Sudan University of Science and Technology

College of Petroleum Engineering and Technology

Exploration Engineering Department

Graduation Project Submitted in Partial FulFilament for the degree of Bachelor (honor) Degree in Exploration Engineering

About:

Hydrocarbon Potentiality in NW Muglad Basin Using Integrated 2D Seismic and logging Data

مشروع تخرج مقدم لانجاز جزئي لنيل درجة البكلاريوس (مرتبة الشرف) في هندسة الاستكشاف

بعنوان:

امكانية تواجد الهيدروكربونات في شمال غرب حوض المجلد باستخدام البيانات السيزمية ثنائية الابعاد مقرونة مع بيانات تسجلات الآبار

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Date:

الاستهلال

بسم الله الرحمن الرحيم

((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﴾))

[سورة العلق]

صدق الله العظيم

Read in the name of your Lord Who created [1] He created man from a clot [2] Read and your Lord is Most Honorable [3] Who taught (to write) with the pen [4] Taught man what he knew not [5]

SurahAl-ALAQ (The Clot)

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 sunshine's 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 left aside.

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

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Abstract

Integrated structural interpretation process of the reflective seismic data with wells data was conducted in AbuGabra area, northwest Muglad basin in West Kordofan state. Seismic data represented by three two dimensional seismic lines, the study area is mainly covers a part of Rakuba sub-basin and is surrounded on the northeastern side by AbuGabra-Sharaf ridge and the northwest by Tomat High. The study aims to identify the subsurface structures in terms of tectonic movements and its influence on composition of oil traps and therefore the potentiality of delineating zones of oil accumulations. In this study, the interpretation processes were done using Petrel™2014 software where the data are loaded. The interpretation was done for four formation tops: Amal, Darfur Group, Bentiu and AbuGabra formations, by tying and correlating them withKereidiba-1 well, then the existing faults identified, and created two-way time structural maps for top Bentiu and AbuGabra formations which were converted to depth structural maps using the analysis of seismic velocity. Based on the interpreted seismic sections and generated structural maps, it was found that Rakuba sub-basin is an extensional rift basin with rotated parallel fault blocks similar to the structural basins model published by Ben in 2004. Three fault trends were observed: northwest-southeast fault trend which is the dominant faults in the study area especially in the middle part where Rakuba sub-basin shows its maximum depth, the northeast-southwest faults trend which are observed in the northwestern part of the area and expected to be the northwestern extension of Rakuba sub-basin, then north northwest-south southeast faults trend which are minor trend represent the strike component of the extension force. Integrated interpretation of the seismic sections and structural maps calibrated with the well data and the stratigraphic column of the Muglad basin, two potential hydrocarbon accumulations zone were identified as zone A and B. Zone A represents the depth of AbuGabra source rock between 1900-2000 meters at a rate of an estimated thickness of about 3600 meters, besides the presence of faults which could have a role on presence of oil traps in the reservoir rocks of Bentiu formation, while zone B was found that AbuGabra formation depth range between 1900-2100 meters at a rate of an estimated thickness of about 1100 meters with the presence of a small number of faults with little structural effect on the formations to form traps. The study recommends these points: interpreting more seismic

lines calibrated with more well logging data to improve the vertical and horizontal extension of the sedimentary formations in Rakuba sub-basin, conducting quantitative interpretation using seismic attributes and amplitude versus offset analysis. Vertical seismic profiling data gives accurate and reliable extracted velocity values to convert the two-way times into true depths of these sedimentary formations.

الخلاصة

أجريت عملية التفسير التركيبي للبيانات الزلزالية الانعكاسية المتكاملة مع بيانات الآبار في منطقة ابوجابرة شمال غرب حوض المجلد في ولاية غرب كردفان. البيانات الزلزالية متمثلة في ثلاثة خطوط زلزالية ثنائية الأبعاد، تغطي منطقة الدراسة بصورة أساسية جزء من حوض راكوبة ومحاطة من الناحية الشرقية الشمالية بمرتفع ابوجابرة-شارف ومن الناحية الشمالية الغربية بمرتفع التومات. هدفت الدراسة لتحديد ودراسة التكوينات تحت السطحية من حيث تشوهها بالحركات التكتونية وعلاقة هذه التشوهات بتكوين المصائد النفطية في هذه التكوينات وبناء على ذلك إيجاد أكثر المناطق إمكانية لتواجد التراكمات النفطية. في هذه الدراسة تمت عملية التفسير بواسطة البرنامج الحاسوبي بتريل 2014 حيث تم تنزيل البيانات في البرنامج وتفسير السطح العلوي لأربعة تكوينات رسوبية رئيسية وهي: امل، مجموعة دارفور، بانتيو و ابوجابرة عن طريق مضاهاتها بواسطة معلومات بئر كريديبة-1، ومن ثم حددت الفوالق الموجودة وأنواعها، ومن ثم أنشأت الخرائط التركيبية لأزمنة وصول الموجات الزلزالية لكل من السطح العلوي لتكوين بانتيو والسطح العلوي لتكوين ابوجابرة، ثم حولت هذة الخرائط الزمنية إلي خرائط تركيبية بدلالة عمق هذه التكوينات باستخدام تحليل السرعة السيزمية. بناءً على المقاطع السيزمية الراسية ثنائية البعد المفسرة والخرائط التركيبية المنشأة وجد أن حوض راكوبة عبارة عن حوض امتدادي يحتوي على كتل صدوع متوازية مائلة شبيه بالنموذج التركيبي للأحواض الرسوبية الناتجة من التخدد والذي نشره بن في 2004. من تحليل الخرائط، تم ايجاد ثلاثة توجهات رئيسية للفوالق وهي: اولا شمال غرب–جنوب شرق وتعتبر التوجه الرئيسي والغالب في منطقة الدراسة وخاصة فى وسط المنطقة حيث يظهر اقصي عمق لرسوبيات حوض راكوبة، تانيا فوالق ذات توجه شمال شرق–جنوب غرب وتم التحفظ عليه في الجزء الشمالي الغربي لمنطقة الدراسة حيث يتوقع ان يكون الامتداد الشمالي الغربي لحوض راكوبة، ثالثا فوالق ذات توجه شمال شمال غرب-جنوب جنوب شرق وهي تمثل توجهات ثانوية الناشئة من القوه في اتجاه مضرب الحوض. من تفسير المقاطع السيزمية والخرائط التركيبية مقرونة بمعلومات بئر كريديبة-1 والعمود الطباقي لحوض المجلد تم تحديد منطقتين (أ) و (ب) تمثلان إمكانية تواجد التراكمات النفطية حيث المنطقة (أ) تمثل عمق صخر المصدر ابوجابرة حيث يتراوح بين 1900-2000 متر بمعدل سمك مقدر بحوالي 3600 متر، إضافة لتواجد الفوالق التي يمكن أن يكون لها دور في تكوين مصائد نفطية في صخر المكمن تكوين

بانتيو بينما المنطقة (ب) وجد أن عمق تكوين ابوجابرة بها يتراوح بين 1900-2100 متر بمعدل سمك حوالي 1100 متر مع تواجد عدد قليل من الفوالق ذات اثر تركيبي ضئيل على التكوينات لتكوين المصائد. اوصت الدراسة الحالية ببعض النقاط بناءً على النتائج المتوصل اليها: تفسير مزيد من المقاطع السيزمية المقرونة بمعلومات اكبر من الابار في منطقة الدراسة سوق يزيد من ايضاحية الامتداد الافقي والراسي للتكوينات الرسوبية في حوض راكوبة ومن ثم عمل تفسير كمي باستخدام المعاملات السيزمية وعلاقات سعة النطاق مع المسافة، كما ان وجود بيانات عن السبر السيزمي العمودي يعطي نتائج ادق واكثر اعتمادا لقيم السرعات السيزمية للاستفادة منها في تحويل ازمان الوصول الي سمك حقيقي للتكوينات الرسوبية.

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Chapter One

1. Introduction

1.1. Introduction:

The construction of Sudan basins began in the late Jurassic (154-135MA) and continued up to the middle of The Neogene (15.8-11MA).There are many rift basins interior Sudan including the Blue Nile, Khartoum, White Nile, Melut, Atbara, Muglad and Baggara basin.

The Muglad basin is the most important sedimentary basin in Sudan in which hydrocarbons accumulation have been discovered. (Fairhead, 2009)

The Muglad rift basin (fig.1.1) locates in the south west of the Sudan considered as the largest rift basin in Sudan and represents the western flank of the Sudanese interior rift basins which are parts of the Central African rift system(CARS), it has width of 300km and more than 1200km long, extends predominantly northwest -southeast, it crosses two provinces within the Sudan which are Southern Darfur province at its northern part , and Southern Kordofan province at its southern part, at The South Sudan the Muglad basin crosses the upper Nile and equatorial provinces and eventually link with Anza trough in Kenya. (Sayed, 2003), it's bounded approximately by the longitude 26 00' & 30 00'E, and the latitude 8 00' & 12 00'N, terminated at its northwest side by Baggara basin and by the Nuba mountains in its southeast side.

The basin filed with the lower cretaceous (135-96MA) to the Neogene (23.5-5.3MA)(USGS, 2011), Ranging in thickness from 6000m to more than 13000m of fluvial an lacustrine sediments. (Sayed, 2003; USGS, 2011)

1.2. Study Area:

The study area located at the northwest side of the Muglad, Its terrain is generally flat and it's covered by loose sand of the Umm Ruwaba formation of the Tertiary (56-1.75MA) to the recent age, the sedimentary thickness of the area is up to 9000m in deep sub basin, an average of 6000m thick represent the thickness of AbuGabra-Sharaf formation. (Mohamed et al., 2001)

The area, (fig.1.2), falls in Rakuba sub-basin northwest of Muglad basin in the vicinity of the Baraka and Tomat Highs, sharaf_AbuGabra ridge, Baggara basin, Abu

Sufyan, Nugara and Hiba Sub basins, all these areas are considered as prospects. After wells have been drilled within 14 localities in the area there were two proved discoveries have been made that are AbuGabra and Sharaf fields. (RRI, 1991)

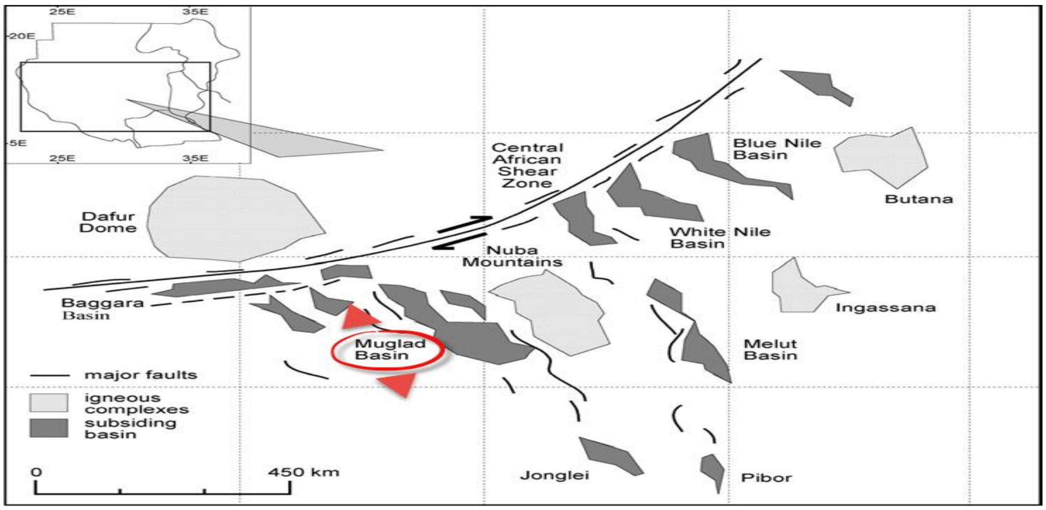


Fig.1.1: Location of the Muglad basin in the SW Sudan in relation to the Central African Shear Zone.(Sayed, 2003)

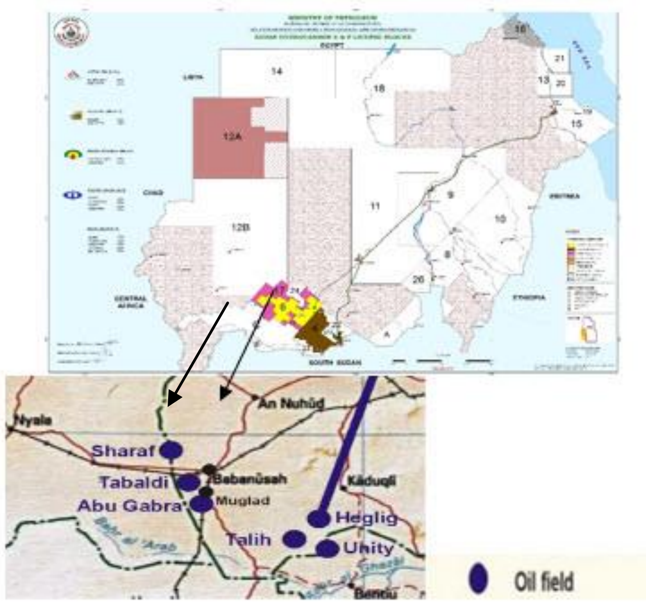


Fig.1.2: Location of the study area (Rakuba sub-basin) in NW Muglad Basin and the adjacent oil fields.

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 potential traps is required as it will be conducted in this study by accurate interpretation of seismic reflection data integrated with borehole information.

1.4. The Study Objectives:

The study aims mainly to make use the interpretation means of seismic reflection data integrated with well data of the area to provide delineated structural interpretation which help in assessment the trapped hydrocarbon accumulation potential and further specifically:

- Generate surface structural maps for subsurface horizons.
- Determine the best location for drilling well and the targeted depth.

1.5. Available Dataset:

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

1. Three 2D seismic lines
2. Well information of (Kerediba_1) which include:
   i. Horizon tops of (Amal, Darfur group, Bentiu and AbuGabra Formations).
   ii. Check shot data.
   iii. 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 AbuGabra 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 et al. (2001) 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 modeled 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-AbuGabra western fault to the east, with a maximum depth of AbuGabra is 6.7km.

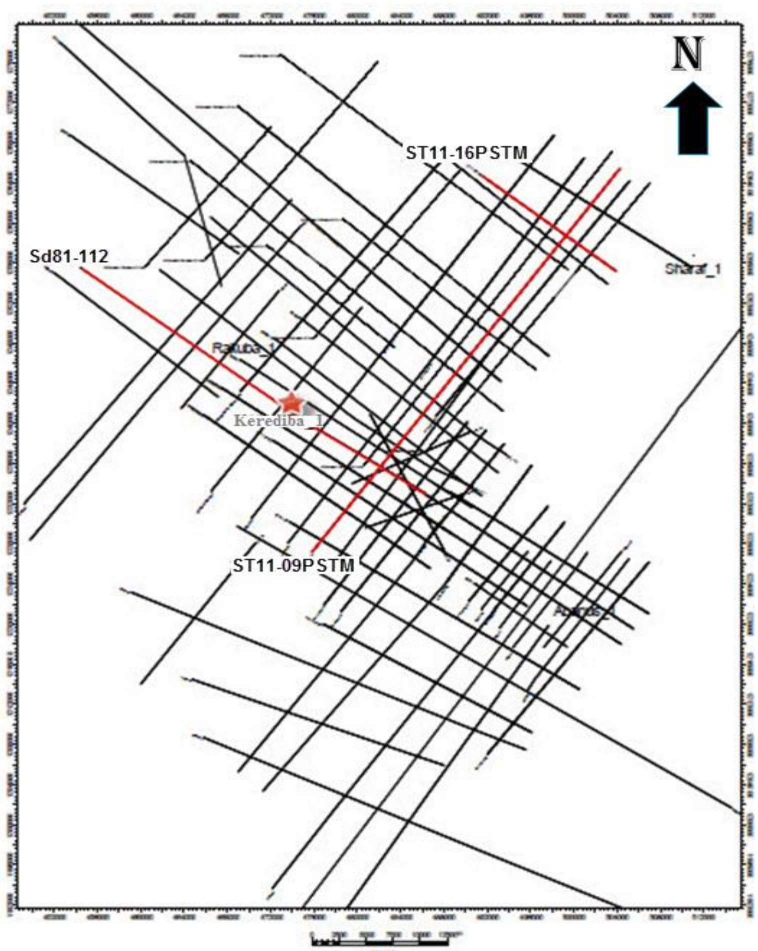


Fig.1.3: Location map of the used data set in the study which are three 2D seismic lines and one well logging data.

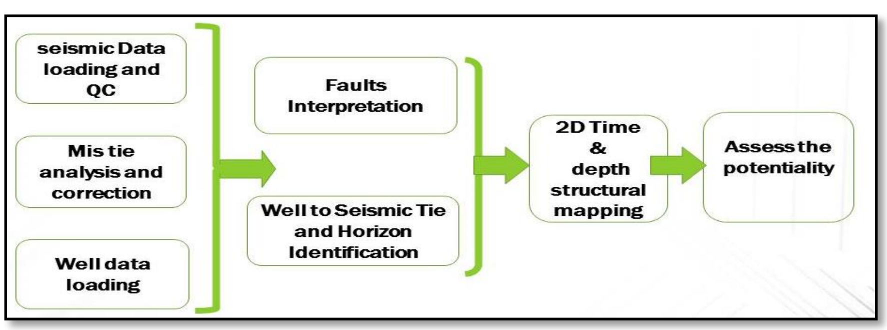


Fig.1.4: A flow chart of the adopted methodology to achieve the study objective.

Chapter Two

2. Tectonic Evolution 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 (135–96 MA).

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 African shear zone, 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 (23.5–1.75 MA) and developed northwest southeast oriented rift basins, The rifting can be divided into two rifting events in the western part and three rifting events in the eastern part. (USGS, 2011)

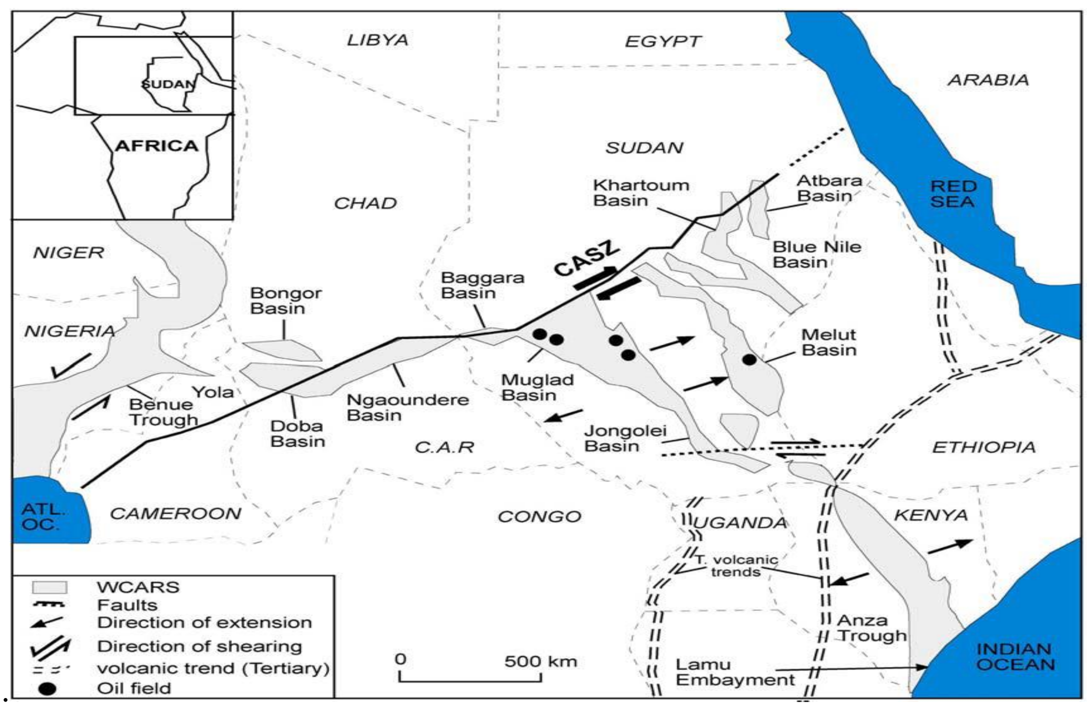


Fig.2.1:Tectonic model of the central African shear zone and West and Central African Rift System from Fairhead (1988).

2.2. The Tectonic Evolution:

The southern 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.

2.2.1. 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.

2.2.2. Rifting phase:

Due to crustal extension relative to extensional tectonics three separated rifting phases had happened in the region extended through the early Cretaceous (135–96 MA) and the late Cretaceous (96–65 MA) to the Oligocene (33.7–23.5 MA). 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)

2.2.2.1. Early rifting phase:

It had begun in the Jurassic (?) – Early Cretaceous up to near the end of the Albian (108–96 MA), 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 had known to be associated.

2.2.2.2. Second rifting phase:

It had started in the Turonion (92–88 MA) and continued up to the late Senonian (88.5 – 65 MA). these rifting phase 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 (which were not proved in northwest of Muglad basin) 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 phase differ from the last phase in that the second phase was accompanied by minor volcanism. (Sayed, 2003)

2.2.2.3. Final rifting phase:

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

2.2.3. Sag Phase:

Began in the middle Miocene (15.8–11 MA) 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 are 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-AbuGabra formations and Bentiu formation, the second cycle sediment have deposited Darfur group and Amal formation, the third cycle includes Kordfan 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-AbuGabra Formations:

Sharaf-AbuGabra formations consist of Neocomain-Barremian (131–126 MA) Sharaf formation and the Aptian-Albian (126–100 MA) AbuGabra formation which were deposited during the late Jurassic-early cretaceous period. The formations 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 AbuGabra formation consist of interbedded claystone, shale and sandstone with localized development of siltstone, the top of the AbuGabra 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. (IRR, 1991)

2.3.2. Bentiu Formation:

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

Formation lithology comprises primarily of sandstones interbedded with thinner beds of siltstone and claystone. The formation thickness range from 1835 to 5255 ft (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.

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 (56–23 MA) 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)

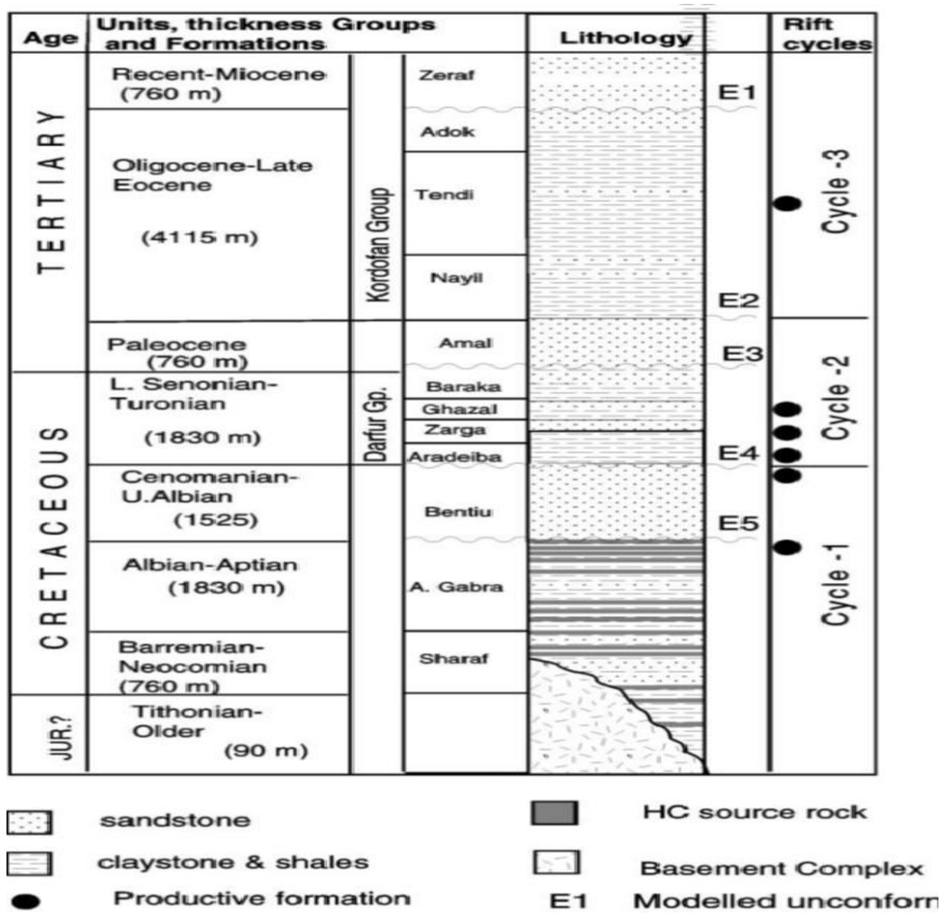


Fig.2.2: the sedimentary sequence of the Muglad basin with the depositional cycles from Mohamed et al., (2001).

Chapter Three

3. Methodology

3.1. Introduction:

Seismic reflection become the most common method in oil and gas prospecting, it is applied to obtain a description of subsurface geology, through mapping subsurface structures and find which of them are traps for hydrocarbon, also this geophysical method can be used to generate maps for faults that may be barriers to fluid flow in producing field .the predominance of the seismic method over other geophysical methods is due to the high accuracy ,high resolution and great penetration of which the method is capable. (Telford et al., 1976)

3.2. 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.

3.2.1. 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 in1914 by Ludger Mintrop to locate enemy artillery, and then the seismographs were applied for the determination of rock structures in1919. In 1921 Mintrop founded seismos to do the geophysical exploration.

Later, the evolution in the equipment and methods continued, in the last third of 20th century 1960s, the digital revolution impacted on seismic exploration industry, it supported the ability to record digitized seismic data on magnetic tape, then process and interpret it in a computer which improve the reliability of data in imaging the earth structures, that helps improve the productivity of seismic crews.

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)

3.2.2. 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 on 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.

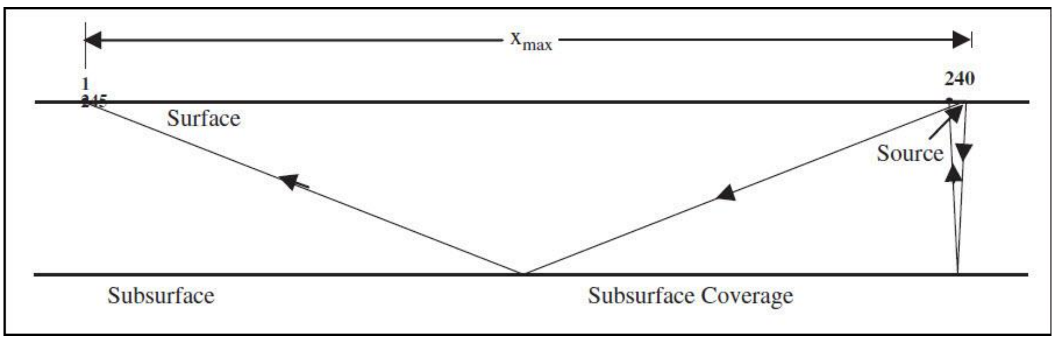
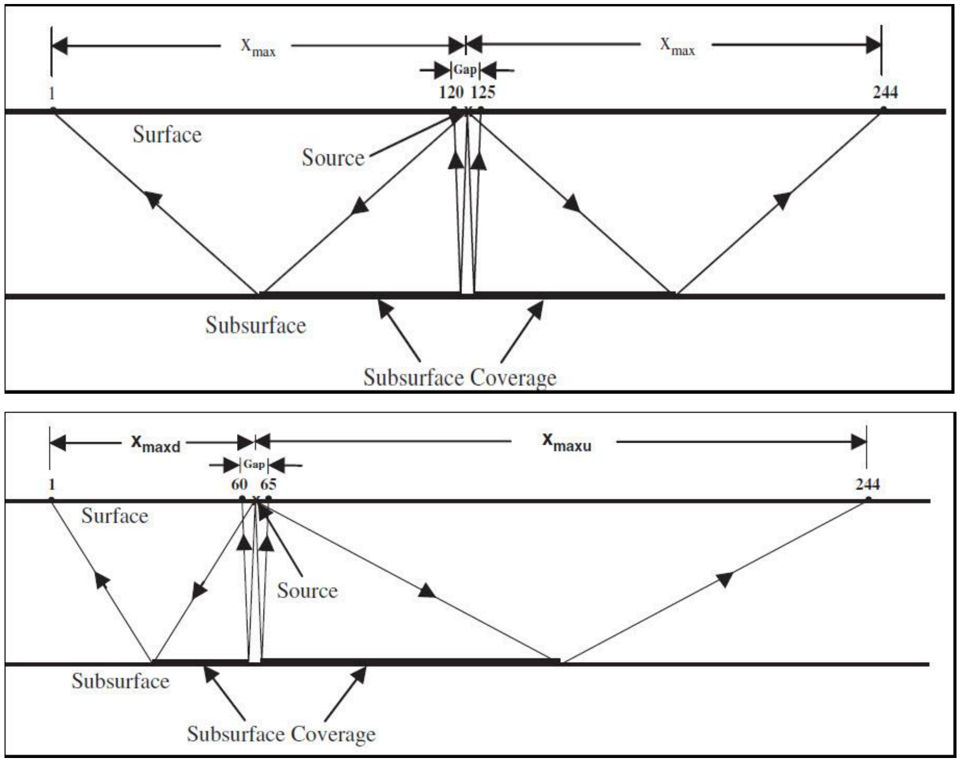


Fig.3.1: the off end spread figure where all receiver groups are on one side of the source.

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.

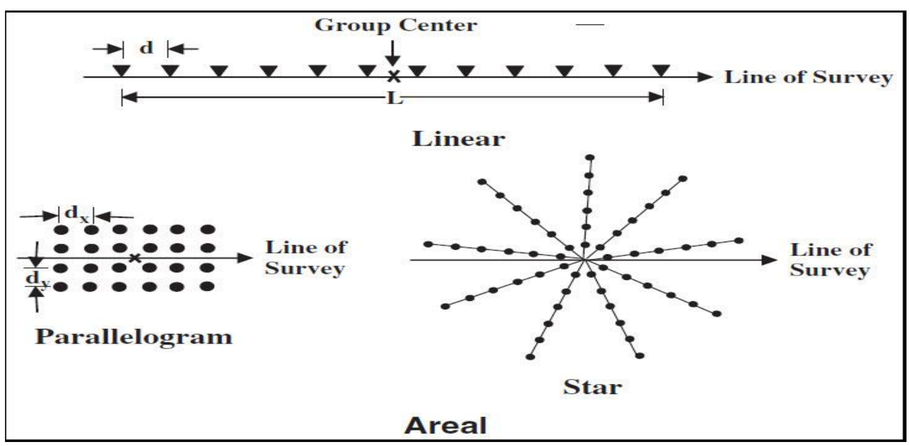


Fig.3.3: the different types of arrays, which are an arrangement in specific pattern of receivers to provide receivers with a directional response that facilitate the enhancement of signal and the suppression of certain type of noise.

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 reflections.

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

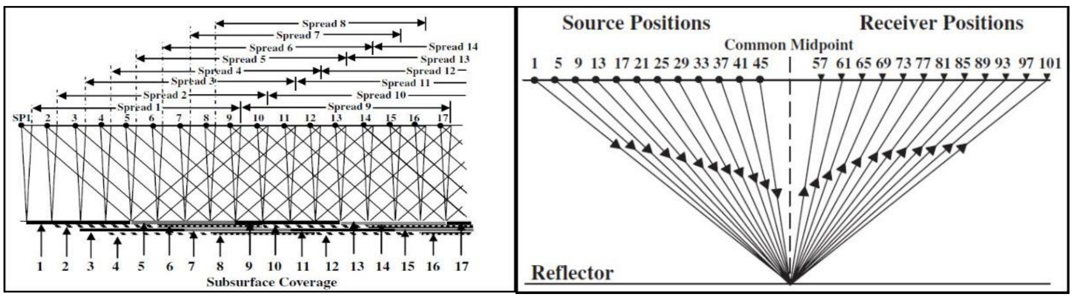


Fig.3.4: it shows: (a) the multifold shooting, and (b)common midpoint creating.

3.2.3. 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).

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

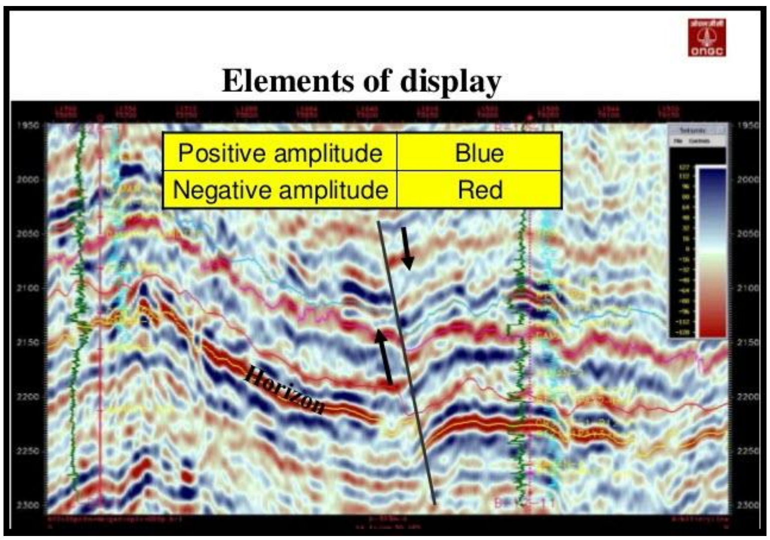


Fig.3.5: seismic record section as an end products of the process of data acquisition and processing.

3.2.3.1. 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.

3.2.3.2. 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).

3.2.3.4. 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 color 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 color 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.

3.2.3.4. 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.

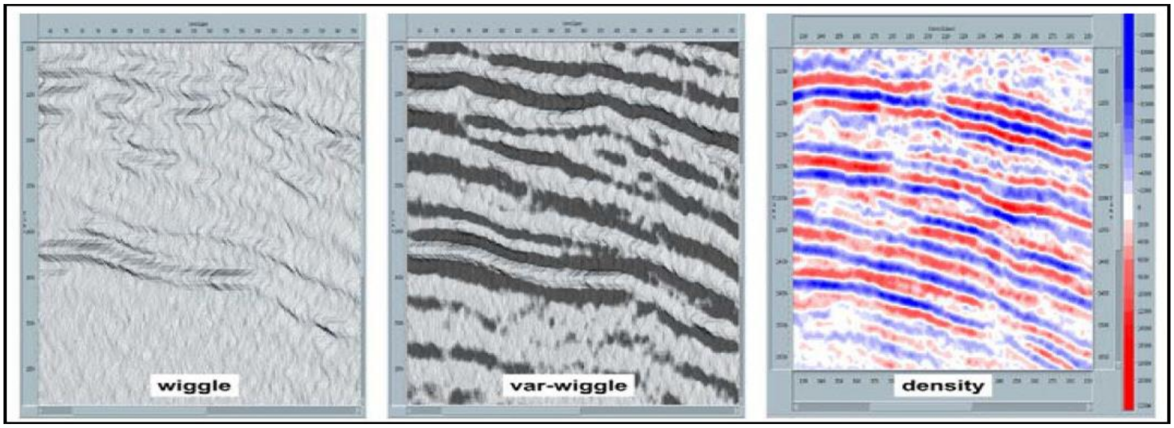


Fig.3.6: wiggle, var-wiggle and variable display of seismic data.

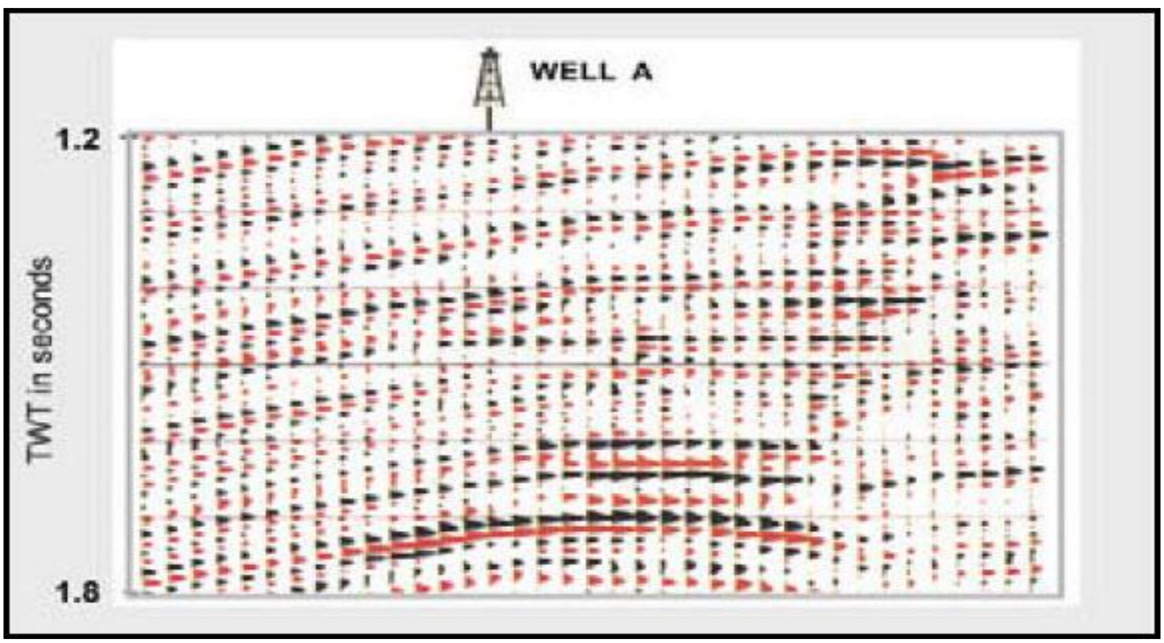


Fig.3.7: dual polarity display.

3.2.3.4. 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.

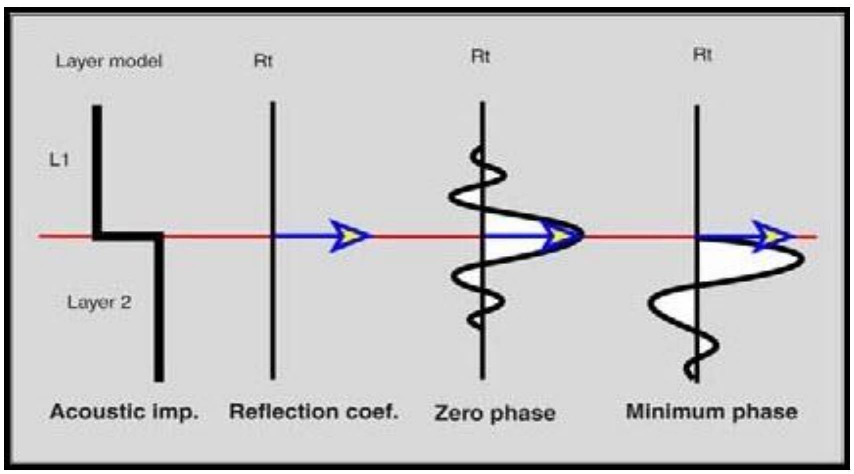


Fig.3.8: the zero-phase wavelet, whereby the maximum amplitude of the wavelet is coinciding with the lithological interface the minimum-phase wavelet, whereby the start of the wavelet is coinciding with the exact position of the subsurface interface.

3.2.3.6. 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. (Veeken, 2007)

3.2.3.7. 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.

3.2.3.8. 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.

3.2.4. Seismic Data Processing:

Data processing involves converting field recording into meaningful cross section that reveals and helps delineate the subsurface stratigraphy and structure that may bear hydrocarbons.

The objectives of data processing may be summarized as the following:

- To enhance the signal to noise ratio (S\N).
- To produce seismic cross section representative of geology.
- To meet the exploration objectives of the client.

There are three primary steps in processing seismic data:

- De-convolution.
- Stacking.
- Migration.

3.2.4.1. De-convolution:

It is a process that improves the vertical resolution of seismic data, vertical resolution implies how closely two seismic events can be positioned vertically, yet be identified as two separate events. It improved by compressing the basic wavelet, also De-convolution used to attenuate ghosts, instrument effects, reverberations and multiple reflections.

A seismic trace is a product of the convolution of the input signature (basic seismic wavelet) with the reflectivity function of the earth impulse response, including source signature, recording filter, surface reflections, and geophone response. It is also has primary reflections (reflectivity series), multiples, and all types of noise. The objective of de-convolution shown on figure (6.9) is to remove the effect of the Convolution of the basic wavelet with the reflectivity, output seismic trace to be the reflectivity series.

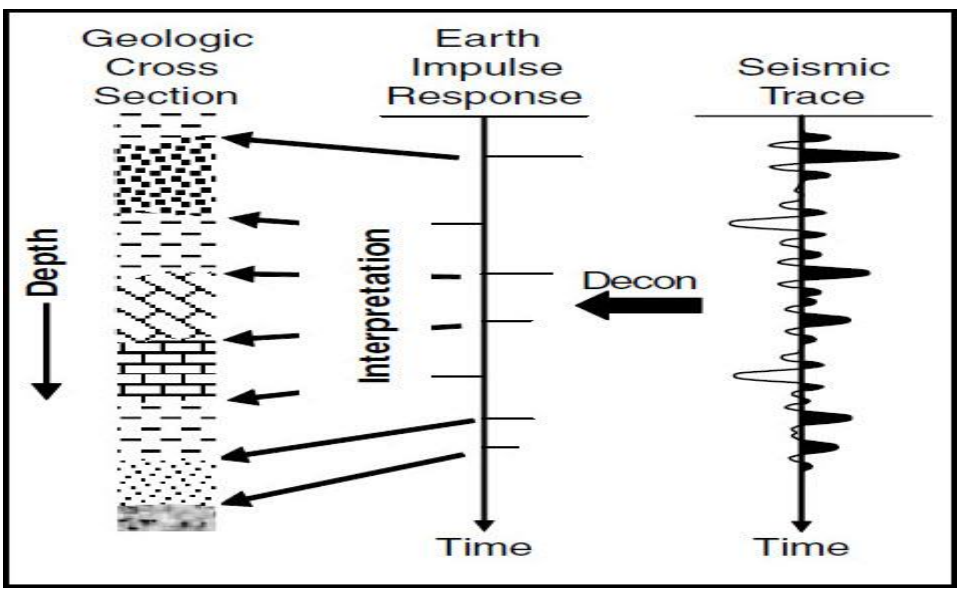


Fig.3.9: De-convolution process, used to remove the effect of the Convolution of the basic wavelet with the reflectivity, output seismic trace to be the reflectivity series.

3.2.4.2. Stacking

It is a process of summing of all traces that have a common midpoint (CMP). The process is applied to increase signal to noise ratio (S/N) and to suppress the random noise. Figure (3.10) shows the ways of stacking and its principles.

Before final stacking, normal moveout (NMO) correction are applied to correct for the horizontal component of reflection raypaths. The normal moveout correction, shown on figure (3.11), converts all times to zero offset times at common midpoint stack, in effect, moves all sources and receivers of the records to their (CMP) position, so that the final output of (CMP) stacking is zero offset stacked section.

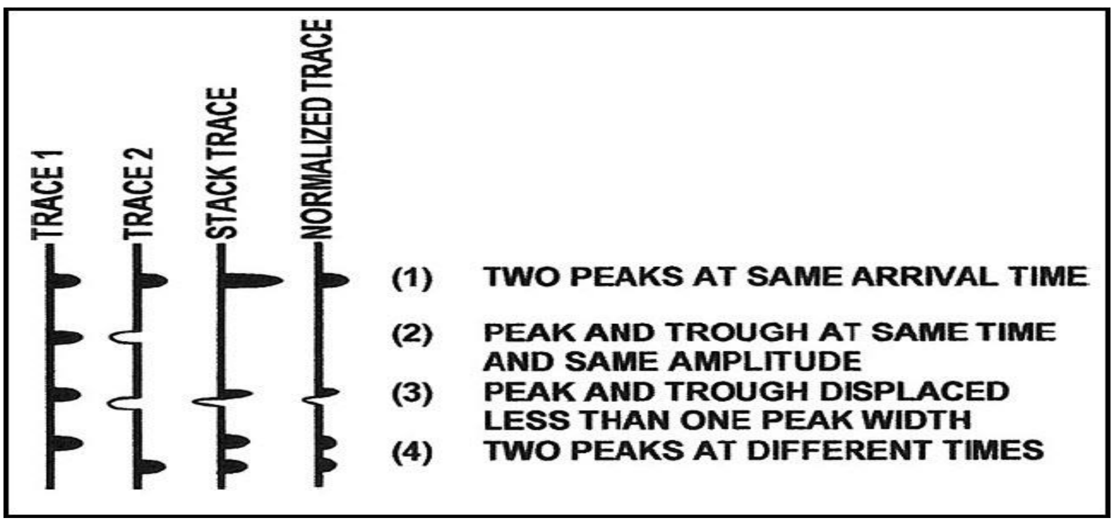


Fig.3.10: common midpoint (CMP) stacking process and its principles.

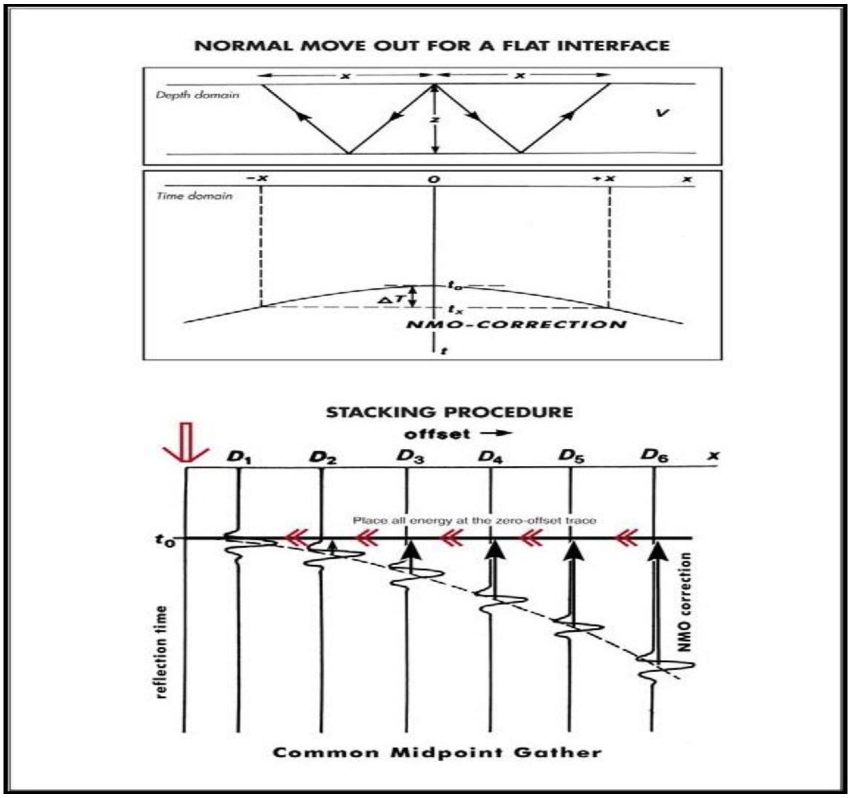


Fig.3.11: the normal moveout (NMO) correction, applied to correct for the horizontal component of reflection raypaths.

3.2.4.3. Migration:

It is a process of moving the reflections to their proper places with their correct amount of dip. Figure (3.12) Shows that the reflections are in wrong place and have wrong dips if the interface corresponding the reflection in the section is steeper dipping.

Migration is done to rearrange seismic data so that reflection events may be displayed at their true subsurface position, therefore migration process applied to do the following:

- Improves horizontal resolution and collapses Fresnel zone.
- Collapses diffraction back to their point of origin.
- Provides more accurate depth section.

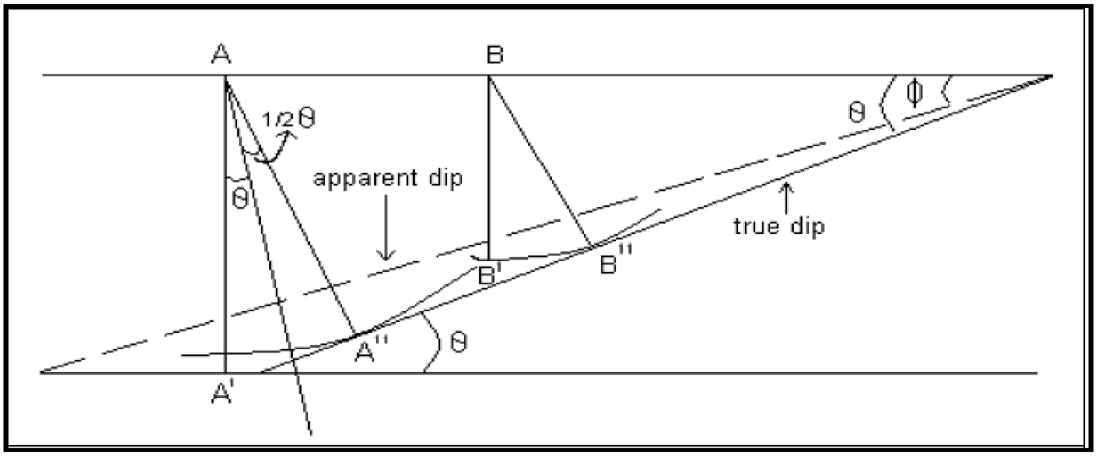


Fig.3.12: the reflections are in wrong place and have wrong dips if the interface corresponding the reflection in the section is steeper dipping.

3.2.5. Seismic Data Interpretation:

3.2.5.1. Background:

Seismic interpretation is the science and art of inferring the geology at some depth from processed seismic records (Sheriff and Geldart, 1995), it involve all principles, means and steps that enable the interpreter to coordinate the geological information with the seismic information (Dobrin and Savit, 1988), It also includes data reduction, selecting events believed to be primary reflections, and locating the reflection with which they are associated.

There are two modes of seismic data interpretation, that are vary according to the circumstances of the province, the first mode is the interpretation in areas of substantial well control, which the well information includes, lithology, stratigraphy information, is tied with the seismic information, and seismic supplies the continuity between the wells for the zone of interest. The second mode is in area of on well control (frontier area). In such area of the interpretation of seismic data defines the structure and estimates depositional environment, as well as the lithology is defined through estimation of seismic velocities and link it with the stratigraphic concepts. Pore constitutes is also detected through analysis of seismic amplitude change.(Dobrin and Savit, 1988)

As more information is incorporated with the interpretation, the reliability of interpretation become sufficient, (Gadallah and Fisher, 2009)the data that used to the interpretation include:

- Vertical seismic section.
- Velocity models, well logs and VSP data.
- Amplitude versus offset (AVO analysis).
- Geochemical analysis.
- Other information obtained from previous drilling such as the presence of high pressure zones in subsurface.
- Other geophysical serving results.

The test of a good interpretation is the constancy rather than the correctness, so the good interpretation most be consistent with seismic data, and all known data like gravity, magnetic and surface geology (Sheriff and Geldart, 1995).

Mainly the interpretation of seismic data aims to:

- Locating hydrocarbon accumulations by generating subsurface structural maps which describe the traps.
- Providing stratigraphic information through delineating seismic sequence with represent different depositional units, recognizing seismic facies characteristics and analyzing reflection character variation to locate both stratigraphic change and hydrocarbon accumulation and also deducing the historical geology of the area.

3.2.5.2. Well to seismic tie:

The interpretation aims to establish the relationship between seismic reflection and Stratigraphy, so the reflection on a seismic section are inferred correctly to its corresponding stratigraphic units, seismic to well tie is used on this purpose.

The drilled well in the area provides the most reliable geological data such as (formation tops, lithology, depositional environment, the location of faults, unconformities) through interpretation of well logs (Bacon et.al.,2003). Well to seismic tie involves using well logs (using sonic log and density logs) to manufacture synthetic seismograms that provide a mean of identifying reflection with formation tops.

3.2.5.3. The synthetic seismogram:

Synthetic seismogram represents the respected response of rock to the seismic waves, it is generated to be compared with the real seismic, the generation of synthetic seismogram depends on the edited well log and the wavelet extracted from real seismic data.

3.2.5.4. Horizon Identification:

If the area is well controlled the horizon identification should base on tying well information with seismic. The identified horizons on well section are then picked on seismic cross-section and this section is compared with the section for the cross lines in order to identify the same horizon on the cross line, where the horizons are picked on the all sections, it must tie around closing loops of lines, since the horizon end up with the same arrival time which it started. This closing of loop provides an important check on the interpretation reliability, sometime a loop may not close, that means seismic feature between lines in their intersection are different in arrival time, which referred as mistie (misclouse) (Telford et al., 1990), in this case the Couse of mistie must investigated, mainly the mistie is due to the following:

- Error in correlation record.
- Inaccurate corrections.
- Change in reflection character.
- Error in correlating across faults.
- Different used acquisition and processing parameters.

Mistie around can be corrected through either static shifting (constant mistie), and dynamic shifting(variable mistie) depending on whether the differences in values are constant or variable at lines.

Horizons on the section are followed away from the tying well in order to determine the discontinuity whether that be stratigraphic variation, faulting or unconformity.

3.2.5.5. Fault Interpretation:

Fault play a second role in hydrocarbon trapping mechanisms that can provide adequate lateral seal to subsurface or be a significant barrier to fluid flow during production from a reservoir, it can also provide a routes for hydrocarbon migration.

On seismic section fault planes should be picked in such accuracy that aid to find out fault segments seen on different lines involving the same faults in order to determine the fault strike and check the interpreted fault, also a fault should be followed on all lines.

3.2.5.6. Mapping and Contouring:

To complete processes of interpretation, the picked horizons on the seismic section are mapped to realize the conclusion of the seismic survey on the area. Map can provide delineation of existing traps through determine whether closure exist (the area within the closing contour and the highest point on the structure) (Sheriff and Geldart, 1995), which aid to determine the best location for drilling well, maps are also useful in describe the fault trends and recognizing its patterns.

The mapping process is done on a base map which shows the locations of seismic lines and other features such as oil wells, rivers, roads and political boundaries. Features on seismic sections are mapped using either structure time maps or depth maps, in time mapping the arrival time values of each picks are firstly measured by horizontal interval between sampled values varies according to the degree of the complexity of structure discernible on the section (Ahmed et al., 2012) these measured values of arrival time are converted to depth values if a depth is to be made rather than a time map, since the values are measured, the next step is to posting these values on the base map of the area .

Faults that have been identified on the section are down on the map in shape of polygons, and decide how to join them together through the correlation, additional relevant information such as well data, regional trends, anticlinal and synclinal axes, the location of gravity highs and lows might be down in map, the posted values on base map are then connected to represent the structures by contouring, the selection of contour interval , which is the difference between two respective contour line values, depend on the desired resolution of generated map and the size of the geologic feature that will be mapped.

3.2.5.7. Depth conversion:

Depth conversion is an important step of the seismic reflection method, in which the acoustic wave travel time is converted to actual depth, based on the acoustic velocity of subsurface medium (sediments, rocks, water).

Depth conversion integrates several sources of information about the subsurface velocity to derive a three-dimensional velocity model:

- "Well tops", i.e., depth of geological layers encountered in oil and gas wells
- Velocity measurements made in oil and gas wells (sonic log, checkshot or vertical seismic interpretation).
- Empirical knowledge about the velocities of the rocks in the area investigated
- Root Mean Square (RMS) stacking velocities which are derived from the processing of the seismic reflection data.

The conversion permits the production of depth and thickness maps that depict subsurface layers that are based on reflection data. (Wikipedia, 2016)

3.2.5.8. The role of workstation:

The previous mentioned interpretation processes are previously carried out in full manual manner, the interpreter would put the lines as stack of paper print and start to mark up horizons of interest on a line through a well location and follow them along the line to the intersections with other lines in order to verify the consistency is maintained, until all loop of intersecting lines be closed, consequently the interpretation is consistent around the loop. This process would take more time of solid mechanical effort if there are abundance of data.

After interpretation had conducted by workstation the problem of prerequisite more time was solved, and enable the interpreter to improve the interpretation of subsurface.

As Sheriff and Geldart 1995 mentioned that the workstations are characterized by:

- Arbitrarily chosen portions of stored data at computer provides a quick mean to verify the consistency of the data with no more spent time to cover all aspects of it.
- Workstation with its display capabilities permit to visualize the data in term of its various kind of attribute that helps seeing the data from various viewpoint to

lessen the likelihood of missing significant features, also the ability to color display contributes to the see nonobvious features.

- Workstation considered as a tool for restoring (working out) the history of structure changes through flattening of picked horizons to aid in seeing attitudes of bedding at the time of picked horizon was deposited.

3.2.6. Reflection Data over Geologic Structures sought in Oil Exploration:

The development of modern field and processing techniques obtain processed data (stacked seismic section) that can appear the presence of many types of structural features that could entrap hydrocarbons are obvious to eyes.

The most common structural target associated with oil entrapment are the anticlines and faults, this structures have recognizable evidences on seismic section, anticlines are generally easy to be seen on record section and faults of more marginal displacement are discernable, structural deformations caused by salt dome and other intrusive can also be mapped.

3.2.6.1. Faults:

Faults can be identified on seismic record through the following main evidence:

- **Termination of reflection:** where the events terminated sharply in the fault plane and then they resumed again in displaced position on other side of the fault.
- **Change in reflection character:** the reflection has a sufficiently distinctive character on two opposite of the fault plane.
- **Change in dip:** the reflection dip is seen different on two sides of the fault. This dip change is due to rotation of horizon as the fault moved along a slight curved fault plane, drag, or other phenomena. (Sheriff and Geldart, 1995)
- **Diffraction events:** several diffractions can be identified along the fault trace, diffraction patterns originate from the edge of beds disturbed by faulting. Figure (3.13) shows the major evidences of faulting.

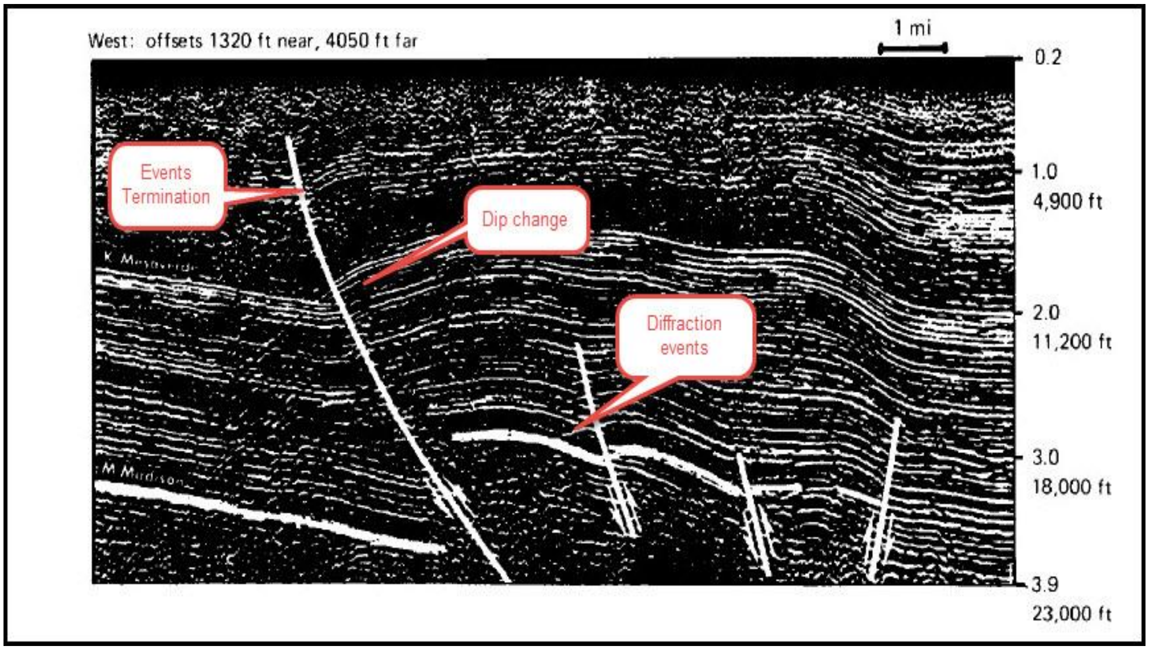


Fig.3.13: the major evidences of faulting, that are termination of reflection where the events terminated sharply in the fault plane, Change in dip where the reflection dip are seen different on two sides of the fault, and Diffraction events that originate from the edge of beds disturbed by faulting.

Recognition of fault types:

Faults considered a brittle deformation of rock blocks of a certain tectonic normal faults are related extensional tectonic whereas, reverse fault associated with compressional tectonic, wrench fault (strike slip) are commonly associated with transform boundary.

Normal faults:

Normal faults defined by a horizon cutout as presented on figure (3.14), and it also defined by the downward motion of the hanging wall relative to the foot wall. This produces the rotation of reflectors as shown figure (3.15).

Reverse faults:

Reverse faults defined by horizon overlap (fig.3.14), revers fault also defined by antiform that develops due to the upward motion of the hanging wall with respect to the foot wall (fig.3.16).

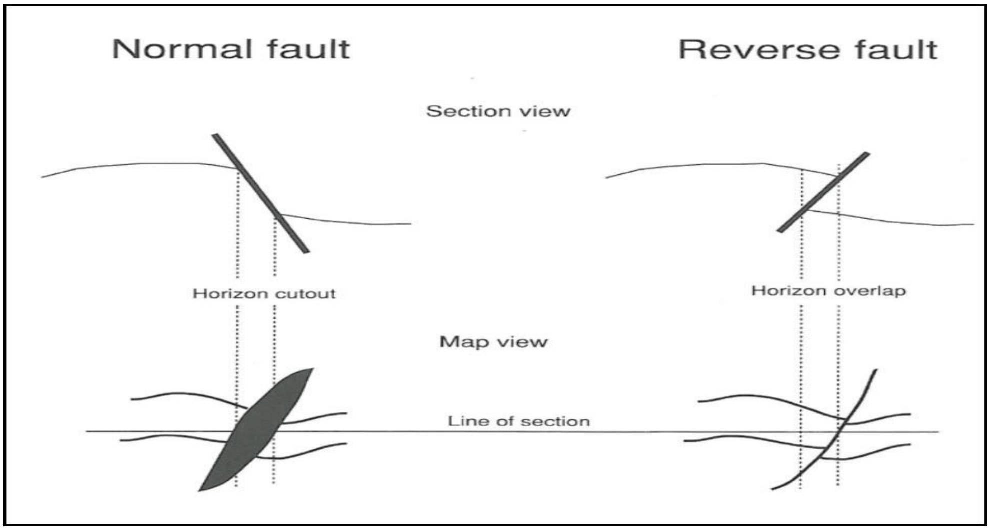


Fig.3.14: left side horizon cutout which characterizes the Normal faults, right side is horizon overlap through which the revers faults are defined.

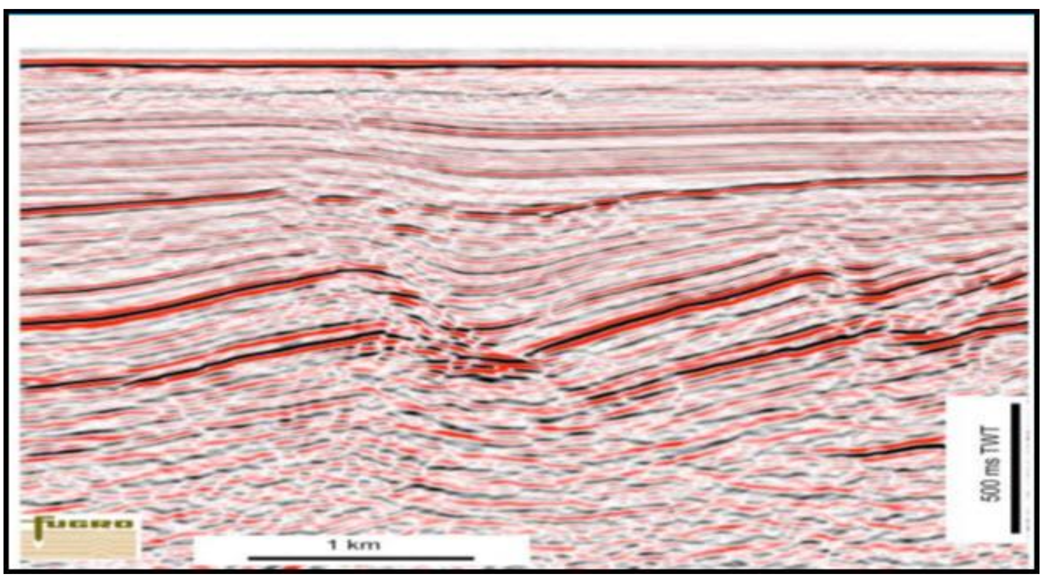


Fig.3.15: the downward motion of the hanging wall relative to the foot wall, which produce the rotation of reflectors.

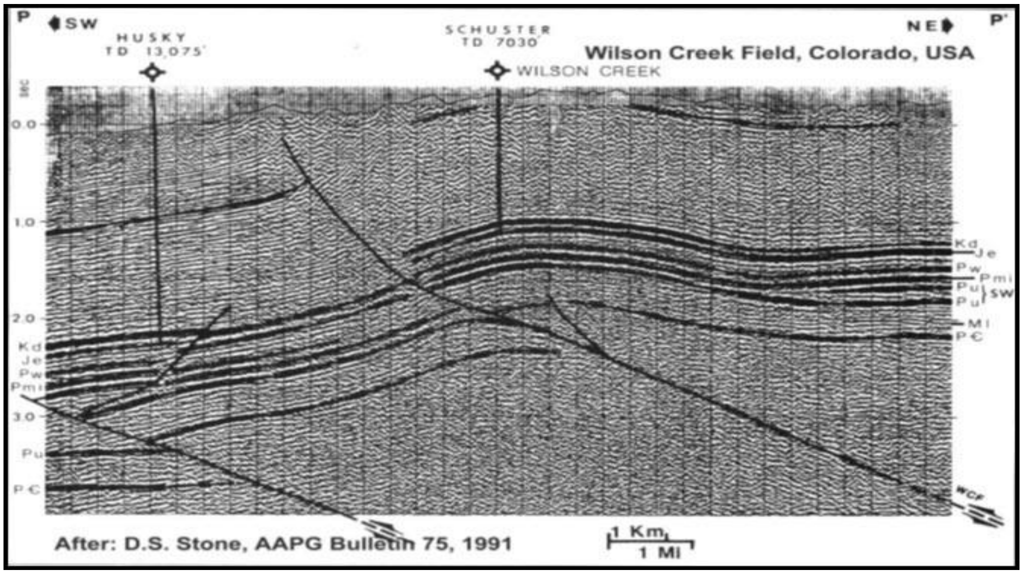


Fig.3.16: an antiformal structure developed due to the upward motion of the hanging wall with respect to the foot wall.

Strike slip faults:

Features related to the strike slip faults are usually confined to relatively narrow linear zones along the principal strike slip direction. Fault trace is generally straight and steepens with depth figure (3.17).

3.2.6.2. Anticlines:

The anticlines formation is related to compressive tectonic forces as well as to deformations caused by salt flow or other diapiric features.

Anticlines are characterized by an area where the reflection dip on both directions from a common point figures (3.18). The interpretation can be relatively simple when the reflections are in good quality and anticline is steep enough to be recognized and also anticlines should has closure greater than spurious irregularities in apparent structures such this irregularities are caused by lateral velocity change or near-surface irregularities.

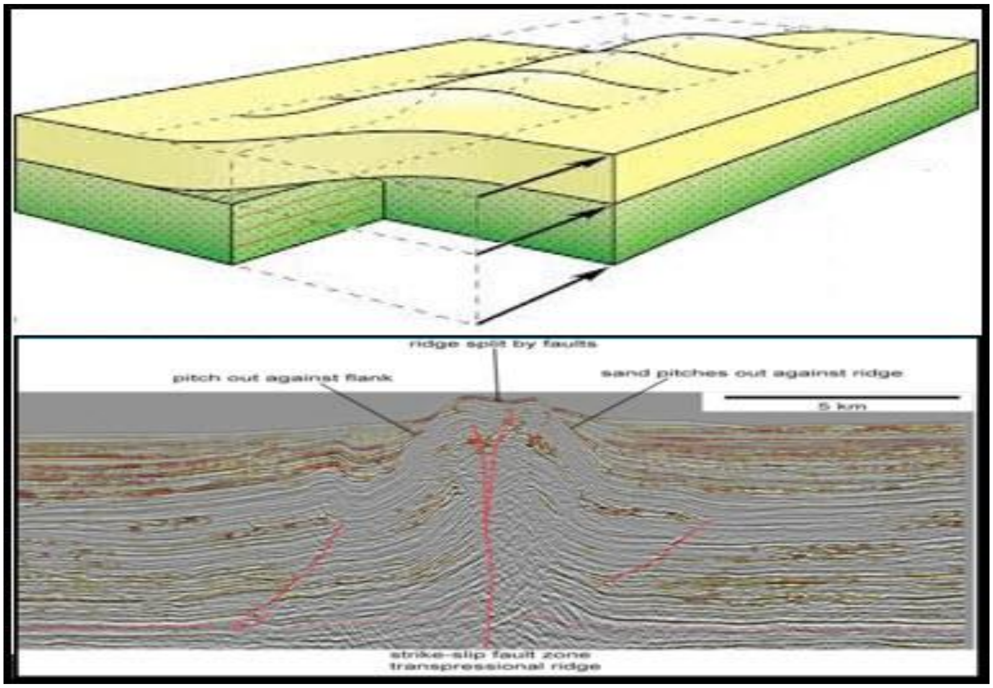


Fig.3.17: the feature relative to strike slip fault that restricted on relatively narrow linear zones along the principal strike slip direction.

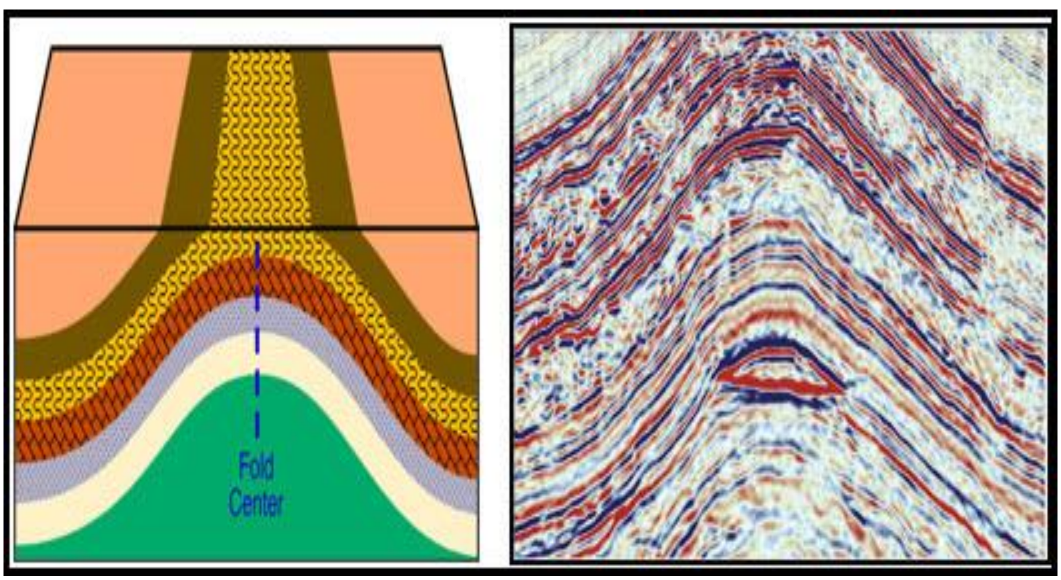


Fig.3.18: Anticlines that characterized by an area where the reflection dip on both directions from a common point.

3.2.6.3. Salt Domes:

Salt domes (fig.3.19) are formed as a result of salt flow, the salt flow occurs when thick salt deposits have been buried fairly rapidly beneath relatively unconsolidated sediments, below some critical depth the salt is less dense than the overlying sediments due to the compaction makes the salt flow upward to form a salt dome, arching the overlying sediments and sometimes piercing through them.

Graben and radial normal faults often result from arching the overlying sediment, salt dome tend to formed along zone of weakness in the sediments, such as a large regional faults.

Salt domes have the following evidence on seismic section: (Sheriff and Geldart, 1995)

- Steep dips may be seen in the sediments adjacent to the salt it's as a result of sediment has been dragged up with the salt.
- The sediments show rapid thinning toward the dome.
- The salt itself is devoid the primary reflections.

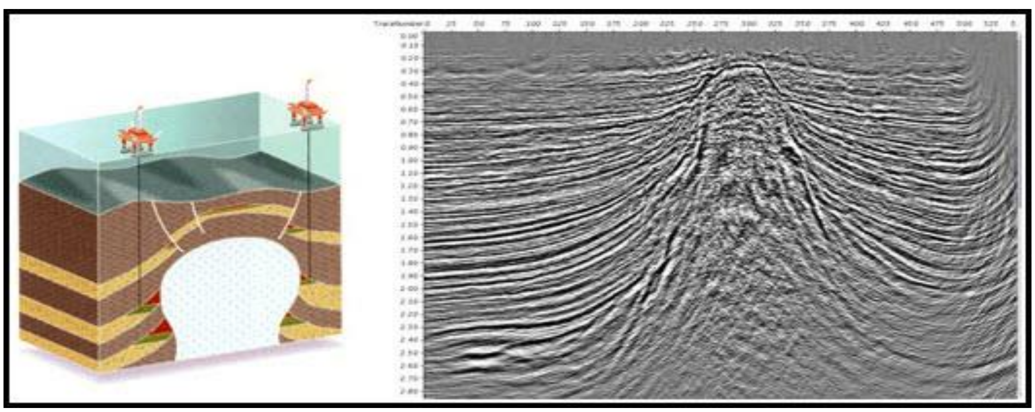


Fig.3.19: Salt domes are formed as a result of salt flow, arching the overlying sediments and sometimes piercing through them, and may Cause to develop Graben and radial normal faults often result from arching the overlying sediment.

3.3. Well Logging Method:

3.3.1. 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. (Asquith and 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 (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.

3.3.2. Wireline logging (Principles and processes):

The wireline logging process is the process 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 (3.20).

3.3.3. The main logs used in seismic interpretation:

3.3.3.1. 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 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.

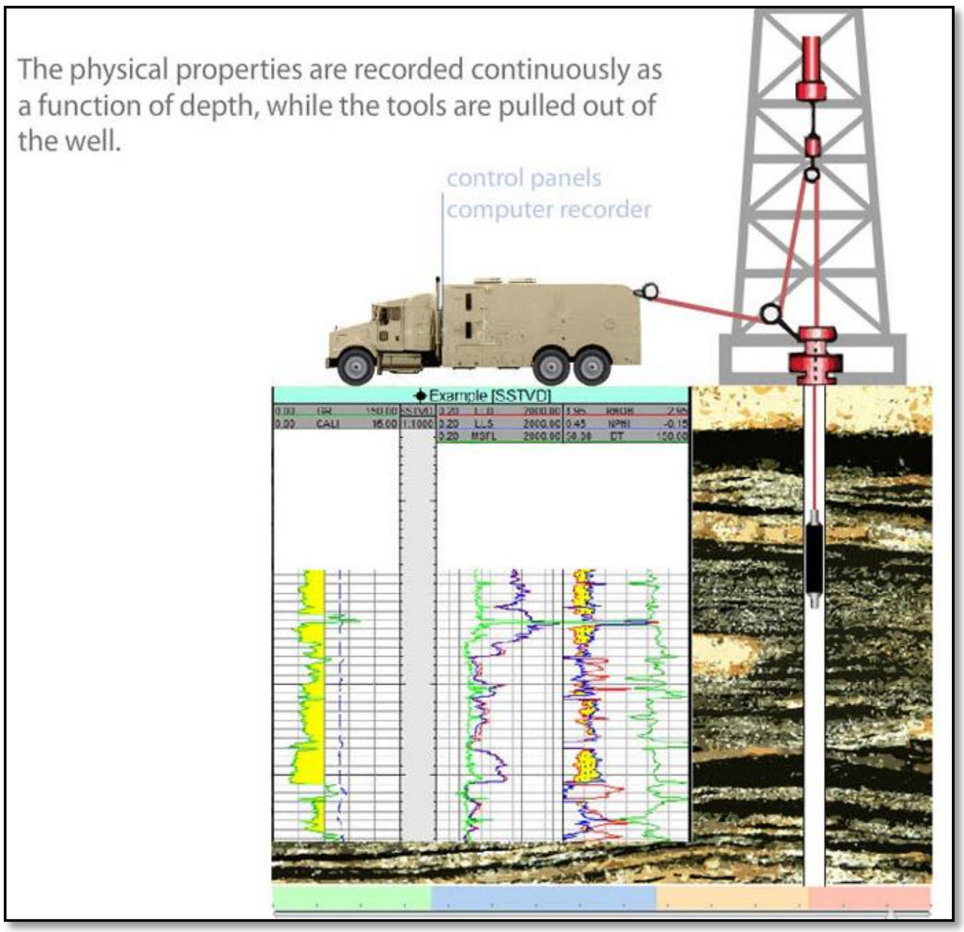


Fig.3.20: well logging its measurements and recording.

Fig.3.21: 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 R_W (hence formation water salinity).

3.3.3.2. 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.

3.3.3.3 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).

3.3.3.4. 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 (fig.3.22).

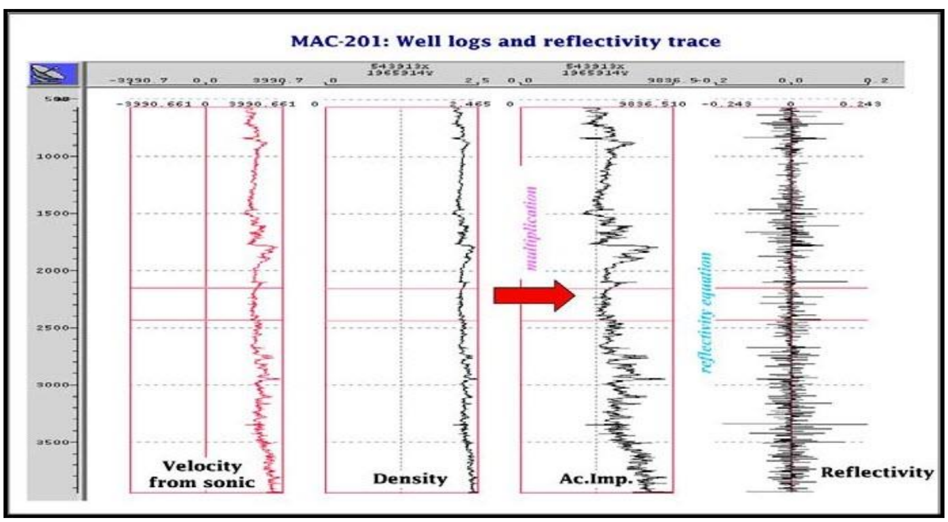


Fig.3.22: the sonic and density log are used together to calculate the acoustic impedance and thus the reflectivity variation with depth.

3.3.4. 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: (Sim and Bacon, 2014)

- **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 modeling.
- **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 travel time it required to establish time -depth relationship through the following:

3.3.5. Velocity survey:

Is a measurement 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. (Schlumberger, 2016)

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

3.3.6. 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 is:

- A sonic log.
- A density log.
- A checkshot survey or VSP.
- A seismic wavelet.

The integrated sonic log, calibrated with the checkshots, 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):

Sonic velocity = (1/DT) 304800.

The velocity and density log are multiplied together to generate an acoustic impedance log (AI) 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 (3.23), is created.

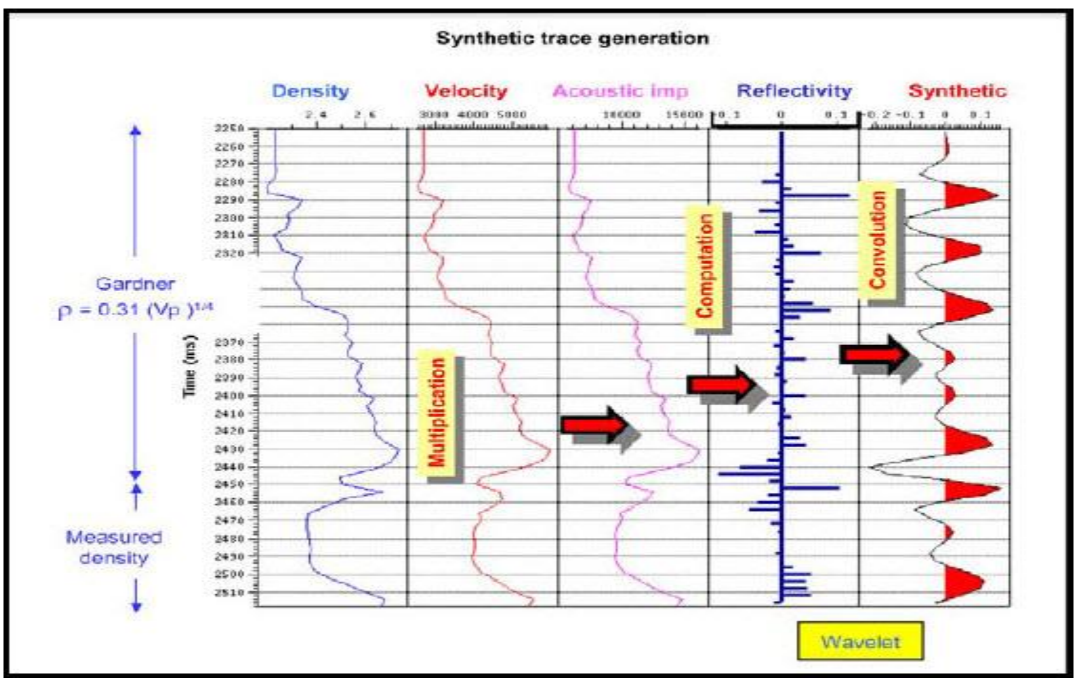


Fig.3.23: synthetic trace generation, the velocity and density log are multiplied together to generate an acoustic impedance log, the AI contrast at each sampling point is

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)

3.3.7. Technical method:

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

3.3.7.1. 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. It's effortlessly to moving from interpretation to structural model building and back using the modeling-while-interpreting workflow (Schlumberger, 2016).

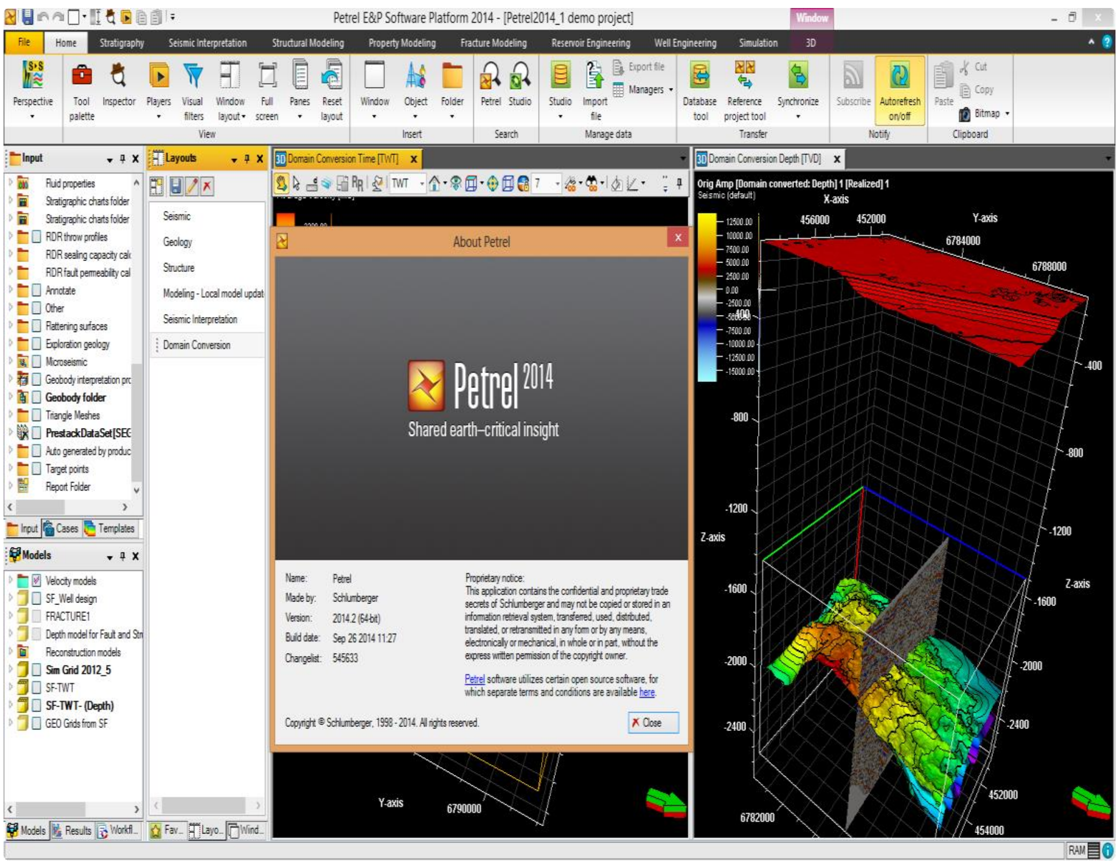


Fig.3.24: the desktop of petrel program.

Chapter Four

4. Integrated Data Interpretation

4.1. Introduction:

Seismic data interpretation of three selected 2D seismic lines was integrated with well data (Kereidiba-1) to delineate the dominant structures of study area and its influences on the hydrocarbon accumulation. These lines were loaded on the Petrel™ software that provides an Environment of multi points of view at them Figure (4.1), where:

a. Line Sd 81-112, of 22.500 Km length and strikes NW-SE, shows generally poor data quality.
b. Line ST11-16PSTM, of 9.500Km length and strikes NW-SE, shows good data quality.
c. Line ST11-09PSTM, of 38.160 Km length and strikes NE-SW, shows good data quality as well.

Tying between Line Sd 81-112 and Line ST11-09PSRM shows shift as shown in figure (4.2), which was tried to resolved using constant shift correction in Petrel unlikely the results was not satisfied thus it was manually adjusted. Synthetic seismogram was then generated to tie Line Sd 81-112 to well (Kereidiba-1), unfortunately the software failed in matching correctly the synthetic seismogram to the line Figure (4.3), that was due to some dis-functions in Petrel that were not applicable, therefore the well tops data are only used and the generated synthetic seismogram was ignored.

Petrel 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.

Four horizons were selected, picked and Interpreted on the three seismic lines. Each horizon is described based on its quality, continuity, reflectivity and the picked TWT range. Later, TWT and depth structural maps for only two horizons tops (AbuGabra and Bentiu formations) were created to delineate its dip trend and the dominant fault network.

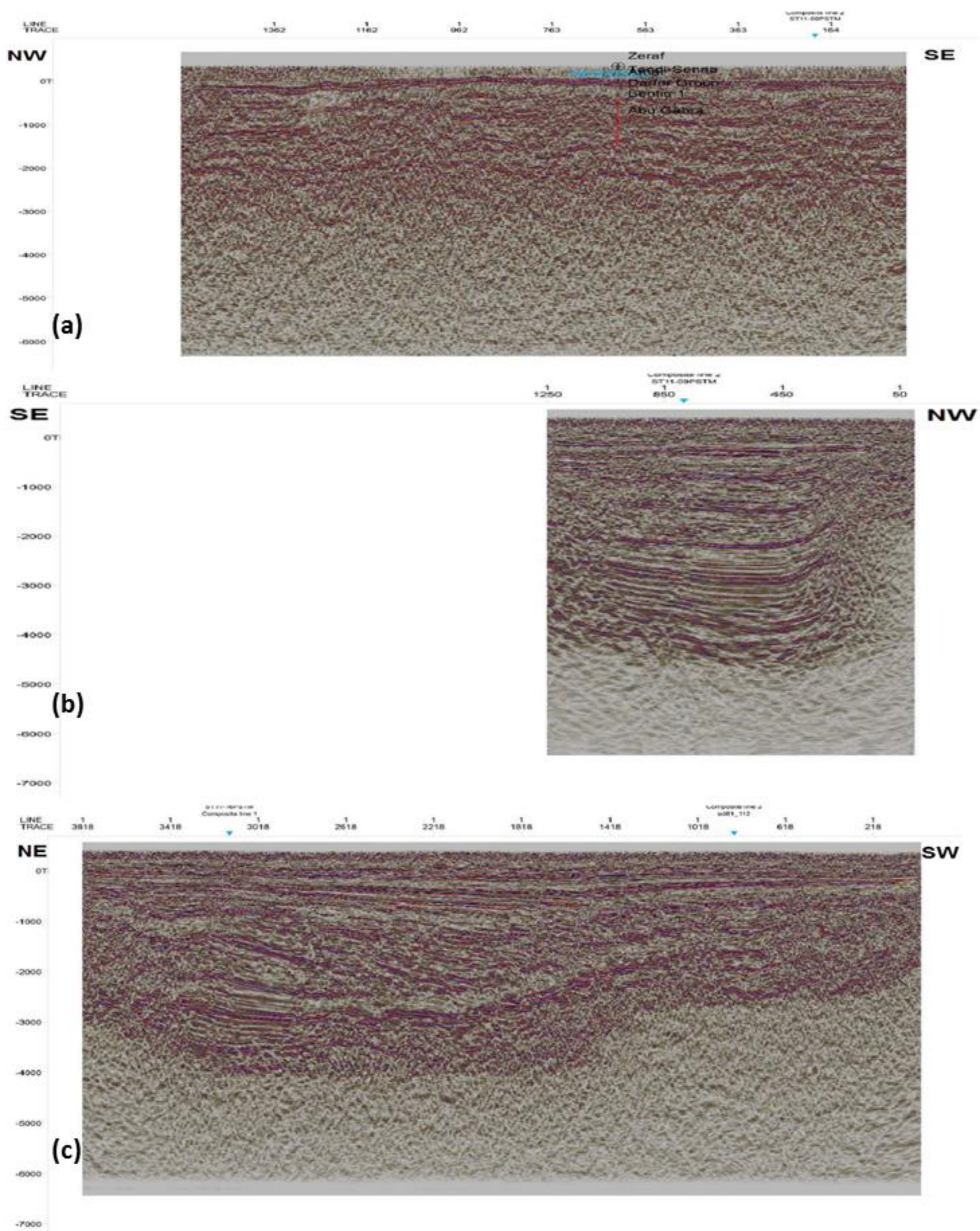


Fig.4.1: the three 2D seismic lines: (a) Line Sd 81-112 of 22.500 Km length and strikes NW-SE, shows generally poor data quality. (b) Line ST11-16PSTM of 9.500 Km length and strikes NW-SE, shows good data quality. (c) Line ST11-09PSTM of 38.160 Km length and strikes NE-SW, shows good data quality as well.

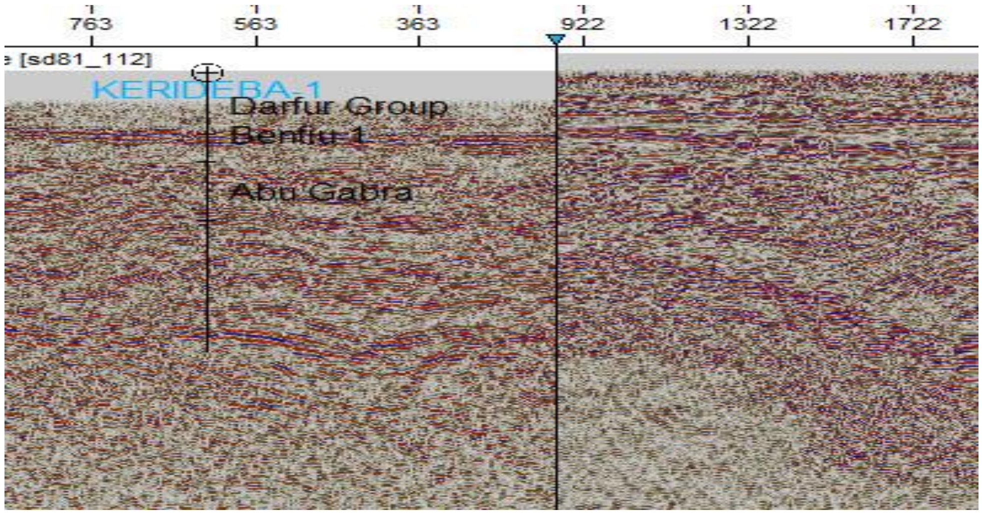


Fig.4.2: shows the shift of tying both Line Sd 81-112 and Line ST11-09PSTM.

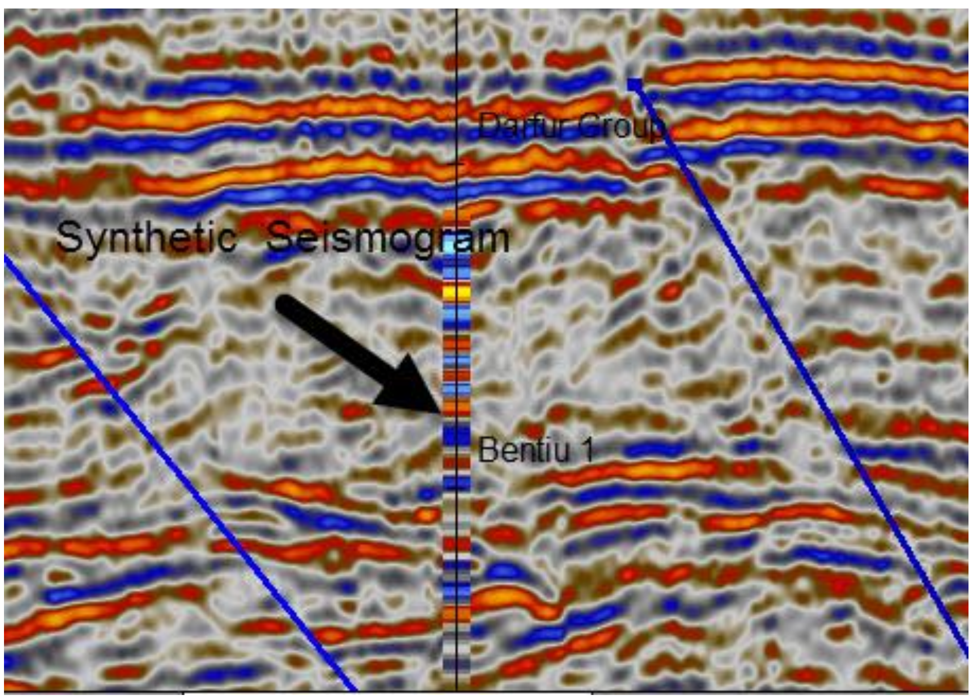


Fig.4.3: synthetic seismogram was generated to tie Line Sd 81-112 to well (Kereidiba-1) which was difficult to be adjusted correctly.

4.2. Interpreted Horizons:

4.2.1. Top Amal Formation:

The reflector of Top Amal formation Figure (4.4) demonstrations good quality, easy to pick. Besides strong and continuous reflectivity along the horizon. The picked two-way time of top Amal ranges from 171.28 to 588.74 ms (149.82 – 637.49 meter).

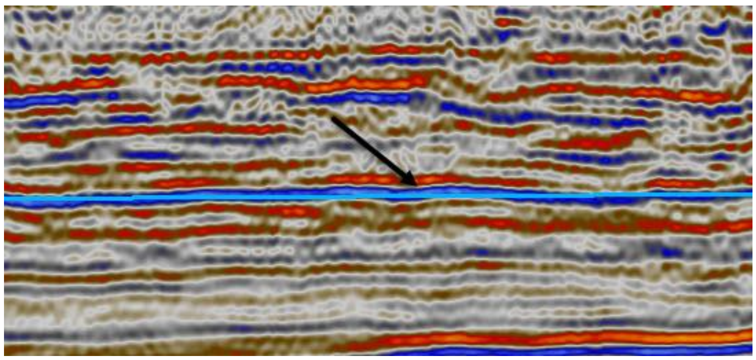


Fig.4.4: the interpreted top Amal formation that indicates good quality, easy to pick. Strong and continuous reflectivity with two-way time ranges from 171.28 to 588.74 ms.

4.2.2. Top Darfur Group:

Top of Darfur group as shown in figure (4.5) varies in its quality along the composite line but generally it is fair and can be picked. The reflected amplitude from top Darfur is continuous and medium that ranges in two-way time from 548.19 – 1050.24 ms (588.60 – 1217.18 meter).

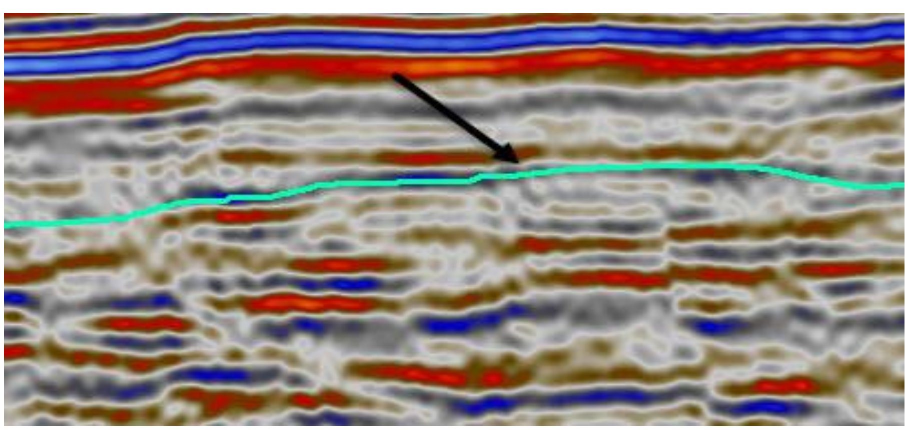


Fig.4.5: top of Darfur group which is generally fair and can be picked.

4.2.3. Top Bentiu Formation:

Top of Bentiu formation as shown in figure (4.6) shows low data quality, which reflects in the difficulty of it picking. The reflector is not continuous, but has strong value of reflectivity, that ranges in TWT 623.25 – 1573 ms (679.37 – 1925.29 meter)

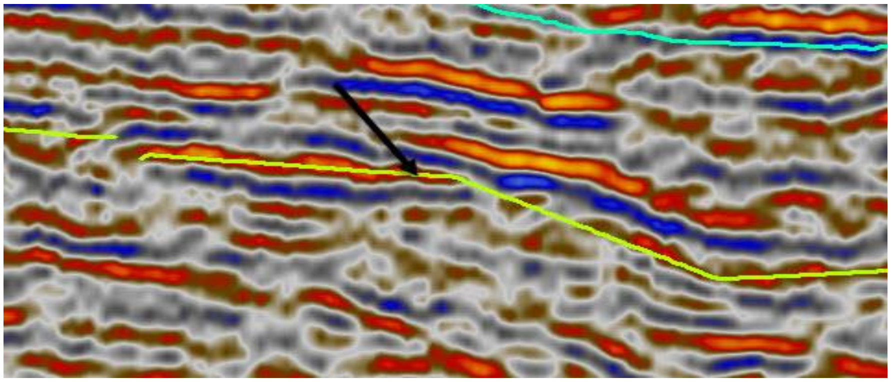


Fig.4.6: top of Bentiu formation shows low data quality, difficult picking, and discontinuous, but strong value of reflectivity.

4.2.4. Top of AbuGabra Formation:

Top of AbuGabra formation as shown in figure (4.7) shows low data quality, hard to be picked, clear discontinuity and has strong to medium reflectivity. It ranges in two way time from 985.65 to 2257.76ms (1113.50 – 2935.5 meter).

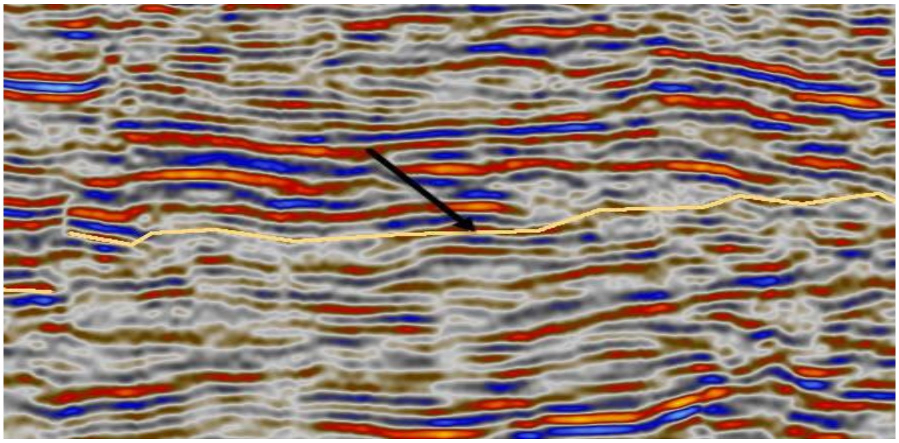


Fig.4.7: top of AbuGabra formation shows low data quality, hard to be picked, clear discontinuity and strong to medium reflectivity.

4.3. 2D Seismic Lines Interpretation:

4.3.1. Line (ST11-09 PSTM):

Is a dip line as shown in figure (4.8) located in the southeastern part of study area, oriented SW – NE, and perpendicular to strike direction of Rakuba sub-basin. This line shows a structural pattern of an extensional rift basin, characterized by dip slip normal faults built the basin with geometry identical to (Rotated Fault Block) model that was developed by Ben et.al in 2004. Figure (4.9) is a model describes rift basin structural style, which represents parallel rotational faults before faulting and after faulting, and the fault blocks are tilted. (Ben et al., 2004)

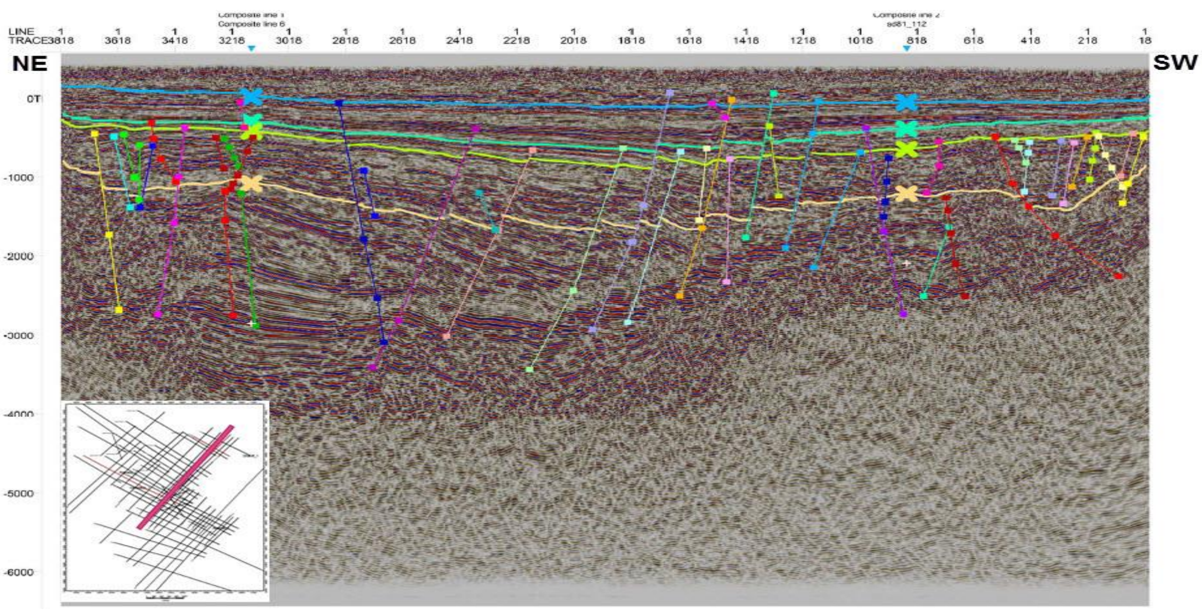


Fig.4.8: Line ST11-09 PSTM, a dip line that perpendicular to the strike direction of Rakuba sub-basin. It shows an extensional rift basin characterized by dip slip normal faults of rotated fault blocks.

The interpreted normal faults reveal two downthrown dipping directions: NE at the right side, and SW at the left side of the section. Due to these normal faults, the middle part of the section caused to subside and shows a graben structure, therefore the formation thicknesses vary along this section. Moreover, this complex fault system consisted of antithetic and synthetic faults that break up the hanging-wall block. From the interpretation, AbuGabra formation has the largest thickness among the other interpreted formations which reflected the intensive structural activities during the rifting phase and the difficulty of mapping the top to Basement rocks.

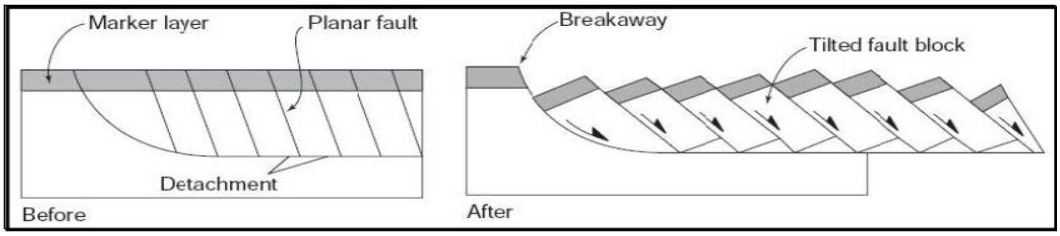


Fig.4.9: a model represents parallel rotational faults before faulting and after faulting, and the fault blocks are tilted (Ben et al., 2004).

4.3.2. Line (ST11-16 PSTM):

Is strike line as shown in fig (4.10), located on NE part of the study area and oriented NW-SE, as it is parallel to strike of AbuGabra-Sharaf ridge to the east. This line shows at the right side normal fault with listric plane considered as a major fault that caused the formation blocks on the south of Tomat high to slipping SE. Other faults at the left side (the south eastern part) are considered associated faults related to strike component forces. These faults have fewer effects on the basin fill.

The middle part of this section observed thick subsided sediments, which shows part of the graben structure that observed previously in Line ST11-09 PSTM.

4.3.3. Line (Sd81-112):

Is strike line as shown in figure (4.11), located at NW side of study area and oriented NW-SE. The line is approximately crossing Kereidiba-1 exploratory well, of 3000m depth drilled by (CNPC) and was calibrated to the other seismic lines. Generally, the line shows the formation thickness are gently varying, because of the little effect of major faulting related to the presence of strike component force. This section shows synthetic and antithetic faults structures.

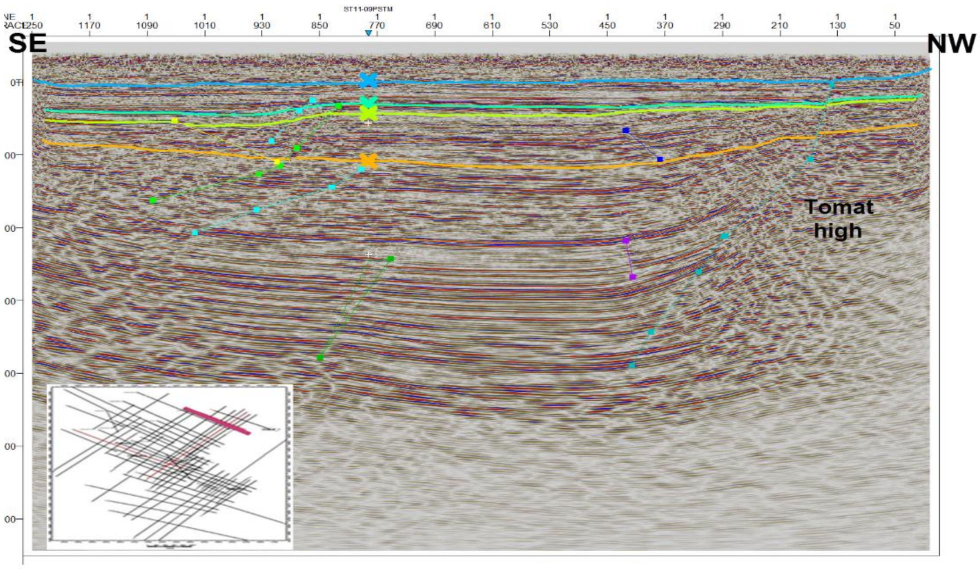


Fig.4.10: Line ST11-16 PSTM strikes NW-SE and parallel to the strike of AbuGabra-Sharaf ridge. It shows normal fault with listric plane considered as a major fault causing the formation blocks on the south of Tomat high to slip southeast-wards.

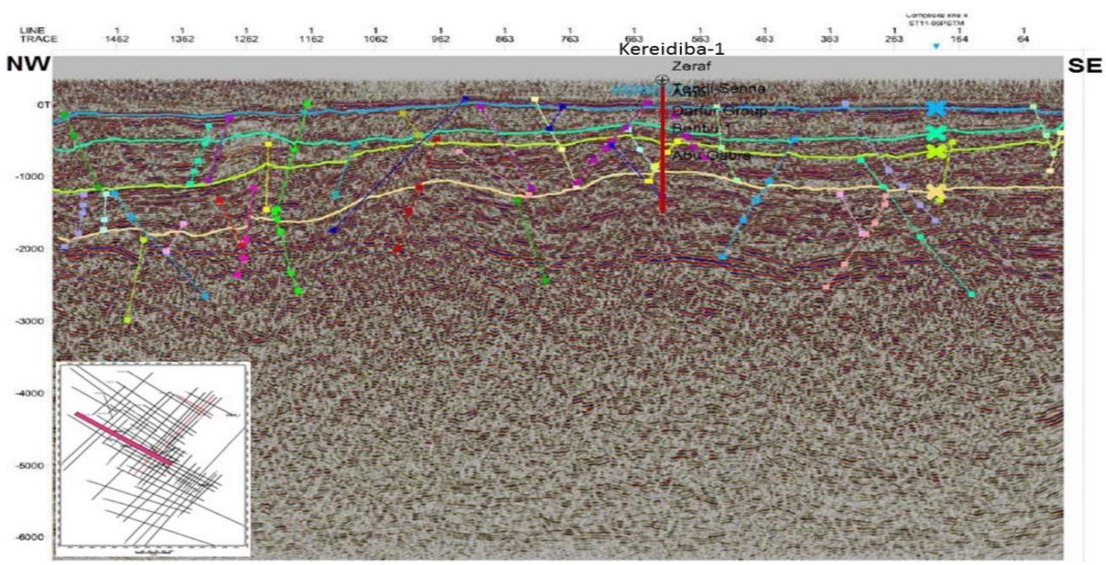


Fig.4.11: Line Sd81-112 strikes NW-SE and located at the northwestern part of the study area, it crosses Kereidiba-1 exploratory well and shows gentle varying of the formation thickness due to the little effect of major faulting related to the strike component force.

4.4. Structural Maps Interpretation:

Two-way time structural maps were created for both top Bentiu and top AbuGabra formations. These maps were converted to depth structural maps for both studied horizons using velocity values that are extracted from the available check shot data, and the used velocity equation as shown in figure (4.12).

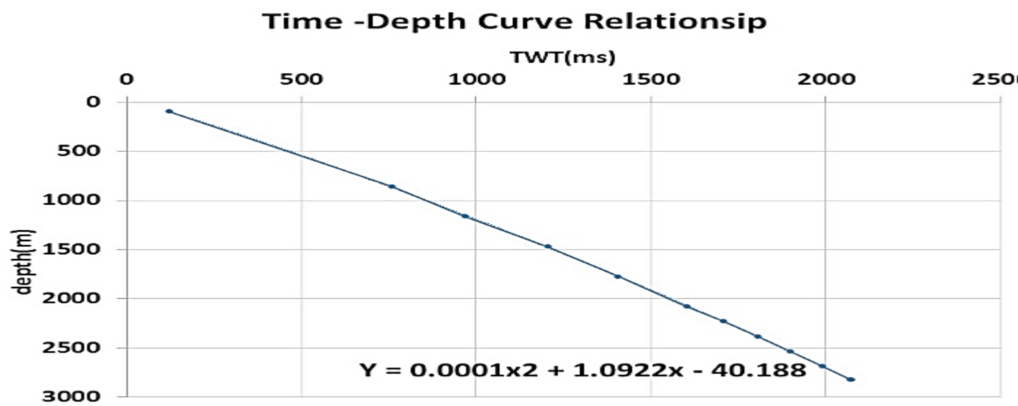


Fig.4.12: conversion to depth maps utilized a velocity equation that is extracted from the available check shot data. Where Y is the depth in meter and X values is the two-way times in milliseconds.

4.4.1. AbuGabra Structural Maps:

There are three fault trends are delineated in this horizon: the dominant NW-SE which reflected the major rifting structures of Rakuba sub-basin in east and central part of the area and south of Tomat high, secondary NE-SW that observed mainly in the northwestern part of the area suggesting a NW extension of Rakuba sub-basin, then a minor N-S faults semi parallel to AbuGabra-Sharif ridge to the east.

The western part of the area does not affect by Tomat normal fault in both structural maps of this horizon, which stepped to SE direction and toward the depocentre direction. As observed results that the eastern side shows the deepest values in term of both two-time and depth values. To the western side the top AbuGabra steeply dipping towards the northeast although one major fault was delineated with a downthrown to the southwestern part indicating possible new sub-basin that required more seismic data.

4.4.2. Bentiu structural maps:

Bentiu structural maps as displayed in figure (4.15 a & b) and Tomat high are 0observed in the northeastern part of the map. Similarly to top AbuGabra maps, three faults trends are observed in Bentiu maps: dominant NW-SE trends intensively in the central and east part of the study area which are corresponded to the rifting phase, NE-SW that are parallel to Tomat high and suggest a graben extension of Rakuba sub-basin, and last minor NNW-SSE fault trend observed in the central part which indicate a re-activated component of the rifting fault network. The southern part of the map shows shallow depths to top Bentiu as suggested the southwestern flank of the basin, however more seismic data in this part are required to prove this interpretation.

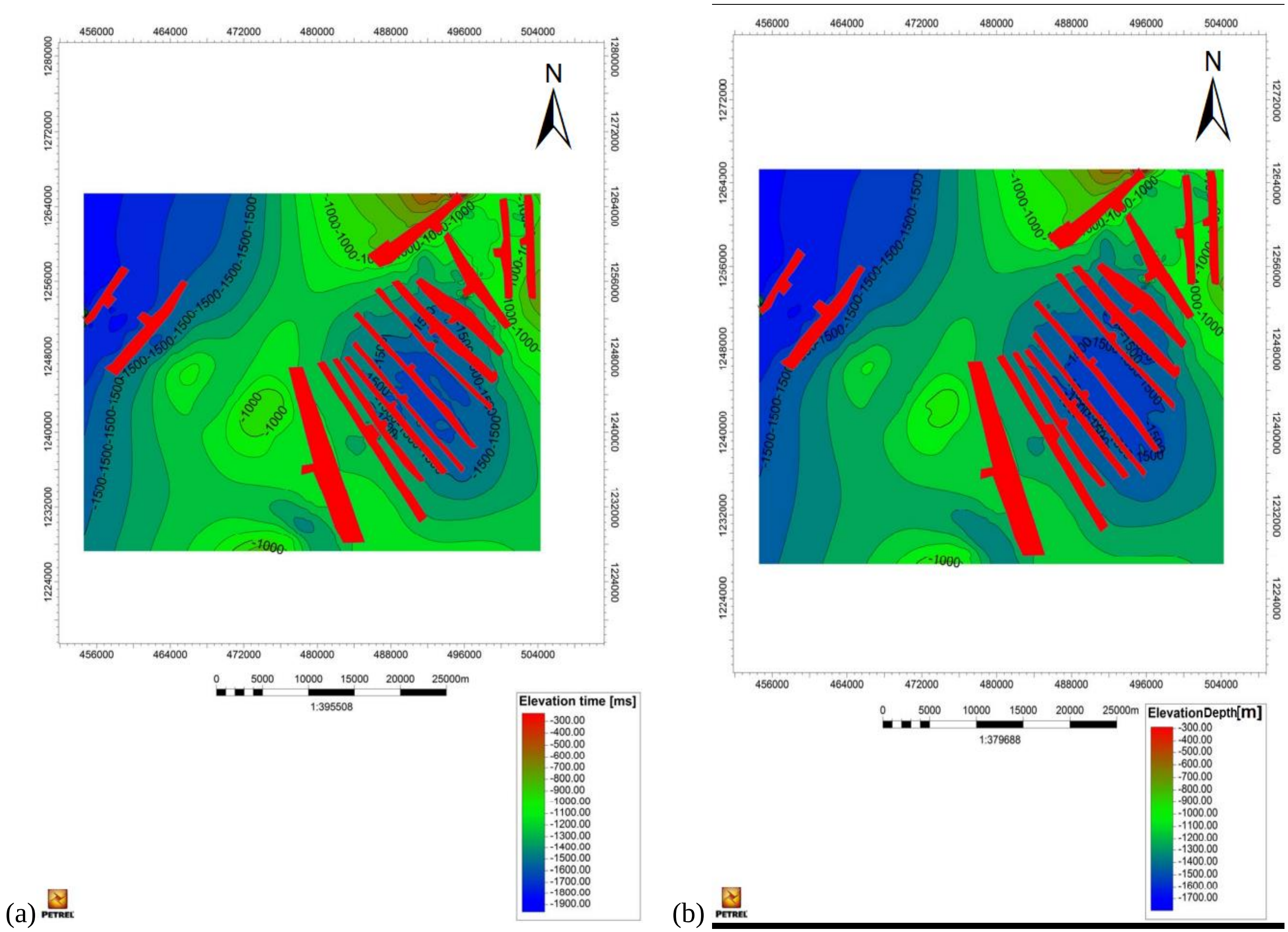


Fig.4.13: (a) Two-way structure map of top AbuGabra, (b) Depth structure map of top AbuGabra horizon

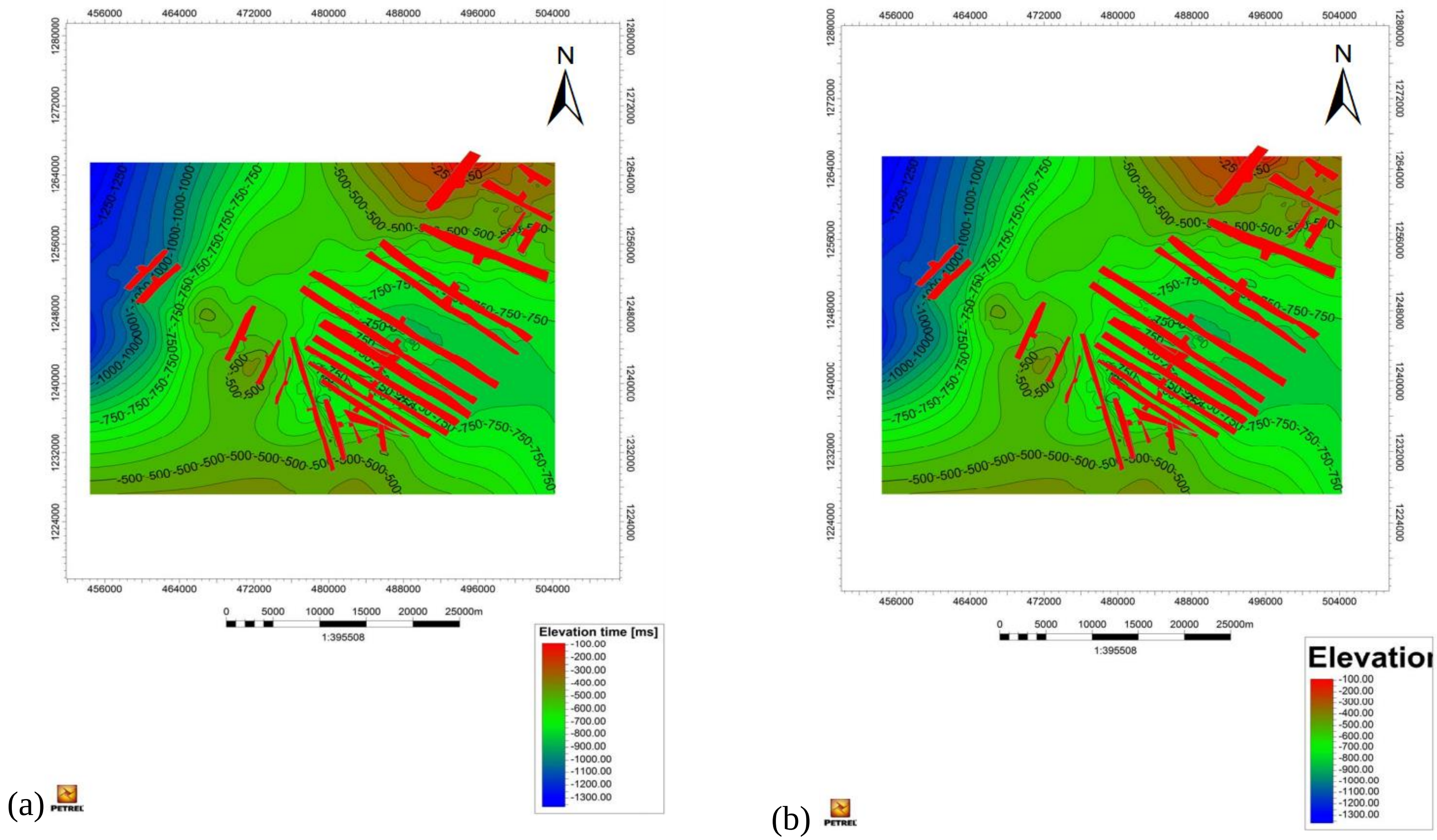


Fig.4.14: (a) Two-way structure map of top Bentiu horizon, (b) Depth structure map of top Bentiu horizon

Chapter Five

5. The Hydrocarbon Potentiality

5.1. Introduction:

The occurrence of hydrocarbon accumulations on the subsurface requires several geological elements, these elements are the following (Izzal-Din, 2016):

i. Source Rock: Is a rock with abundant hydrocarbon-prone organic matter.
ii. Reservoir Rock: is a rock in which oil and gas accumulates, it should has a reasonable (porosity, permeability).
iii. Seal Rock: is a rock through which oil and gas cannot move effectively (such as mudstone and claystone).
iv. Migration Pathways: are Routes in rock through which oil and gas moves from source rock to the trap.
v. Trap: is the structural and stratigraphic configuration that focuses oil and gas into an accumulation.

5.2. Potential Source Rock:

Out of average source rock 99% is fine grained mineral matter and 1% organic matter. The maturation of the organic matter within the source rock into hydrocarbon happens in such depths where the pressure and temperature are enough to degrading the kerogen that form the oil (oil window), frequently at depth range 1.5-3 km. (Sheriff and Geldart 1995)

To pointing out the potentiality of hydrocarbon generation, it's feasible to integrating the existing source rock data into structural depth map that structurally follow the source rock that help on mapping the generative source rock. (Handler, 2016)

From the stratigraphic column of Muglad basin, the major source rock is AbuGabra formation which composed of shale stones intercalated with sand as shown in figure (5.1). The illustrated figure displayed the lithological units that composed AbuGabra, Bentiu, Darfur group, and Amal formations.

5.3. Potential Traps:

The potential structural traps are linked to the presence of fault networks in the area, the faults cause to juxtapose the permeable beds on the fault plane against impermeable beds, as shown in figure (5.2) (Sheriff and Geldart, 1995).

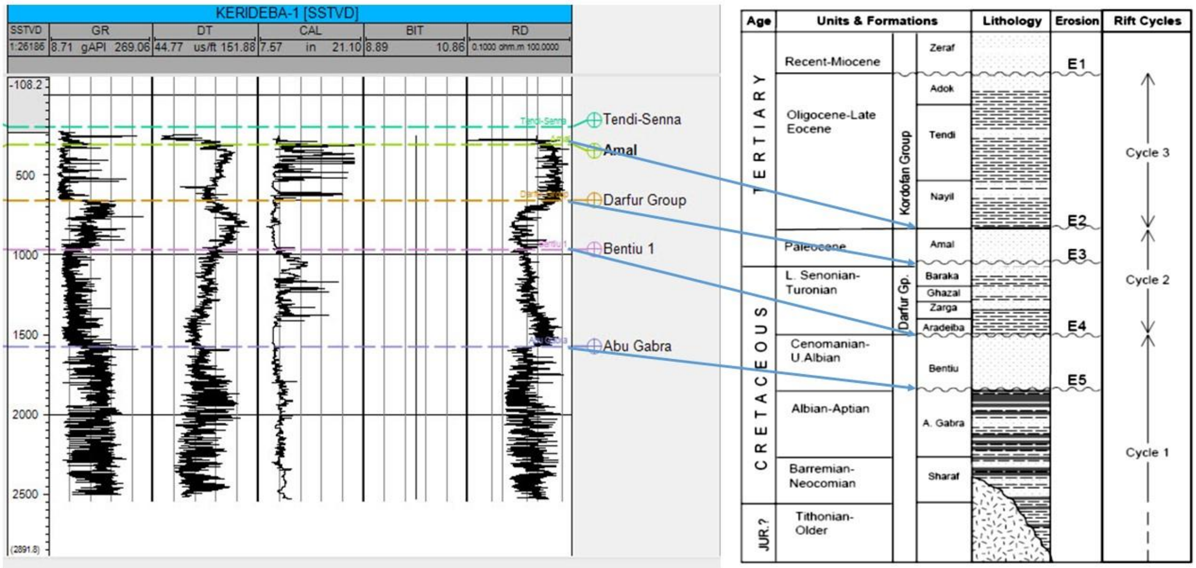


Fig.5.1: calibrated log data of Kerdieba-1 well with the stratigraphic column of Muglad basin for the interpreted four horizons (Top Amal, Darfur group, Bentiu, and AbuGabra formations).

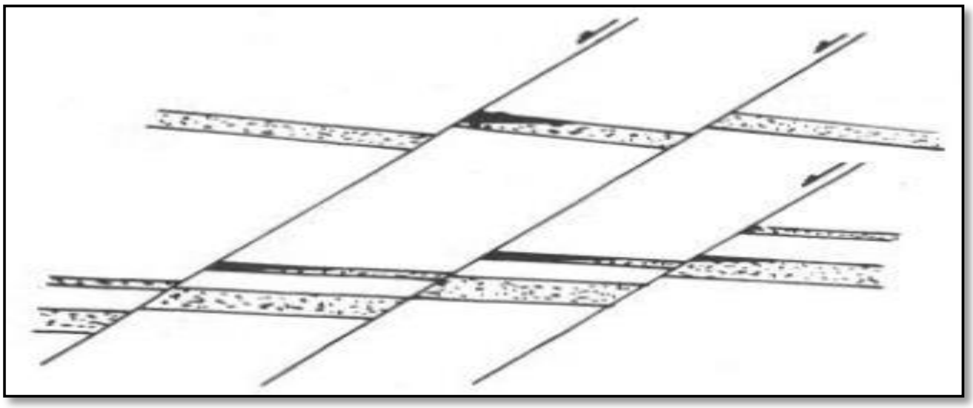


Fig.5.2: developed traps where faults cause to juxtapose the permeable beds on the fault plane against impermeable beds.

Figure (5.3) presents the Kereidiba -1 logs (Gamma ray) which reveals the AbuGabra formation as shale stone, Bentiu formation grossly as sandstone and the Aradeiba formation within Darfur group is shale that emphasize the integration of hydrocarbon system elements in seismic line Sd 81-112.

Based on the interpreted sections and structural maps, the potentiality of hydrocarbon was evaluated in sights of the depth and the thicknesses of the formations, and else the structural deformation of formation to develop the traps. Two zones (A and B) were identified as having good hydrocarbon potentiality as shown in figure (5.4).

Zone A overlain the depth ranges 1900-2000 m of AbuGabra formation and average thickness of 3600m approximated from sections by using the deduced T-D relationship. The zone also overlain Bentiu formation where there is dense fault network that support the trap development, the structural deformation caused to Aradeiba shale juxtaposed against Bentiu sand and providing sealing. Zone B as displayed in figure (5.4) shows top AbuGabra ranges in depth 1900-2100 m from surface with average thickness about 1100 m, the Bentiu formation at zone B is not efficiently deformed to develop hydrocarbon traps.

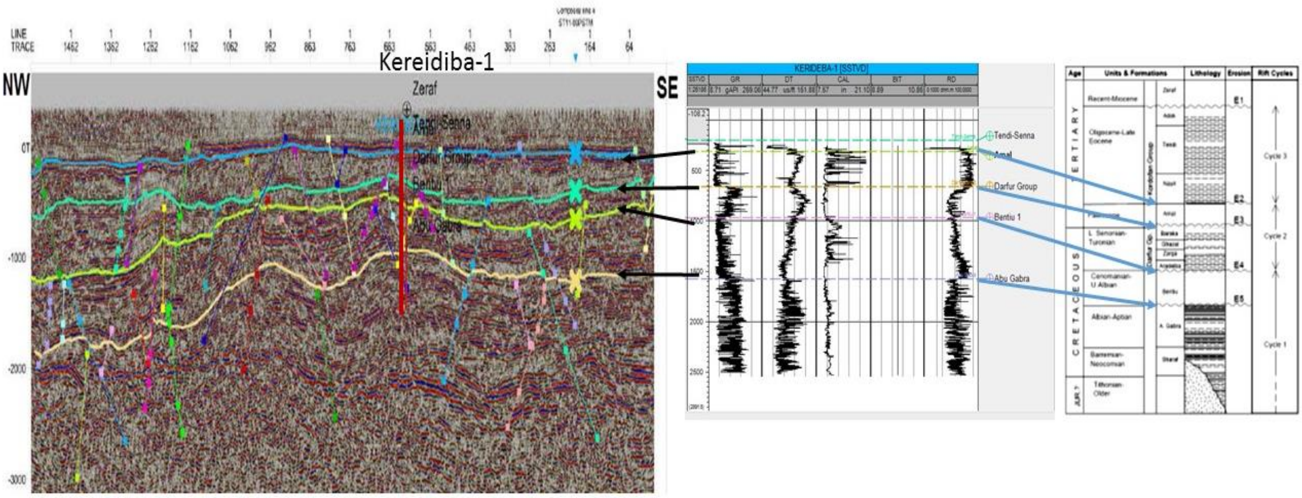


Fig.5.3: Line Sd 81-112 calibrated with the well log data of Kerdidieba-1 and the stratigraphic column of Muglad basin.

In the sub-zone A* on zone A, selected as a key area locates above the subsurface where it was observed on the seismic line of (ST11-09 PSTM) a flat spot shown on figure (5.5) that may be a direct hydrocarbon indicator, where the flat spot can result from the increase in acoustic impedance when a gas-filled porous rock (with a lower acoustic impedance) overlies a liquid-filled porous rock (with a higher acoustic impedance). It may stand out on a seismic image because it is flat and will contrast with surrounding dipping reflections.

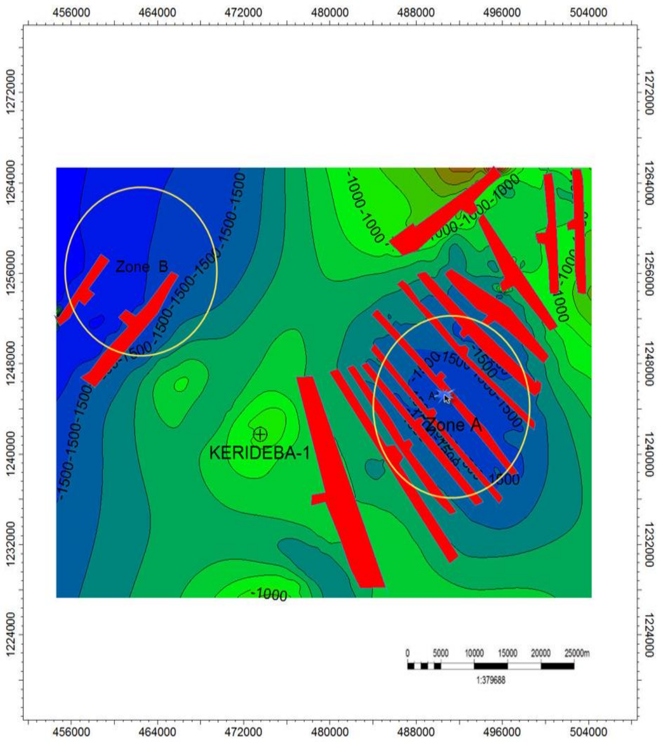


Fig.5.4: Two-Way Time map of top AbuGabra map, in which two zones (A and B) represents the good potentiality of hydrocarbon accumulation in Rakuba sub-basin, based on log data and the interpreted sections and created structural maps.

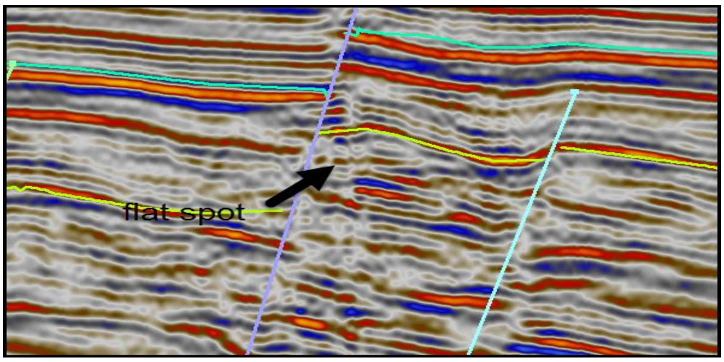


Fig.5.5: a flat spot that may be a direct hydrocarbon indicator, it stand out on a seismic image because it is flat and will contrast with surrounding dipping reflections.

Although the flat spot is a seismic attribute to referring the presence of the hydrocarbon, it also may indicate to horizontal stratigraphy, hence advance quantitative method like amplitude versus offset analysis should be used to discriminate the observed point.

Chapter Six

6. Conclusions and Recommendations

6.1. Conclusions:

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 three 2-D seismic lines and integrated with (Kereidiba-1) well information, in order to describe the structural influence on the subsurface and further identify zones with stronger hydrocarbon potentialities.

Petrel software were used as a mean for interpreting four horizon tops of (Amal, Darfur Group, Bentiu, and AbuGabra) and also the observed faults on the three seismic lines, then structural maps (TWT and depth maps) of the AbuGabra and Bentiu formation tops were generated and analyzed.

Based on the interpreted seismic lines and structural maps, It was found the geometry of the Rakuba sub-basin looks like rotated fault blocks model which published Ben et.al at 2004, Also it was observed from the two structural maps three fault trends, NW-SW as dominant faults at the central area which had played important role in basin development, secondary NE-SW at the northwestern side of the area, the third trend is NNW-SSE trend observed in the central part of Bentiu maps which indicate a re-activated component of the rifting fault network.

Two zones (A&B) were selected on the maps as prospects based on the interpreted seismic lines, structural maps and the stratigraphic column of the Muglad basin, at zone (A) The AbuGabra formation top depth range 1900-2000 m and average thickness of 3500 m, additionally zone A present efficient structural deformation to develop traps on Bentiu formation, on the other hand AbuGabra formation shows at zone B depth range 1900-2100 m, and average thickness of 1100m, but the zone does not show effective structural deformation to build the traps with respect to zone.

6.2. Recommendations:

- Interpreting more seismic lines calibrated with better logging data to improve the vertical and horizontal extension of the sedimentary formations in Rakuba sub-basin.
- Conducting quantitative interpretation using seismic attributes and amplitude versus offset analysis.
- Vertical seismic profiling data gives accurate and reliable extracted velocity values to convert the two-way times into true depths of these sedimentary formations.

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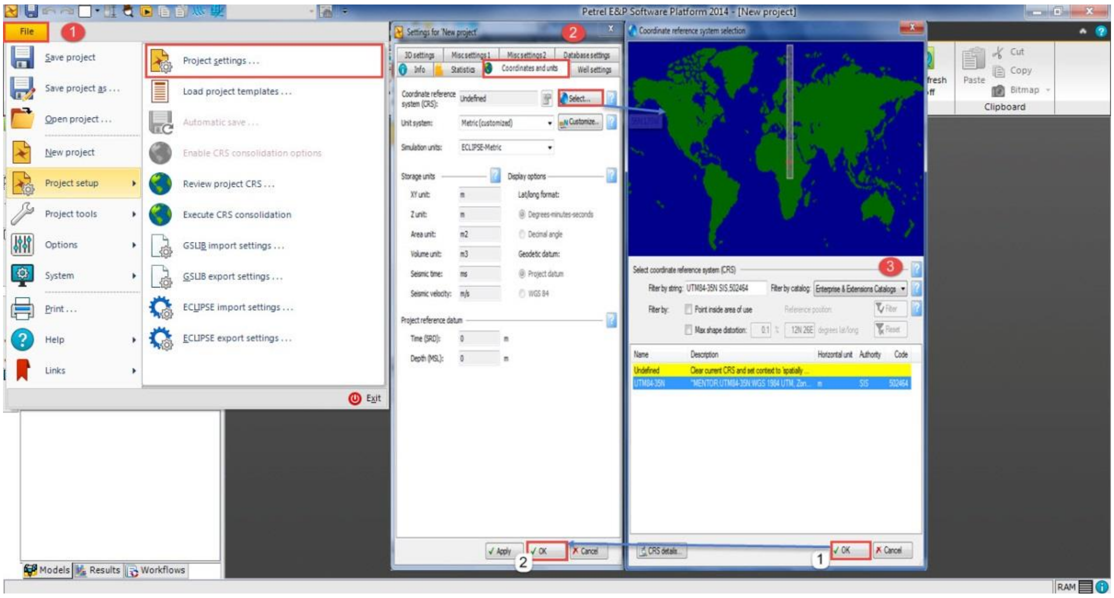
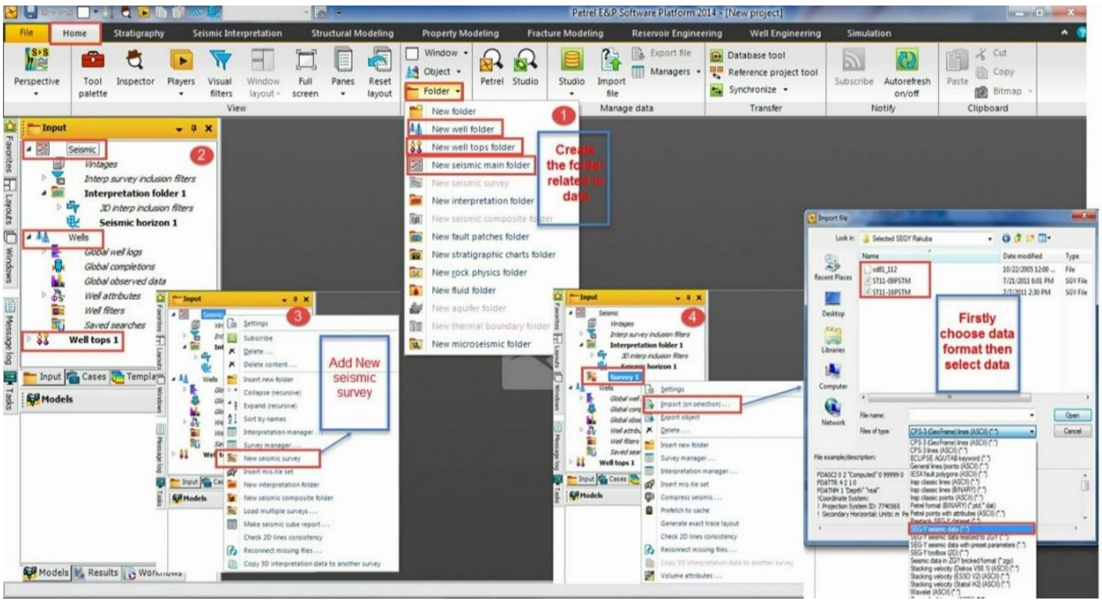
Appendix

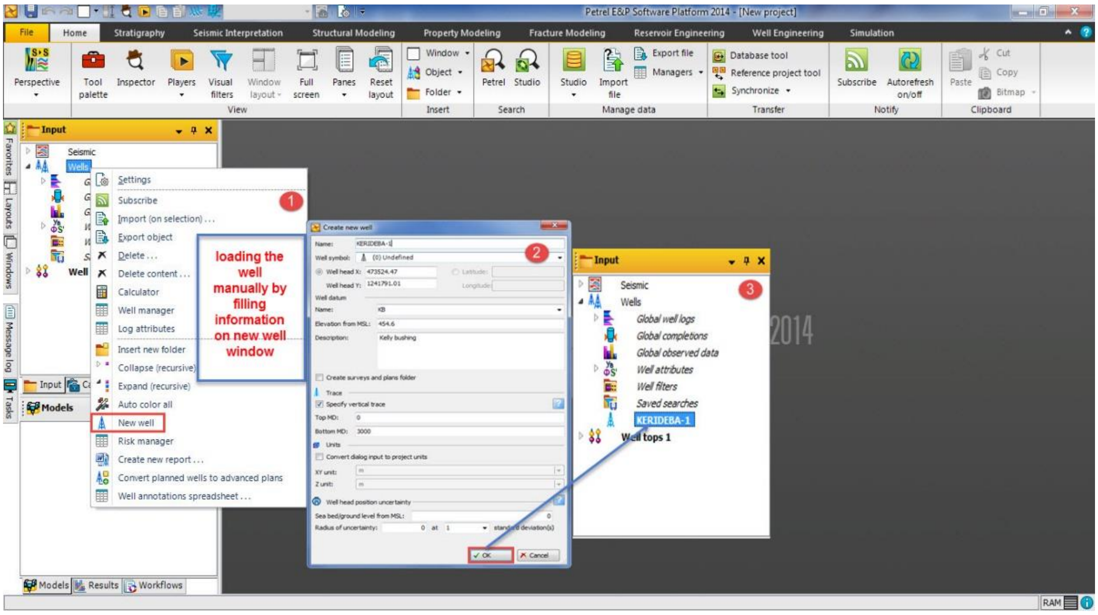
Appendix



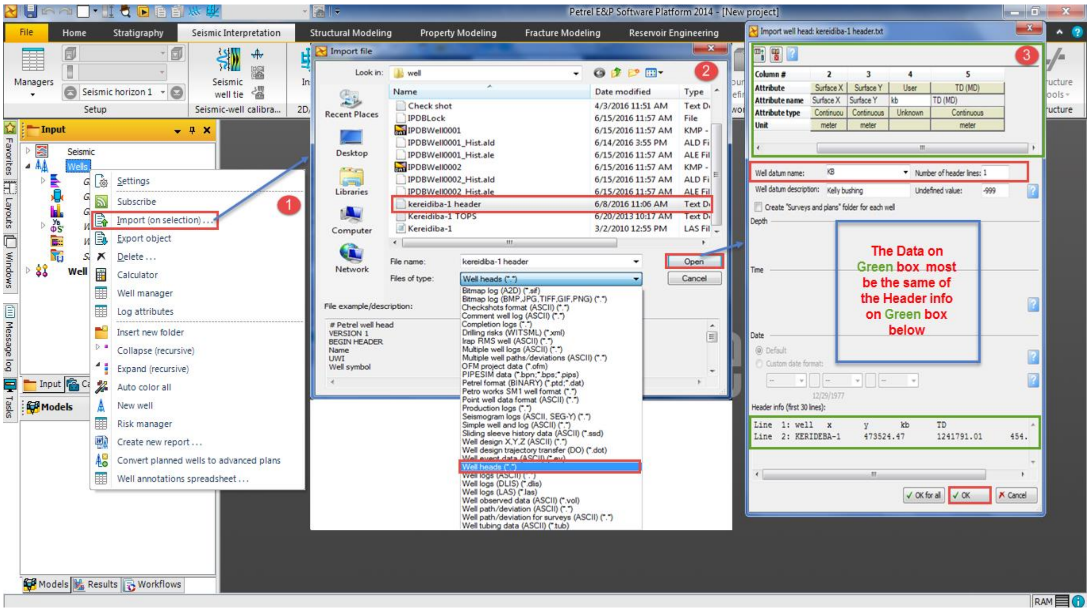
A.1: selection of Coordinate Reference System (CRS) to provide a geodetic reference for project



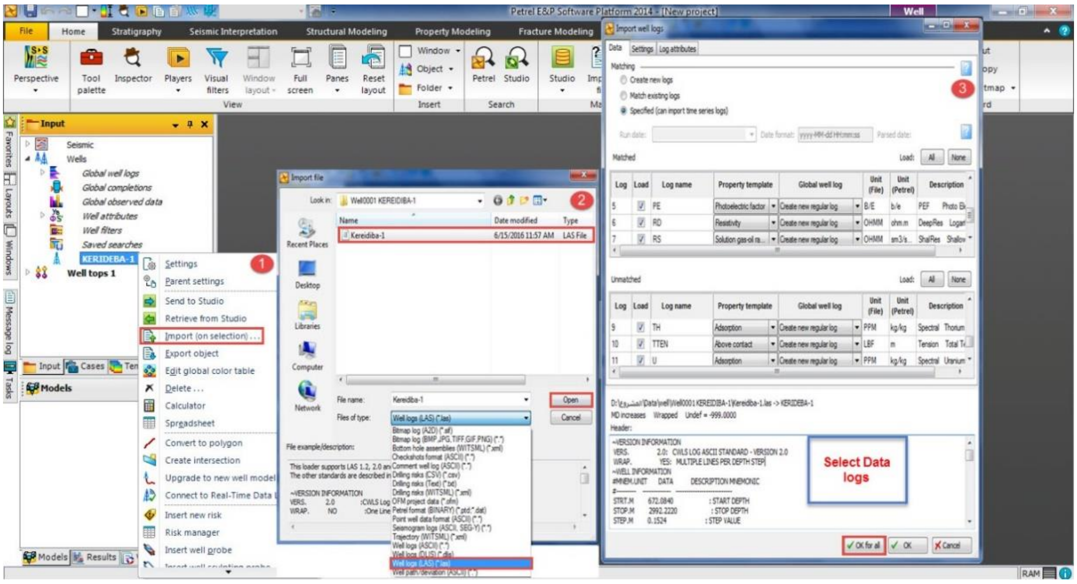
A.2: Loading of new folders of seismic, wells, well tops and seismic sections with their data format



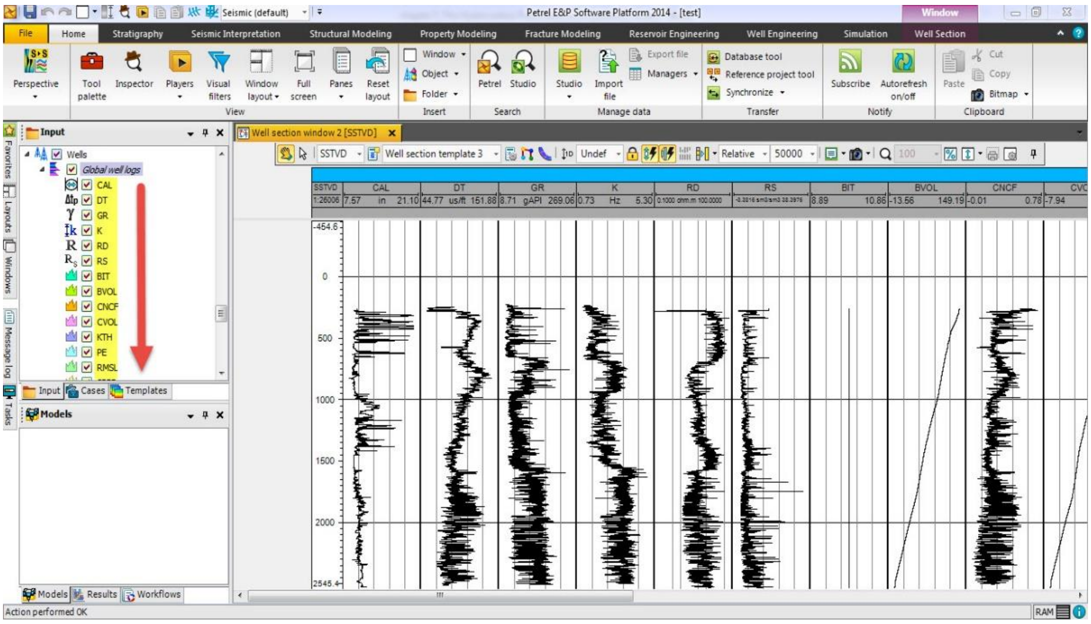
A.3: Loading of well with log data manually without a header info



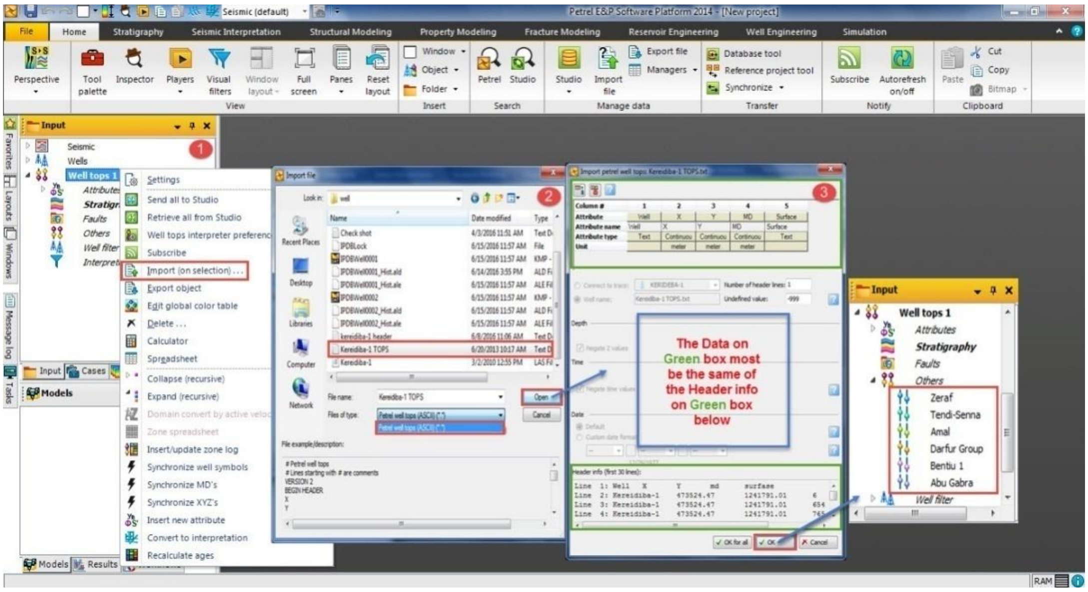
A.4: Loading of well with log data by using header info



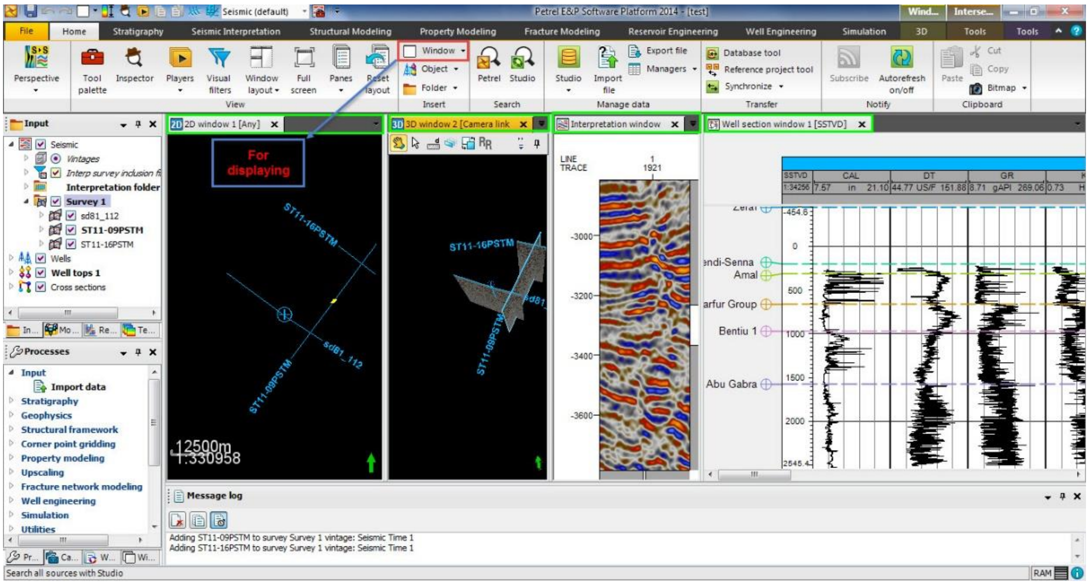
A.5: Loading of data logs



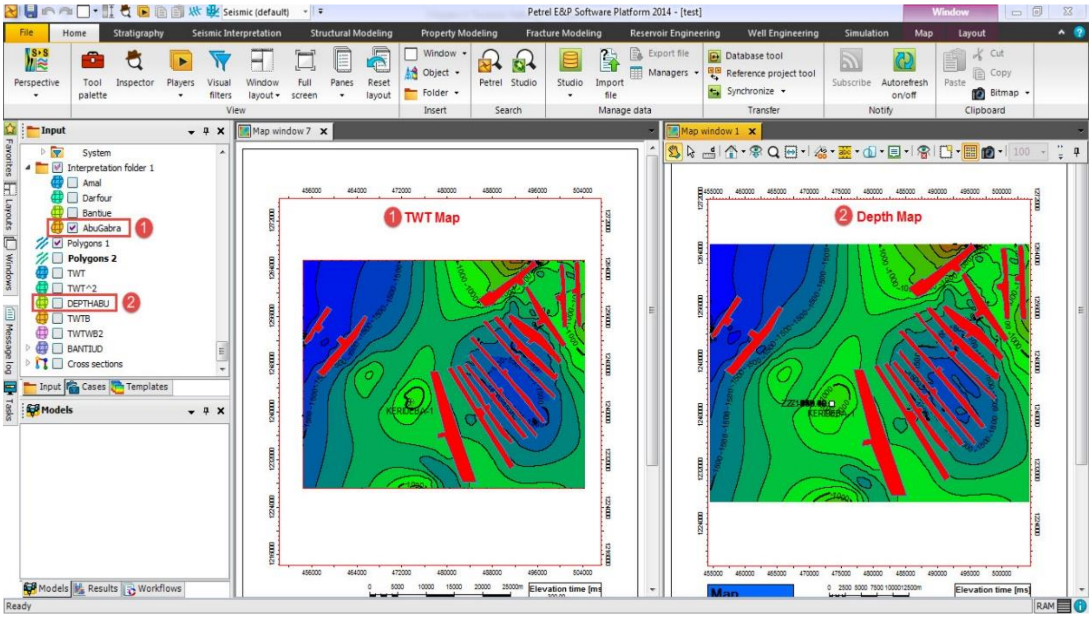
A.6: Types of loaded data logs



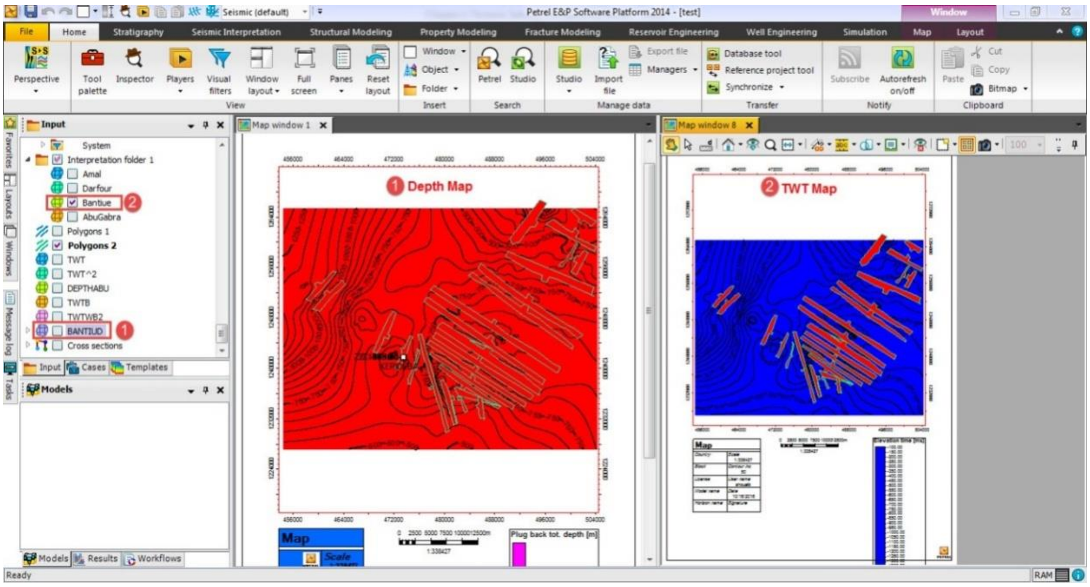
A.7: Loading of well tops



A.8: displaying of seismic section, well data and other related data



A.9: Generated TWT and Depth Maps for AbuGabra Top



A.10: Generated TWT and Depth Maps for Bentiu Top