in some place with more than 6,000m of Mesozoic and Cenozoic sediments, in addition to Plio-Pleistocene basalts. The Anza Basin comprises a system of sub-basins with Blocks 9 and 10A covering most of the northern and central Anza Graben and Block 3A the Southern Anza Graben and Mochesa Basins.

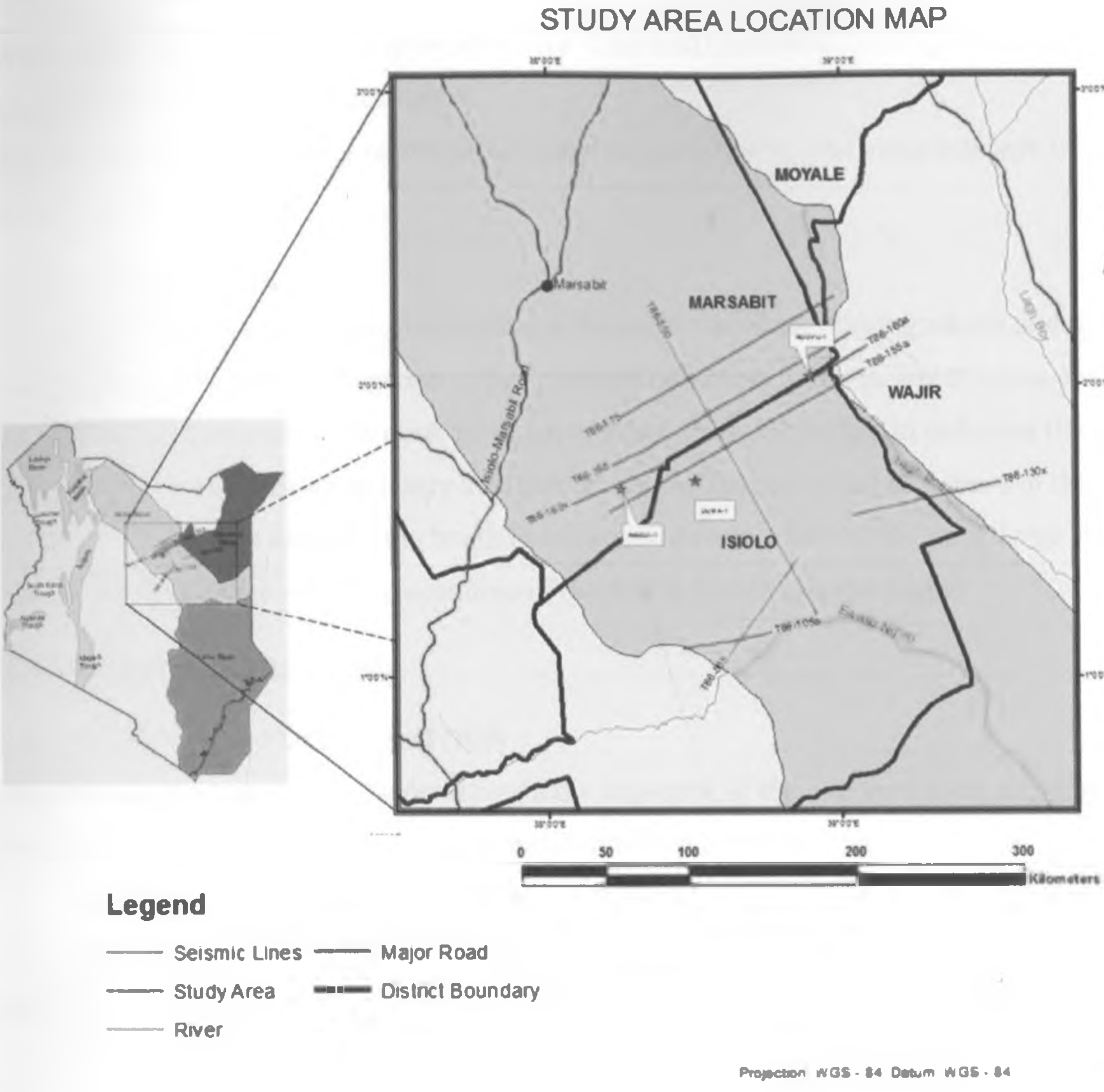

Figure 1.1 The Anza Basin(modified from the Topographical Map of Kenya)

1.3.2 PHYSICAL SETTING

Much of northeastern Kenya is a flat, shrub-covered plain. The road network is rudimentary, and in some places non-existent. The few roads constructed decades ago are in poor condition.

Telecommunications are still restricted to major towns and along highways. Very few districts in northern Kenya receive adequate radio and television coverage even after the recent liberalization of the airwaves.

Limited access to electricity restricts the scope for investment. The main soil type in the area is sand.

1.4 JUSTIFICATION

Play analysis from a trap type perspective, will play a role in identifying where and to what extent objective future exploration activity should be directed that is, which areas or trends are likely to become core future oil productive areas. This will be key in reducing the risk in the petroleum exploration industry and increasing the chances of oil discovery in this region which in turn will be a big boost in economic development of Kenya at large and a significant improvement of the economy of the North Eastern Kenya region.

1.5 LITERATURE REVIEW

1.5.1 PETROLEUM PLAY DEFINITION

Magoon (1995) states that, "Depending on the objective of the explorationist, the play concept ... can have any degree of geologic similarity."

Miller (1988) Describes a play as an area within a basin in which the geology and geophysics indicate that any prospects present may have similar combinations of the major assessable geologic attributes: hydrocarbon sources, reservoir beds, and traps.

The play is a useful analytical concept that allows the analysis to be sensitive to the physical processes involved in the entrapment of oil and gas and in the discovery of oil and gas accumulations.

According to Doust (2010) general agreement is that the play describes groups of accumulations and prospects that resemble each other closely geologically, sharing similar source, reservoir, seal and trap conditions, but there's no clear agreement on a definition and an inherent lack of precision

The play is employed in day-to-day risk management and planning activities for most explorers the most important decisions concern the areas and trends to investigate, rather than which individual prospects to drill (Doust, 2010).

Play analysis is a popular techniques used for petroleum resource assessment. In play analysis a basin is divided into prospective resource areas called plays. Miller (1988), notes that the resource-appraisal technique focuses on the play as a basic unit of geologic analysis in which one or more prospects are present in a common or fairly homogeneous geologic setting. A fundamental assumption is that geologic characteristics are significantly correlated within the play but show substantially less correlation between plays.

1.5.2 TRAP TYPE/GEOMETRY

The trap type is usually the most restricted geographically & usually comprises the most specific element of a play (Doust, 2010). Binns (2006) references the Levorsen (1966) characterization of oil and gas fields according to three trap dimensions, namely hydrodynamic, structural and stratigraphic. Figure 1.2 below shows the elements of a stratigraphic and structural hydrocarbon traps respectively.

Binns(2006) however notes that, there are a wide variety of unconventional traps such as basin centred gas accumulations and sand injectites (Hurst 2006) which are not readily classified by these attributes. A similar view is that of Charpentier & Cook (2004), who characterize trapping as a spectrum from discrete 'conventional' traps through to continuous traps, such as basin-centred gas accumulations. Another approach by Corcoran (2006) uses a seal based classification from Milton & Bertram (1992), whereby stratigraphic traps are characterized as poly seal traps, in which closed contours at the reservoir/seal interface do not exist or do not explain the trap, thus demanding one or more base or lateral seals.

Magoon (1994) states that to be a viable trap a subsurface feature must be capable of receiving hydrocarbons and storing them for some significant length of time. This requires two fundamental components: a reservoir rock in which to store the hydrocarbons, and a seal (or set of seals) to keep the hydrocarbons from migrating out of the trap.

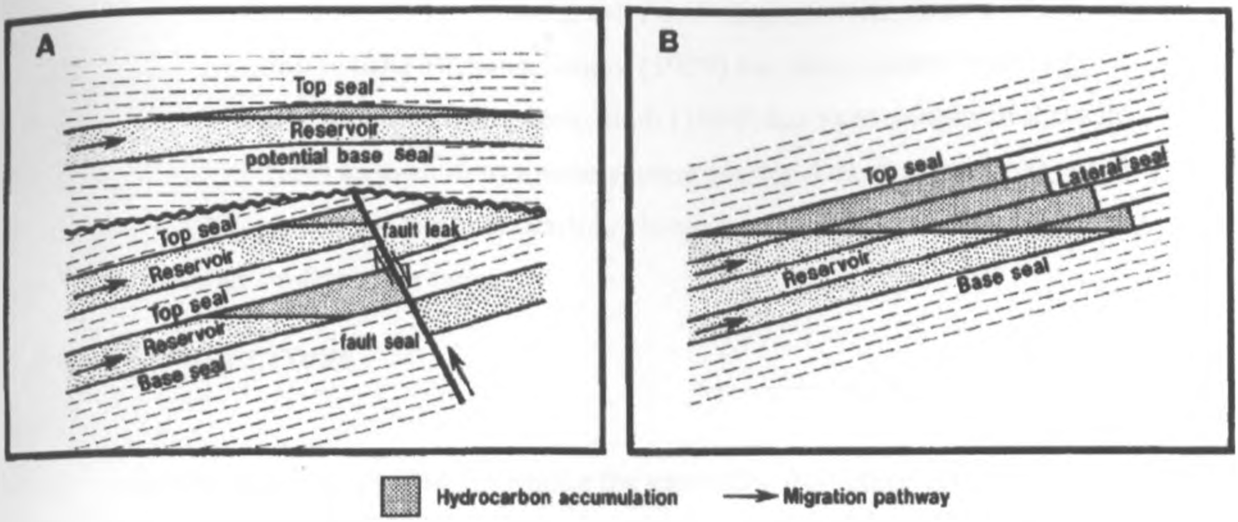

Figure 1.2 Key elements for (A) structural and (B) stratigraphic hydrocarbon traps (after Biddle, 1994)

1.5.3 PREVIOUS WORK DONE IN THE ANZA BASIN

Activity and progress reports of petroleum exploration activities by oil companies are available at the Ministry of Energy and at the National Oil Corporation of Kenya (NOCK). Patrut (1977) used information such as geophysical measurements, borehole and geological data from various sources to formulate models for the sedimentation history of this area. Swain (1979) points out that there are three gravity anomalies over the Anza Graben that are the most significant. Bosworth & Morley (1994) notes that, The Anza Rift of Kenya, where a number of wells have been drilled without success on valid structures. A source quality or timing problem may well exist in this basin and reservoir risks may also be high.

The Kenyan government in the 80's compiled a report that outlined previous findings and studies in the area that covers North Eastern province and parts of the Rift Valley province that led to the compilation of a report on the Kenyan Rift Valley (NOCK, 1986) and in the production of a revised Kenyan Geological Map, a structural contour map and a Bouguer anomaly map (NOCK, 1987).

Fairhead (1986) has done some work on the tectonic evolution of the West and Central African rift system (WCAS) that extends 4000 km from the Gao trough in Mali to the Anza basin in Kenya. Reeves et al. (1987) modeled gravity and magnetic data of the sedimentary belt stretching from Lamu to Lake Turkana. Simiyu (1989) has done studies involving gravity and seismic reflection in the Lamu area. Dindi (1992) has done geophysical studies of the Anza graben of North Eastern Kenya mainly using gravity data. Doust (2003) noted that petroleum systems with similar hydrocarbon charge and accumulation conditions can occur in separate but similar basin types.

1.6 AIM AND OBJECTIVES

1.6.1 AIM

The main objective of this study is to determine the geometry /structure of the trap types, stratigraphy of the area and to delineate the structures identified in the study area. This will be done by means of seismic interpretation.

1.6.2 OBJECTIVES

1. To identify and map different trap geometries
2. To use existing well log stratigraphy to aid in lithological interpretation of the seismic data
3. To identify and delineate the structures of Anza Basin

CHAPTER 2 GEOLOGY OF THE ANZA BASIN

2.1 INTRODUCTION

The Anza Basin is a NW-SE trending rift basin which forms part of a Late Jurassic-Cretaceous rift system which extends across central Africa. According to the Africa Oil Corporation Report No. 352280, the basin is over 580 km long and 150 km wide with a potential prospective area in excess of 50,000 km^2. The basin is filled in places with more than 6,000 m of Mesozoic and Cenozoic sediments and locally by Plio-Pleistocene basalts. Bouger and residual gravity anomalies have highlighted several sub-basins separated by intra-basin highs. Figure 2.1 below shows the geological map of the study area.

GEOLOGICAL MAP OF STUDY AREA

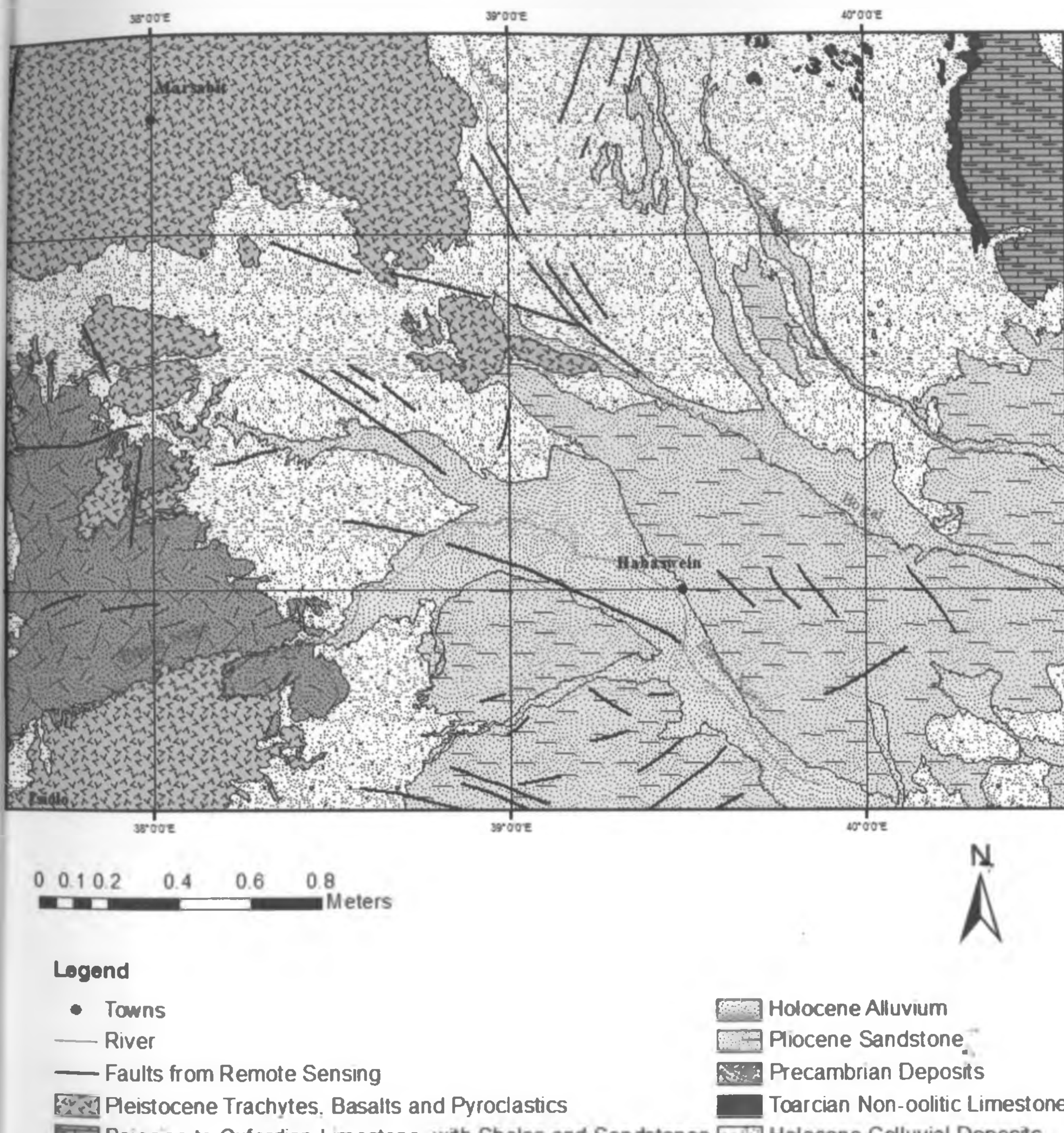

Figure 2.1 Geological Map of the study area (Modified from the Geological Map of Kenya)

2.2 TECTONIC EVOLUTION OF THE ANZA BASIN

According to the Africa Oil Corporation Report 352280, a Karoo-aged, NE-SW trend rift occurred in the eastern part of Mozambique, Kenya, Ethiopia and Somalia, and renewed extension along this trend during Mid Triassic-Early Jurassic resulted in the separation of Madagascar from Africa and marine transgression into Eastern Kenya. The subsidence of the NW trending Anza rift began during the Late Jurassic at the time of the deposition of the marine limestone deposition in the central Anza Basin. Rift expansion during the Neocomian, during a continent-wide extension phase in the Anza Graben was contemporaneous with the formation of the along strike NW trending Muglad and Melut rift basins of Sudan. Further extension during the Late Cretaceous reactivated the subsidence in the Anza Basin and the Cretaceous saw the deposition of up to 6 km of the predominantly continental and fluvial lacustrine sediments in the deepest parts of the basin. Further rifting in the Paleocene-Eocene saw thick continental deposition in subsiding troughs.

During the Oligo -- Miocene, as a result of the tectonic movements related to the formation of the East African Rift System in Ethiopia and Northern Kenya, the Anza Basin was affected by significant compressional and/or transpressional movements. Some of the normal faults formed during Cretaceous-Paleogene rift phases were reactivated and large scale inversion occurred. New faults with different fault orientations were also formed which uplifted large basement blocks. Basin modelling and well data indicate that several thousand feet of sediments were locally eroded. Following basin inversion during the Micoene, thick lacustrine and continental fluvial sediments were deposited above the regional base Miocene unconformity.

The basin has undergone two periods of extensive flood basalt extrusion associated with the East African Rift System during the Latest Miocene-Early Pliocene and the Late Pliocene-Pleistocene. These basalts covered the whole area of Block 10A and the northern part of block 9 with thickness varying from 30-250 m. This volcanic activity is believed to have had only a limited effect on the petroleum system.

The Petroleum System of the Blocks has been tested by several wells and the presence of reservoir, seals and potential source rocks has been demonstrated. The Anza Graben is interpreted to be an extension of the prolific Sudan Basin, a Cretaceous rift basin system of north-Central Africa.

The low level of exploration activity in both blocks means that ages and thickness of the formations drilled to date are poorly constrained and no formal stratigraphy is defined. Source rocks, reservoirs and seals are known from exploration wells and there is only a partial penetration of most of the units in the basin. In addition, correlation between the wells is difficult because they are drilled in different sub-basins each containing units not present in other wells.

CHAPTER 3 METHODOLOGY

3.1 FUNDAMENTALS OF THE SEISMIC REFLECTION METHOD

3.1.1 BASIC INFORMATION

The physical process of reflection is illustrated in Figure 3.1, where the ray-paths through successive layers are shown. There are commonly several layers beneath the earth's surface that contribute reflections to a single seismogram. The seismic reflection method records acoustic waves at the surface that are reflected off of subsurface stratigraphic interfaces where changes in the material density and conductive velocity of the acoustic waves are significant. The reflection patterns are described by Snell's Laws of Reflection. The unique advantage of seismic reflection data is that it permits mapping of many horizon or layers with each shot. At later times in the record, more noise is present in the record making the reflections difficult to extract from the unprocessed data.

Seismic reflection surveys are used for determining the thickness and structure of subsurface geology and are commonly applied in hydrocarbon and mineral exploration, earthquake and tectonic studies, and in the marine environment for resolving stratigraphic details.

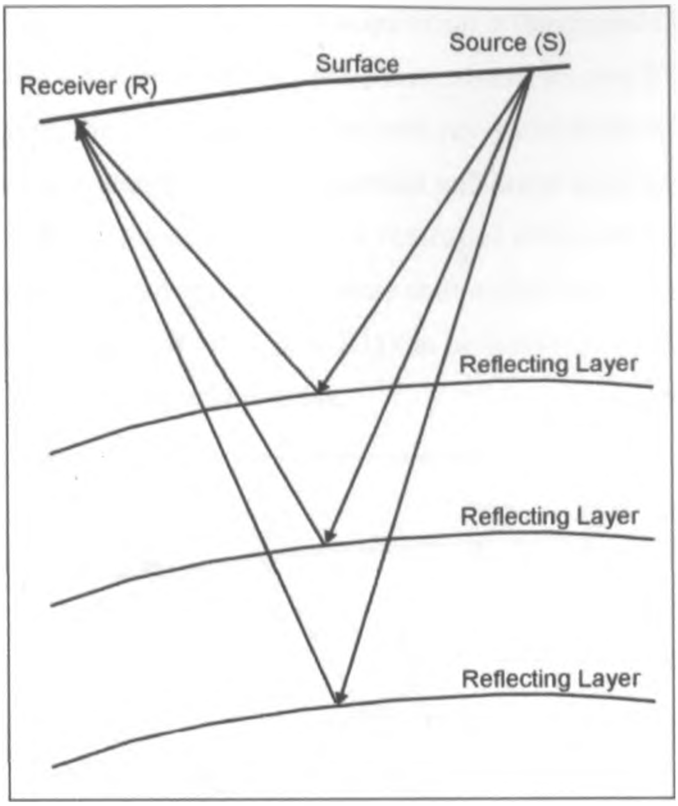

Figure 3.1 Schematic of the seismic reflection method (Environmental Geophysics, 2012)

Figure 3.2 below indicates the paths of arrivals that would be recorded on a multichannel seismograph. Note that the subsurface coverage is exactly one-half of the surface distance across the geophone spread. The subsurface sampling interval is one-half of the distance between geophones on the surface.

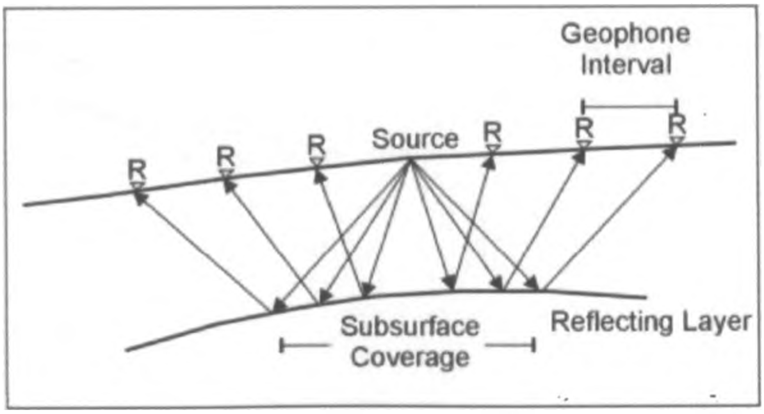

Figure 3.2 Multichannel recordings for seismic reflection (Environmental Geophysics, 2012)

Another important feature of reflection-data acquisition is illustrated by figure 3.3. If multiple shots, S1 and S2, are recorded by multiple receivers, R1 and R2, and the geometry is as shown in the figure, the reflection point for both ray-paths is the same. However, the ray paths are not the same length, thus the reflection will occur at different times on the two traces. This time delay, whose magnitude is indicative of the subsurface velocities, is called normal-moveout. With an appropriate time shift, called the normal-moveout correction, the two traces (S1 to R2 and S2 to R1) can be summed, greatly enhancing the reflected energy and canceling spurious noise.

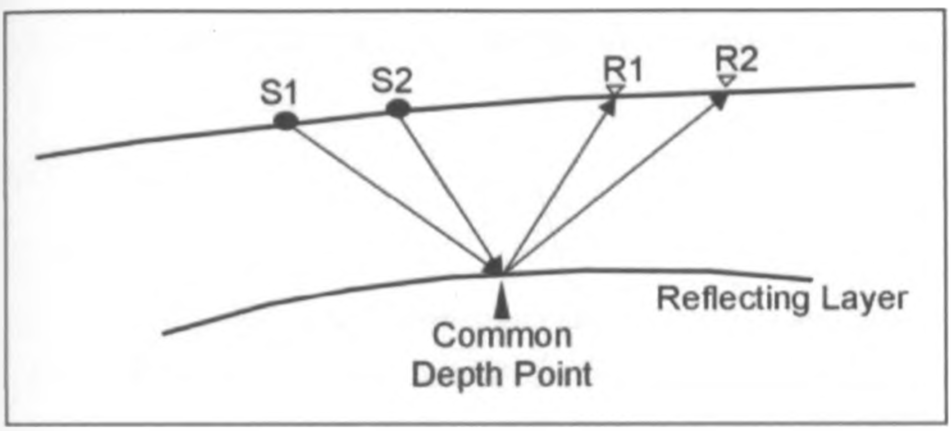

Figure 3.3 Illustration of common depth point (often called common mid point) after (Environmental Geophysics, 2012)

Arrivals on a seismic reflection record can be seen in figure 3.4. The receivers are arranged to one side of a shot, which is 15 m from the first geophone. Various arrivals are identified on figure 3.4. Note that the gain is increased down the trace to maintain the signals at about the same size by a process known as automatic gain control (AGC). The ultimate product of a seismic reflection survey is a corrected cross section of the earth with reflection events in their true subsurface positions.

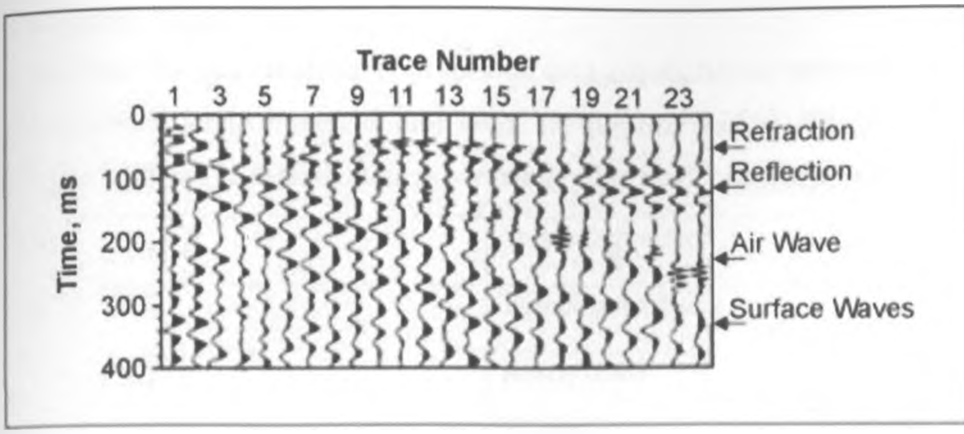

Figure 3.4 Simple seismic reflection record (Environmental Geophysics, 2012)

3.1.2 Seismic data processing

3.1.2.1 Introduction

The purpose of seismic processing is to manipulate the acquired data into an image that can be used to infer the sub-surface structure. Only minimal processing would be required if there was a perfect acquisition system. Processing consists of the application of a series of computer routines to the acquired data guided by the hand of the processing geophysicist. The interpreter should be involved at all stages to check that processing decisions do not radically alter the interpretability of the results in a detrimental manner.

Processing routines generally fall into one of the following categories:

- Enhancing signal at the expense of noise
- Providing velocity information
- Collapsing diffractions and placing dipping events in their true subsurface locations (migration)
- Increasing resolution

3.1.2.2 Processing Steps

There are number of steps involved from seismic data acquisition to interpretation of subsurface structure. Some of the common steps are summarized in table (3.1) below:

Table 3.1 Steps involved in Seismic data processing (after Environmental Geophysics,2012)

Acquisition	Static Correction
Processing	Velocity Analysis
	NMO/DMO
	Stacking
	Migration (Time/Depth, Kirchhoff's, f-k domain)
Interpretation	Seismic data to subsurface geology

In order to work with above steps, a number of signal processing operations are needed to accomplish the job. Some of them are:

i) Sampling data

ii) Mute

iii) Amplitude recovery/ corrections

iv) Filtering

v) Deconvolution

vi) f-k analysis

3.1.2.3 Data acquisition

<u>Shot gather</u>

The initial display of seismic profile data is normally in groups of seismic traces recorded from a common shot, known as shot gathers. The geophones may be distributed on either side of the shot, or only on one side as shown in figure 3.5.

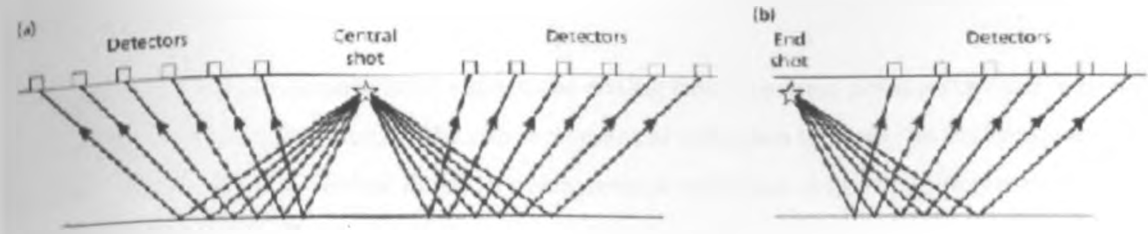

Figure 3.5 Shot-detector configuration used in multichannel seismic reflection profiling. (a) Split spread, or straddle spread (b) Single-ended or on-end spread (Environmental Geophysics, 2012)

Sets of reflected arrivals from individual interfaces are recognizable by the characteristic hyperbolic alignment of seismic pulses (figure 3.6). The late-arriving high-amplitude, low frequency events, defining a triangular-shaped central zone within which reflected arrivals are masked, represent surface waves (ground roll). These latter waves are a typical type of coherent noise.

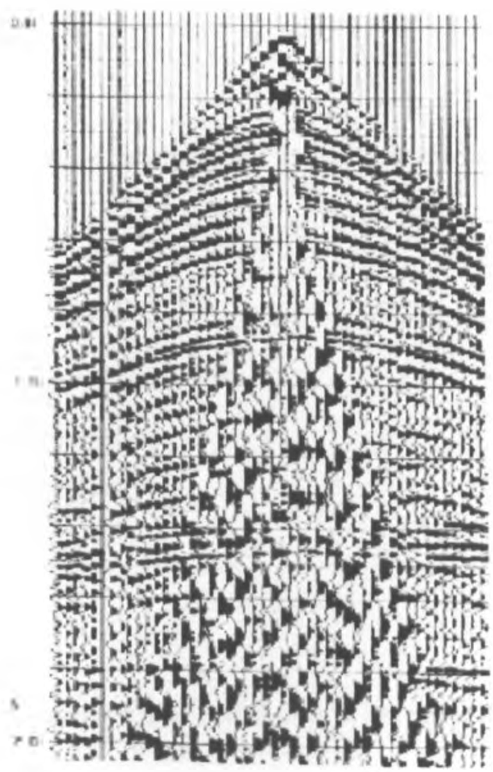

Figure 3.6 Draped seismic records of a shot gather from a split spread (Environmental Geophysics, 2012)

Multiple shotpoints

If more than one shot location is used, reflections arising from the same point on the interface will be detected at different geophones. The common point of reflection is known as the common midpoint (CMP). Figure 3.7 below illustrates how seismic reflection data acquisition is done.

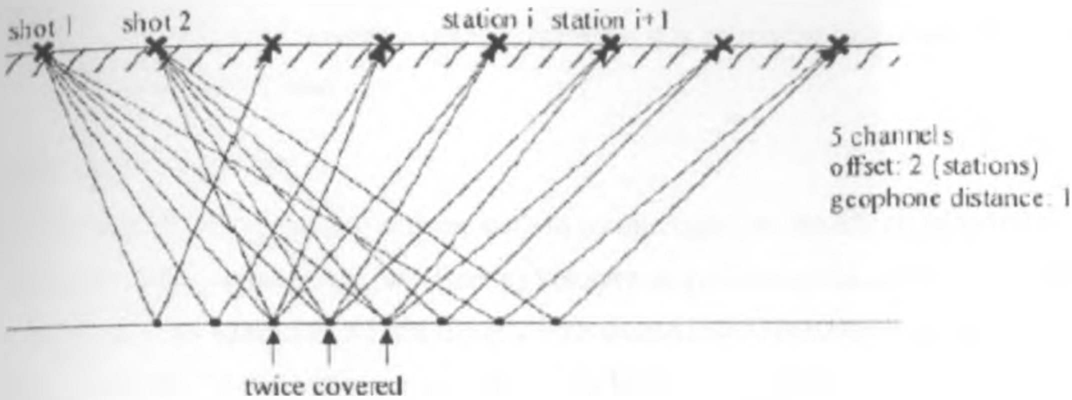

Figure 3.7 Data acquisition for reflection seismic method (Environmental Geophysics, 2012)

CMP

The number of times the same point on a reflector is sampled as the fold of coverage (figure 3.8).

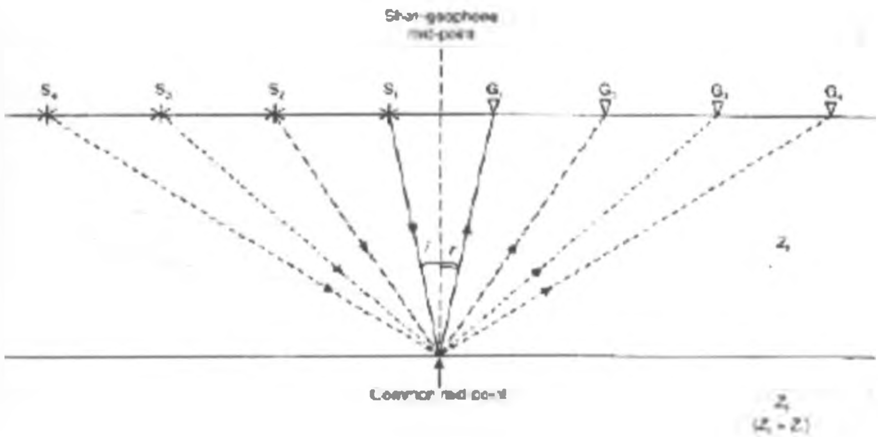

Figure 3.8 Principle of the common mid-point over a horizontal surface (Environmental Geophysics, 2012)

CMP gather

The CMP gather lies in the heart of seismic processing for two main reasons:

i) The variation of travel time with offset, the moveout will depend only on the velocity of the subsurface layers (horizontal uniform layers) and the subsurface velocity can be derived.

ii) The reflected seismic energy is usually very weak. It is imperative to increase the signal to noise ratio of most data.

3.1.2.4 Static Correction

Static corrections are applied to seismic data to compensate for the effects of variations in elevation, weathering thickness, weathering velocity, or reference to a datum. The objective is to determine the reflection arrival times which would have been observed in all measurements that had been made on a flat plane with no weathering or low velocity material present. These corrections are based on up-hole data, refraction first break or event smoothing (figure 3.9).

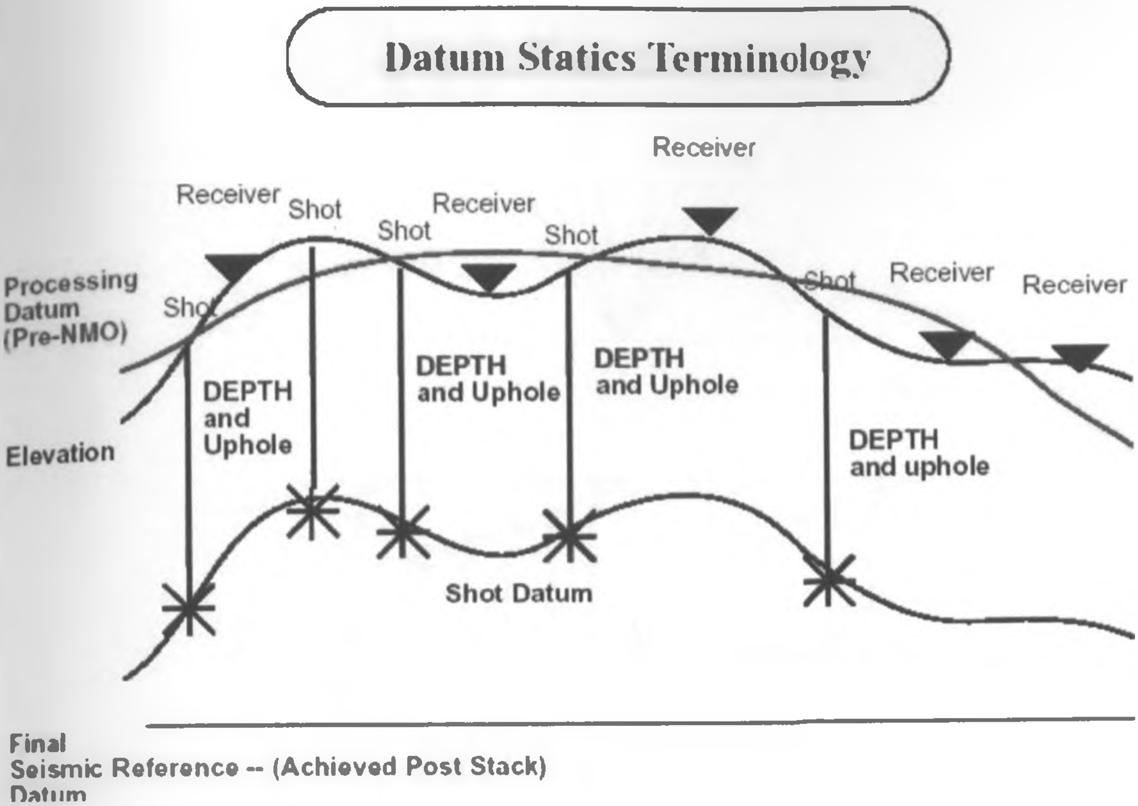

Figure 3.9 Static correction (Environmental Geophysics, 2012)

3.1.2.5 Stacking {Velocity Analysis, NMO (Normal move out) /DMO (Depth move out)}

This section is an approach of iterative process of applying NMO, DMO and standard velocity analysis. DMO improves the quality of the stack and the usefulness of the stacking velocity field as shown in figure 3.1 below. A variety of methods are available (constant velocity stacks, constant velocity gathers, semblance) which work to different extents with different data types. NMO and DMO are used the final velocity field after convergence.

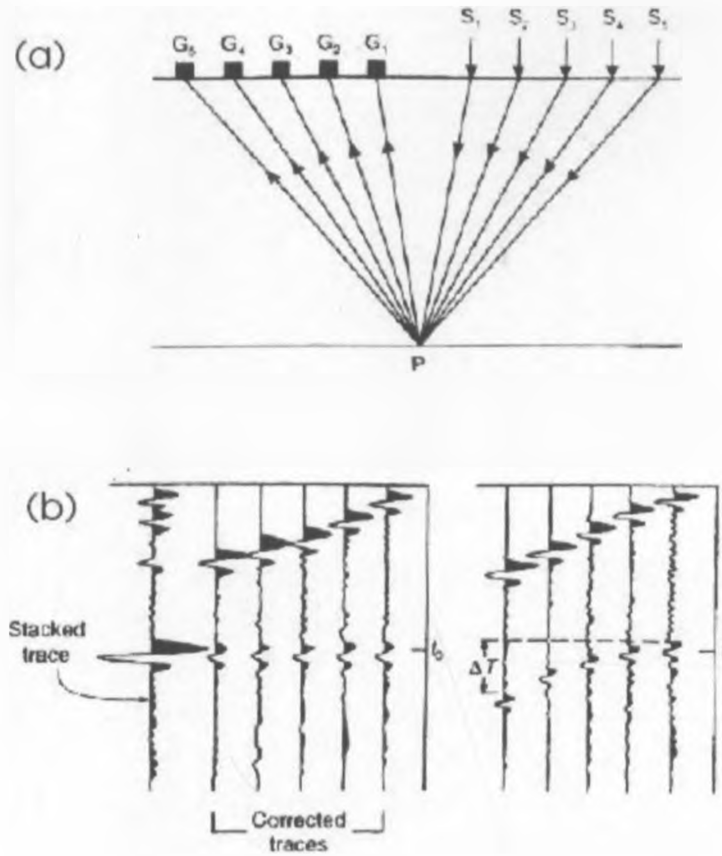

Figure 3.10 Given the source receiver layout and corresponding ray-paths for a common depth point spread , shown (a) the resulting seismic traces are illustrated in (b) uncorrected(on the right), (corrected on the left). Note how the reflection events are aligned and the final stacked trace after (Environmental Geophysics, 2012)

3.1.2.6 Migration

Migration will lead to the final product, either as depth or time. Migration using velocities can be applied based on the velocity analysis if they are good enough, by testing a range of different velocities to determine which collapse diffractions correctly. Care is required to produce a generally smooth velocity field. A seismic section before and after migration is shown in figure (3.11) below for example.

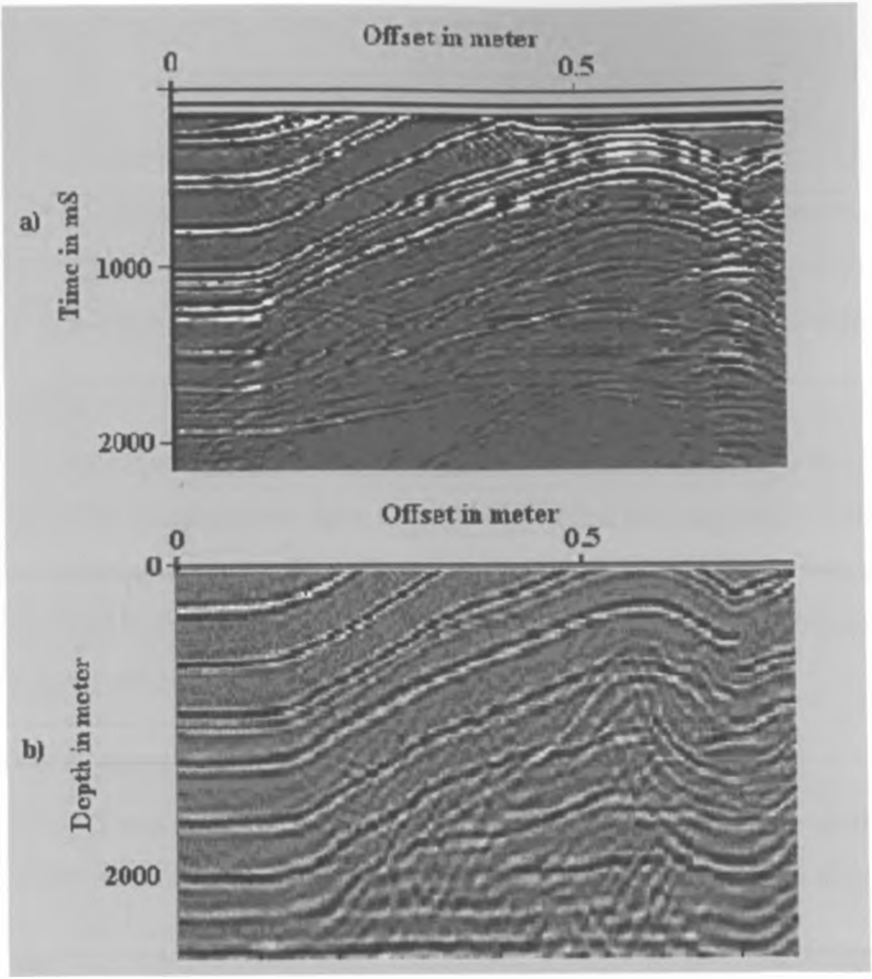

Figure 3.11 (a) Stacked section (b) Post stack migrated section (Environmental Geophysics, 2012)

3.1.2.7. Interpretation

This is the final section, one can say finished product of the seismic processing steps. Subsurface geology is generally derived from this unit.

3.2 PRELIMINARY STUDIES

Much of the information related to this study is from journals, conference proceedings, books, progress reports from petroleum exploration companies operating within the basins. Theses of people that have worked on related topics have also been reviewed. Other information was also from websites.

3.3 METHODOLOGY AS APPLIED IN THE STUDY AREA

3.3.1 DATA

There were two primary datasets used in this investigation. One was a 2D grid of 10 seismic lines acquired over the Central Anza area. The other was a final well log image of the same area. The purpose was to correlate the seismic dataset with the well log information and use the combined dataset for seismic analysis and interpretation.

3.3.1.1 Well Data

The well data were acquired from NOCK. The dataset was an image of the Final log of the respective wells. The image information available from this final log were well tops and well logs collected from Duma 1, Ndovu 1 and Serut 1 wells. The well headers and tops were primarily used in this research project to associate the position of the wells with the interpreted reflective horizons of the seismic lines in SMT Kingdom Suite

3.1.1.2 Seismic Dataset

The seismic dataset was in the Central Anza area. A total of 10 north east-south west and north west-south east west seismic lines were available in the area with 9 aligned north-east-south west and 1 aligned north west-south east.

A location map (Fig 3.12) shows the spread of the lines in the area. In this map, a previously georeferenced topographic map of the area is shown. Well heads and the seismic lines were at their respective plotted geographic locations.

LOCATION MAP OF WELL HEADERS AND SEISMIC LINES

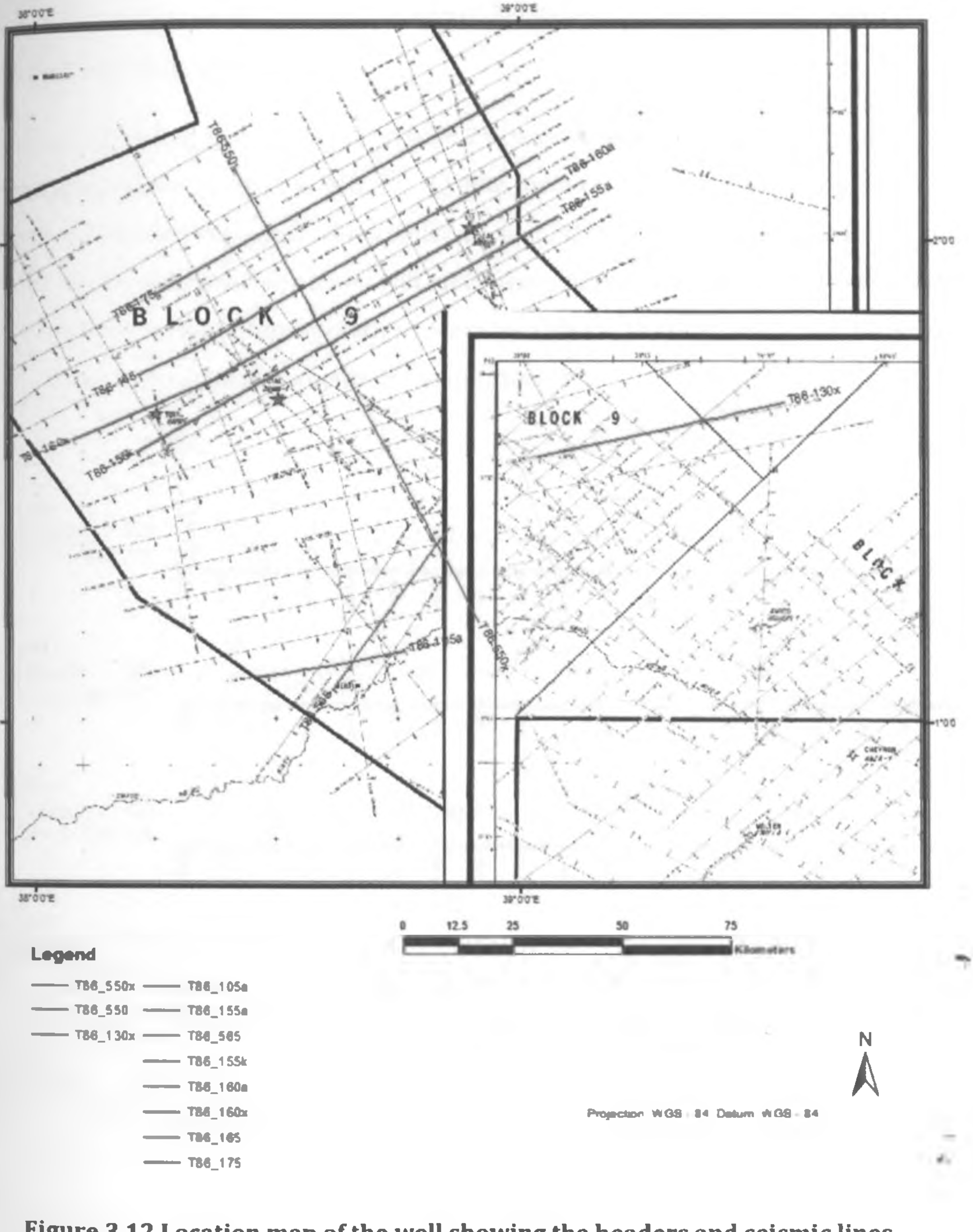

Figure 3.12 Location map of the well showing the headers and seismic lines

3.3.2 SEISMIC DATA ACQUISITION

Vibrator trucks were used in-line as the seismic source. The vibrators used linear 6–second upsweep of 10 – 48 Hz, with 3 seconds of additional listening time for 10 seconds uncorrelated record lengths.

A 24-channel recording system was used with 24 geophones per station along a linear array. The geophone-frequency was 8 Hz and data were recorded at 4 ms sample rate. A symmetric split spread was used which rolled on and off the ends of each line. The mechanism of the vibroseis roll on and roll off is demonstrated in Figure 3.13 respectively. During processing, twelve dummy stations were inserted at the beginning and the end of each line while constructing geometry of the dataset.

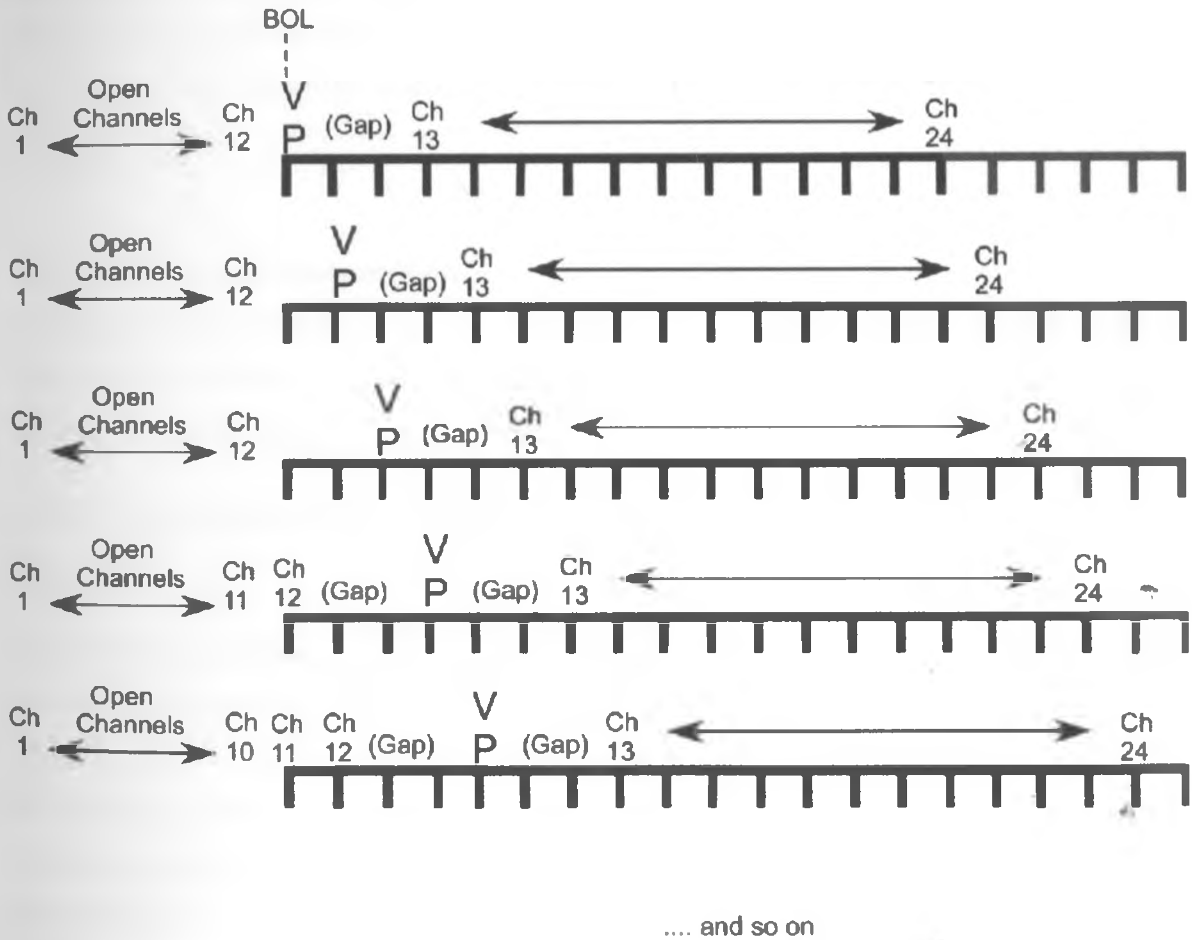

Figure 3.13 Sketch demonstrating Vibroseis roll on to a seismic line (after Nilanjan, 2008)

VP = Vibrator Point, BOL = Beginning of Line. Each tick is a station location. At the start of the line the vibrators are situated at the first station in a symmetric split – spread configuration. As a result, recording channels 1 – 12 are not live channels at ground locations, but channels 13 – 24 are at live locations beyond a two – station gap. As the VPs & the split spread incrementally shift, eventually the lower channels roll onto the stations of the line where they become "live", recording the output of the geophones at those stations.

3.3.3 PRE PROCESSING DATAMANAGEMENT

The Arc GIS 10.0 software package was used to determine geometry of the 2D seismic lines and the stations points constituting them. The shapefile of the study area was then loaded into Arc Map and projected to UTM Zone 37N so that the assigned spatial attribute correlates with well data. Information available on the original topographic sheets was used to determine the geographic location and length of the seismic lines on the shapefile. The X and Y coordinates and shot points of the line were picked and recorded (Appendix 1). This method defined the spatial structure of the seismic dataset in the desired projection system.

3.3.4 Analysis and interpretation

SMT Kingdom Suite seismic interpretation software was used in the interpretation process. The method included analysis of the processed seismic reflection data that were used to recreate the crustal geometry of the area.

3.3.4.1 Data analysis and interpretation Methods

Well Data

Final well log information was used in conjunction with the seismic lines in SMT Kingdom Suite for interpretation of the stratigraphy of the area. In this case new well dataset was created in ArcView GIS by refining the original well information. A new version of the stratigraphic section was creates by correlating the seismic section with the lithological section available in the final well log. This was done for all the wells in this study area namely Ndovu-1, Duma-1 and Kaisut-1. The new versions of the sections were smaller versions of the original final well log data.

Seismic Dataset

The set of 10 seismic lines were imported into SMT Kingdom Suite in the SEG-Y format. For importing, the "Import SEG Y File(s) into single 2D or 3D Survey" format was used for the line detection method. A new 2D survey folder was created in SMT Kingdom to store the lines. A number was assigned to each line and they were sorted and organized. To get a 3D view of the 2D profiles the 3D window was used. A plan view of the area with the seismic lines included could be seen in the 2D windows. In SMT Kingdom, a unique interpretation window was assigned to each seismic profile. 2D windows were used in combination with the interpretation window for seismic interpretation. Horizons delimiting the upper and lower margins of the lithologies were generated by use of the horizon management tab whereas faults were generated by use of the fault management tab. Other features such as the unconformity and pinch-outs were generated by use of the annotations tab. Figure (3.14) shows the base map of the seismic lines when they were uploaded to SMT Kingdom Suite.

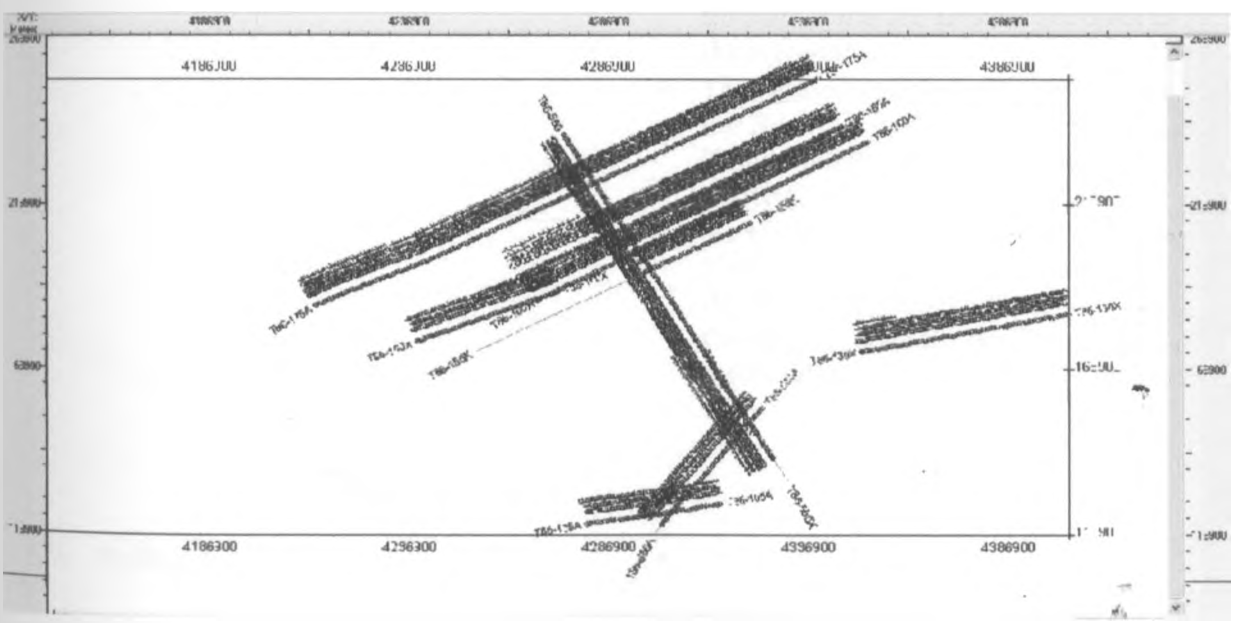

Figure 3.14 Base map of the seismic lines as uploaded on SMT Kingdom Suite

The steps that were involved in interpreting the data acquired for NOCK are summarized in the Table 3.2 below.

Steps Involved in interpretation of the seismic data

Table 3.2 Steps Involved in interpretation of the seismic data

1. Pre-Processing Data Management	• Arc GIS 10.0 software package was used to determine geometry of the 2D seismic lines. • The shapefile of the study area was then loaded into Arc Map and projected to UTM Zone 37N so that the assigned spatial attribute correlates with well data. • The X and Y coordinates and shot points of the line were picked and recorded (Appendix 1).
2. Identification of reflectors	• Reflectors were picked by inspecting seismic sections passing through boreholes. Reflectors are identified through tying the seismic sections to the well data. • The refined stratigraphic section of the Ndovu-1 well was imported into Kingdom Suite along line T86-165A figure (3.15). • Six strong reflectors were identified. These were distributed at various depths throughout the area. Correlating with the well lithologic information, these reflective horizons were interpreted to represent shale formations in the seismic lines.
3. Picking and correlation of reflectors	• Studied horizons were picked up across seismic lines after the reflector identification. • When reflectors are either displaced vertically or disappear, this interruption may be due to faulting or pinch-out, respectively. • The horizons were picked along all

	seismic grids by correlating the seismic events, tying their times.
4. Fault location detection	• Faults of large vertical displacements were easily recognized, especially from the sudden stepping-out of reflections across their planes. • Faults with small displacements were traced on the bases of identification of reflection gaps
5. Construction of seismic structural cross-sections	• To visualize the subsurface structural configuration, interpreted geo-seismic cross-sections were constructed to show the structures and potential traps.

CHAPTER 4 USE OF EXISTING WELL LOG STRATIGRAPHY TO AID IN LITHOLOGIC INTEPRETATION OF THE SEISMIC DATA

4.1 INTRODUCTION

4.1.1 STRATIGRAPHY DEFINITION

According to Pettijon(1984), stratigraphy in the broad sense is the science dealing with strata and could be construed to cover all aspects including textures, structures and composition. He further indicates that in practice, however, stratigraphers are mainly concerned with the stratigraphic order and construction of the geologic column. Hence the central problems of stratigraphy are temporal and involve the local succession of beds (order of superposition), the correlation of local sections, and the formulation of a column of worldwide validity.

4.1.2 IMPORTANCE OF STRATIGRAPHY

The fossil record of past life is commonly preserved in ancient sediments and sedimentary rocks. Sediments accumulate in subsiding basins that contain different kinds of depositional environments such as rivers, lakes, deltas, and marine seaways. These environments are friendly to life, and often support assemblages of plants and animals. Through integrative studies of stratigraphy, sedimentology, and paleontology, we can reconstruct ancient life communities and the environments in which they lived.

Plate tectonic forces determine where sedimentary basins form, how long and how fast sediments accumulate, and how they may later be faulted, uplifted, and eroded at the surface. Climate also affects basins and sediments; precipitation, wind, and temperature variation affect surface processes such as erosion and soil formation.

4.1.3 DEPOSITIONAL ENVIRONMENTS

Basins that have a marine connection will show significant stratigraphic variations, especially in coastal deposits that result from eustatic sea-level fluctuations. Other key factors will include the availability of sediment and the role of tectonically induced subsidence and uplift.

Land-locked basins whose fluvial systems drain ultimately into a lake will preserve a stratigraphy dominated by local relative uplift and subsidence (local tectonics), by climatic controls and the rate of sediment supply. Tectonic activity is an important factor in controlling stratigraphy in the majority of sedimentary basins.

4.2 SEDIMENTATION IN CONTINENTAL RIFTS

Continental rifts have been dominated by two themes of models of sedimentation. Within the developing rift systems, climate and structure have been claimed to be the single most important control on sedimentary facies distribution. Olsen (1986) has suggested that periodically fluctuating climate controls and has led to small-scale vertical variations in sedimentary facies in Mesozoic rift basins of the eastern USA. Frostick & Reid (1989) have also concluded that climate is the most important control on sedimentation in East Africa today. On the other hand, other authors have proposed that structure is equally important in East Africa (Frostick & Reid 1990; Morley *et aL* 1990; Tiercelin 1990), and others have proposed models illustrating this control (such as Leeder & Gawthorpe 1987).

The large-scale vertical facies changes observed in many rifts have been included in the same debate. Transitions between fluvial/alluvial and lacustrine environments have been attributed to regional climatic changes by many researchers (such as Kreuser *et al.* 1990; Yemane & Kelts 1990). In contrast, Lambiase (1990) and Schlische & Olsen (1990) have proposed general models that explain observed stratigraphic sequences as a consequence of evolving rift basin geometry. Lambiase's model was derived from field observations and drill hole and reflection seismic data in rifts that formed in a wide range of climates and ages. A consistent vertical succession was recognized in those non-marine rifts that contain significant lacustrine deposits. This succession was attributed to equally consistent and predictable changes in general sedimentation patterns caused by evolving structural geometry.

In old rift settings, details of the structural history and its relationship to specific sedimentary features often cannot be resolved. However, in modern rifts, structures can be seen to control sedimentation in a manner consistent with the stratigraphic record of ancient rift basins.

4.3 STRATIGRAPHY OF THE STUDY AREA

The central part of the Anza Graben is represented by wells Ndovu-1 from the Yamicha Basin on the eastern side of the graben and Duma-1 from the 'tilted blocks area' and Kaisut-1 from the Kaisut Basin on the western margin of the graben.

4.3.1 NDOVU-1 WELL

The Ndovu-1 well was drilled in the Nyamicha sub-Basin in Block 9 in 1988 by Total. It was drilled to a total depth (TD) of 4267m but was plugged and abandoned with only traces of gas and cut noted. Well Ndovu-1 is a deep well that provides a complete profile from the Lower Cretaceous (Hauterivian) through to the Pleistocene. Quaternary volcanic are underlain by Tertiary sands, Upper Cretaceous sandstones and claystones with a significant Lower Cretaceous shale interval at (2670-3950m). According to the completion report of the Ndovu-1 well, analyses performed on the Lower Cretaceous shales indicate them to be good to very good source rocks with a potential for both gas and oil. These Lower Cretaceous sands also contain significant deep lake sand lobes. There's a gradual coarsening upward and basin shallowing trend through the Cenomanian to Turonian, followed by thinner sequences of fluvial and lacustrine facies in the Santonian, when subsidence and sand supply to the region appear to have been reduced. The overlying Neocene section show a bulk coarsening upward trend, with a dominance of fluvial sands, followed by lake transgression and volcanic activity in the late Tertiary. Figure 5.1 below shows the refined stratigraphic section along this well depicting the lithologies present and their age.

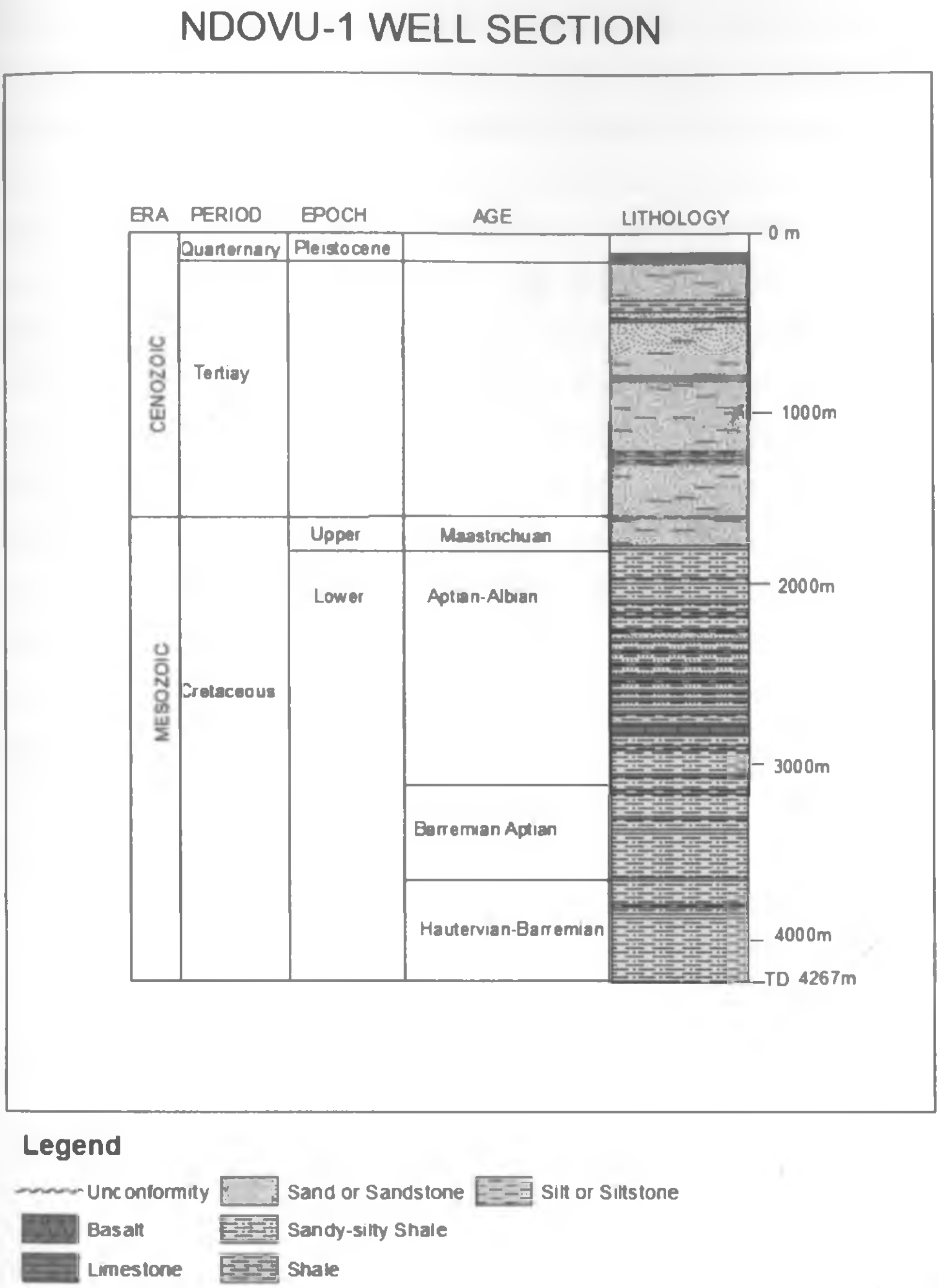

Figure 4.1 Stratigraphic Section through the Ndovu-1 well

4.3.2 DUMA-1 WELL

This well was drilled by Total in 1989 to a depth of 3337m with TD in the Cretaceous. Duma-1 provides a thick succession from the Upper Cretaceous, preserved with an uplifted horst which is draped by a thin succession of Tertiary clastics. Here the Cenomanian – Turonian succession is shale prone, followed by a marked shallowing upward trend in the Senonian. The thickest and most proximal fluvial facies were deposited during the Camppian and early Maastrichtian, followed by a significant transgression in the Maastrachtian. The overlying Tertiary succession is thin but sand-rich, characterized by proximal fluvial and fan facies. The drilled section was dominated by sandstones. According to the completion report of this well, it was noted that source rock development is poor. Total's laboratories in France conducted TOC and Rock pyrolysis analysis on the shaly lithologies and noted that shales and claystones were generally lean with below average (1%) TOC content. Several exceptions were however noted with TOC contents of 1.6% at 900m, 1.4% at 1435m, 1.7% at 2850m and 1.5% at 3035m. Despite this, hydrocarbon potential is believed to be only fair and restricted to a few very narrow intervals (870-900m, 1785-1800m). A general increase in depth was noted with values off 445ºC being reached at around 985m suggesting that oil-prone source rocks below this depth would be generating oil. Figure 5.2 shows a stratigraphic section through the Duma-1 well.

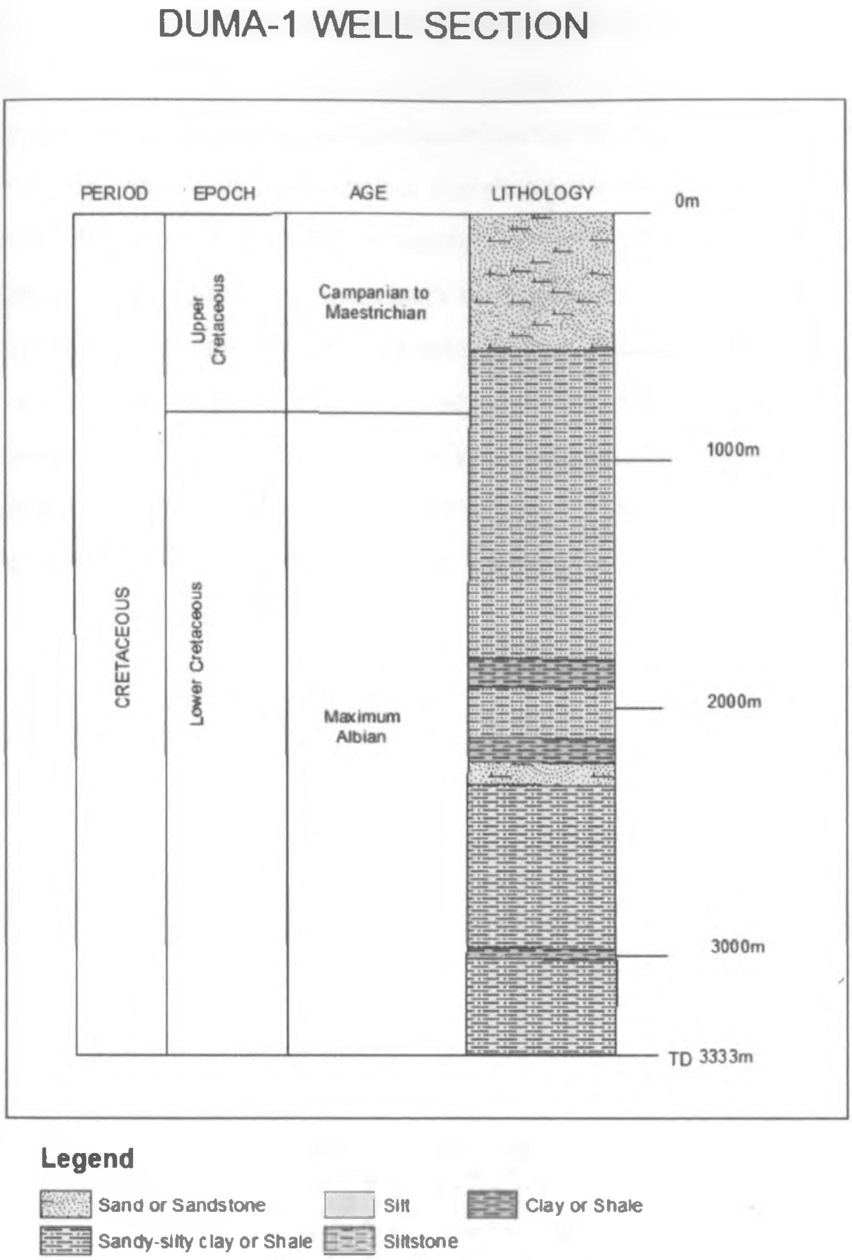

Figure 4.2 Stratigraphic section through the Duma-1 well

4.3.4 KAISUT-1 WELL

This well was drilled in the Kaisut sub-basin some 30km south west of Ndovu-1, the well penetrated some 1450m (TD) of Quaternary and Tertiary sediments. The Tertiary is very sand-rich here, and according to the completion report of the Kaisut-1 well is dominated by proximal fluvial braid plain and fan facies but there's a fairly thick transgressive lake unit present in the middle part of the drilled succession that may represent a regionally significant shale with seal potential. These were mostly sands but with intercalations of clays and shales and a more significant shaly interval at 527-660m. The report further states that no gas shows or fluorescence were noted during drilling and a limited geochemical program (TOC and Rock Eval Pyrolysis) carried out by the Total laboratories showed the candidate source rocks to be organically lean. Figure 5.3 below shows the refined stratigraphic section through the Kaisut-1 well.

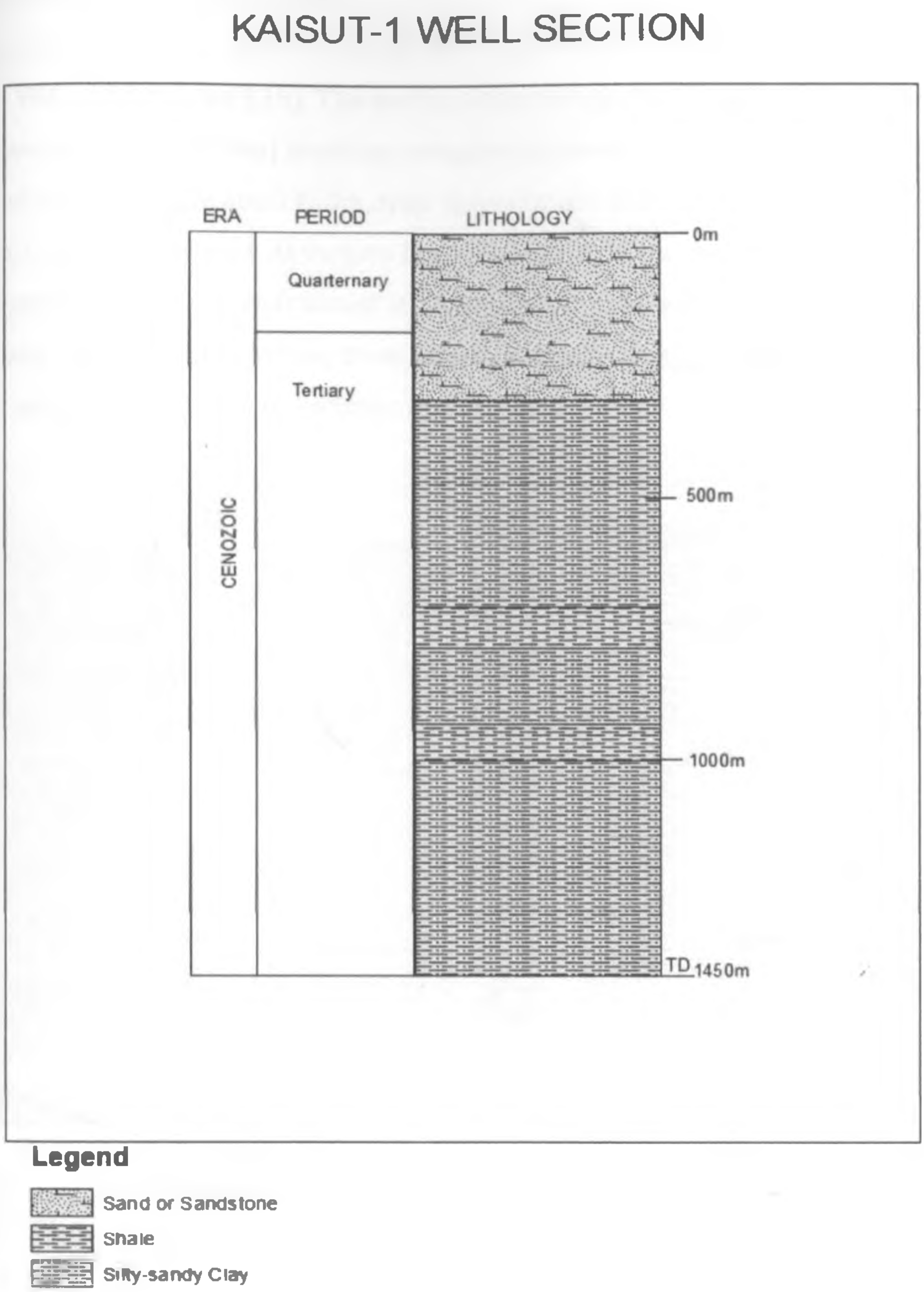

Figure 4.3 Stratigraphic section through the Kaisut-1 well

4.3.5 STRATIGRAPHICAL STRUCTURE

The refined stratigraphic section of the Ndovu-1 well was imported into Kingdom Suite along line T86-165A figure (3.15). The section from Ndovu-1 well was preferred because it covers a deeper depth (3490m) depth as compared to the other two wells (Duma-1 and Kaisut-1 which are 3333m and 1450m deep respectively) and therefore deeper depth of lithologies could be identified. At various levels in the depth sections, six strong reflectors were identified. These were distributed at various depths throughout the area. Correlating with the well lithologic information, these reflective horizons were interpreted to represent shale formations in the seismic lines.

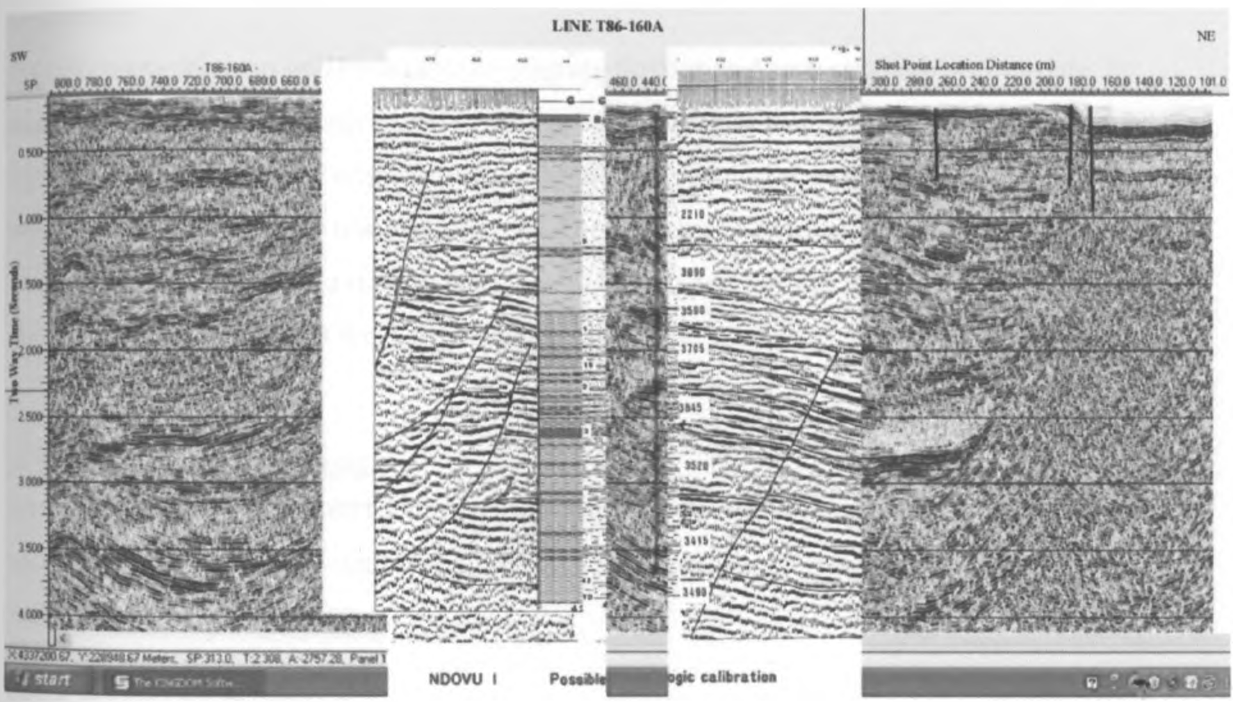

Figure 4.4 Refined stratigraphic section of the Ndovu-1 well imported into Kingdom Suite along line T86-165A

CHAPTER 5 TRAP GEOMETRY OF THE ANZA BASIN

5.1 INTRODUCTION

Petroleum is generated in a source rock reservoir formation and is then expelled from the source rock formation into an overlying or underlying reservoir. It will escape to surface as seepage where it is lost if it is not overlain by an impervious layer formation that forms a cap rock or seal examples of which are shales and evaporates. There must also be some sort of blockage to prevent further oil migration that may be caused by either the the interruption of the upward continuity of the reservoir or by the reservoir itself dying out. This blockage is what is known as a trap and it is necessary if we are to find any oil still preserved.

Oil getting to the trap will be unable to migrate further and so it starts to accumulate, by displacing the water already there in the porosity. Many at times, the location of a trap in the subsurface is the first objective of an exploration program. In the past of oil exploration, before there was a better understanding of the geology of petroleum, exploration used to consist largely of finding a trap, drilling a well into it, and hoping for the best. In the study areas two classes of traps were identified, structural traps and stratigraphic traps.

5.2 STRUCTURAL TRAPS

Structural traps are created by the syn-depositional to post-depositional deformation of strata into a geometry (a structure) that permits the accumulation of hydrocarbons in the subsurface (Biddle, 1994).

5.2.1 ANTICLINAL TRAPS

Anticlines are compressive structures. On reaching the crest of the anticline, petroleum migrating up along a reservoir can go no further and it accumulates there. Still, there are different types of anticlines with different shapes and geometries that can affect both their prospectivity and the positions of optimum drilling locations. Traps can also be formed against faults if a chopped-off reservoir is thrown against an impervious rock such as shale.

5.2.1.1 Implications for Oil Exploration

It is important to note that if in cross-section, the anticline is asymmetrical, with one flank steeper than the other then the position of the crest will shift with increasing depth. This means that in order to drill a reservoir near its highest point where we expect the oil to be which is at the crest it's depth has to be known so as to know where best to locate the well. Seismic exploration is of help in this case but some form of geometrical construction has to be undertaken interpret what is happening at depth (Rondeel, 2001).

Some folded structures have a range of shapes between the purely concentric or parallel anticline and the similar fold, depending on the nature and strength of the rock layers being folded.

In the concentric fold the tops and bottoms of all the layers remain strictly parallel to each other, so that the beds maintain a constant thickness throughout. These conditions mean that the anticline becomes smaller and tighter at deeper levels until a common centre of curvature is reached. Below this point we have there's normally too much rock to fit into the anticline, so that the beds become intensely crushed and thrust together such that we may no longer even have an anticline at all. In this type of structure, we can thus expect to find only smaller and smaller accumulations of petroleum down to the centre of curvature, beyond which there may be no trap left to explore as the consequence of decoupling of layers. There is a definite limit to the depths to which we should drill.

The similar anticline, on the other hand, maintains its shape constant down to depth. This can only happen if there is an apparent thickening of some beds over the crest of the fold. In this case, we can find the trap present at all levels down to the basement and exploration may be done down to depths where we have to stopping may be due to other reasons. This is a very different from the concentric anticline. In practice, many anticlinal structures have forms in-between the two extremes, but an understanding of the shape and size of a prospect is clearly critical to programming an exploration well.

Other types of anticline can be formed without any lateral compression at all: an important one is the drape or drape-compaction structure.

If the first sediments in a basin were deposited over a hilly surface, or over an up- faulted block or horst, then they will blanket the hill as an anticline. Higher beds will gradually mute and suppress the structure until it is no longer present at shallow levels. A second effect comes into play here because there is a greater thickness of beds off the structure than over the top, those near the bottom of the sequence are going to be squeezed and compacted more on the flanks than on top of the feature as it gets buried. This compaction enhances the anticline formed by the drape it is not always easy to separate out the two effects, and hence the combined name.

The anticlinal traps in the Anza Graben were formed by sediments deposited over a basement high. The anticlinal trap in noted along line T86-550 figure 4.1below is also faulted. Sandstone, siltstone and sandy silty shale act as the reservoir rocks whereas Shale is the sealing material.

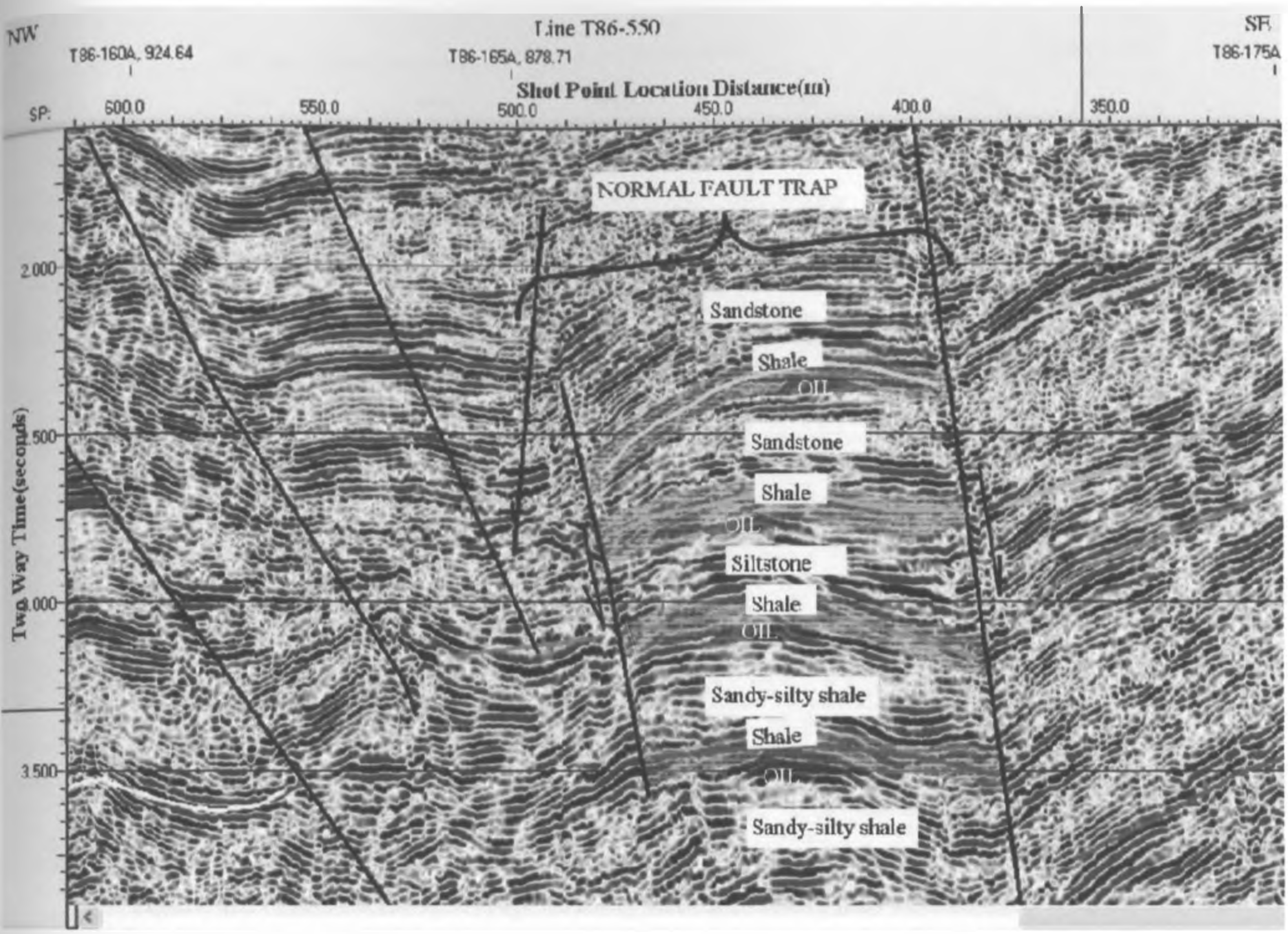

Figure 5.1Cross-sections of trap-forming faulted anticline along line T86-550

In figure 4.2 below the anticline is along Line T86-550X. One flank of the anticline is observed here. The anticline is a result of sediments being deposited over a basement high. Sandstone, siltstone and sandy-silty shale are the reservoir material whereas shale serves as the sealing rock.

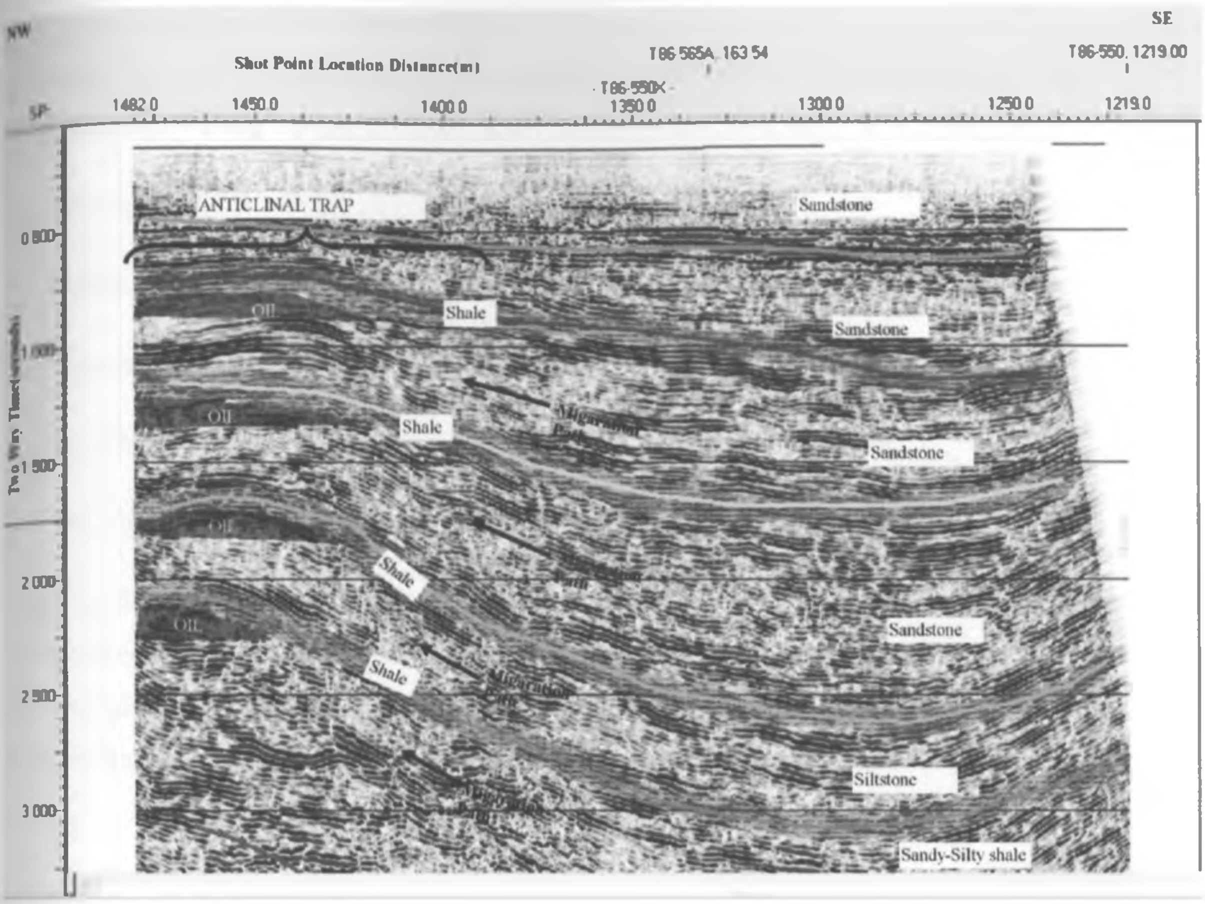

Figure 5.2 Cross-sections of trap-forming anticline along line T86-550X

5.2.2 FAULT TRAPS

It is important to note that faults are important in determining the viability of a trap by providing either seals or leak points. They are capable of acting as top, lateral or base seals by juxtaposing relatively impermeable rock units against more permeable reservoir units or by acting as sealing surface due to the impermeable nature of the fault.

They may be formed where a dipping reservoir is cut off up-dip by a fault, setting it against something impermeable. The provision is that there must also be a lateral closure. This may be provided by further faulting, or by opposing dips.

5.2.2.1 Implications for exploration

Although there are many problems in trying to locate them in the subsurface, and in understanding them, whether or not there is a trap, and how big it is, will depend on:

1) The dip of the reservoir as compared with that of the fault
2) Whether the fault is normal or reverse
3) The amount of displacement on the fault
4) Whether or not the reservoir is completely or only partially offset
5) Whether the fault itself is sealing or non-sealing

Figure 4.3 and Figure 4.4 below shows a normal fault trap. The sealing rock in this case is shale whereas sandy-silty shale acts as the reservoir rock. The normal fault trap on figure 4.3 was identified in seismic line T86-155K whereas the normal fault trap on figure 4.4 that is characterized by conjugate faults was identified along line T86-565A.

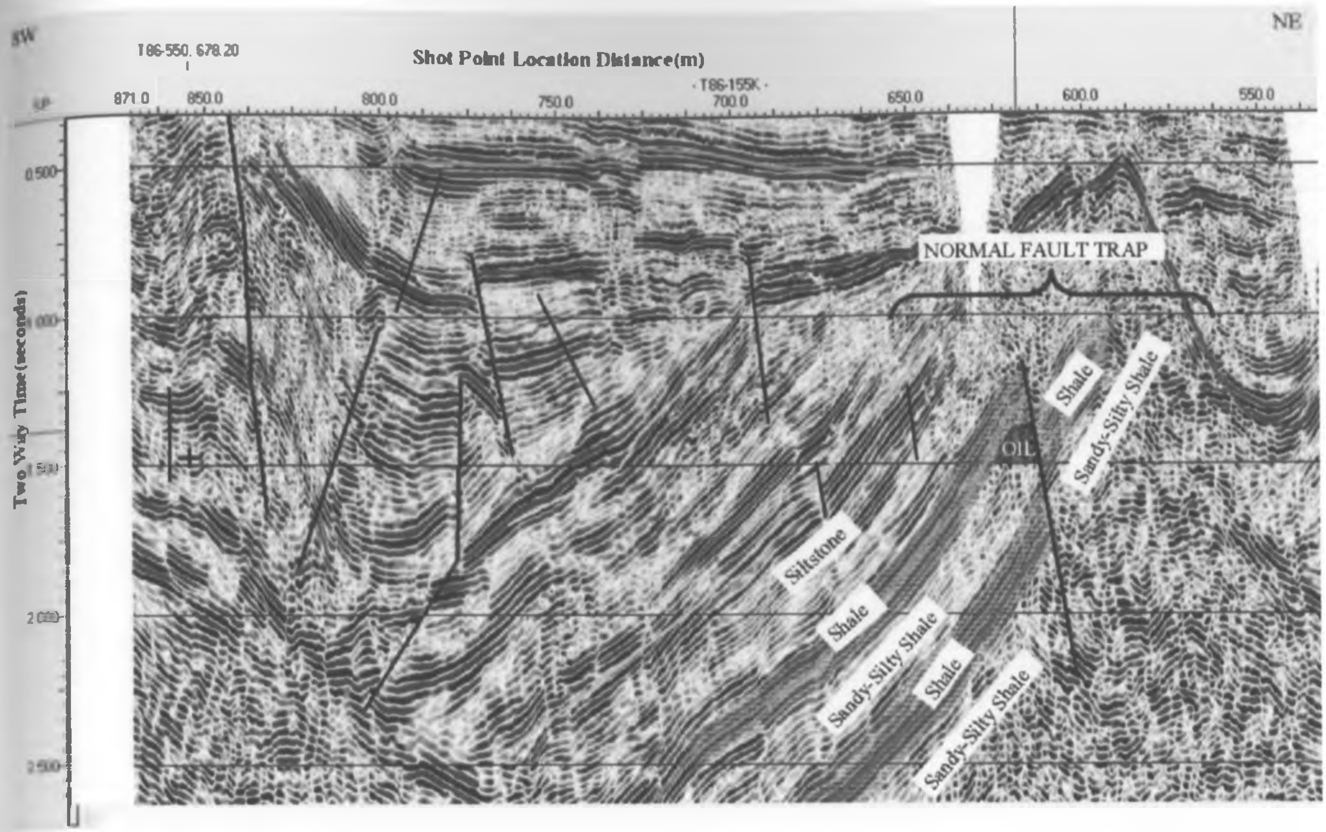

Figure 5.3 A normal fault trap along line T86-165

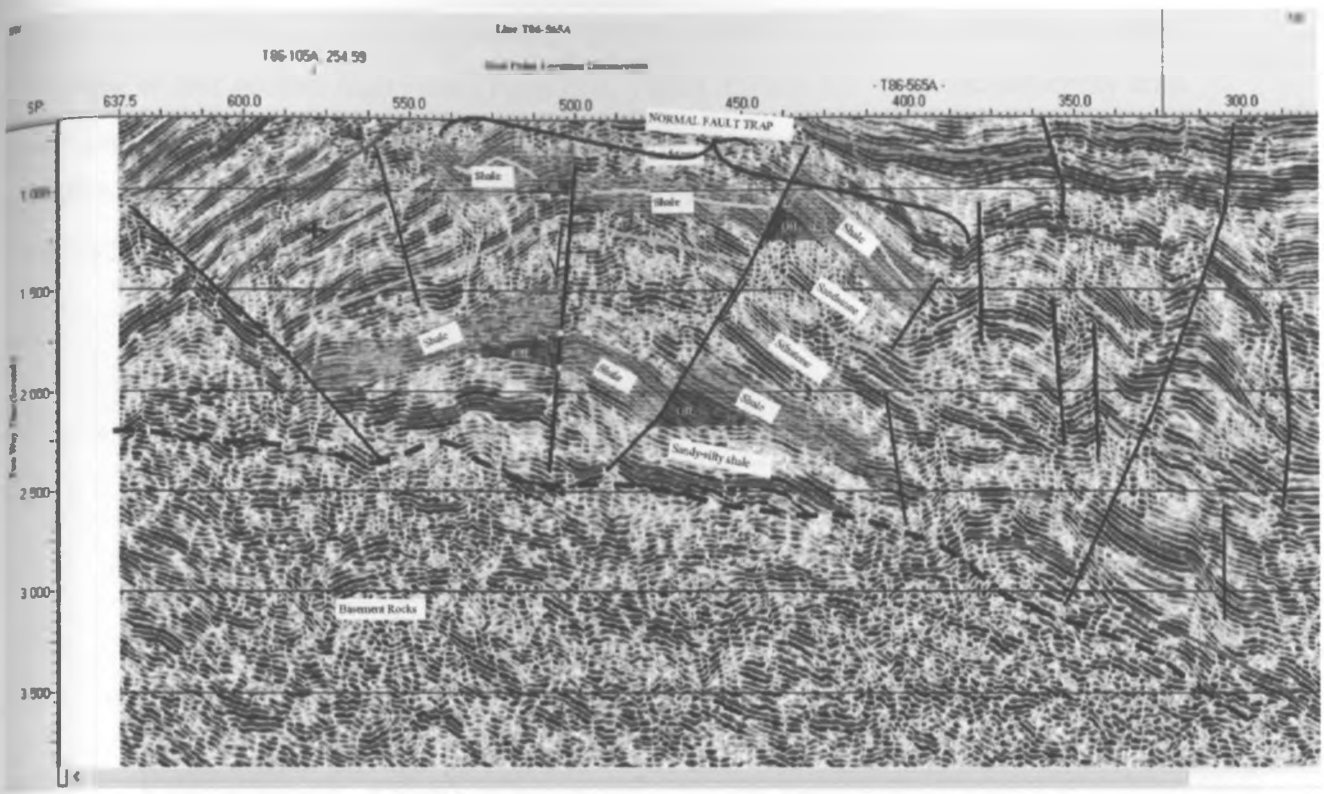

Figure 5.4 Normal fault trap along line T86-565A

5.3 STRATIGRAPHIC TRAPS

The term stratigraphic trap was proposed by Levorsen in 1936(p. 524) for features in which "in which a variation in stratigraphy is the chief confining element in the reservoir which traps the oil." Petroleum may be trapped where the reservoir itself is cut off up-dip, thus preventing further migration. In this case, no structural control is needed. The variety in size and shape of such traps is enormous, to a large extent reflecting the restricted environments in which the reservoir rocks were deposited.

5.3.1 UNCONFORMITY TRAPS

Unconformity traps play a major role in hydrocarbon migration and trapping. First, an alternating sequence of potential reservoir rocks and cap rocks must accumulate. Then they must be deformed and truncated by an erosion surface. Then the erosion surface must be covered by relatively fine grained sediment that will become the cap rock. This indicates that the chief factors are the presence of an effective seal in a position overlying an older and more or less eroded high zone (Perrodon, 1983). Figure 4.5 is an unconformity trap along line T86-565A. Figure 4.6 on the other hand shows another unconformity trap along line T86-550K. This unconformity trap is attributed to the upper Cretaceous Tertiary boundary.

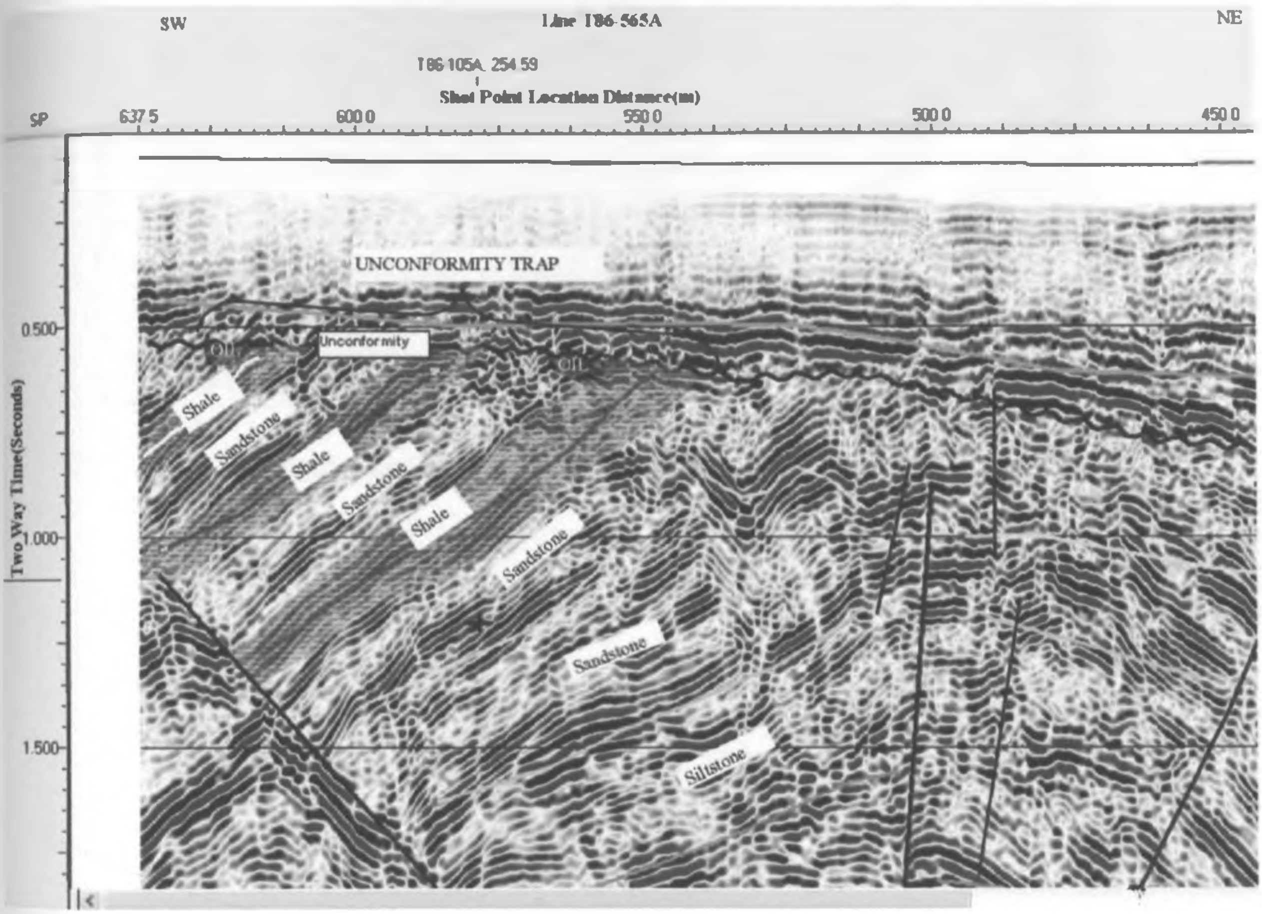

Figure 5.5 Unconformity trap type along line T86-565A

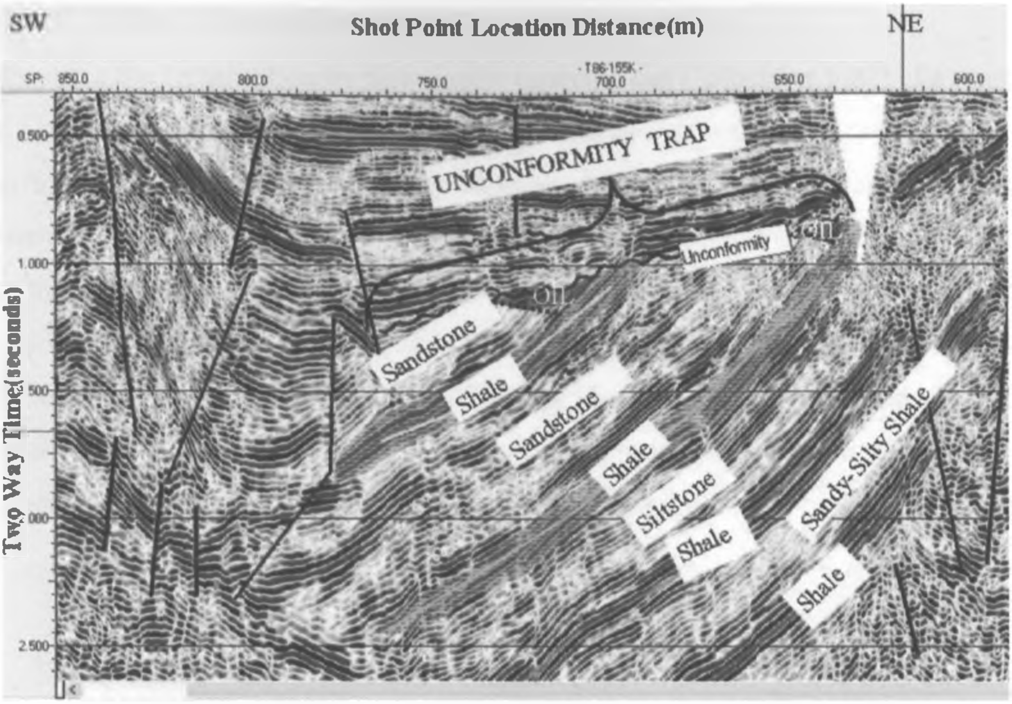

Figure 5.6 Unconformity trap along line T85-155K

5.3.2 DEPOSITIONAL PINCH-OUT TRAPS

A pinch-out is the termination by thinning or tapering out ("pinching out") of a reservoir against a nonporous sealing rock. This creates a favorable geometry to trap hydrocarbons, particularly if the adjacent sealing rock. In most cases this kind of trap requires a component of regional deep to be more effective. In the pinch-out trap in Figure 4.7 below a siltstone which is a potential reservoir rock layer is covered by a thin layer of shale, the pinch-out trap in Figure 4.8 with a sandstone reservoir rock is covered by a thin layer of shale and in Figure 4.9 the pinch-out trap along Line T86-130X has sandstone as the reservoir rock and shale as the sealing material. The sandstone and siltstone in this case allow petroleum to accumulate and the shale seal the petroleum so that it cannot escape.

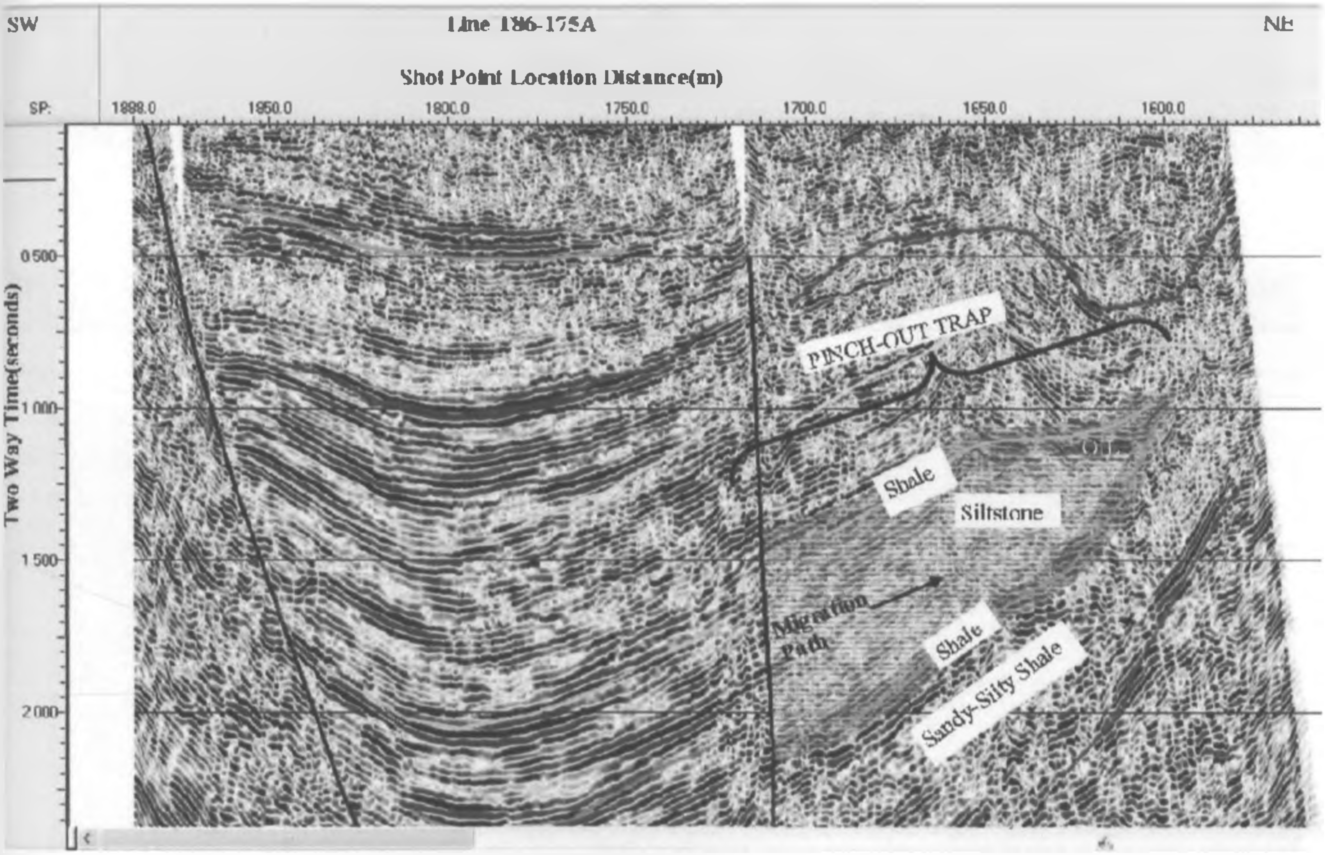

Figure 5.7 A pinch-out trap along Line T86-175A

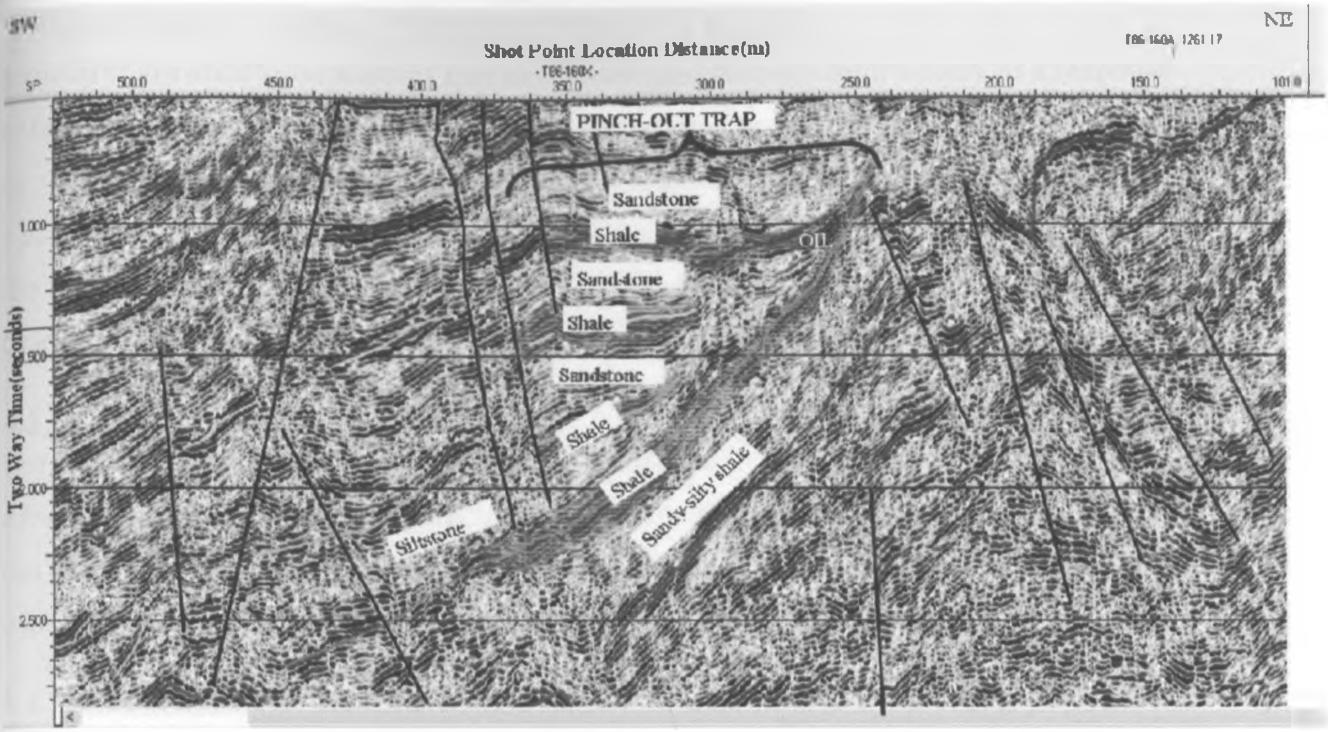

Figure 5.8 A pinch-out trap along line T86-160X

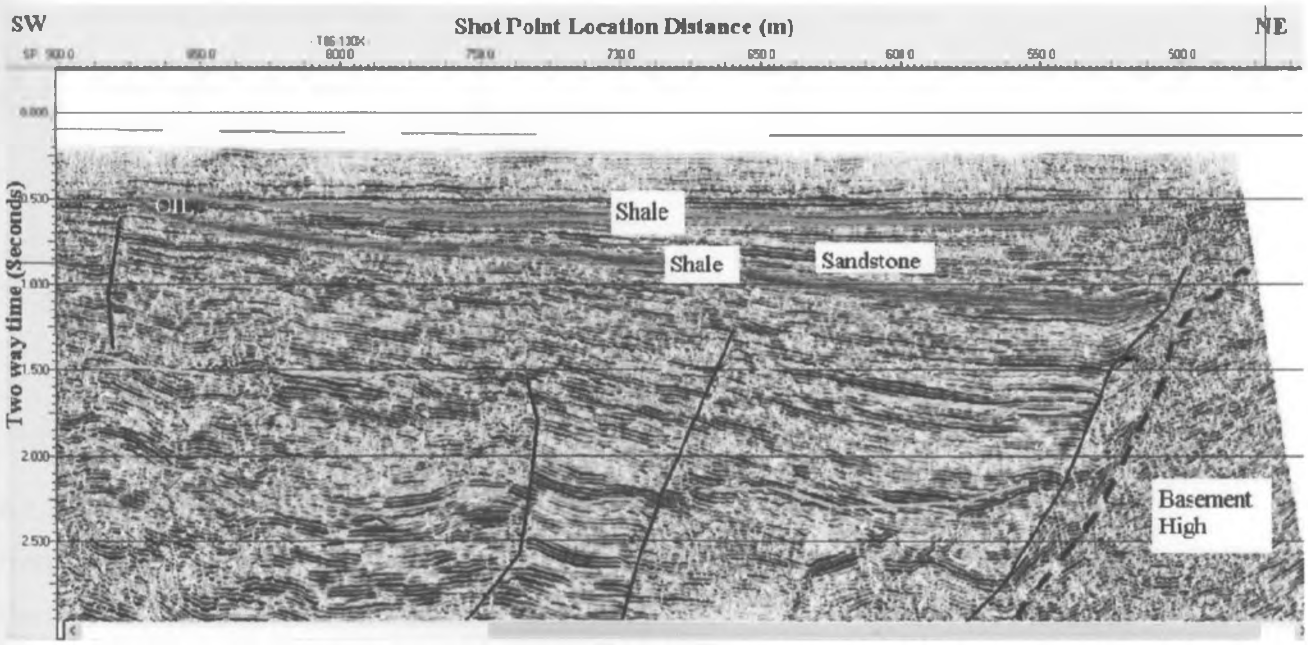

Figure 5.9 A pinch-out trap along line T86-130X

CHAPTER 6 STRUCTURE OF THE ANZA BASIN

Structures are architectural forms that have developed through deformation, as a response to forces and stresses. Davis and Reynolds (1996), states that deformation refers to the structural changes that take place in the original location, orientation, shape and volume of a body. He also adds that it may refer to the physical and chemical processes that produce the structural changes as well as to the geologic structures that form to accommodate the changes.

6.1 FAULTS

The definition of the word fault given in the Tectonic Dictionary (Dennis, 1967) is that "it is a fracture surface or zone along which appreciable displacement has taken pace." Faults can occur as single discrete breaks, but where the rock has been repeatedly faulted, or where the rock is especially weak, no discrete break may be evident.

6.1.1RECOGNITION OF FAULTS

Suppe(1986) outlines the principle criteria for the recognition of faults as:

1) Structural discontinuity
2) Lithologic discontinuity
3) Fault zone deformation, often with associated weakened rocks with poor outcropping characteristics
4) Fault related deformation of the land surface in the case of recent faulting
5) Fault related sediments and sedimentation patterns in the case of syn-depositional faulting

6.1.2 NORMAL FAULTS

Normal faults occur in a case where the hanging wall is displaced downwards relative to the footwall. Normal faults in a given area may exist in two sets with parallel strikes but opposite dips, called conjugate normal faults. A set of normal conjugate faults are shown in figure 6.1. The two faults have quite a different aggregate slip. The fault with relatively minor displacement is called antithetic (Suppe, 1986) with respect to,the principle fault set.

In Figure 6.1 the set dipping to the right is antithetic to the set dipping to the left because it has much less aggregate slip. Figure 6.2 shows a series of normal faults.

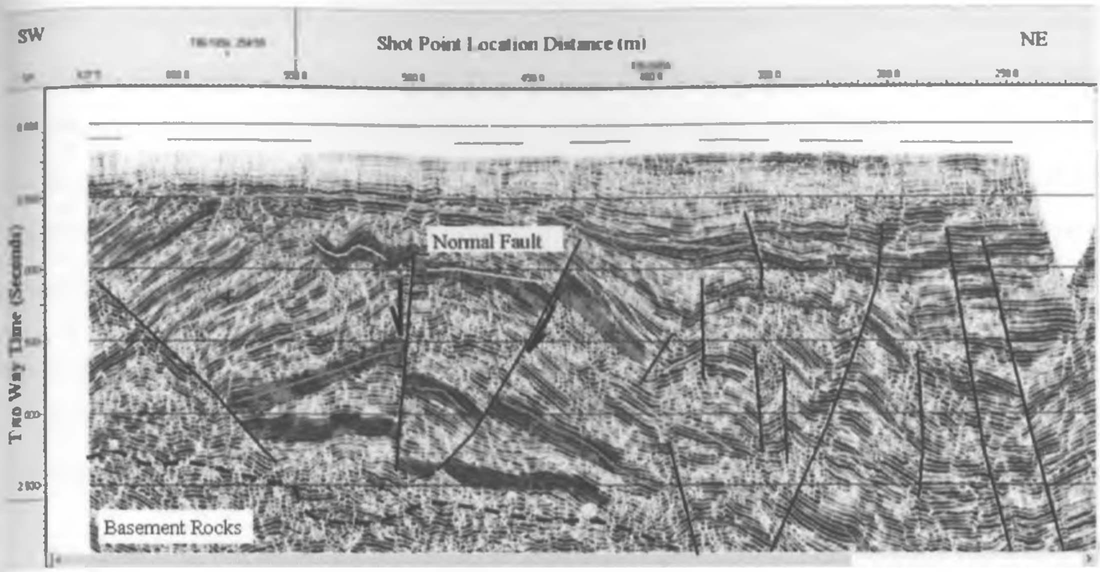

Figure 6.1 Conjugate normal faults along Line T86-565A

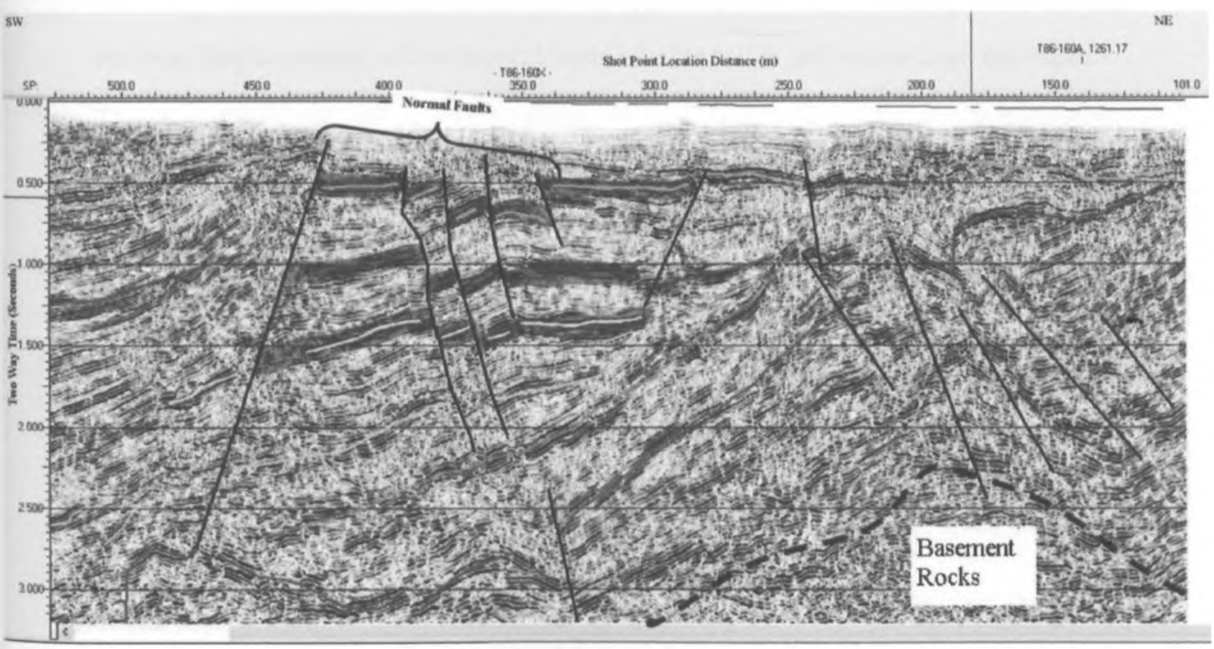

Figure 6.2 Normal faults along line T86-160X

6.2 FOLDS

6.2.1 INTRODUCTION

Generally, folds occur on all scales from the microscopic to the regional. Geoscientists pay a keen interest in folds because in addition to the economically interesting concentration of minerals, hydrocarbons are also found in association with folds. These concentrations may occur either in response to stress gradients that are set up during the formation of a fold, or particularly, in the case of hydrocarbon concentration, as a result of the entrapment of material after the fault has formed (Price and Cosgrove, 1990.)

6.2.2 MECHANISMS OF FOLDING

According to Suppe (1986), three general physical mechanisms are responsible, singly or in combination for the majority of folds we observe in rocks. These are:

1) Buckling – if a compressive force is applied to the rock layers, they normally will not shorten indefinitely parallel to the length of the layers but will be deflected perpendicular to the layering. This transverse deflection is what is called buckling.

2) Bending – is the transverse deflection of layers in response to an applied couple. The vertical displacement of horizontal beds of a laccolith intrusion is an example.

3) Passive amplification – If a curved surface or fold already exists in a rock, it may grow by passive amplification solely as a result of the homogeneous flow of the rock even if the folded layers are only geometric markers and not layers in the mechanical sense.

The anticline and syncline in Figure 6.3 is formed by the bending mechanism as explained above. The anticline rests over a basement high. This is also the same in other folds in the area.

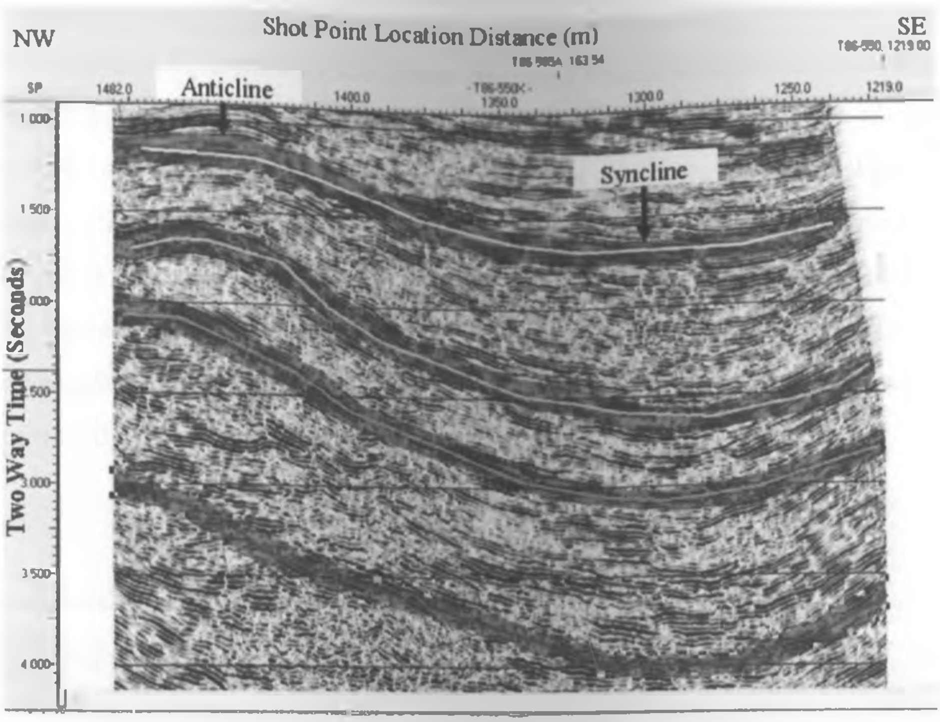

Figure 6.3 A syncline and anticline along Line T86-550X

Synclines is fold in rocks in which the rock layers dip inward from both sides toward the axis. Figure 6.4 below shows a syncline along line T86-565A.

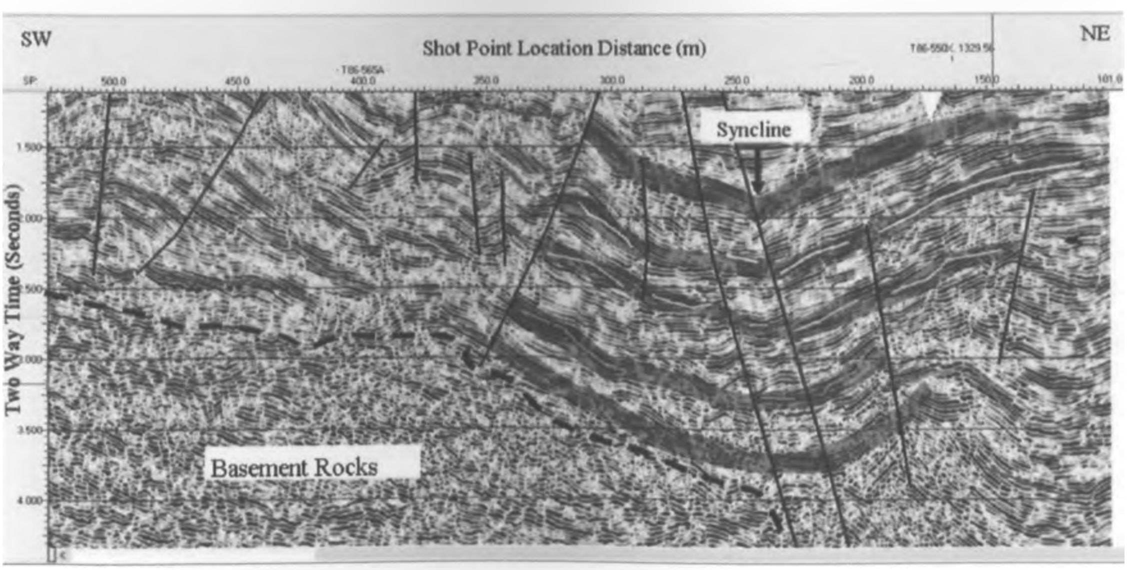

Figure 6.4 A syncline along line T86-565A

6.3 GRABEN/HALF GRABEN

Grabens are basins formed by the down-dropped blocks within active normal fault terrains. Grabens maybe bounded by either a single set of faults on one side of a tilted block, called half graben or by a conjugate pair on both sides of the basin called a full graben. According to Suppe (1986) however, the term graben has also several additional meanings in addition to the above topographic meaning: it is also applied to ancient, sediment filled normal fault basins that are no longer topographic basins involving recent fault slip Figure 6.5 below shows a sediment filled graben along line T86-160X while Figure 6.6 shows another sediment filled graben along line T86-565A.

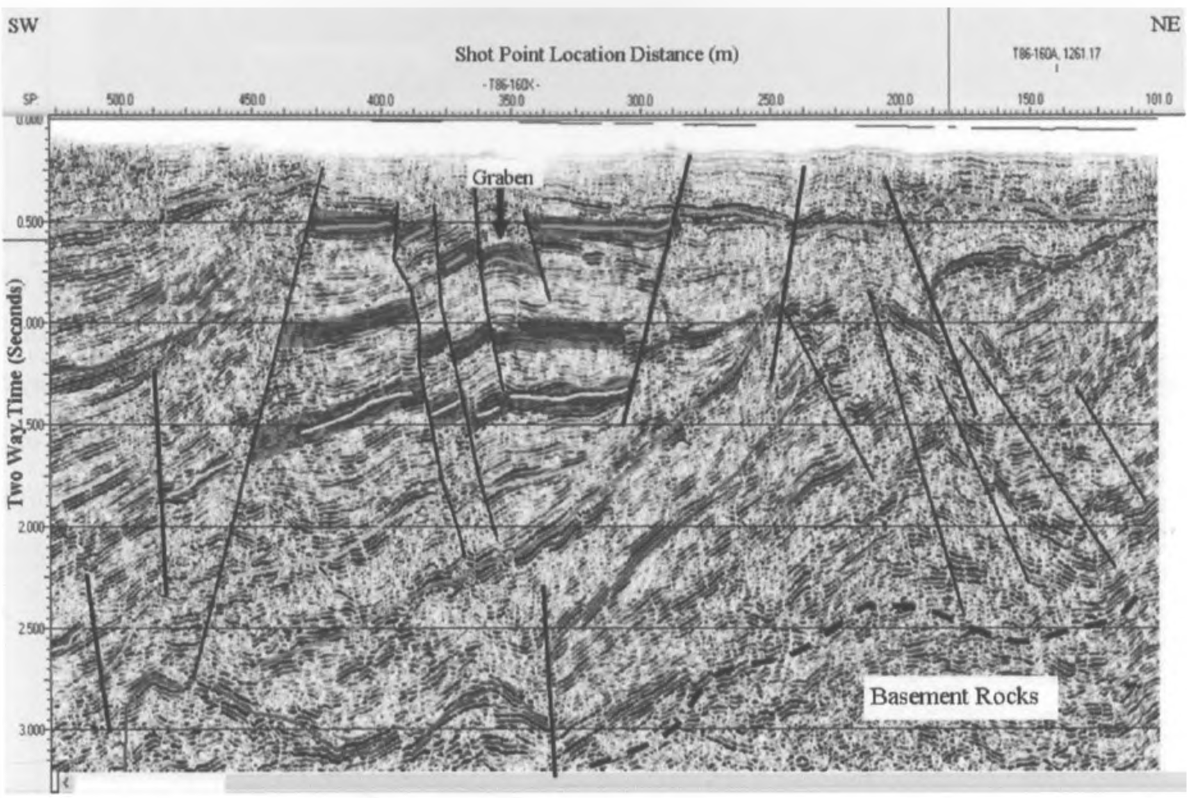

Figure 6.5 A graben along line T86-160X

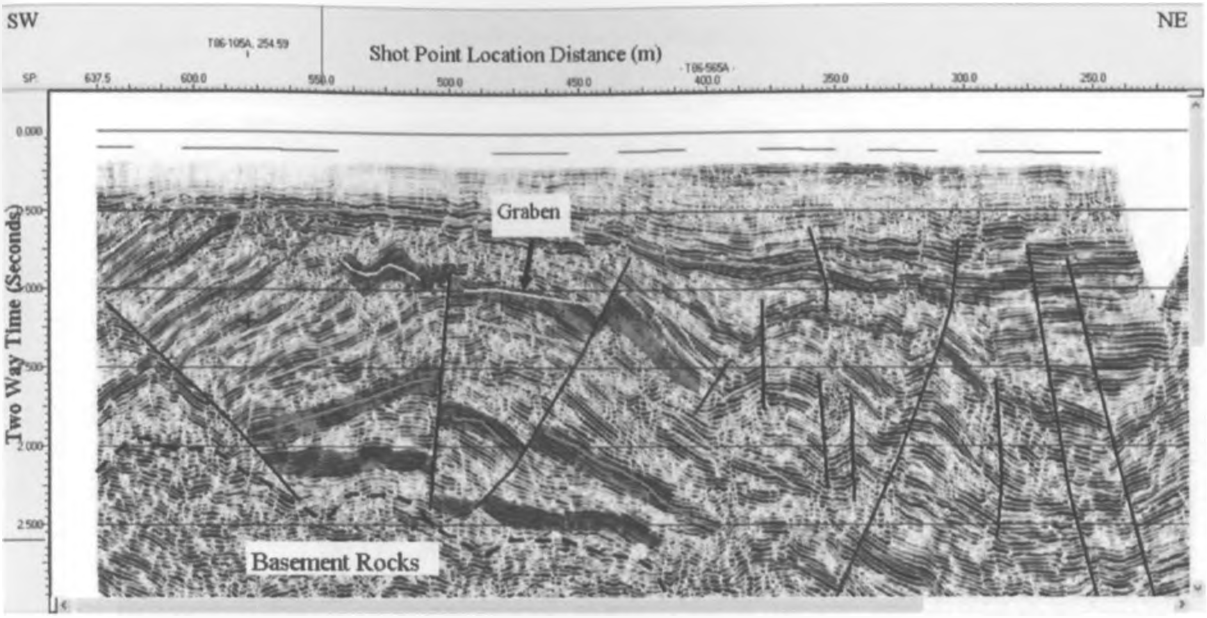

Figure 6.6 A graben along line T86-565A

6.4 UNCONFORMITY

An unconformity is a surface in the rock record in the stratigraphic column, representing a time from which no rocks are preserved. It could represent a time when no rocks were formed, or a time when rocks were formed but then eroded away. An angular unconformity can be seen in figure 4.7 below. An angular unconformity is the contact that separates a younger, gently dipping rock unit from older underlying rocks that are tilted or deformed layered rock.

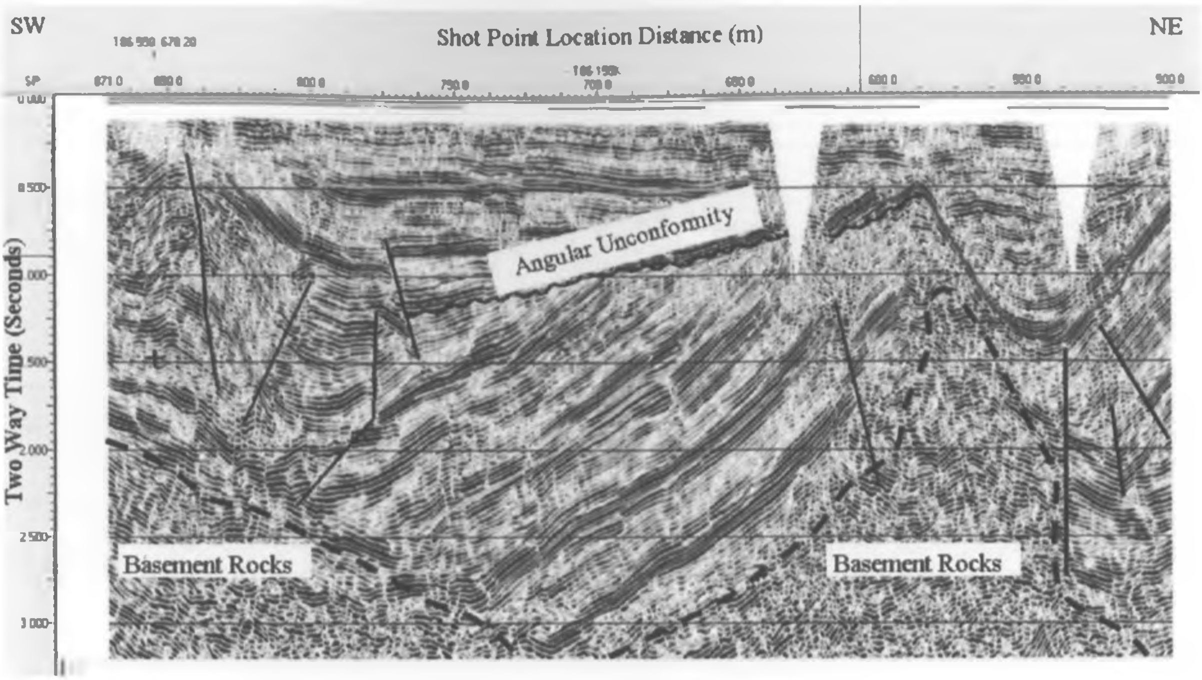

Figure 6.7 An angular unconformity along line T86-150K

6.5 PINCHOUT

A pinch-out is a stratigraphic structure formed by the termination of lithology. Figure 6.8 and Figure 6.9 shows pinch-out trap that were identified in the study area along Line T86-160A and Line T86-130X.

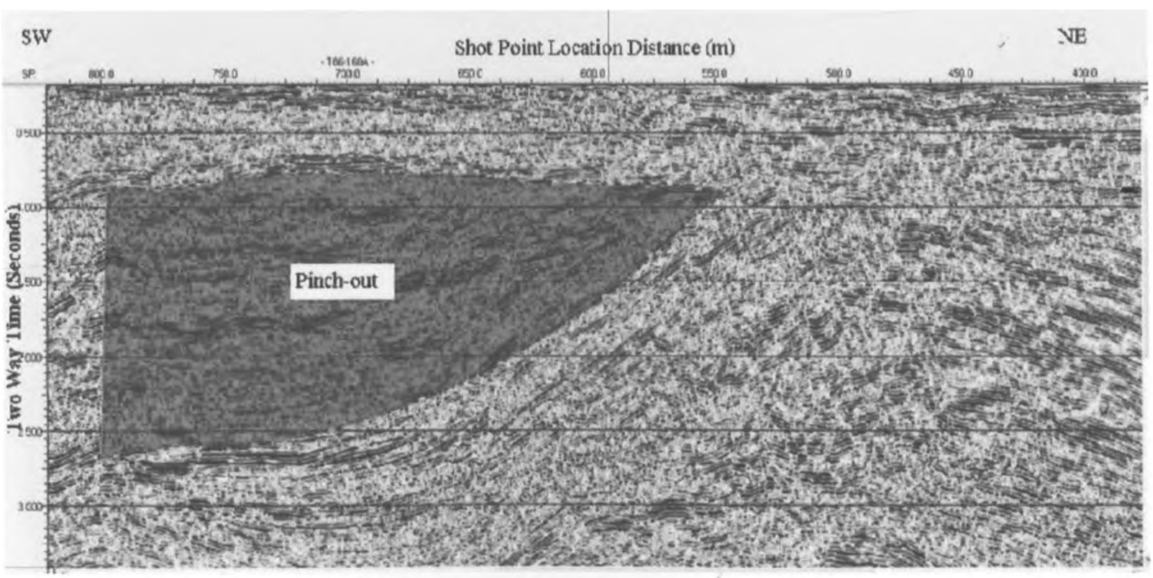

Figure 6.8 A pinch-out along line T86-160X

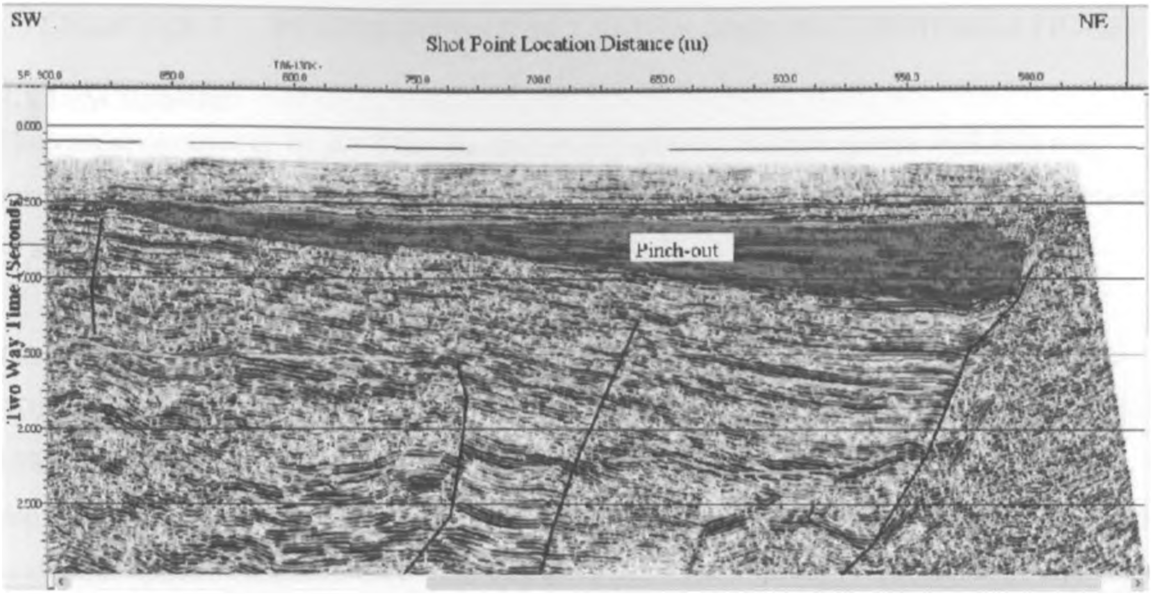

Figure 6.9 Pinch-out along line T86-130X

CHAPTER 7 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

7.1 DISCUSSION

The vast area covered by the Anza Basin under explored and the sparse well data and seismic data sets does not allow a complete assessment of the petroleum system elements (trap, seal, and source and reservoir rocks).

The potential traps encountered include Anticlinal traps along lines T86-550X and T86-550, fault traps along lines T86-565A and T86-155K, Unconformity traps along lines T86-155K and T86-565A and pinch-out traps along lines T86-160X and T86-550. Effective source rock units cannot be identified from the available dataset. However, reservoir and seal rocks could be identified by correlating information available from the final well logs of the wells in the area and from completion reports.

From the stratigraphy study a significant part of the Cretaceous and Tertiary in Ndovu-1 and Duma-1, and the Tertiary in the Kaisut-1 section contained intercalations of sandstone and sandy-silty shale as well as shales which could be good reservoir and seal rocks respectively. This suggests that further exploration of this frontier region is warranted. Both the Cretaceous and Tertiary units contained shales that would make effective seals at all scales.

The structures found in this area were a variety of folds, faults, pinch-outs and an angular unconformity.

7.2 CONCLUSIONS

This investigation revealed both structural (folds and faults) and stratigraphic traps (pinch-outs and angular unconformity). The trap types as well as structures were indicated by strong sub-horizontal or dipping reflectors which were observed to exist at depth from the Quaternary Period formations. It was noted that these sub-horizontal or dipping reflectors corresponded to the shale lithologies. Dipping faults that truncated the lithologies were also identified. The unconformity identified was attributed to the upper Cretaceous-Tertiary boundary.

Based on the trap types identified, the plays or prospective areas in this study area can be classified as anticlinal plays, fault plays, unconformity plays and pinch-out plays.

The lithologies present in this area extended from the Cretaceous to the quaternary period. The main lithologies identified from the stratigraphic sections from the wells in this area were sandstones, shales, sandy-silty shales and siltstones.

The well dataset was absent and such data could greatly improve the correlation with the seismic data. These combined dataset would have been useful for seismic analysis and interpretation of the overall structural model in terms of two way travel time in SMT Kingdom Suite.

7.3 RECOMMENDATIONS

This study area is underexplored and more research will help in understanding the structure, stratigraphy and other exploration plays in the area.

Efforts should also be made to acquire raw well data so as to aid in accurate well and seismic data correlation and thus a much more accurate identification of the lithologies and thus the stratigraphy.

Shooting of 3D seismic data will also give more detailed information of the area and will enable 3D modeling of the structures that could be potential petroleum traps and will also give a better visualization and understanding of the study area in general.

The areas identified as potential traps in this study should be further investigated as plausible site for drilling.

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APPENDIX 1

Line Number	Shot Point	X	Y
T86-105A	101	4314863.572	127975.031
T86-105A	200	4307087.961	126317.397
T86-105A	300	4299148.769	124725.196
T86-105A	400	4291329.536	123514.688
T86-105A	500	4283335.816	122347.801
T86-105A	520	4281114.126	121969.138
T86-130X	453	4402082.269	185410.503
T86-130X	500	4398418.026	184596.227
T86-130X	600	4390711.483	182865.89
T86-130X	700	4382815.912	181179.175
T86-130X	800	4374963.963	179448.838
T86-130X	900	4367082.933	177703.96
T86-130X	1000	4359318.228	175988.164
T86-130X	1100	4351538.982	174272.368
T86-130x	1175	4345591.858	172949.169
T86-155K	101	4650388.272	288485.858
T86-155K	200	4243528.722	224559.883

T86-155K	300	4336560.117	220710.427
T86-155k	400	4329580.607	216773.367
T86-155K	500	4322448.42	212858.298
T86-155K	600	4315359.855	208932.342
T86-155K	800	4301422.646	201014.942
T86-155K	900	4294377.703	197078.062
T86-155K	1000	4287474.531	193184.804
T86-155K	1100	4280379.15	189291.394
T86-155K	1110	4279683.925	188931.513
T86-155K	1175	4275128.159	186363.272
T86-155K	1200	4273296.038	185349.062
T86-155K	1300	4266249.731	181424.45
T86-155K	1400	4259182.977	177454.854
T86-155K	1484	4253304.921	174161.398
T86-160A	101	4351841.414	237536.577
T86-160A	200	4345093.646	233567.662
T86-160A	300	4338088.235	229469.926
T86-160A	400	4331236.183	225451.936
T86-160A	500	4324279.847	221483.022
T86-160A	600	4317225.361	217489.569

T86-160A	700	4310391.712	213428.64
T86-160A	800	4303392.436	209416.784
T86-160A	900	4296307.279	205337.452
T86-160A	1000	4289442.958	201325.596
T86-160A	1100	4282443.681	197270.801
T86-160A	1200	4275462.808	193252.811
T86-160a	1293	4268856.129	189461.026
T86-160X	101	4274054.524	191979.962
T86-160X	200	4266758.754	188959.143
T86-160X	300	4259310.308	185861.985
T86-160X	400	4251927.295	182710.3
T86-160X	500	4244511.566	179504.088
T86-160X	579	4238644.415	177072.165
T86-165A	101	4345443.19	242261.299
T86-165A	200	4338494.096	238348.53
T86-165A	300	4331460.059	234378.934
T86-165A	400	4324491.454	230431.149
T86-165A	500	4317326.551	226526.985
T86-165A	600	4310390.662	222524.672

T86-165A	700	4303334.814	218664.131
T86-165A	800	4296355.304	214640.007
T86-165A	900	4289397.604	210659.505
T86-165A	1000	4282418.094	206657.192
T86-165A	1100	4270542.021	199972.13

T86-175A	101	4339552.835	256547.17
T86-175A	200	4332749.009	252713.119
T86-175A	300	4325718.181	248764.526
T86-175A	400	4318654.031	244899.236
T86-175A	500	4311523.238	240867.339
T86-175A	600	4304575.713	236952.068
T86-175A	700	4297544.885	232903.51
T86-175A	800	4290580.699	228988.238
T86-175A	900	4283533.21	225039.645
T86-175A	1000	4276569.024	221141.034
T86-175A	1100	4269621.499	217209.101
T86-175A	1200	4262657.314	213260.508
T86-175A	1266	4258058.952	210728.077

T86-550	105	4275858.807	239524.638
T86-550	200	4279490.333	232763.237
T86-550	300	4283307.253	225652.861
T86-150	400	4287113.267	218586.107
T86-150	500	4290821.132	211617.502
T86-150	600	4294692.579	204201.773
T86-150	700	4298356.822	197364.034
T86-150	800	4302271.891	190231.847
T86-150	900	4305957.945	183197.809
T86-150	1000	4309742.148	176141.961
T86-150	1100	4313559.067	169020.679
T86-150	1200	4317343.271	161888.495
T86-150	1219	4318084.844	160492.59

T86-550X	1219	4318084.844	160492.59
T86-550X	1300	4321171.096	154854.455
T86-550X	1400	4324900.772	147722.268
T86-550X	1585	4331891.187	134646.592

T86-565A	101	4325241.454	156892.895
T86-565A	200	4320543.128	150328.567

T86-565A	300	4315911.445	143897.525
T86-565A	400	4311246.44	137266.554
T86-565A	500	4306481.471	130685.565
T86-565A	600	4301749.824	124037.933
T86-565A	680	4298217.749	118989.732