بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Petroleum and Mining Engineering and Technology

Exploration Engineering Department

Graduation Project Submitted in Partial Fulfillments for the degree of BSc (honor) in Exploration Engineering About:

Seismic Sequences Stratigraphy Study in Sufyan Sub-basin

دراسة التتابعات الطبقية في حقل سفيان النفطي

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الاستهلال

((اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ﴿١﴾ خَلَقَ الْإِنسَانَ
مِنْ عَلَقٍ ﴿٢﴾ اقْرَأْ وَرَبُّكَ الْأَكْرَمُ ﴿٣﴾ الَّذِي عَلَّمَ
بِالْقَلَمِ ﴿٤﴾ عَلَّمَ الْإِنسَانَ مَا لَمْ يَعْلَمْ ﴿٥﴾))

صدق الله العظيم

سورة العلق

Dedication

It's my second home where I belong .

I thank you for everything I learned inside you and what I've become.

Sudan University of science and technology

She is precious in every way.

The source of kindness. The sun shines in my day.

The joy in my soul and the love of my life.

Mother

He's a role model and a source of strength and inspiration.

He's the greatest man I've ever known and I'm so proud to be addressed with him.

Father

They are ones who share me my childhood and stand beside me while no one leftaside.

Brothers and sisters

To whom I appreciate. To whom I love and care.

To whom I won't ever forget.

To whom I do respect.

My friends and classmates

For your patience, caring, supporting and kind

words sharing.I just want to say thank you for

everything along this period .

Dear teachers

Acknowledgements

This research project would not have been possible without relief and the will of ***Allah*** and the support of many people, we would like to extend our deepest gratitude to our supervisor ***Prof. Abbas Musa Yagoub*** for giving us the opportunity to our research. We greatly indebted to her for her enduring confidence in us. we have learned many things from her rich academic and practical experience. Her encouragement, support and patience always guided us throughout this period. We are also thankful specially **Mr. Abubaker Shoaib** for providing us his time and knowledge through teaching his wide practical experience in conducting software and how we can use it in our research project perfectly.

Abstract

stratigraphic interpretation process of the reflective seismic data which was done in Sufyan sub-basin in NW Muglad basin in East Darfur State. Seismic data represented by four 2-D seismic lines which include in-lines and cross-lines, the study area is mainly covers a part of Sufyan sub-basin. The study aims to identify the subsurface stratigraphic terminations and define the dominant stratigraphic termination in study area from the set of data available. Interpretation processes were done using Petrel version 2015software. Interpretation of the seismic sections was calibrated with the stratigraphic column of the Muglad basin. We found stratigraphic bodies such as (top-lap, down-lap, truncation and concordance).

مستخلص

عملية تفسير طبقي لمعلومات الانعكاس الزلزالي في حوض سفيان الذي يقع شمال غرب حوض المجلد الموجود في ولاية شرق دارفور. حيث تم استخدام أربعة خطوط زلزالية ثنائية البعد ومتقاطعة تغطي جزء من حوض سفيان. حيث تهدف هذه الدراسة لعمل تفسير طبقي للتتابع الرسوبي الموجود والسائد في منطقة الدراسة وذلك باستخدام برامج (Petrel Software© 2015) لتفسير المقاطع الزلزالية وربطها بالعمود الطبقي لحوض المجلد ووجد بعض الاجسام الطبقية مثل (Top–lap, Down–lap, Truncation and Concordance)

Table of Contents

List of Figures

Chapter One

Introduction

1.1 Introduction:

Muglad basing is recognized to be a major part of Sudanese interior rift basing. It trends northwest – southeast covering an area of 1200km long and in excess of 300km wide. The major segment of the faulted strata in the basin lies beneath the late tertiary sediments.

The Muglad basin is part of a trend of cretaceous sedimentary basins of apparent rift origin, which cut across north central Africa from the Benue trough in Nigeria, through Chad and the Central African Republic, into Sudan figure (1.1).

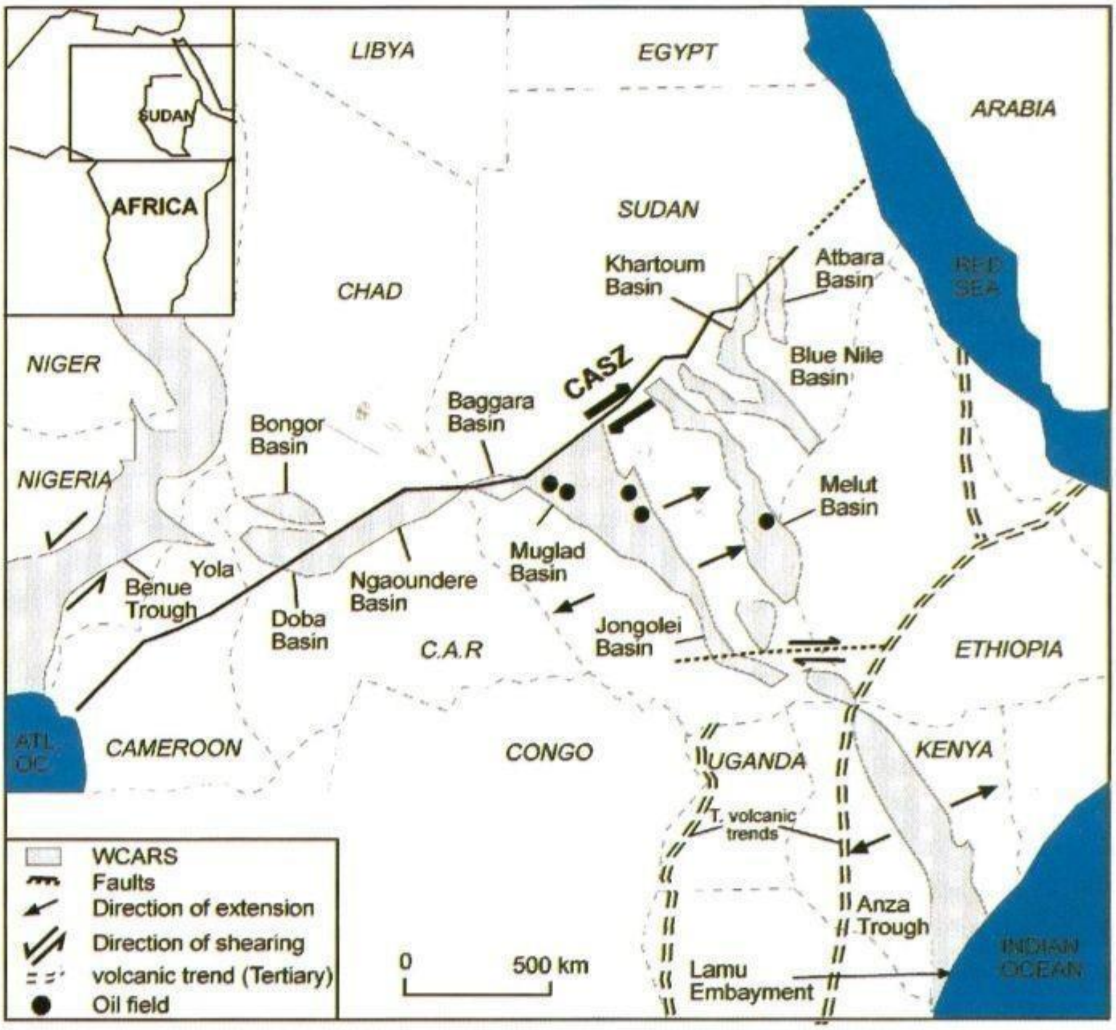


Fig.1.1: Location of the Muglad basin across north central Africa from the Benue trough in Nigeria, through Chad and the central African republic.(Fair head,1988).

Regional data are limited, but the aeromagnetic and gravity surveys indicate as much as 5km of sediments. Seismic data suggest large numbers of tensional faults have affected the overall basin and have defined several sub-basins. Structures within these sub-basins show significant variations in age of formation, complexity and size. The Muglad basin is predominantly Precambrian and Cambrian metamorphic rocks with limited occurrences of intrusive igneous rocks. The rock types are mainly metamorphic rock, which include granitic gneiss, and granodioritic gneiss. This gneissic basement is overlain by quartzite of Paleozoic age. The Muglad basin was the location of an extensive continental platform, the oldest sedimentary rock are non-marine of lower Jurassic salt.

The deepest part of the Muglad basin lies to the west of unity field, it is estimated to contain over 4500m of tertiary and 6000 to 9000m of cretaceous non-marine sediments derived from surrounding basement complex. The establishment of the stratigraphic column reflects three cycles of deposition in Muglad basin. The Sharef, Abugabra, and Bentiu formations represent the first cycle, second cycles is the cretaceous of Darfur group and is characterized by a coarsening upward sequence and the third one is Nayil formation.

1.2 Study Area:

The study area located at the northwest side of the Muglad, Strike W-E, different from the other sub-basins figure (1.2). The Sufyan sub-basin is relatively independent structural unit in the Muglad basin. It is 70 km long and 40 km wide with a total area of about 2800 km. in the Muglad basin, three rift cycles are recognized and dated as early late cretaceous and paleogene age. Each tectonic cycle seems to consist of a rift-initiation phase, active rifting phase (syn-rift phase), and thermal sag phase (post-rift phase) (McHargue et al., 1992). Every tectonic cycles is represented by a basal sandstone unit followed by a coarsening upward cycle (grading from lacustrine shale to marginal lacustrine mudstone and sandstone into fluvial mudstone and being covered by alluvial and fluvial sandstone) (McHargue et al., 1992).

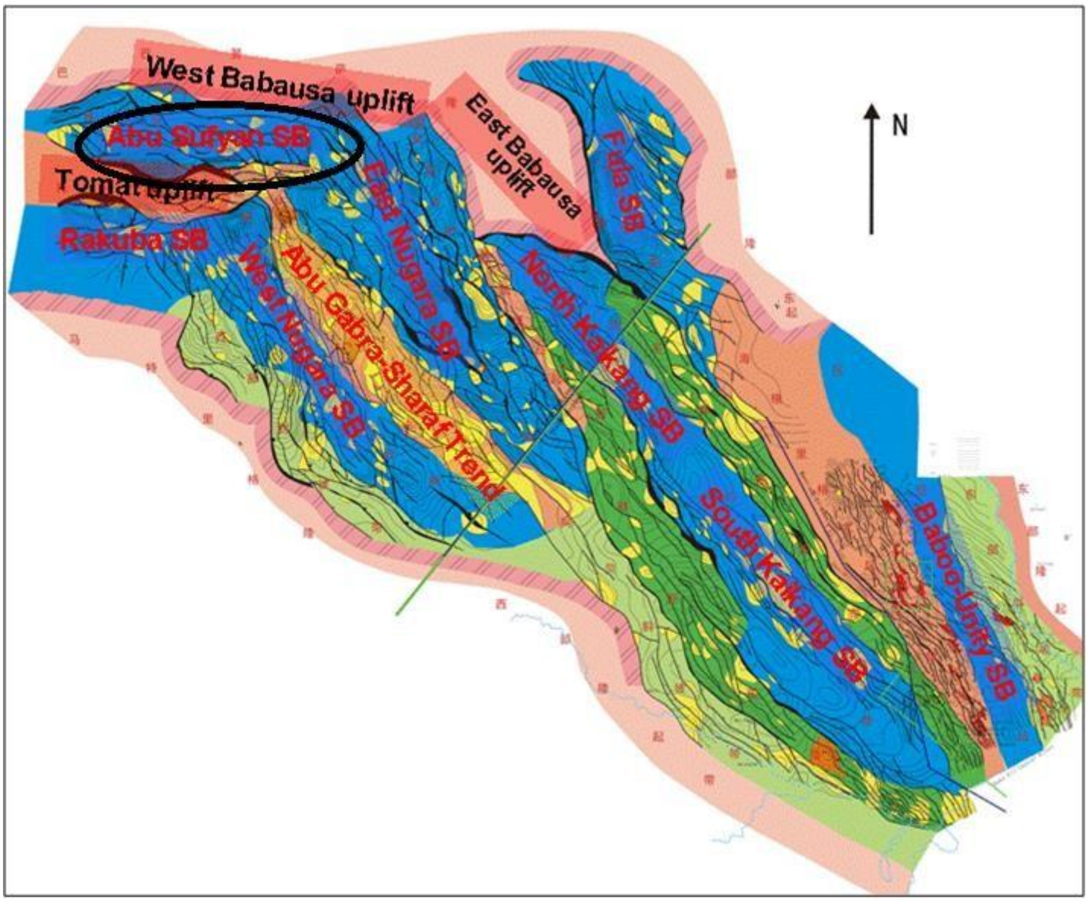


Fig.1.2 Location map of the study area northwest side of the Muglad.

1.3 Problem Statement:

From previous studies, Abu Gabra and Sharaf formations in the area are up to 5000m thick of the whole sedimentary section of the basin, in which it has been found rich hydrocarbon source rock. Abu Gabra and Bentiu formations, Darfur and Kordofan groups contain reservoir rocks and structurally controlled by complex fault network, therefore, there are complications in assessment the potential traps that have capability of retaining the generated hydrocarbon. Proper assessment of trap potential is required as it will be conducted in this study by accurate interpretation of seismic reflection data integrated with borehole information.

1.4 Study Objectives:

The study aims mainly to make use the seismic stratigraphy data integrated with well data of the area to provide stratigraphic interpretation of seismic reflectors which help in predictive:

- Detected Termination Pattern at the Upper Sequence Boundary.
- Detected Termination Pattern at the Lower Sequence Boundary.
- Identified the faults.

1.5 Available data Set:

The available data in fig (1.3) that used in the study were the following:

1. 19 2D seismic lines
2. Well information of(Abu sufyan-1, Suf-1, Suf-C-1) which include:
   i. Horizon tops of (Amal, Darfur group, Bentiu and Abu-Gabra Formations).
   ii. The logs.

1.6 Previous Studies:

In 1974, the Government of the Sudan Republic and Chevron signed a Production Sharing Agreement (PSA), chevron directed their exploration efforts in Muglad basin through shooting seismic lines and drilling wells. The year 1976, Baraka-1 well was drilled in the NW of the Muglad Basin, in the term between (1976-1980) chevron had made several oil discoveries such as in Unity-1, Unity-2, and Abu-Gabra wells.

During the 1990´s the Sudan Ministry of Energy and Mining drilled two wells in the AbuGabra-Sharaf area in NW Muglad Basin with the intention of commercializing the oil discoveries in that area. The area has been studied by several geoscientists in aspects of structural geology & HC potentiality. Some studies are mentioned below.

Brown and Fairhead (1983) determined the Muglad basin geometry based on gravity, they realized that the Basin has depth of 4.5 KM and extension of crust approximated about 48KM.Fairhead at (1986) noted that there were some volcanism was presented in the Muglad Basin but is a minor component of the geology with respect of the geology the Tertiary rifts of East Africa.

Scull (1988), Mann (1989), and HC Hargue (1992) studied the stratigraphy and structure of Central African basins, and they found that the Basin contains as much as 13KM of sediment. Scull (1988) conducted the routine analysis of whole rock pyrolysis and organic carbon content based on 1000 of rock samples from 65 well. The result of analysis indicated that dark grey lacustrine claystone and shale of the early rift phase are moderately rich oil prone source rock and average total organic content of 1.3% range 1 to 5%. The primary source of kerogen are degraded algal and plant material.

Mohamed Y.A et al (2002) conducted studies object to model the petroleum maturation and generation of NW of the Muglad basin by utilizing seismic profiles, well information, and gravity data. They constructed structural cross section of AbuGabra-Sharaf Ridge, in addition to structural maps of AbuGabra. The burial history analysis indicated that the subsidence rates at the first rifting phase were higher than that in the subsequent two rifting phases. The thermal history analysis estimated the geothermal gradient range between 18 and 27.5 C^o/KM and heat flow between 37-63 W/m^2 on the other hand the routine geochemical analysis and source rock evaluation techniques results were used to model the source rock of AbuGabra and Sharaf in term of hydrocarbon generation with generation amount of 4 MgHC/g rock in the lower three modelled layers with a timing range between 120MA and the present.

Elhaj (2016) conducted seismic structural interpretation focused on the Rakuba sub-basin and found that two major fault set are dominant, WNW-ESE, and NWN-SES in the area, also Rakuba sub basin is controlled by two major faults: the southern fault of Tomat high in the north and Sharif- Abu Gabra western fault to the east, with a maximum depth of Abu Gabra is 6.7km.

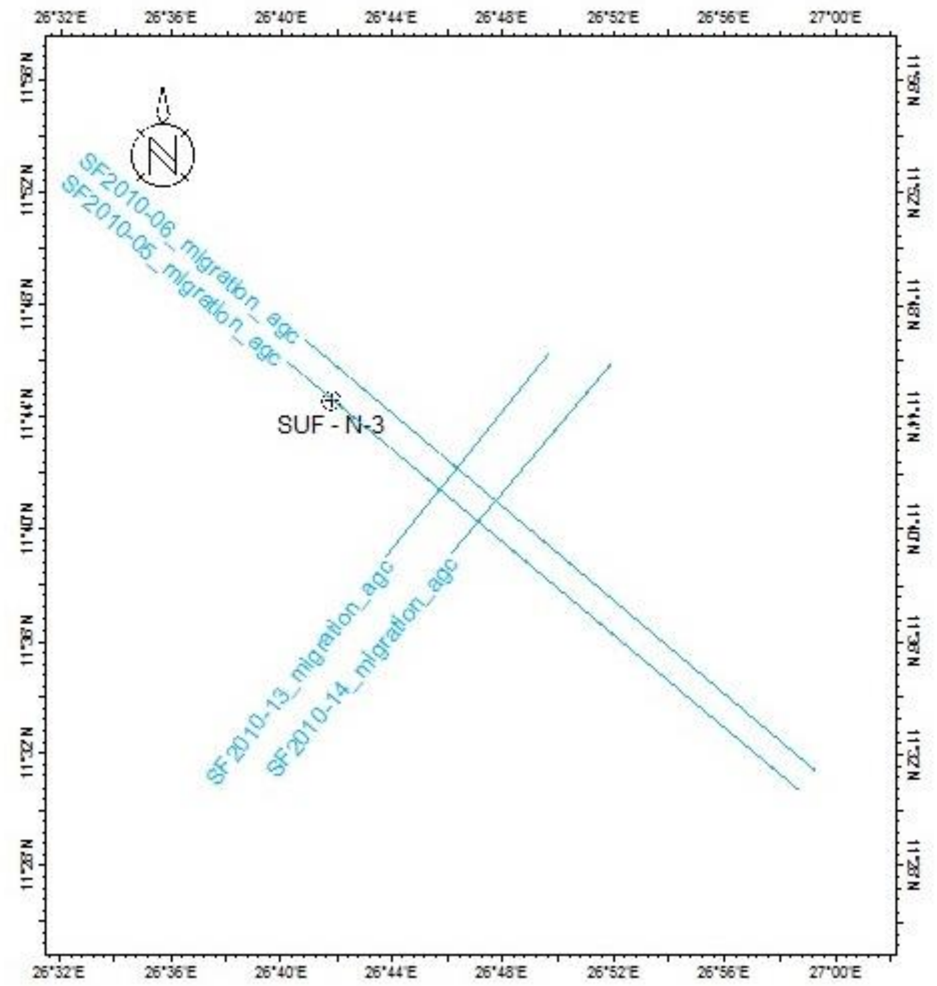


Fig.1.3: Location map of the used data set in the study which are 19 2D seismic lines and one well logging data.

Chapter Two

Tectonic setting and sedimentary setting

2.1.Introduction:

The Muglad rift basin is a part of the central Africa rift system (CARS) That were developed as a result of the transitional and extensional tectonics due to fragment of Gondwana and opening of south Atlantic and Indian ocean during the early cretaceous(135-96MA).

The extensional and transitional tectonics led to shear reactivation along the Central African Shear Zone(CASZ) fig(2.1), that the reason of developing wrench fault system with dextral movement along the central Africa, extended from gulf of guinea up to Sudan direction(Sayed, 2003; Elhaj,2016), further, the extensional tectonic caused the rifting in African continent to continue into the Neogene(23.5-1.75MA) and developed northwest southeast oriented rift basin, The rifting can be divided into two rifting events in the western part and three rifting events in the eastern part. (USGS, 2011)

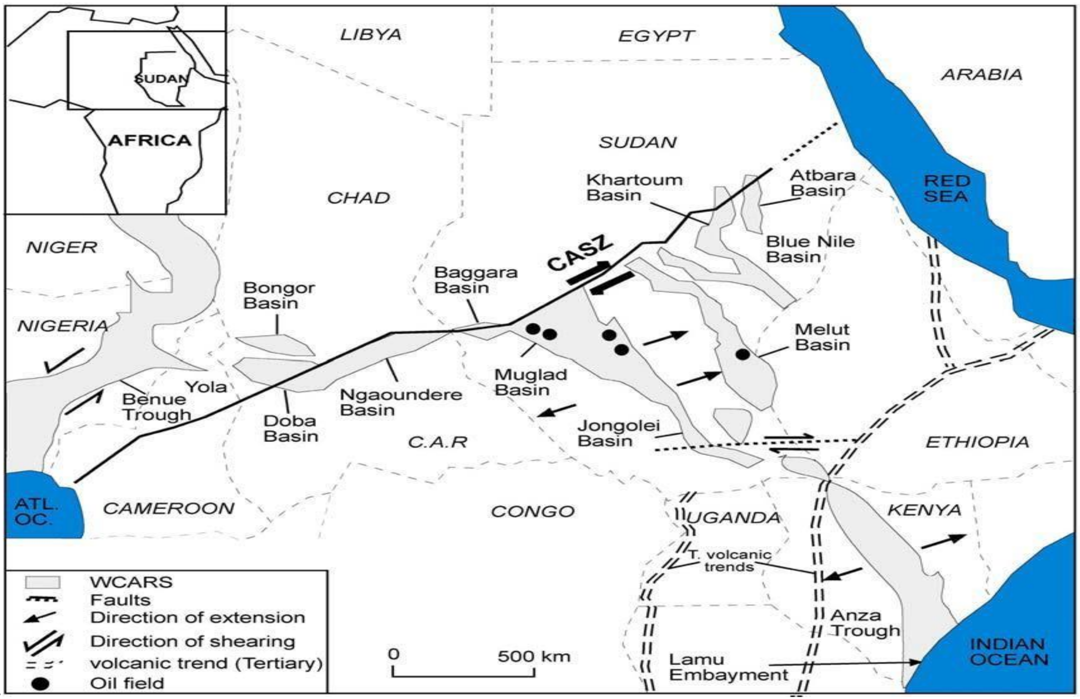


Fig.2.1:Tectonic model of the central African shear zone and West and Central African Rift System from Fair head (1988)

2.2 The Tectonic Evolution:

The south region of the Sudan affected by extensional tectonics that resulted several episodes of rifting along the early cretaceous up to the Oligocene. The Muglad basin evolution has been divided into (Shull,1988; Mohamed et al.,2001): Pre-rifting phase, Rifting phase, and Sag phase.

2.1.1. Pre-rifting phase:

The region became consolidated platform during the Paleozoic and the early Mesozoic after the pan African Orogeny had ended at (550MA+-100M.Y), the near subsiding areas of the region have been supplied by poorly sorted and various types of sediments.

2.1.2. Rifting phase:

Due to crustal extension relative to extensional tectonics three separated rifting phases had happened in the region extended through the early Cretaceous (135-96MA) and the late Cretaceous (96-65MA) to the Oligocene (33.7-23.5MA). These rifting phases provided the isostatic mechanism for subsidence which was accomplished by normal faulting parallel and sub-parallel to the basinal axes and margin, each rifting phases activated in a certain period and followed by thermal subsidence. (Sayed, 2003; Elhaj, 2016)

2.1.2.1. Early rifting phase:

It had begun in the Jurassic (?) – Early Cretaceous up to near the end of the Albian (108-96MA), simultaneously with the initial opening of the South Atlantic and the subsequent extension at the Benue Trough. Due to resulted shear movements, some basins developed within and in the immediate vicinity of the Cretaceous shear zones in the period from (120

– 90 Ma), these phase characterized by no volcanism is known to be associated.

2.1.2.2. Second rifting phase:

It had started in the Turonion (92-88MA) and continued up to the late Senonian (88.5-65AM). these rifting phases got risen due to tectonic effects of the changes in the opening of the southern Atlantic account for the late cretaceous period of shear movement in the west and central African rift system, these tectonic effects came as compressional stress at the Benue area and as dextral reactivation along Central African fault system during the late cretaceous time. The main evidence which the phase has left is in the southeast Muglad, the trend appeared to have been terminated and replaced by the northwest-southeast trending basins, which are extensional in their development. These phases differ from the last phase in that the second phase was accompanied by minor volcanism.

2.1.2.3. Final rifting phase:

It had initiated in the late Eocene (40-33.7MA) to the Oligocene (33.7-23.5Ma), approximately with the initial opening of the Red sea. there were evidences of volcanism.

2.1.3. Sag Phase:

began in the middle Miocene (15.8-11MA) when the basinal areas entered an intracratonic sag phase of very gentle subsidence accompanied by little or no faulting. (Sayed, 2003)

2.3 Sedimentary Setting:

The Muglad basin is filed with lower Cretaceous to Neogene sedimentary rock ranging in thickness from 6000 m to more than 13000 m were deposited in fluvial and lacustrine environment (USGS,2011).

The sediments were limited by Precambrian basement complex which are grandiorites encountered in Baraka-1 well and granitic basement encountered in Adilla-1 well. (RRI, 1991)

The sediment sequence figure (2.2) has three cycles each one deposited during a certain rifting phase. The first cycle has deposited Sharaf-Abu Gabra formations and Bentiu formation, the second cycle sediment have deposited Darfur group and Amal formation, the third cycle includes Kordofan group and end with Adok sandstone formation. The sediment sequence ended by the deposition of the late Miocene to recent Zaraf and Umm Ruwaba formations as post-rifting sediment. (Elhaj, 2016).

2.3.1. Sharaf-Abu Gabra Formations:

Sharaf-Abu Gabra formation consist of Neocomain-Barremian (131-126MA) Sharaf formation and the Aptian-Albian (126-100MA) Abu Gabra formation which were deposited during the late Jurassic-early cretaceous period. The formation represents 5 km of thickness of the Gross sediment in the basin.

The Sharaf formation consists of claystone, shale with interbeds of fine sandstone of lacustrine and fluvial environment, is relatively thick and has good source rock potential (Mohamed et al., 2001).

The Abu Gabra formation consist of interbedded claystone, shale andsandstone with localized development of siltstone, the top of the Abu Gabra formation underlies the Bentiu formation through Rakuba member. AbuGabra formation is also considered mainly as source rock and Reservoir rock in some parts. The ambient deposition environment is realized to be continental fluvial - lacustrine.

2.3.2. **Bentiu Formation**:

The end of the Albian (100MA) is the start the deposition of Bentiu sands (Mohamed et al., 2001), the deposition continued to the upper Cenomanian (100-94MA).

Formation lithology comprises primarily of sandstones interbedded with thinner beds of siltstone and claystone. The formation thickness ranges from 1835' to 5255' (RRI, 1991), bounded by Darfur group at the top, Bentiu sediment deposited through fluvial, lacustrine environment. The top of Bentiu formation is marked by an unconformity, and typically shows good reservoir quality.

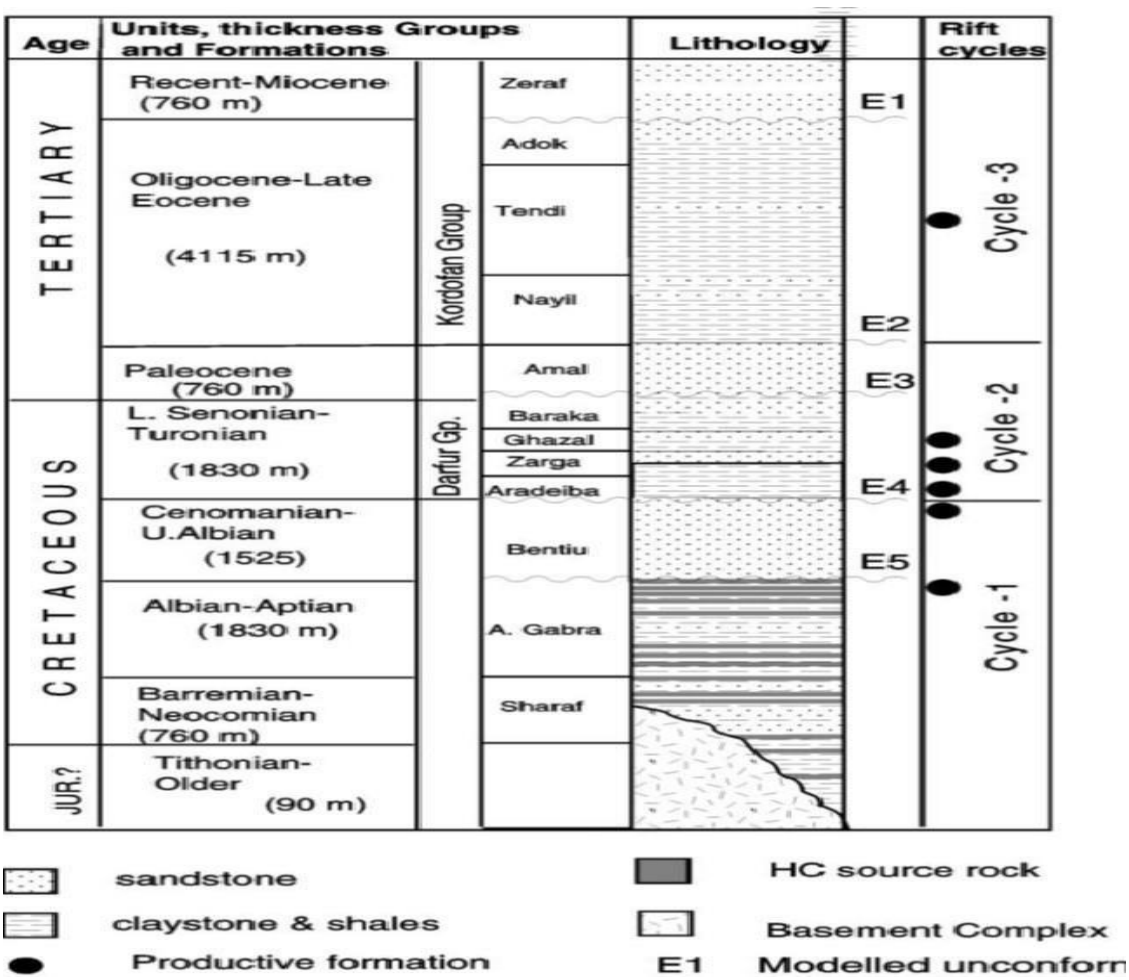


Fig (2.2): the sedimentary sequence of the Muglad basin with the depositional cycles from Mohamed et al.,(2001)

2.3.3. Darfur Group:

Darfur group contain late Cretaceous Early Tertiary sediment which consist of shale and siltstone in the Aradeiba and zarga formations and sandstone with thin beds of clay stones in Ghazal and Baraka formations. (Mohamed et al., 2001). The Group is overlined by marked unconformity separate it from thick sediment of Amal sandstone formation. The major sediment deposited in a fluvial and lacustrine environment. (RRI, 1991)

2.3.4. Kordofan Group:

Kordofan group sediments deposited during Tertiary rift phase, Eocene-lower Miocene(56-23MA) sediments consist primary of Nayil , Tendi, Adok and Zaraf formations. The Nayil, Tendi and Adok formation contain shale with interbedded sandstone, the top of Adok formation is marked by a major unconformity and the upper boundary is gradually going to a clear massive sequence of sand and sandstone of Zaraf formation. The majority of sediment deposited in fluvial, lacustrine environment (RRI, 1991; Mohamed et al., 2001)

Chapter Three

Methodology

3.1. Reflection Seismic Method:

Reflection seismology (or seismic reflection) is a method of exploration geophysics that uses the principles of seismology to estimate the properties of the Earth's subsurface from reflected seismic wave.

Seismic reflection become the most common method in oil and gas prospecting, as it is applied to map the subsurface to explore the following:

- The subsurface structure (fault, fold & salt dome) that may be a trap of the hydrocarbon.
- The stratigraphy & the depositional environments.
- Reservoir characterization. (Estimate the reservoir properties using amplitude information.)

3.1.1. Development of Seismic Method:

The application of seismic started after1912 in ice berg detection, then during World War I the Germans and Allis experimented the use of three or more mechanical seismographs which were invited in 1914 by Lodgers Mintrop to locate enemy artillery, and then the seismographs were applied for the determination of rock structures in 1919. In 1921 Mintrop founded seismos to do the geophysical exploration.

In the last third of 20th century 1960s, the digital revolution effected the seismic exploration industry. The seismic instruments became record the data digitally on magnetic tape and then computer can deal with this recording for further processing and interpretation to improve the reliability of data in imaging the subsurface structures.

The late 1970s showed the development of the three dimensional (3D) to resolve the interpretation ambiguities. The gain of enhanced computer capabilities in the late 1980s provided a rapid mean for interpretation through workstations, workstations solved many of the data handling problems, it reduced the time required for complete the interpretation, and also allowing for accurate interpretation. In the 1990s the processing of data had been improved therefore the focus was in depth section rather than time section.

Recently in the 2000s data is being acquired with an additional parameter of time as the 4th dimension of the existing 3D data acquisition system.

The development of 4-C seismic method where the recoding involves p-wave and also converted s-wave enable to better image the sub-salt and sub-basalt target also to detect oil-water contact and the top or base of the reservoir limit. (Talagapu, 2004)

3.2 Seismic Data Acquisition:

Seismic data acquired through producing seismic waves by one of common types of energy source (dynamite, viborsis, or air gun), the generated waves travel through the earth and when it encounters boundary between two layer that differ in density, seismic velocity and other elastic parameters, a portion of wave will transmit to the second layer and the balance part will have reflected to be received by ground motion detectors on land, or pressure variation at sea. The detectors convert the motion or pressure variation to electricity that is recorded by electronic instruments (seismograph).

Generally, there are some requirements in seismic data acquisition including the following: (Gadalla and Fisher, 2009)

- Surveying/navigation system to locate precisely the locations of source and receiver positions.
- Energy sources to generate Seismic waves having appropriate amplitudes and frequency spectra.

- Receivers to detect the reflected Seismic waves and convert it into electrical signals.
- Cables to transmit Signals output from the receivers to the recording system with minimum attenuation and distortion.
- Recording system to record transmitted Signals via the cables in a form that provides easy retrieval while preserving as much as possible of the information contained in the original signal.

In the field work the data acquisition methodologies vary with whether the type of the acquired data is 2D or 3D. Where 2D line required to be surveyed, the set of receiver groups are laid out along the line and source shot to them, and the receiver groups and the source are moved along the line to get the desired subsurface coverage.

The spread type implies the geometrical relationship between the receiver groups and the sources, the types of spread include off end spread shown on figure (3.1) where all receiver groups are on one side of the source. Other type of spreads is split spread illustrated on figure (3.2), here the receiver groups are the two sides of the source, if there are an equal number of receivers on each side of the source, the spread referred as symmetric split spread, however the spread is an asymmetric split spread if there are more receivers on one side of the source than the other side.

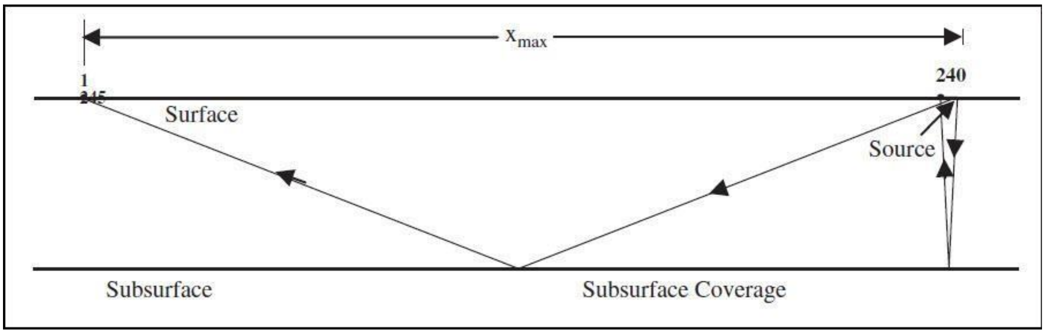
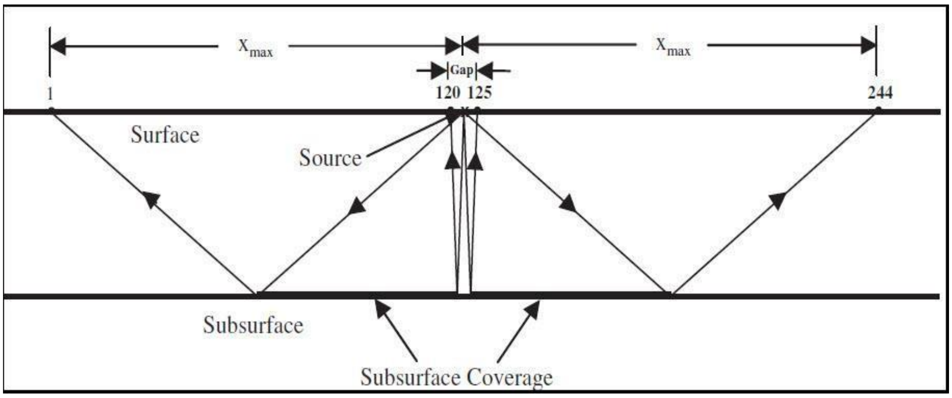
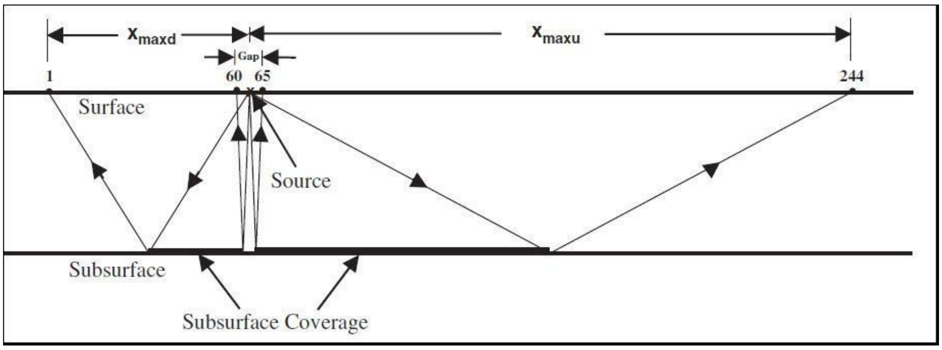


Fig .3.1: The offend spread figure where all receiver groups are on one side of the source.

Each receiver in a conventional reflection spread aligned in an array, the array involves groups of several geophone or hydrophone arranged in a specific pattern and connected together in series or parallel to produce a single channel of output, figure (3.3) shows the different types of arrays, such arrays provide receivers with a directional response that facilitate the enhancement of signal and the suppression of certain type of noise.



a.



b.

Fig. 3.2: split spread the receiver groups are the two sides of the source, (a) symmetric split spread where there are an equal number of receivers on each side of the source, (b) asymmetric split spread, where there are more receivers on one side of the source than the other side.

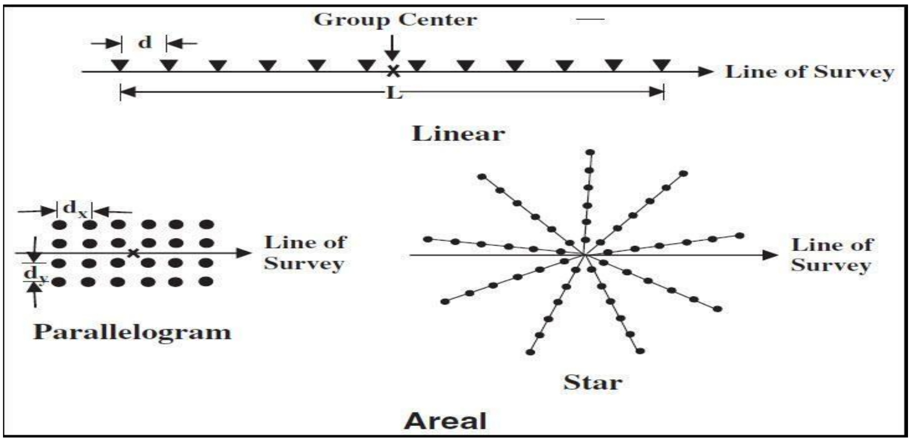


Fig .3.3: the different types of arrays, which are an arrangement in specific pattern of receivers to provide receivers with a directional response that facilitate the enhancement of signal and the suppression of certain type of noise.

In reflection survey a large number of shot record that generated to cover to area under study, a modern multifold shooting considers the recording of single reflection on multiple records, so that there is a common midpoint (CMP) between sources and receivers on many different shot records, this provides:

- Means to determine the velocity to use in normal moveout correction and.
- Traces can be combined by CMPs stacking into CMP trace that enhances signal to noise ratio and attenuate multiple reflection.

Figure (3.4 a, b) show respectively the multifold shooting (4-fold) and common midpoint creating.

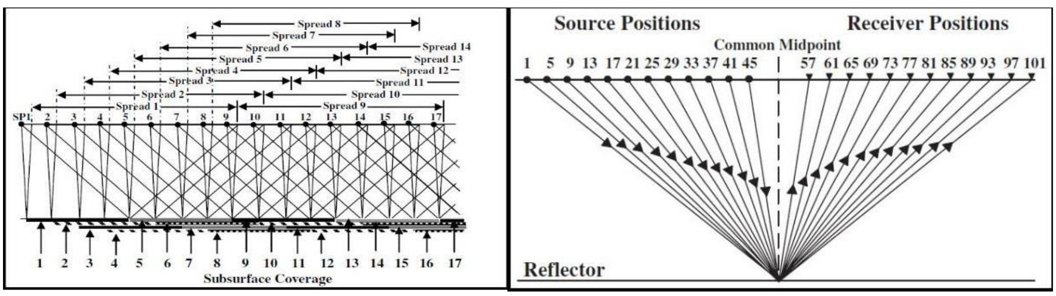


Fig .3.4: It shows: (a) the multifold shooting, and (b) common midpoint creating.

3.3 Seismic Data Recording and Storing:

Seismic data reflect an image for subsurface so it enables to extract information concerning to the subsurface geology, such data considered as end products “record section" of the process of data acquisition and processing, as shown in figure (3.5).

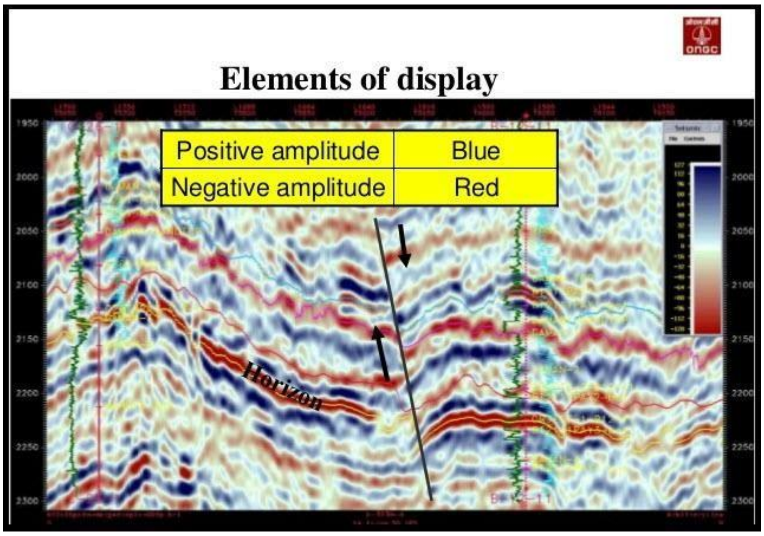


Fig.3.5: seismic record section end products of the process of data acquisition and processing.

Early, the received signals by geophone were recorded as wiggle trace written directly to paper or photographic film chart. Virtually all seismic data are now recorded by digitizing the analog geophone's output, this digitized data are recorded at magnetic tape in different formats. The society of exploration geophysicists (SEG) adopted standard formats which are:

- 1967 – SEG A and SEG B (field data, multiplexed), and SEG X (data exchange, demultiplexed)
- 1972 – SEG C (field data, multiplexed) introduced to accommodate IFP ecorders.

- 1975 – SEG Y (demultiplexed) introduced as new data exchange format to accommodate computer field equipment and newer processing hardware.
- 1980 – SEG D (multi-purpose, multiplexed or demultiplexed, details in the header) introduced to accommodate further advances in data acquisition and processing. SEG D was revised in 1994 to accommodate other developments, including 24-bit recording.

The seismic recording applied to different types of correction and processing sequence to realize resultant seismic sections that give a true representation of geological structures.

3.3.1. Seismic trace and seismogram:

Wiggle trace or seismic trace is a graphical plot of the output of a single detector in a reflection spread that represent visually the local pattern of vertical ground motion (on land) or pressure variation (at sea) over a short interval of time following the triggering of a nearby seismic source. This seismic trace represents the combined response of the layered ground and the recording system to a seismic pulse. Any display of a collection of one or more seismic traces is termed a seismogram.

3.3.2. Seismic section:

A collection of traces representing the responses of a series of detectors to the energy from one shot is termed a shot gather. A collection of the traces relating to the seismic response at one surface mid-point is termed a common mid-point gather (CMP gather). The collection of the seismic traces for each CMP and their transformation to a component of the image presented as a seismic section is the main task of seismic reflection processing.

Seismic data show the response of the earth to seismic waves, and the position of geologic bedding planes is only one of several factors which affect the response. (Baker Hughes INTEQ, 1999).

3.3.3. Seismic display:

There are several modes of display of seismic data that may affect the interpretability, the display modes include:

- **Wiggle display:** which appears the positive and negative loop trace as a continuous sinusoid line.
- **Var-wiggle display:** which show both positive and negative seismic loops one of which is colored.
- **Var-display (variable density display):** is an equivalent colour display where the negative and positive loops are differently colored in.
- **Dual polarity displays:** is a display shows all loops by one polarity regardless of the positive or negative character of the loop excursion.

The colour display brings out certain details on the reflection which are lost in the normal black and white display, figure (3.6) and figure (3.7) show modes of display.

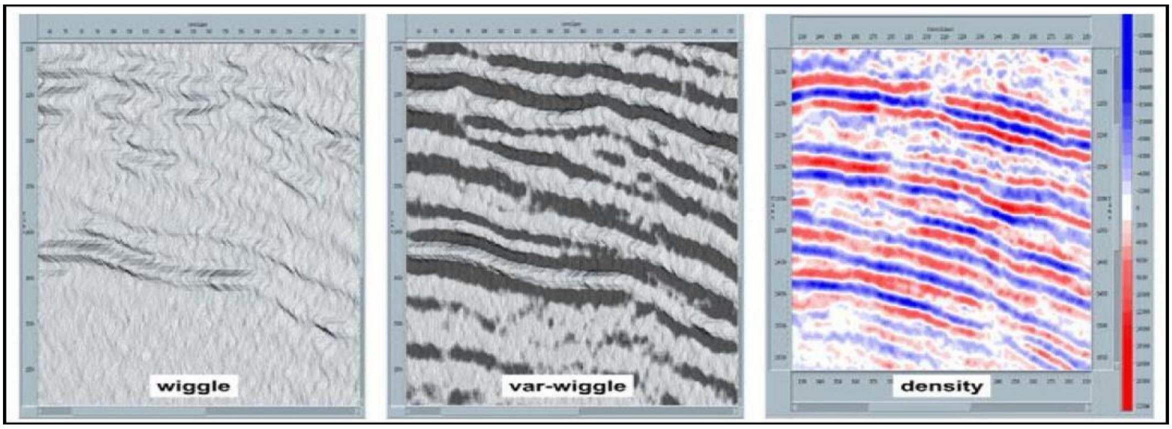


Fig.3.6: wiggle, var-wiggle and variable display of seismic data.

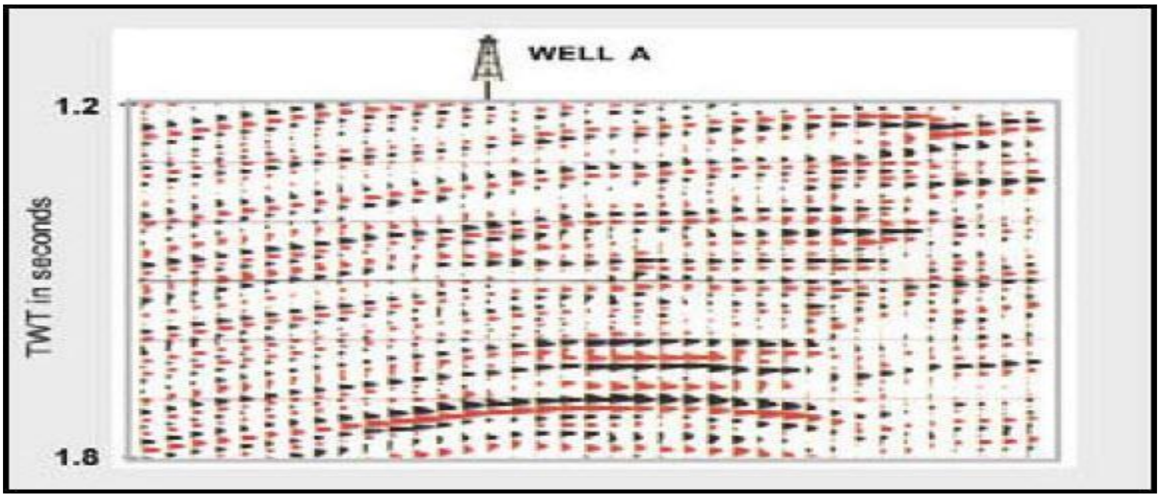


Fig. 3.7: Dual polarity display.

3.3.4. Seismic polarity:

Polarity is defined as the sense in which the seismic wiggle is drown on the seismic section. Polarity specifies whether the wiggle should be drown showing deflection to the left (a trough) or to right (a peak), if an interface give increase in impedance downward.

polarity conversion specifies that the normal polarity display corresponds to an increase in acoustic impedance with depth, display on seismic section by a white loop, being a trough to the left of the wiggle line (Veeken, 2007), on the other hand most interpreter at least in North America consider the normal polarity when having a positive reflection coefficient and displayed as peak.

3.3.5. Seismic wavelet:

There are two shapes of seismic wavelets presented on figure (3.8) which described as:

- **The minimum-phase wavelet**, whereby the start of the wavelet is coinciding with the exact position of the subsurface interface.
- **The zero-phase wavelet**, whereby the maximum amplitude of the wavelet is coinciding with the lithological interface.

Seismic wavelet may further have described by its length (wavelength) and the amplitude value and its polarity and also the frequency of wavelet.

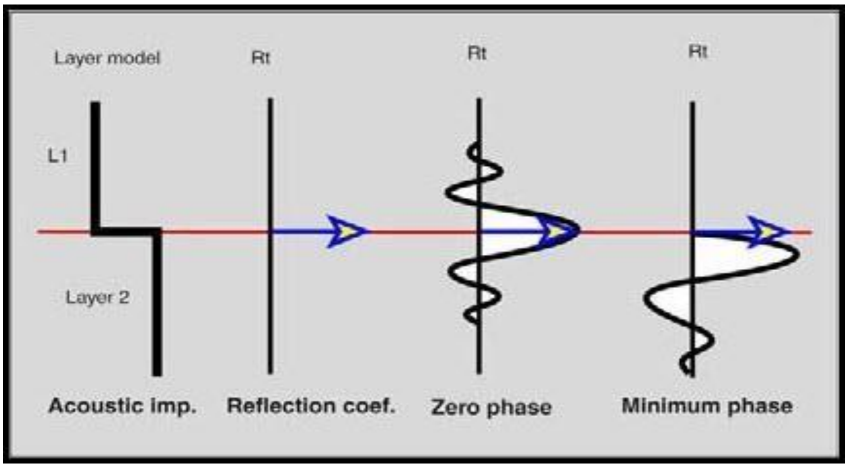


Fig.3.8: The zero-phase wavelet, whereby the maximum amplitude of the wavelet is coinciding with the lithological interface the minimum-phase wavelet, whereby the start of the wavelet is coinciding with the exact position of the subsurface interface.

3.3.6. Seismic resolution:

It is the ability to distinguish between separate points or objects, such as sedimentary sequences in a seismic section.

The number of reflecting interfaces on seismic section is depend primarily on the acoustic impedance value of a layer (Veeken, 2007), and further depends on:

- Original shape of the seismic input wavelet.
- Frequency and bandwidth of the recorded data.
- Filtering/automatic gain level applied.
- Interference effect caused by the presence of closely spaced bedding planes of different lithology.
- Interval velocity of the rocks.

The higher frequency and the shorter wavelength provide better vertical and lateral resolution, but the real seismic wavelets contain a limited range of frequency so, the resolution power of the conventional reflection seismic method is poorer and only under favorable circumstances individual beds of 10 meters are resolved.

3.3.7. Vertical resolution:

Is minimum separation in time or depth to distinguish between two interfaces to show two separate reflectors & depends on dominant frequency, magnitude of events, & Separation between events.

3.3.8. Horizontal resolution:

Is minimum distance between two features required to distinguish them as two separate features in an interface on seismic record. It depends on Fresnel zone dimension, dominant frequency, Velocity, and dip angle.

3.4. Seismic stratigraphy:

The study of seismic data for the purpose of extracting stratigraphic information. However the term seismic stratigraphy become common place in the vocabulary of geologists and seismic interpreters only after publication in 1977 of authoritative AAPG Memoir 26, seismic stratigraphy, Applications to Hydrocarbon Exploration (payton 1977).

Seismic stratigraphy techniques help us for stratigraphic interpretation of seismic reflectors. It is important because geological concepts of stratigraphy can be applied on seismic data and hence, seismic stratigraphy can be used as a predictive tool for petroleum system elements like reservoir, seal and source rock. The basic assumption behind seismic stratigraphy is that individual reflector can be considered as timelines i.e. it is representing a very short time interval of similar sedimentation conditions. This assumption signifies that seismic reflector can have the different depositional environment and therefore it has information of various lithofacies units. However, for seismic stratigraphic analysis, only sedimentary reflections should be used.

3.4.1. Non-sedimentary reflections:

Seismic data contains many non-geological reflectors. These can be artefacts like diffractions, multiples or non-sedimentary reflections like fault planes, fluid contact etc. These non-geological elements need to be recognized before any seismic stratigraphic analysis.

3.4.2. Sedimentary reflections:

The basic assumption is that Seismic reflection represents bedding plane. So, Its characteristics should change with conformable changes in depositional regime. These changes can be energy level, depositional environment, sedimentation rates, source, diagenesis and pore contents.

There are several features of seismic data that can help us to interpret depositional regimes.

- Reflection continuity: It shows the continuity of layers. It is related to energy levels and sedimentary processes in the depositional environment.
- Reflection amplitude: It shows lithology contrast, bedding spacing and fluid content.
- Reflection configuration: It shows the geometry of bedding pattern. Important to interpret palaeogeography.
- Reflection frequency: It gives bed thickness and sometimes fluid information like gas.
- Interval velocity derived from seismic: It is important for gross lithologies, porosity distribution and fluid contact.

Interval seismic velocity also gives additional information on gross lithology, porosity and fluids. Spatial association of these attributes of seismic reflectors give an idea of the depositional environment.

3.4.3. Unconformities:

Unconformities are surfaces of erosion and/or non-deposition. It signifies time-gaps in the geological record. Unconformities can generate reflections because they separate stratigraphic beds of different lithologies and hence, different physical properties.

Often, there is angular contact between beds of two units across unconformity. This angular relationship shows tectonic deformation before the deposition of the younger sediments were deposited. Erosion truncates the underlying strata or time units. If beds of both units are parallel then it would be difficult to recognize unconformity from seismic. In this case, other techniques like bio-stratigraphy, isotopic analysis may be helpful.

Several types of reflection terminations can be seen on seismic at these unconformable interfaces:

- **Erosional truncation**

  Older sediments are eroded. Underlying sediments may be deformed.This can indicate a time of hiatus before other overlaying strata was deposited.

- **Top-lap**

  If erosion is affecting a prograding geometry. The underlying unit mustshow a depositionally inclined layering.

- **Concordance**

  It is the case when interface and the overlain or underlain stratum aredeformed in the same manner.

- **On-lap**

  It is the case when the younger sediments are progressively oversteppingeach other.

- **Down-lap**

  It is the case when younger strata's forests abut on the unconformity.The inclined foresting gives indication sediment of supply direction.

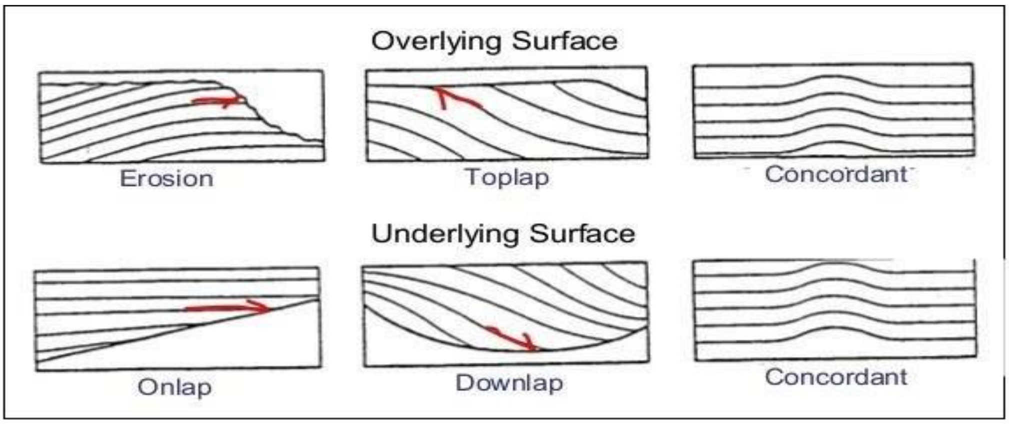


Fig.3.9: Bedset terminations are named according to their angular relationship with underlying and overlying bounding surfaces

The structural configurations of the beds of both sides of the unconformity and the internal reflection patterns displayed by overlain an underlain units gives tectonic and environmental significance of the interface. It can give hints such as

- It was subaerial, submarine, fluvial or glacial in origin

- Time gap is erosional or non-depositional. Non-depositional may indicates sediment bypass.

- Topographic relief is planar, irregular

- Unconformity is local or regional

- It may indicate relative sea level behavior, sediment supply etc.

Above mentioned reflection terminations need to be mapped out on seismic data. After mapping, it is possible to outline the unconformities. These boundaries separate genetically related depositional units and hence, subdivide seismic sections into various Depositional Sequences. A variety of seismic facies units may be present in a single depositional sequence. Next step in seismic stratigraphy to map out these seismic facies units.

3.4.4. Sequence Stratigraphy:

Sequence Stratigraphy is the study of rock units within a Chronostratigrphic framework bounded by erosional surfaces, nondeposition, or conformities.

The concept of sequence stratigraphy was first developed by Peter Vail in the 1960s. While he was a senior scientist at Exxon, he come up with three core concepts that define sequence stratigraphy.

- Seismic reflections are generated by physical bedding surfaces.
- Seismic reflections create patterns or sequences that can be used to interpret depositional environment and lithology.
- Unconformities that form sequence boundaries are the same age when located in multiple basins are located.

Vail also believe that eustacy is the main control on unconformities, sedimentary systems, and system tracts within a stratigraphic sequence.

Sequences, Parasequences, and Parasquence Sets

Sequences are bounded by unconformities and their correlative conformity. A sequence is formed in response to sea level change, subsidence, and sediment supply. They can be broken down into system tracts (the next section). Within in a sequence is a parasequence and parasquence set. Parasequences are defined by marine flooding planes, and are usually aggradational. Para-sequence sets are genetically related parasequences which form distinct stacking patterns that are bounded, usually by flooding surfaces.

Both sequences and Para-sequences are defined by their physical relationship of the strata. Sequences and Para-sequences allow geologiststo predict stratal relationships and infer geologic age.

3.4.5. System Tracts:

System tracts are associated with seismic stratigraphy and eustacy. A system tract is an indicator of the deposition sequences that would be present within a sea level cycle. They fall into three categories.

1. Low System Tract (LST): This is created when sea level is low, but sea level is starting to rise. There is high sedimentation rates coupled with little accommodation space which causes layer stacking. Within a LST there will be progradational Para-sequences moving out from the shelf.
2. Transgressive System Tract (TST): This is created when sea level is rising. Here, there accommodation space is greater than the sedimentation rate, which causes a retogradational set of parasequences. At the very top of the TST is the maximum flooding surface (MFS). This is where the furthest amount of flooding occurred on the surface before sea level begins to drop.
3. Template: High System Tract High stand System Tract (HST): This is created when sea level starts to drop. Accommodation space is once again less than sedimentation rates first causing aggradationalstacked parasquences then to progradational stack. At the top of the HST is where a sequence boundary is formed. This boundary can be affected by erosion, especially if there is a long period of low sea level.

3.4.6. ABC Method:

Seismic facies mapping was definitively explained in Ramsayer’s (1979), based upon 2D seismic sections interpreted prior to the advent of seismic workstations. This is referred to as the “A-B-C” mapping approach, as observations are made upon the upper boundary (A), the lower boundary (B), and internal reflection character (C). For example, a prograding seismic package with oblique clinoforms, toplap at its upper surface and down-lap at Its base would be noted as Top-Dwn/Ob.

The three categories (A-B-C) of Ramsayer's (1979) seismic facies codes each include five types, thus providing 15 different variations for a given seismic interval of interest. Although the technique was developed largely from 2D seismic data, it can be used on modern 2D and 3D sections displayed on conventional industry workstations. In addition to A-B-C seismic facies maps, other observations include marking stratal terminations (e.g., arrows indicating downlap and toplap), isochron thickness, or depositional limits of the individual lobes and interpreted progradation direction or sediment input orientation. Different seismic facies sometimes correspond to different progradational lobes. It is useful to indicate paleoshelf margin location by symbols, such as triangles or filled circles. Rather than mapping the entire sequence, it is recommended that individual maps be constructed for each depositional systems tract. These often have different seismic facies character and map geometry. Note how the interpreted high-stand systems tract (HST) is characterized by offsetting lobes, which define the high-stand shelf phase deltas, which in aggregate prograde the shelf margin from the maximum flooding position. The transgressive systems tract (TST) has a different map pattern than the overlying high-stand systems tract. Few stratal terminations can be identified. The mapped seismic facies is located largely inboard of the shelf margin position. Only one seismic facies (largely parallel continuous reflections) can be recognized, in contrast to four facies mapped in the HST. The low-stand systems tract (LST) is largely formed seaward of the shelf margin position.

Two distinct seismic facies are represented:

1) a large mounded to parallel seismic facies thought to be the basin-floor fans or thick.
2) more lobate but a really limited packages near the shelf margin, interpreted as lowstand-wedge-prograding complexes.

Comparing these maps, one can see the variations in map pattern through one eustatic sea level cycle. Stacking all the systems tracts for one cycle, by contrast, leaves a very complicated map. Seismic facies mapping on the workstation can be done with both 3D and 2D seismic, although the latter case involves some interpretative interpolation between 2D lines. Using the map geometries and seismic facies characteristics tied to well control, interpretation of the depositional sand bodies is made.

Key Stratigraphic Units Are Broken Out by using A B C method where:

$$\frac{A - B}{C}$$

A = Termination Pattern at the Upper Sequence Boundary

Tr = Truncation Tp = Toplap C = Concordant

B = Termination Pattern at the Lower Sequence Boundary

On = Onlap Dn = Downlapn C = Concordant

C = Internal Reflection Pattern

3.5 Well Logging Method:

3.5.1. Background:

As logging tools and interpretive methods are developing in accuracy and sophistication. They are playing an expanded role in the geological decision-making process.

Today, Petrophysical log interpretation is one of the most Useful and important tools available to a petroleum geologist. Beside, their traditional use in exploration to correlate zones and to assist with structure and isopach mapping, logs help define physical rock characteristics such as lithology, porosity, pore geometry, and permeability. Logging data is used to identify productive zones, to determine depth and thickness of zones, to distinguish between oil, gas, or water in a reservoir, and to estimate hydrocarbon reserves. Also, geologic maps developed from log interpretation help with determining facies relationships and drilling locations. (G.Asquith and C.Giboson, 1982)

There two main types of logs that may be run are the following: Logging While Drilling (LWD) Where the formation properties are being measured at the time the formation is drilled by use of special drill collars that hold measuring devices (R. M. Bateman, 1985), whereas the Wireline Logging Where the measurement of formation properties is made through a tool that are lowered by a wireline after a section of the hole have been drilled. This study utilizes wireline logging data which will be explained in the following.

3.5.2. Wireline logging (Principles and processes):

The wireline logging process is the practice of making a detailed record (a well log) of the geologic formations penetrated by a borehole. Logs are considered as a continuous record of measurement made in borehole respond to variation in some physical properties (e.g. velocity, density…) of rocks through which the bore hole is drilled. The sonde (measuring tool) is lowered into the wellbore through logging cable connected to the logging truck which contains set of control panel and digital recording system. Survey is normally done from the bottom up. As the sonde is pulled up the hole, a continuous measurement signal is sent to the surface where the data is processed and recorded as a curve as described on figure (3.21).

3.5.3 The main logs used in seismic interpretation:

3.5.3.1. Spontaneous Potential Log (SP):

The spontaneous potential (SP) curve records the naturally occurring electrical potential (voltage) in the formation, the natural potential difference occurring when mud filtrate of a certain salinity invades the formation containing water of a different salinity. The difference in salinity cause to make interactions between the two fluids, and between fluids and shale.

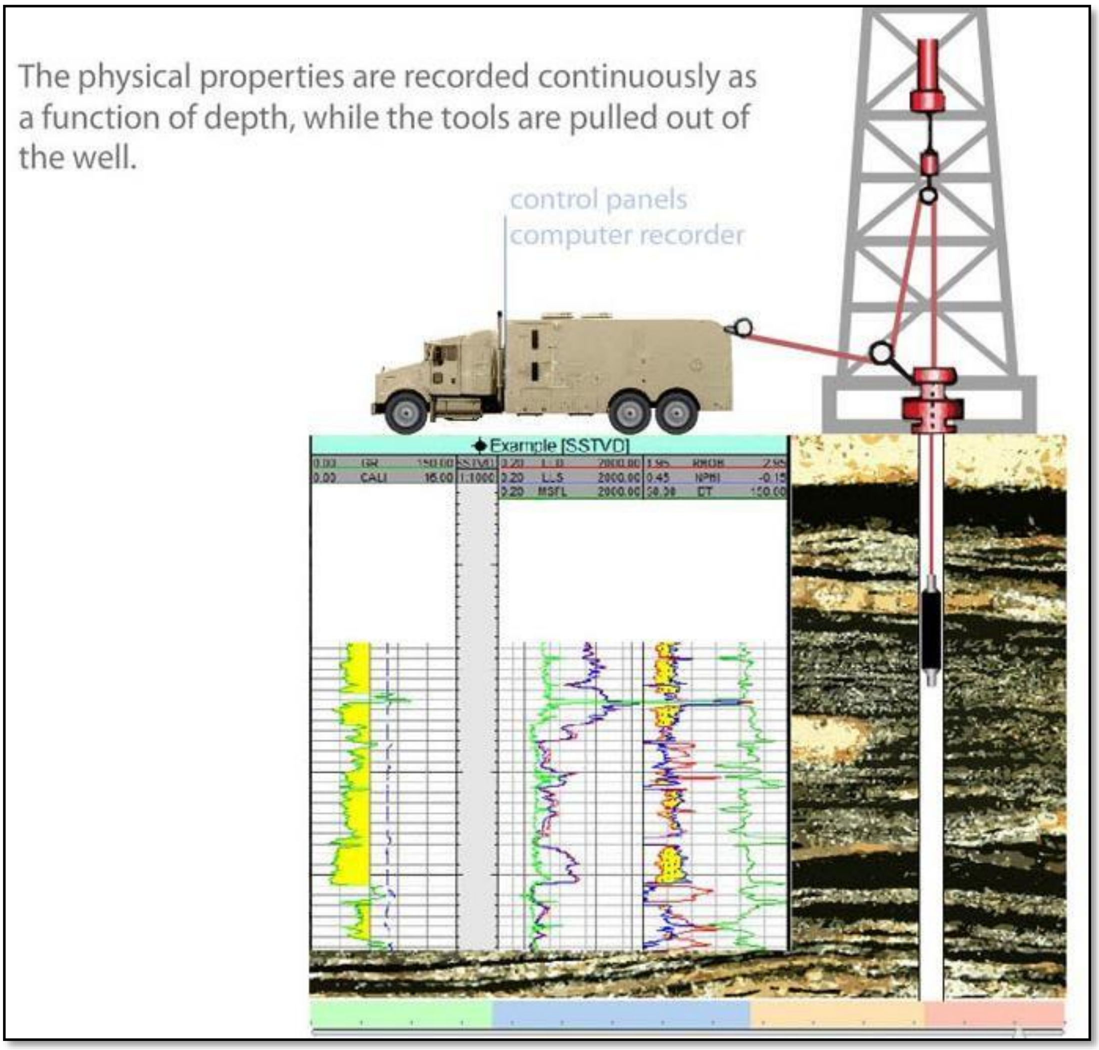


Fig.3.10: well logging its measurements and recording.

Fig.3.11: The Basic Well Logging Tools.

Though the SP is used primarily as a lithology indicator and as a correlation tool, it has other uses as well:

- permeability indicator,
- shale volume indicator
- porosity indicator, and
- Measurement of water true resistivity Rw (hence formation water salinity).

3.5.3.2. Gama ray log (GR):

Gamma ray log is measurement of natural radioactivity in formation verses depth. It measures the radiation emitting from naturally occurring uranium (U), thorium (Th), and potassium (K) in the formation.

GR log can characterize the clean formations from shelly formation where the radioactive elements tend to concentrate in clays and shales, so shelly formation give high GR reading.

3.5.3.3 Sonic log:

The sonic logging tool measures the transit time of an acoustic waveform between an emitter and receiver, spaced several feet apart. The acoustic log can be used to determine porosity in consolidated formations, it is also valuable in other applications, such as:

- Indicating lithology (using the ratio of compressional velocity over shear velocity).
- Determining integrated travel time (an important tool for seismic/wellbore correlation).
- Correlation with other wells.
- Detecting fractures and evaluating secondary porosity.
- Evaluating cement bonds between casing, and formation.
- Detecting over-pressure.
- Determining mechanical properties (in combination with the density log).
- Determining acoustic impedance (in combination with the density log).

3.5.3.4. Density log:

The density of the rocks is registered by lowering a radioactive source (gamma ray particle) in the borehole. The emitted radiation encounters electrons of formation and is backscattered by the Compton Effect. The amount of back scatter is counted by the specially shielded detector. The number of electrons is proportional to the bulk density.

In seismic interpretation the Sonic and density log are used together to calculate the acoustic impedance and thus the reflectivity variation with depth figure (3.23).

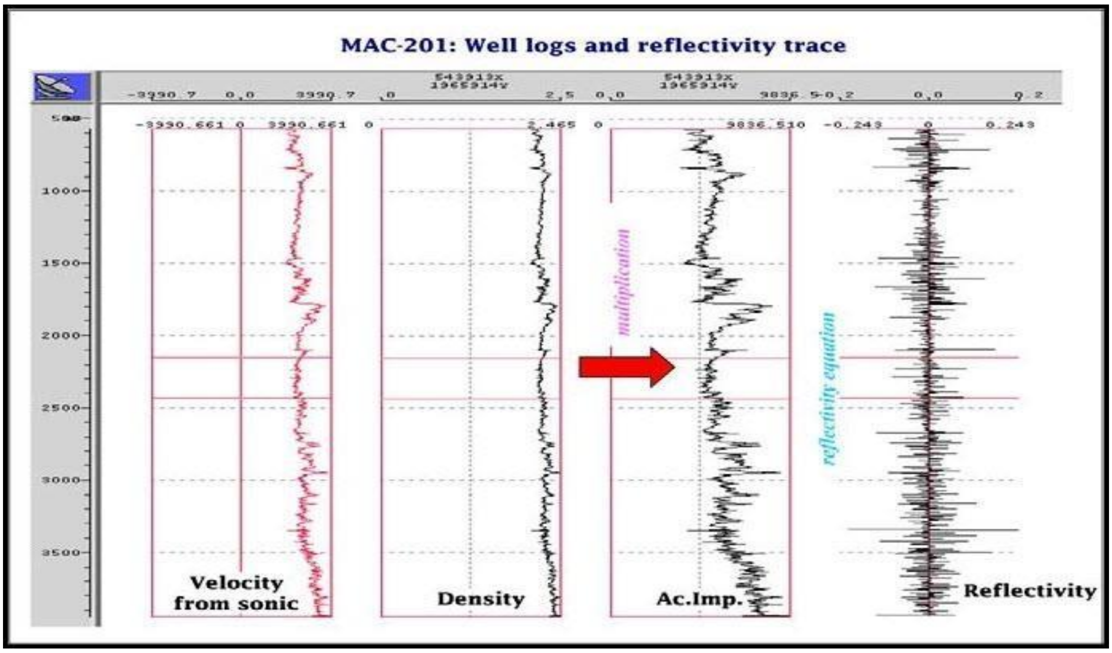


Fig.3.12: The Sonic and density log are used together to calculate the acoustic impedance and thus the reflectivity variation with depth.

3.5.4. Seismic to well tie:

Well information is the most reliable source of stratigraphy so, it provides an important mean aid the interpretation. Frequently well have sonic and formation density log that are used to generate synthetic seismogram.

Well to seismic tie process aim to:

- **Zero phasing:** checking whether da**ta** are zero phase, and helping to adjust the place if required.
- **Horizon identification:** relating stratigraphic markers in the well to loops in the seismic section.
- **Wavelet extraction:** which for seismic inversion or modelling.
- **Offset scaling:** to checking whether the seismic data have been true amplitude processed to have correct AVO behavior**.**

To compare the well data measured in depth with seismic data measured in traveltime it required to establish time -depth relationship through the following:

3.5.5. Velocity survey:

Are Measurements used to determine average velocity versus depth, such as from an acoustic log or check-shot survey in order to conduct depth- time conversion. Acquiring a velocity survey is also known as "shooting a well".

Check-shot is a type of borehole seismic data designed to measure the seismic travel-time from the surface to a known depth. P-wave velocity of the formations encountered in a wellbore can be measured directly by lowering a geophone to each formation of interest, sending out a source of energy from the surface of the Earth, and recording the resultant signal. The data can then be correlated to surface seismic data by correcting the sonic log and generating a synthetic seismogram to confirm or modify seismic interpretations.

Well survey: is a well survey to convert along borehole depths to true vertical depths.

3.5.6. Synthetic seismogram:

Synthetic seismograms are artificial reflection records made from velocity logs by conversion of the velocity log in depth to a reflectivity function in time and by convolution of this function with a presumed appropriate wavelet or source pulse. (Dobrin and Savit, 1988), Since the main input to form the synthetic seismogram are:

- A sonic log.
- A density log.
- A check shot survey or VSP.
- A seismic wavelet.

The integrated sonic log, calibrated with the check shots, allows for time conversion of the well data. A T–Z graph is normally constructed for this purpose. A velocity log can be computed from the sonic log, which measures transit times (DT). The sonic velocity is given by (Veeken 2007):

$$\text{Sonic velocity} = (1/DT)\ 304800.$$

The velocity and density log are multiplied together to generate an acoustic impedance log, The AI contrast at each sampling point is computed, so reflectivity series is obtained, then the reflectivity series is subsequently convolved with a seismic wavelet and a synthetic trace, illustrated on figure (3.24), is created.

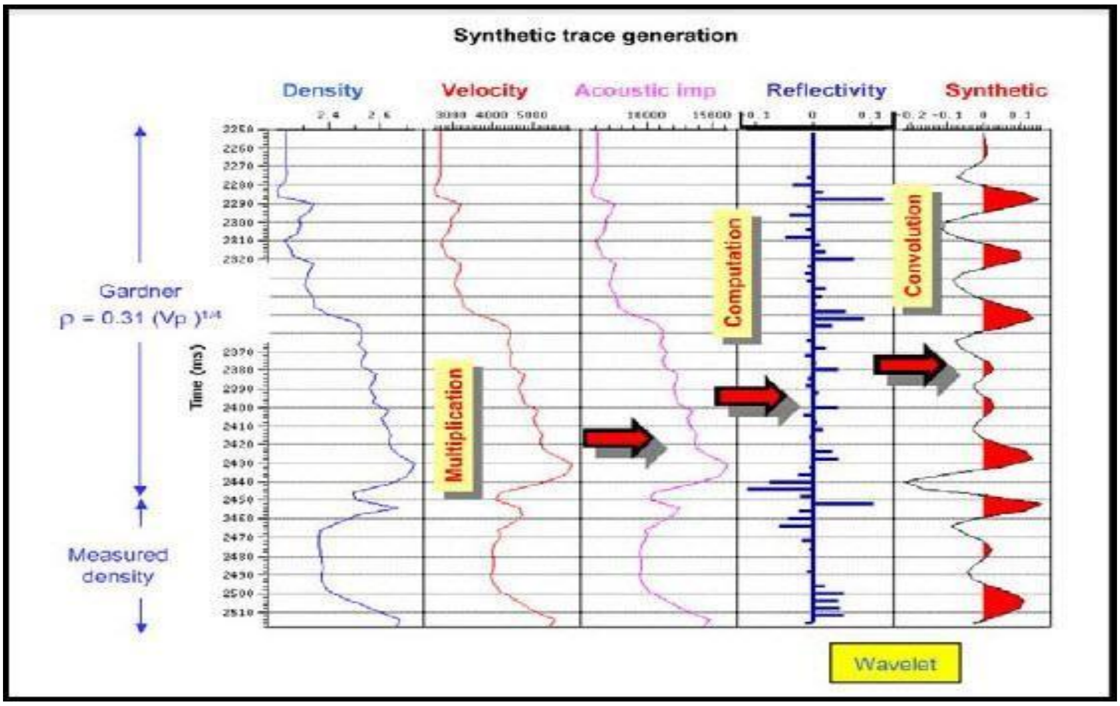


Fig.3.13: Synthetic trace generation, The velocity and density log are multiplied together to generate an acoustic impedance log, The AI contrast at each sampling point is computed, so reflectivity series is obtained, then the reflectivity series is subsequently convolved with a seismic wavelet.

The amplitude spectrum of seismic wavelet can be estimated from the seismic data, to describe the wavelet completely both the amplitude spectrum and the phase spectrum is needed, two particular types of wavelet are often used: the minimum-phase and zero-phase wavelet. A minimum phase wavelet is a causal wavelet.

The synthetic trace is compared to the seismic traces on the seismic sections through the well, to do this purpose the synthetic trace overlaid or split-in with the seismic data at the well location. It's important to consider the differences in reference level taken for the seismic and logs before comparing the well logs and the seismic. If this is not done, it will result in an additional bulk time shift for the synthetic trace.

On the synthetic seismogram the position of various biozones, stratigraphic markers and other relevant well information is precisely known and hence a reliable match is made. (Veeken, 2007)

3.6 Technical method:

In the later years the technical tools took an essential role in applying the theoretical aspects, particularly computer programs that became the important tool in the interpretation of the geophysical data.

3.7 Petrel program:

Petrel is a software platform used in the exploration and production sector of the petroleum industry. It allows the user to interpret seismic data, perform well correlation, build reservoir models, visualize reservoir simulation results, calculate volumes, produce maps and design development strategies to maximize reservoir exploitation. Risk and uncertainty can be assessed throughout the life of the reservoir. Petrel is developed and built by Schlumberger, Newer versions of Petrel include additional functionality such as geological modeling, seismic interpretation, uncertainty analysis, well planning, and links to reservoir simulators.

In the seismic interpretation the Petrel enables basin-, prospect-, and field-scale 2D/3D seismic interpretation and mapping. The work can be with thousands of 2D lines, thousands of kilometers, and multiple 3D vintages and surveys—across multiple coordinate systems with very high visualization performances (GPU based).

Advanced visualization tools enable seismic overlay and RGB/CMY color blending and enhance the delineation of structural and stratigraphic features. Accurate interpretation of those features is made possible by the complete set of tools, such as advanced horizon tracking, multi-Z interpretation, interactive mesh editing, and more. You can move effortlessly from interpretation to structural model building and back using the modeling-while-interpreting workflow (Schlumberger, 2016).

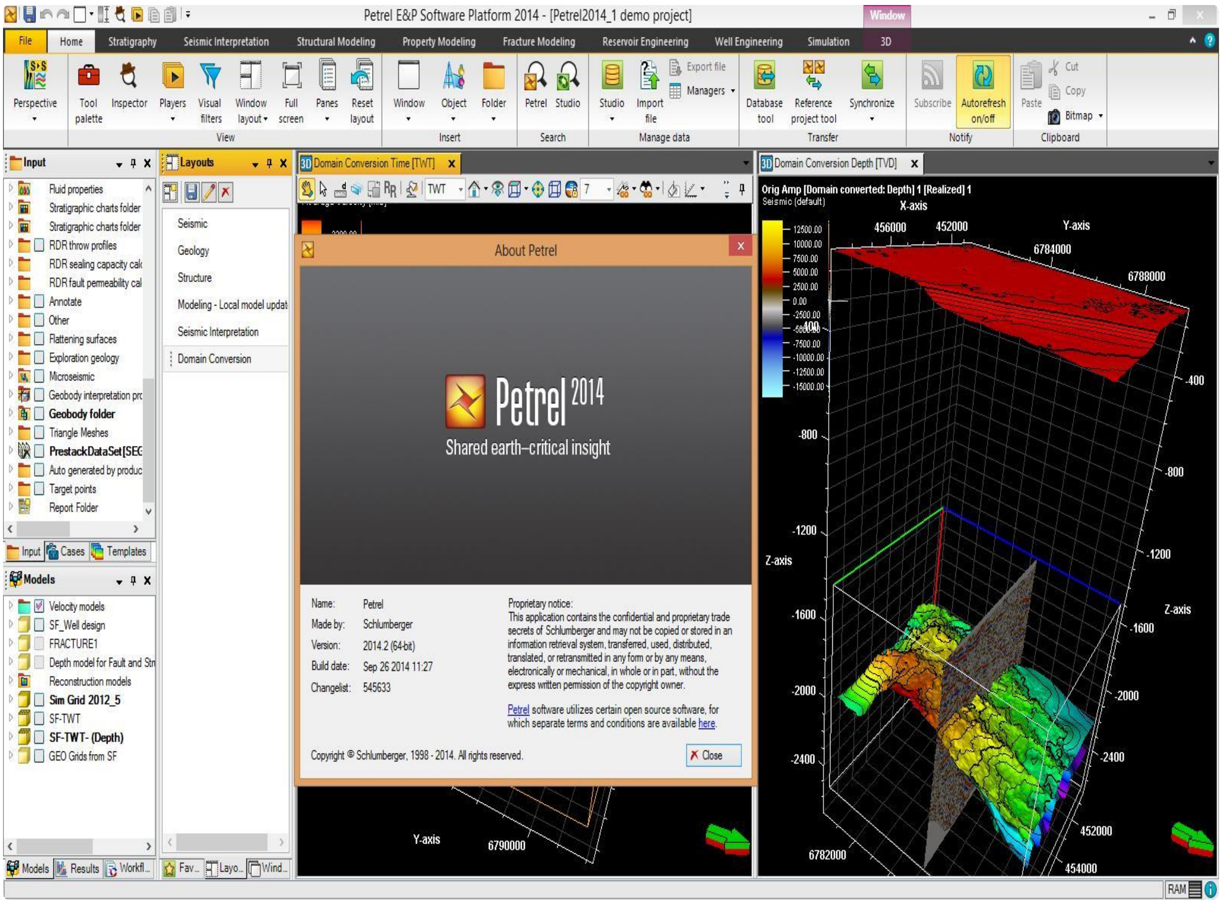


Figure.3.14: The desktop petrel program.

Chapter Four

Integrated Data Interpretation

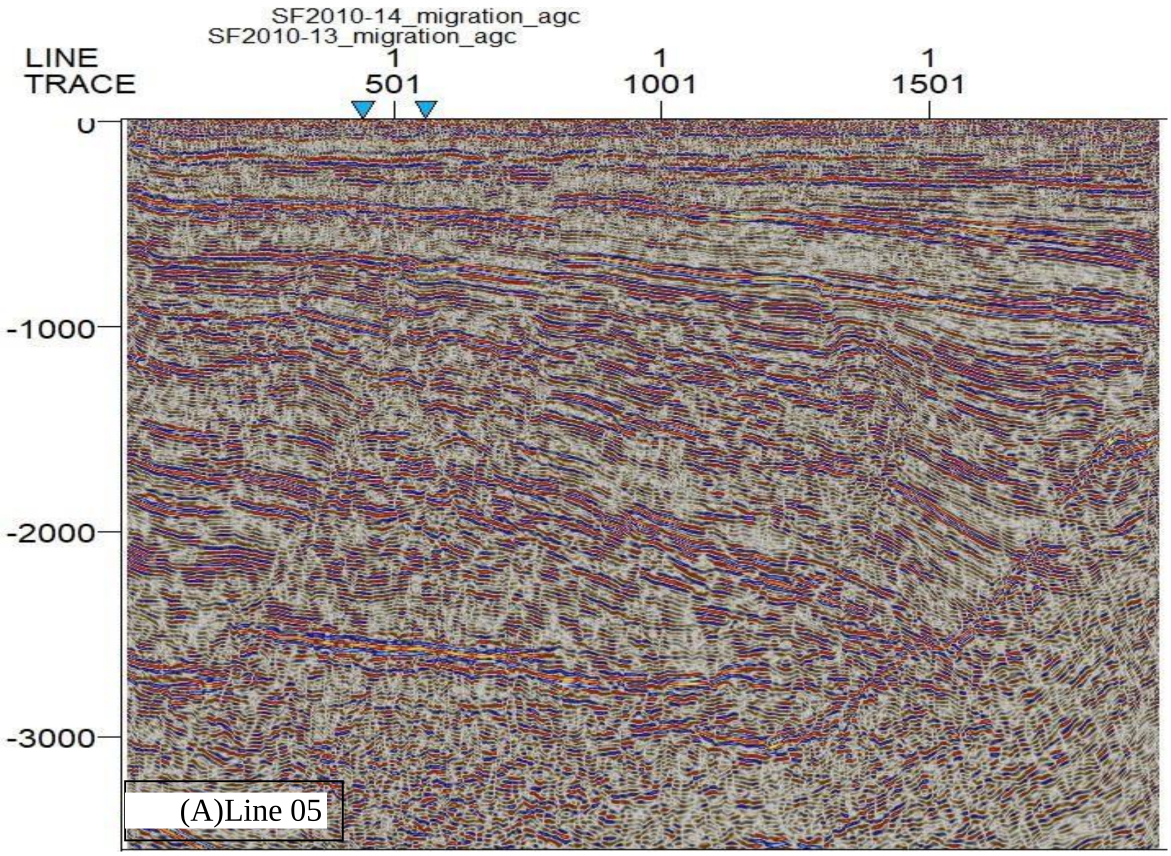
4.1. Introduction:

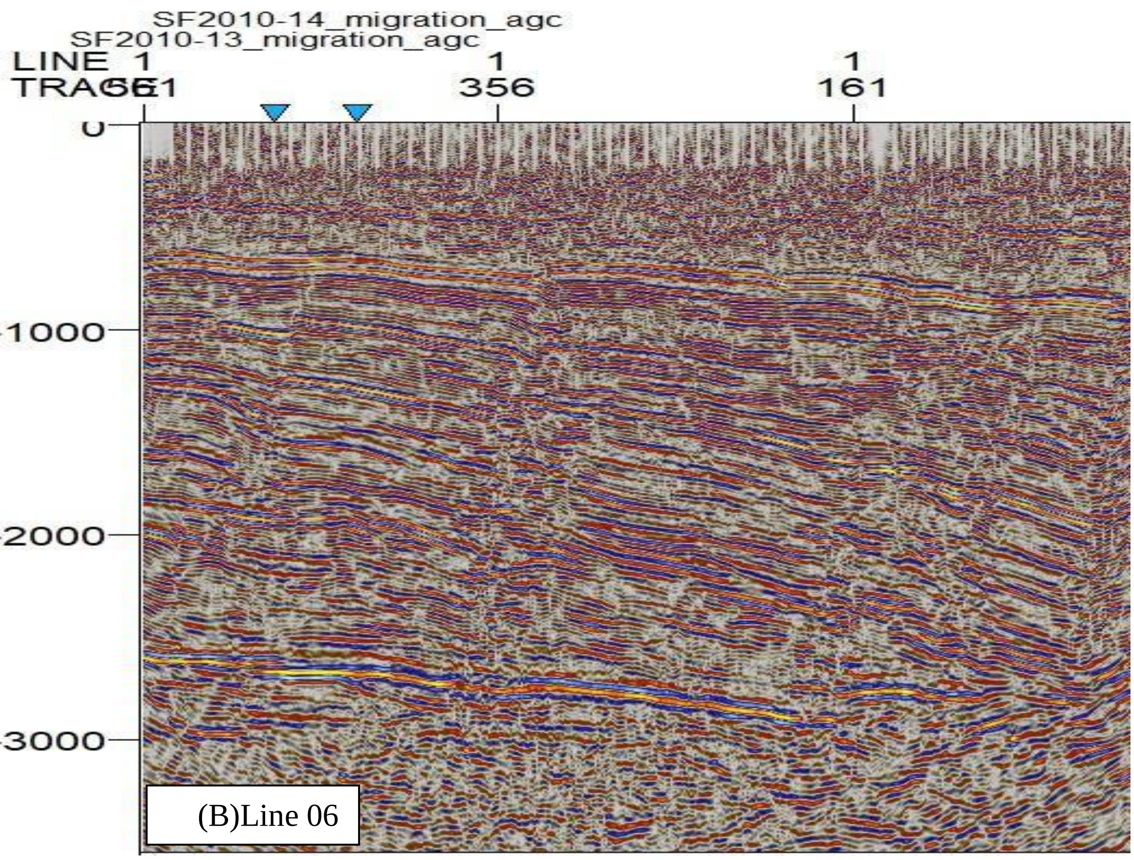
Seismic data interpretation of four selected 2D seismic lines was integrated with well data (Sufyan N-3) to delineate the dominant sequence stratigraphy of study area. These lines were loaded on the Petrel^{TM} software shows in figure (4-1) where:

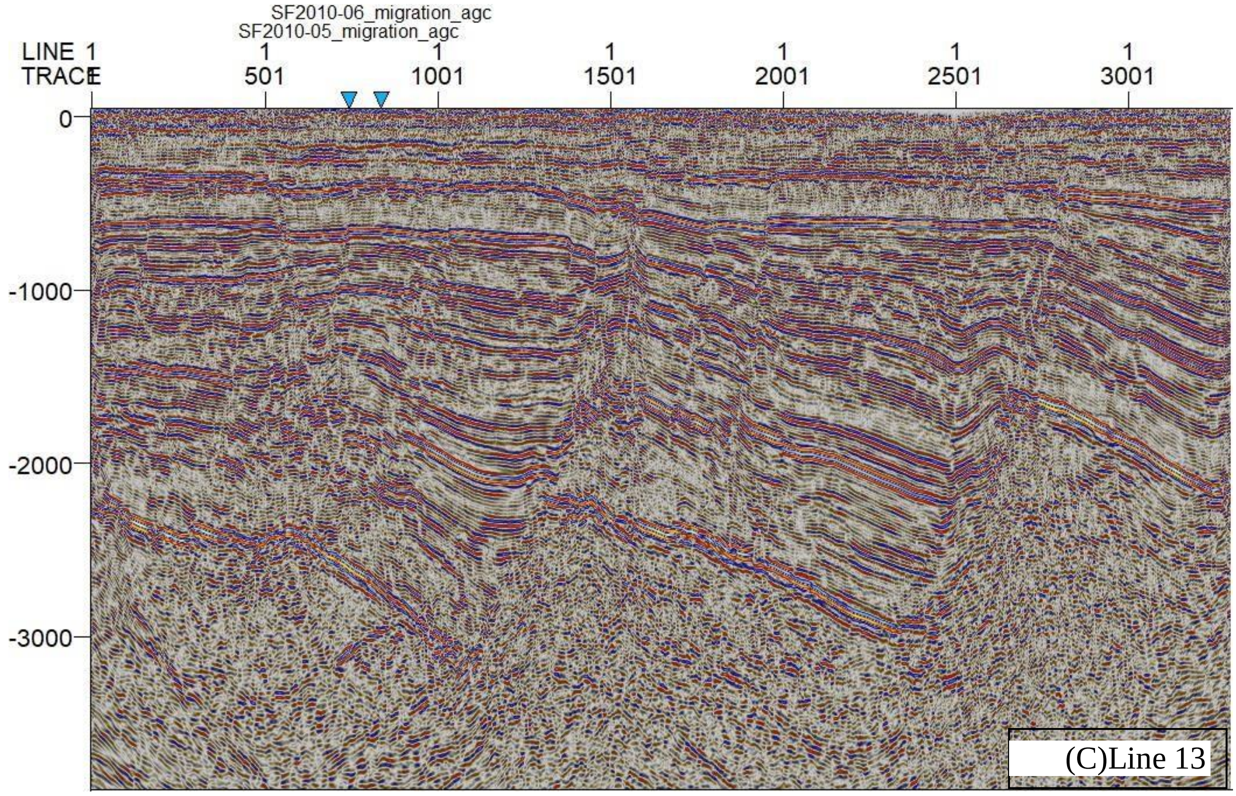
i. SF2010-05_migration_agc
ii. SF2010-06_migration_agc
iii. SF2010-13_migration_agc
iv. SF2010-14_migration_agc

Petrel^{TM} software provides various options for conducting the picking of horizons, it provides Auto tracking that enable to pick the reflector automatically moreover it provides manual picking. The selected picking methods depend on the quality of horizon reflectivity either it was easy to be picked automatically or hard to be picked for which the manual option is prefer. In this study, all horizon tops were picked through manual tracking.

The well location was shifted to location (x: 435789.246, y: 1288762.432) to improve formation tops.


SF2010-14_migration_agc
SF2010-13_migration_agc
LINE
TRACE
1
501
1
1001
1
1501
0
-1000
-2000
-3000
(A)Line 05


SF2010-14_migration_agc
SF2010-13_migration_agc
LINE
TRACE
1
356
1
161
0
-1000
-2000
-3000
(B)Line 06



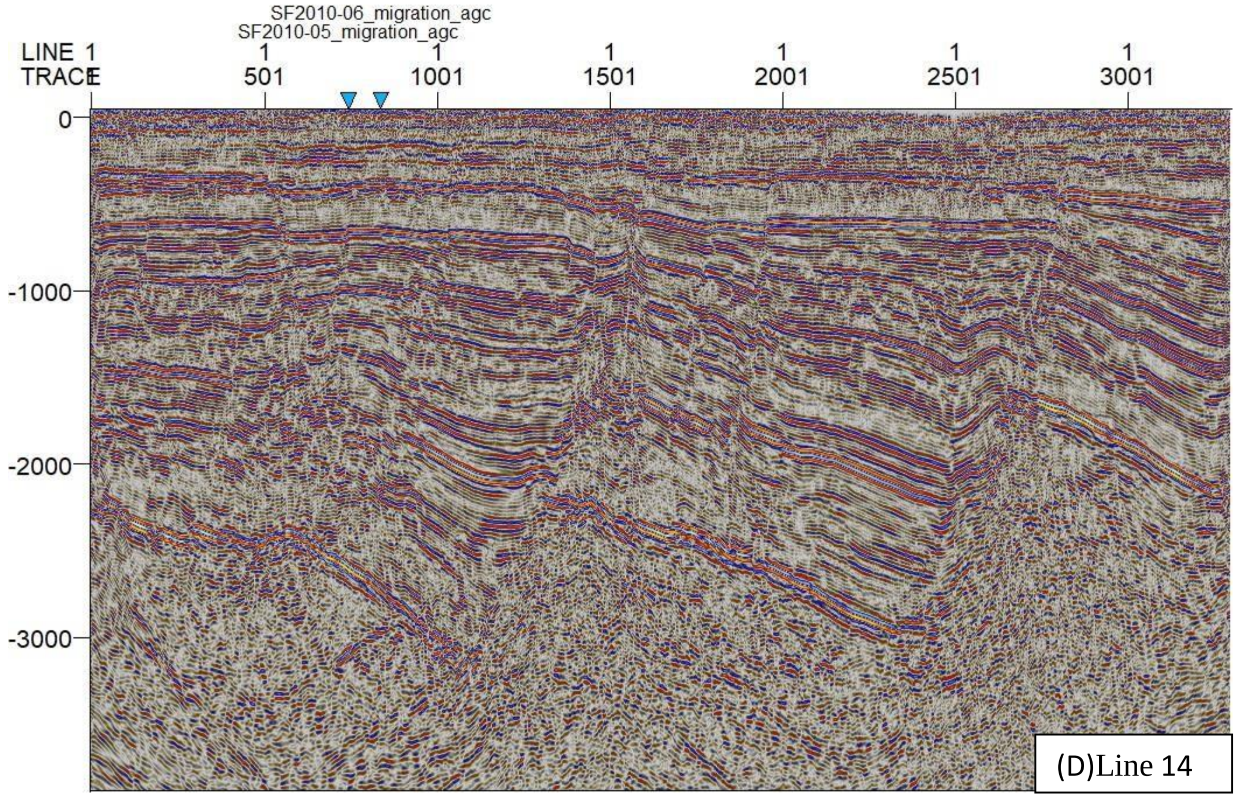


Fig (4-1): show the seismic lines (A: line 5 \B: line6 \C: line13 \D: line14)

4.2. Interpreted Horizons:

4.2.1 Top Bentiu Formation:

Top of Bentiu formation as shown in figure (4.1) shows medium data quality, reflects can be picked and the reflector continuous.

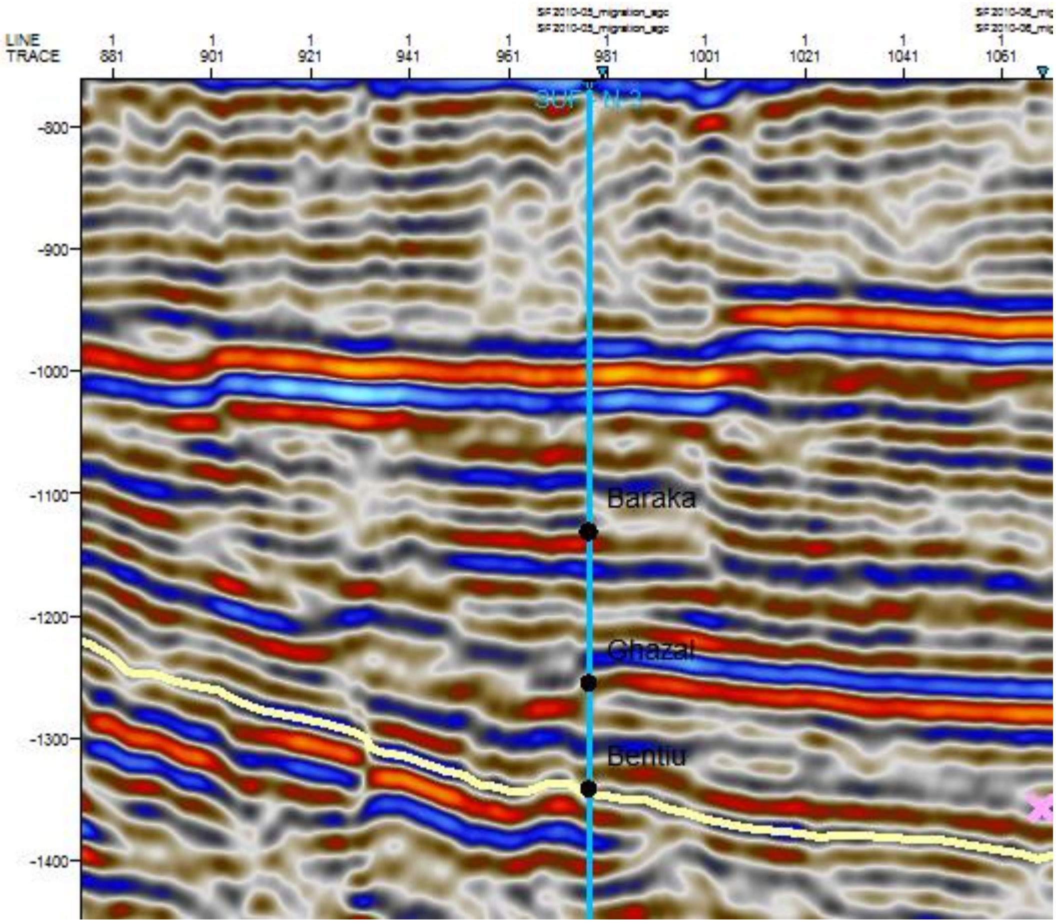


Fig.4.1: Top of Bentiu formation

4.2.2 Top of Abu Gabra Formation:

Top of Abu Gabra formation as shown in figure (4.2) shows low data quality, hard to be picked, clear discontinuity

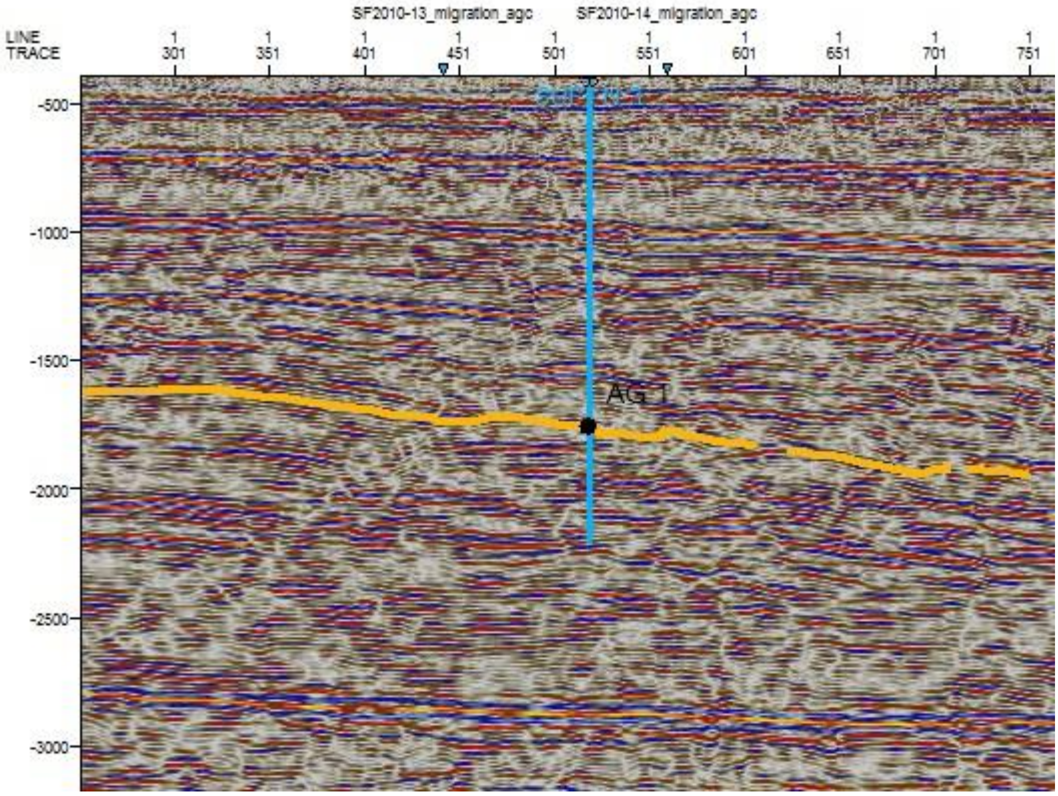


Fig.4.2: Top of Abu Gabra formation

4.3. Interpreted sequence:

4.3.1 Line 5:

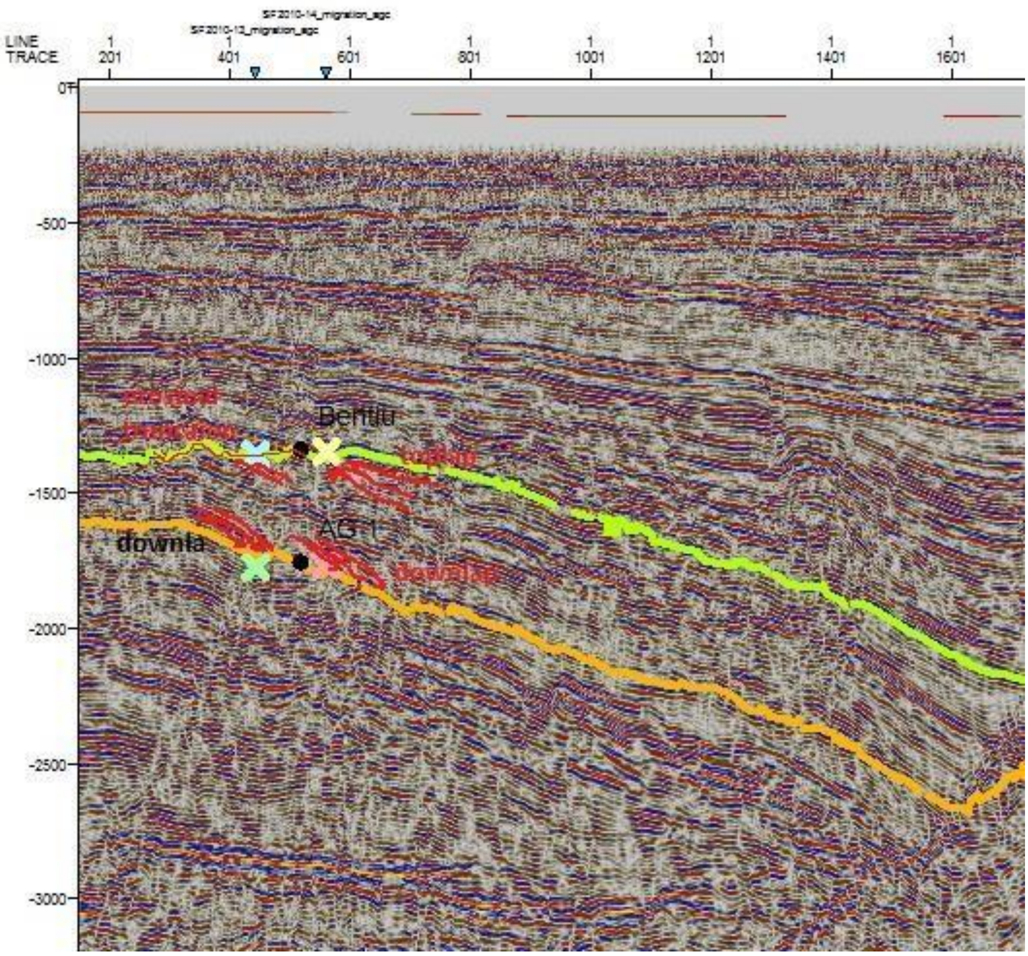


Fig (4-3) show seismic section of line (SF 2010-05)

- In the upper boundary we found two upper termination :

1. Erosional truncation in shot point 550.
2. Top-lab in shot point 650.

- In lower boundary we found two lower termination :

1. Down-lab in shot point 550.
2. Down-lab in shot point 650.

4.3.2 Line 6:

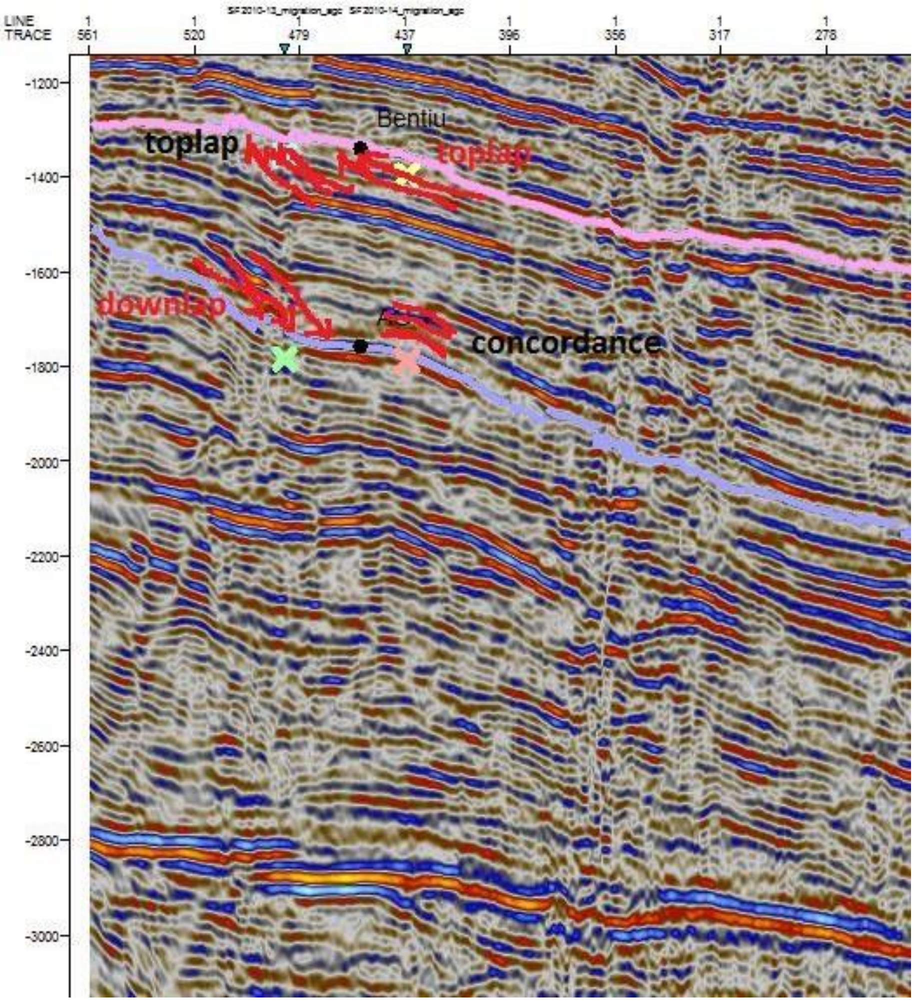


Fig (4.4) show seismic section of line (SF 2010-06)

- In the upper boundary we found two upper terminations:

1. Top-lab in shot-point 490.
2. Top-lab in shot-point 450.

- In the lower boundary we found two lower terminations:

1. Down-lab in shot-point 490.
2. Concordance in shot-point 450.

4.3.3 Line 13:

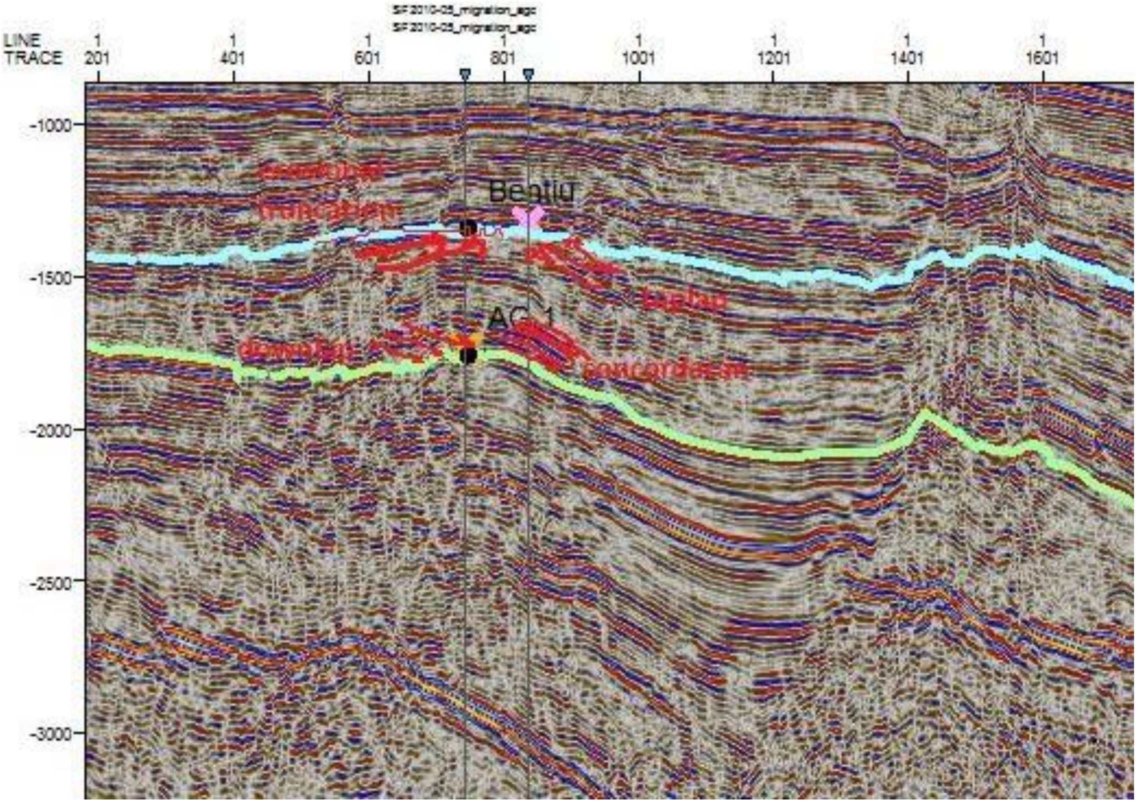


Fig (4-5) show seismic section of line (SF 2010-13)

- In the upper boundary we found two upper terminations:
1. Erosional truncation in shot-point 701.
2. Top-lab in shot-point 850.
- In the lower boundary we found two lower terminations:
1. Down-lab in shot-point 701.
2. Concordance in shot-point 850.

4.3.4. Line 14:

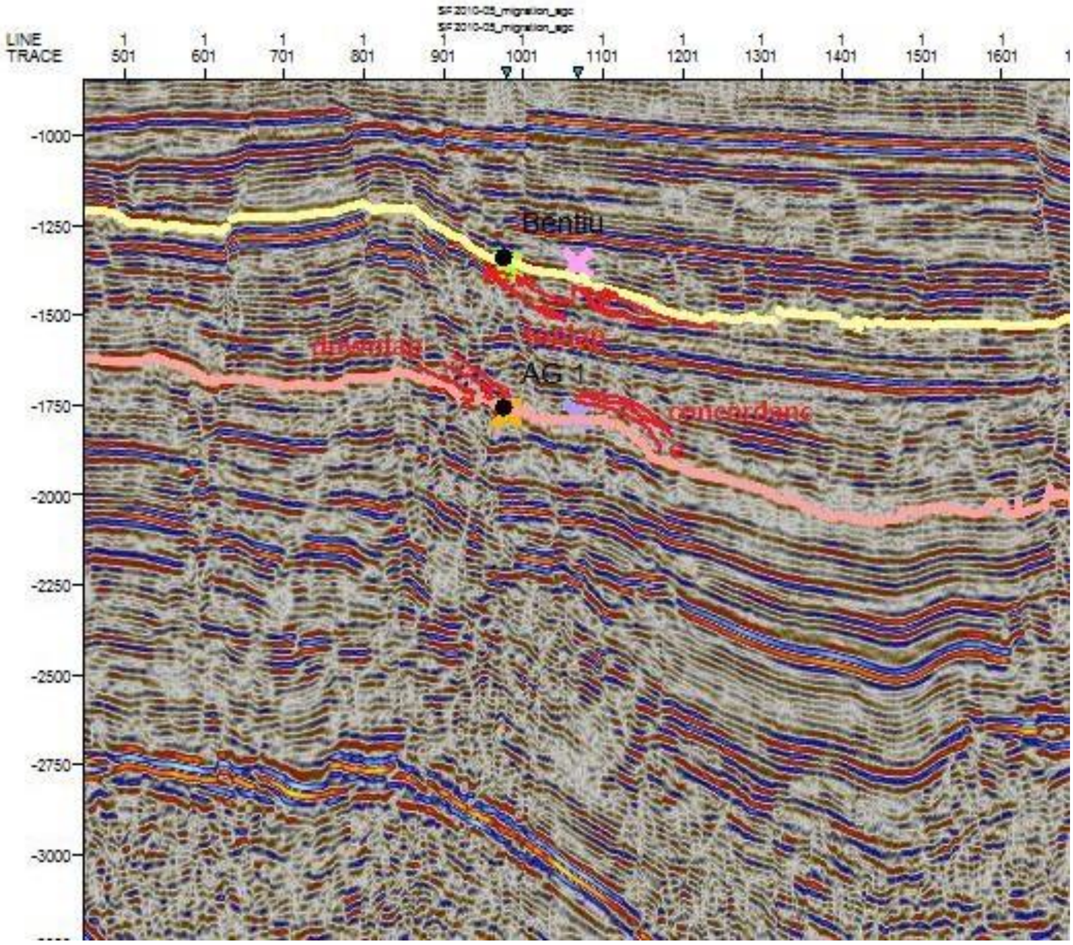


Fig (4-6) show seismic section of line (SF 2010-14)

- In the upper boundary we found two upper terminations:

1. top-lab in shot point 1001.
2. top-lab in shot point 1101.

- In the lower boundary we found tow lower terminations:

1. Down-lab in shot-point 901.
2. Concordance in shot-point 1101.

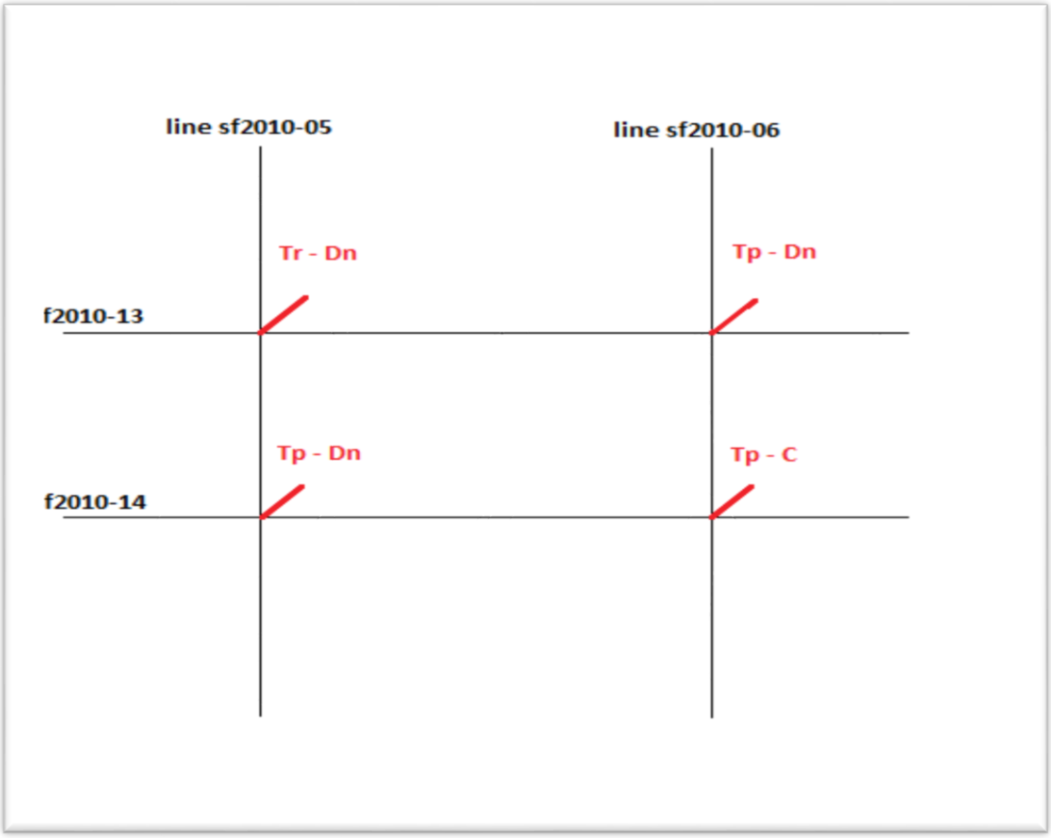


Fig (4-7) show a map defining the dominant termination patterns.

Which: Tr: truncation, Tp: top-lab, Dn: down-lab, C: Concordance.

Key Stratigraphic Units Are Broken Out by using A B C method where:

$$\frac{A - B}{C}$$

A = Termination Pattern at the Upper Sequence Boundary

Tr = Truncation Tp = Toplap C = Concordant

B = Termination Pattern at the Lower Sequence Boundary

On = Onlap Dn = Downlapn C = Concordant

C = Internal Reflection Pattern

Chapter Five
Conclusion and Recommendation

5.1. Conclusion:

Seismic data structural interpretation integrated with well data of the NW Muglad area, where there high structural complexity, was conducted. The interpretation was done on selected four 2-D seismic lines and integrated with (SUFYAN N-3) well information to describe stratigraphic sequence in sufyan sub-basin.

Petrel software was used as a mean for interpreting four horizon tops of (Amal, Darfur Group, Bentiu, and AbuGabra).

In line 5 in the upper boundary, we found two upper termination top-labin shot point 550and top-lab in shot point 650.and in lower boundary we found tow lower termination down-lab in shot point 550 and down-lab in shot point 650.

In line 6 In the upper boundary, we found two upper terminations top- lab in shot-point 490and top-lab in shot-point 450.In the lower boundary we found tow lower terminations down-lab in shot-point 490.concordance in shot-point 450.

In line 13 in the upper boundary, we found two upper terminations erosional truncation in shot-point 701.top-lab in shot-point 850.In the lower boundary we found tow lower terminations down-lab in shot- point 701.concordance in shot-point 850.

In line 14 in the upper boundary we found top-lab in shot point 1001.in the lower boundary we found tow lower terminations: down-lab in shot-point 901.concordance in shot-point 1101.

5.1. Recommendations

The researchers recommended that for comprehensive results in this area or another tohave insure following requirements:

1. Sufficient data (seismic lines and logs) of good quality.
2. To use suitable software programs to analyze integrated stratigraphic studies.

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