Sudan University of Science and Technology

College of Petroleum Engineering and Technology

Exploration Engineering Department

Graduation Project Submitted in Partial Full Filament for the degree of BSc (honor) Degree in Exploration Engineering

About:

Hydrocarbon potentiality in NW Muglad basin using integrated seismic interpretation controlled by comparative study.

(Sufyan and Rakuba Sub-basins)

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Sudan University of Science &Technology

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Date:

الإستهلال

بسم الله الرحمن الرحيم

{وَقُلْ رَبِّ زِدْنِي عِلْمًا}

[سورة طه الآية 114]

{...and say, "My Lord, increase me in knowledge."}

[Surah Ta, Ha]

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 Sufyan sub-basin, northwest_Rakuba sub-basin in NW Muglad basin in West Kordofan State. Seismic data represented by two two-dimensional seismic lines, the study area is mainly covers a part of sufyan sub-basin and is surrounded on the southeastern side by Tomat high. The study aims to identify the subsurface structures in terms of tectonic movements and conduct basic comparison with previous similar study in Rakuba sub-basin. In this study, the interpretation processes were done using Petrel version 2009 and interactive petrophysics (IP V3.5) softwares. The interpretation was done for three formation tops: Aradeiba, Bentiu and AbuGabra formations, by tying and correlating them with Rabah-1_spliced well, then the existing faults were identified, and two-way time structural maps were created for three tops of these formations. Based on the interpreted seismic sections and generated structural maps, it was found that Sufyan sub-basin is an extensional rift basin. Two fault trends were observed: northwest-southeast fault trend which is the dominant faults in the study area especially in the middle part where sufyan sub-basin shows its maximum depth. The second recognized trend was the northeast-southwest faults trend which are observed in the southwestern part of the area. Integrated interpretation of the seismic sections and structural maps was calibrated with the well data and the stratigraphic column of the Muglad basin. The comparative study with Rakuba sub-basin indicates that the overall thickness of sediment was greater than in Rakuba, and the recognized faults in Sufyan were normal faults rather than the rotated faults that were mapped clearly in Rakuba sub basin. Beside Aradeiba formation is thicker compared to all Darfur group in Rakuba, the depocentre of Sufyan sub basin was mapped clearly although the limited number of seismic lines. Picking of all top interpreted formations in both sub basins was similar. The study recommends these points: interpreting more seismic lines calibrated with better well logging data from more wells to improve the vertical and horizontal extension of the sedimentary formations in Sufyan sub-basin, using integrated data to solve two ambiguities that are: Rakuba and Sufyan sub-basins were one sub-basin and separated later by dextral strike slip re-activated motion, and if the Tomat high is extended in the southwestern of Sufyan sub-basin?. Integrated available vertical seismic profiling data and checkshots would give more accurate and reliable extracted velocity values to convert the two-way times into true depths of top Aradeiba, Bentiu and AbuGabra formations.

الخلاصة

أجريت عملية التفسير التركيبي للبيانات الزلزالية الإنعكاسية المتكاملة مع بيانات الآبار في حوض سفيان شمال غرب حوض راكوبة شمال غرب حوض المجلد في ولاية غرب كردفان .البيانات الزلزالية متمثلة في خطين من الخطوط الزلزالية ثنائية الأبعاد، تغطي منطقة الدراسة بصورة أساسية جزء من حوض سفيان ومحاطة من الناحية الجنوبية الغربية بمرتفع التومات. هدفت الدراسة لتحديد ودراسة التكوينات تحت السطحية من حيث تشوهها بالحركات التكتونية بالمقارنة بالدراسة السابقة في حوض راكوبة. في هذه الدراسة تمت عملية التفسير بواسطة البرنامج الحاسوبي بتريل 2009 وتفسير السطح العلوي لثلاثة تكوينات رسوبية رئيسية وهي :عرديبة، بانتيو وأبوجابرة عن طريق مضاهاتها بواسطة معلومات بئر رباح-1 وأيضاً تم إستخدام (IP v3.5) لتصحيح العمق بدقة، ومن ثم حددت الفوالق الموجودة وأنواعها، ثم أنشأت الخرائط التركيبية لأزمنة وصول الموجات الزلزالية لتلك الاسطح. بناءاً على المقاطع السيزمية الرأسية ثنائية الأبعاد المفسرة والخرائط التركيبية المنشأة وُجد أن حوض سفيان عبارة عن حوض إمتدادي. من تحليل الخرائط، تم إيجاد توجهين رئيسيين للفوالق وهي :أولاً شمال غرب جنوب شرق ويعتبر التوجه الرئيسي والغالب في منطقة الدراسة وخاصة فى وسط المنطقة حيث يُظهر أقصي عمق لرسوبيات حوض سفيان، ثانياً فوالق ذات توجه شمال شرق جنوب غرب وتم التحفظ عليه في الجزء الجنوبي الغربي لمنطقة الدراسة. تمت مقارنة التفسير المتكامل للمقاطع السيزمية والخرائط التركيبية مع بيانات الآبار والعمود الطبقي لحوض المجلد. وبمقارنة الدراسة التي أُجريت في حوض راكوبة وُجد أن السمك العام للروسوبيات أكبر في حوض سفيان ، وتفسير الفوالق أوضح بالإضافة إلى أن سمك عرديبة فقط أكبر من سمك مجموعة دارفور لحوض سفيان عن حوض راكوبة، كما أن تحديد أعمق نقطة في الحوض كان واضحاً أكثر في حوض سفيان، ويتمثل وجه الشبه في تفسير الأسطح العلوية للطبقات. أوصت الدراسة الحالية ببعض النقاط بناءاً على النتائج المتوصل اليها :تفسير مزيد من المقاطع السيزمية المقرونة بمعلومات أكثر من تسجيلات الآبار في منطقة الدراسة سوف يزيد من إيضاحية الإمتداد الأفقي والرأسي للتكوينات الرسوبية في حوض سفيان، وإستخدام بيانات متكاملة لحل الغموض حول ما إذا كان حوض سفيان هو إمتداد لحوض راكوبة لكن إنفصل بالحركة الجانبية، وأيضاً تحديد وجود إمتداد لمرتفعات التومات في الجزء الجنوبي الغربي من منطقة الدراسة، كما أن وجود بيانات عن السبر السيزمي العمودي أو تفجيرات الإختبار تعطي نتائج أدق وأكثر إعتماداً لقيم السرعات السيزمية للإستفادة منها في تحويل أزمان الوصول إلى سمك حقيقي لتكوينات عرديبة، بانتيو وأبوجابرة.

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Chapter 1

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 hydrocarbon accumulations 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, in 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 field 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 a lacustrine sediments (Ali Sayed 2003 and USGS 2011).

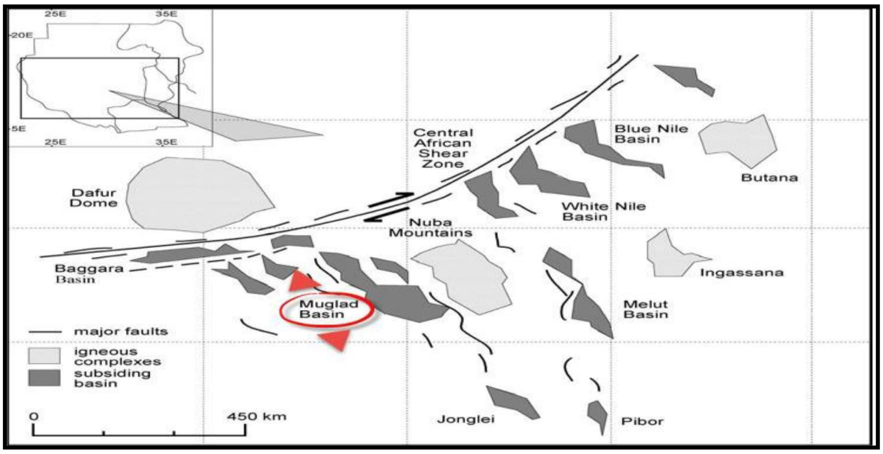

Fig (1.1): Location of the Muglad basin in the SW Sudan in relation to the Central African Shear Zone (Ali Sayed 2003).

1.2. Study Area:

The study area is located at the northwest side of the Muglad, It falls in Block-C northwest of Rakuba sub-basin which is northwest of Muglad basin in the vicinity of the Tomat Highs, as shown in fig (1.2). 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).

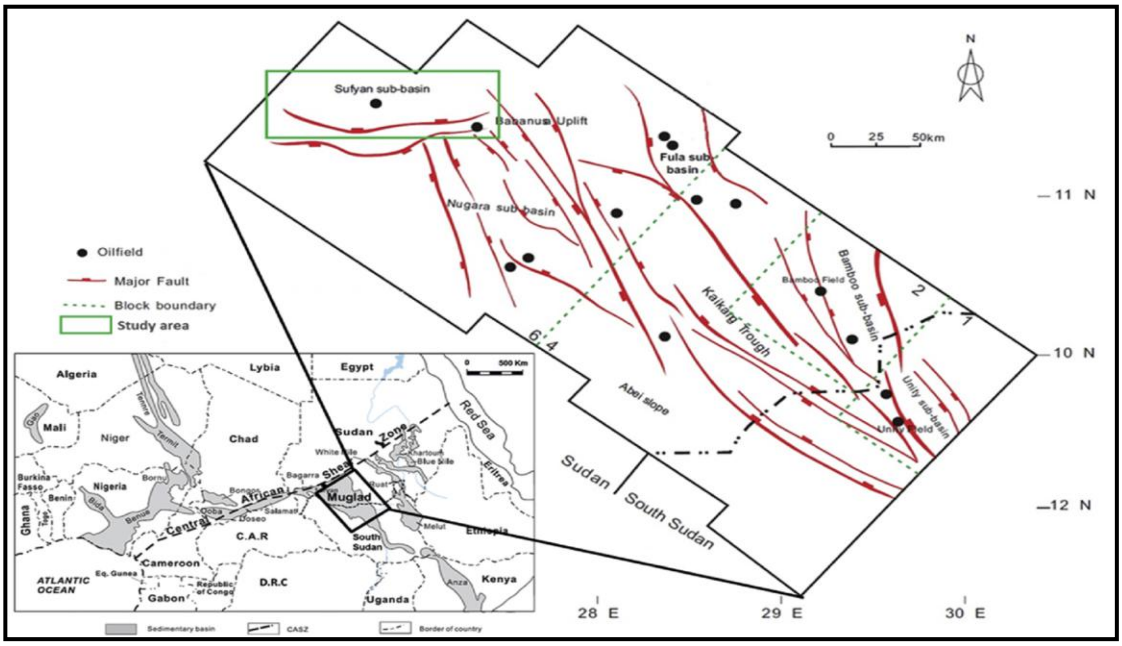

Fig (1.2): Location of the study area (Rakuba sub-basin) in NW Muglad Basin and the adjacent oil fields.

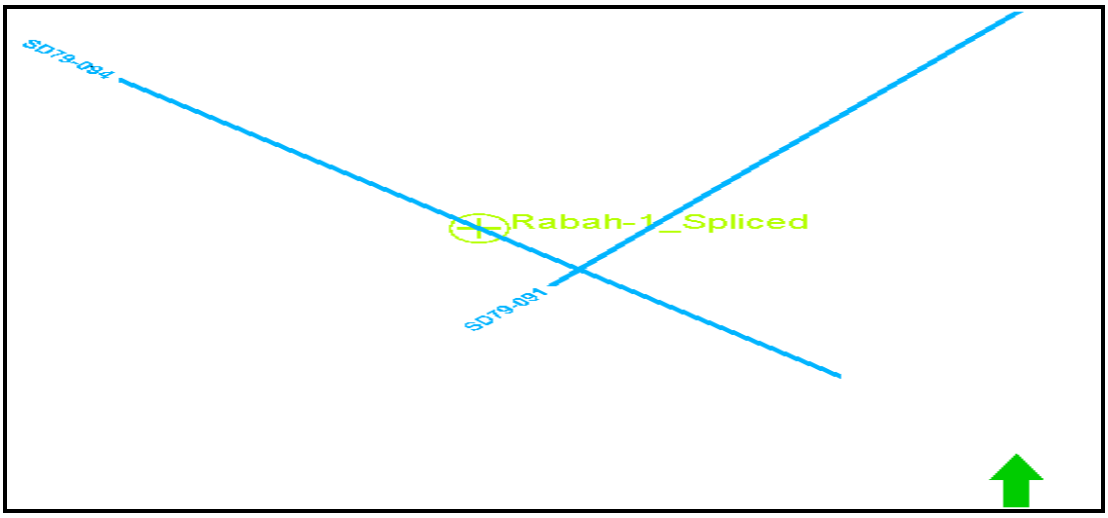

Fig (1.3): Location map of the used data set in the study which there are two 2D seismic lines and one well logging data.

1.3 Problem Statement:

From previous studies, AbuGabra 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. AbuGabra and Bentiu formations, Darfur and Kordofan groups contain reservoir rocks and structurally controlled by complex fault network, therefore, there are complications in the assessment of the potential traps that have capability of retaining the generated hydrocarbon. Proper assessment of the 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:

1. Generate surface structural maps for subsurface selected horizons (Aradieba, Bentiu, and AbuGabra).
2. Conduct comparative study with Rakuba sub basin in SE Sufyan sub basin
3. Determine the potential location for HC drilling well and the targeted depth.

1.5. Used Data:

The available data as shown in fig (1.3) that was used in the current study were the following:

1. Two 2D seismic lines
2. Well information of (Rabah_1) which include horizon tops of (Amal, Darfur group, Bentiu and AbuGabra Formations).
3. Previously created structure maps of Rakuba sub basin.

1.6. Methodology:

Interactive petrophysics software (IP-version 3.5) has been used to correlate the horizon tops depths, which used to create well header and well top LAS file. Petrel software version 2009 has been used to interpret 2D seismic lines.

1.7. 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 (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 thickness. 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 ^{o}C/KM and heat flow between 37-63 W/m2 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 Mg HC/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.

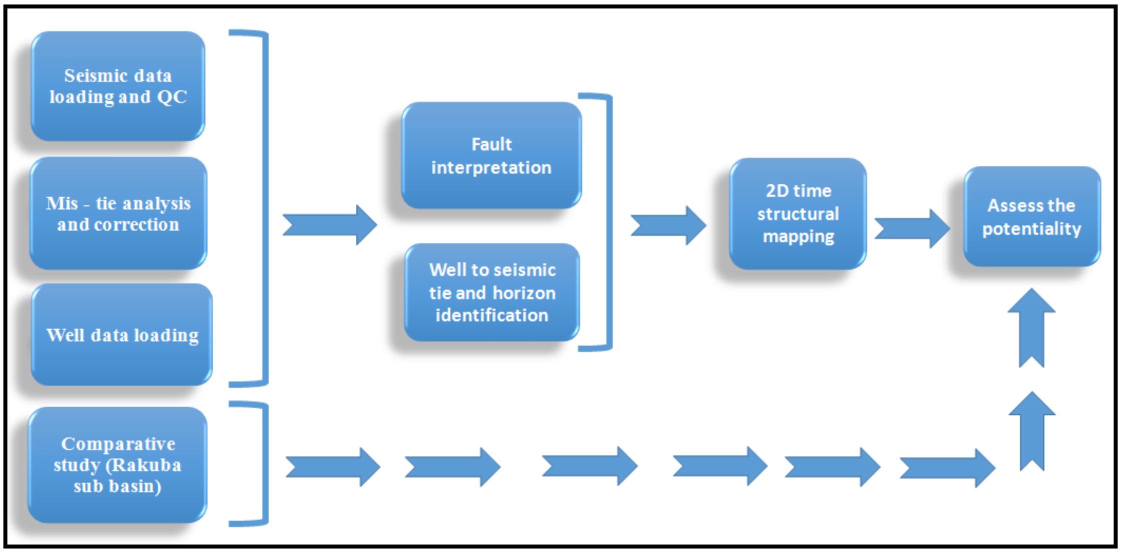

Fig (1.4): A flow chart of the adopted methodology to achieve the study objective.

Chapter 2

2. Regional Tectonic and sedimentary setting

2.1 Introduction:

The Muglad Basin is a part of the Central African Rift System (CARS) (Bermingham et al., 1983; Schull 1988; Fairhead 1988). Rifting resulted from crustal extension which was followed by subsidence and sedimentation. Several sub-basinal areas have been recognized, but half-graben structures dominate the structural style. The maximum sediment thickness in the Muglad Basin, which was determined seismically, reaches about 15 km.

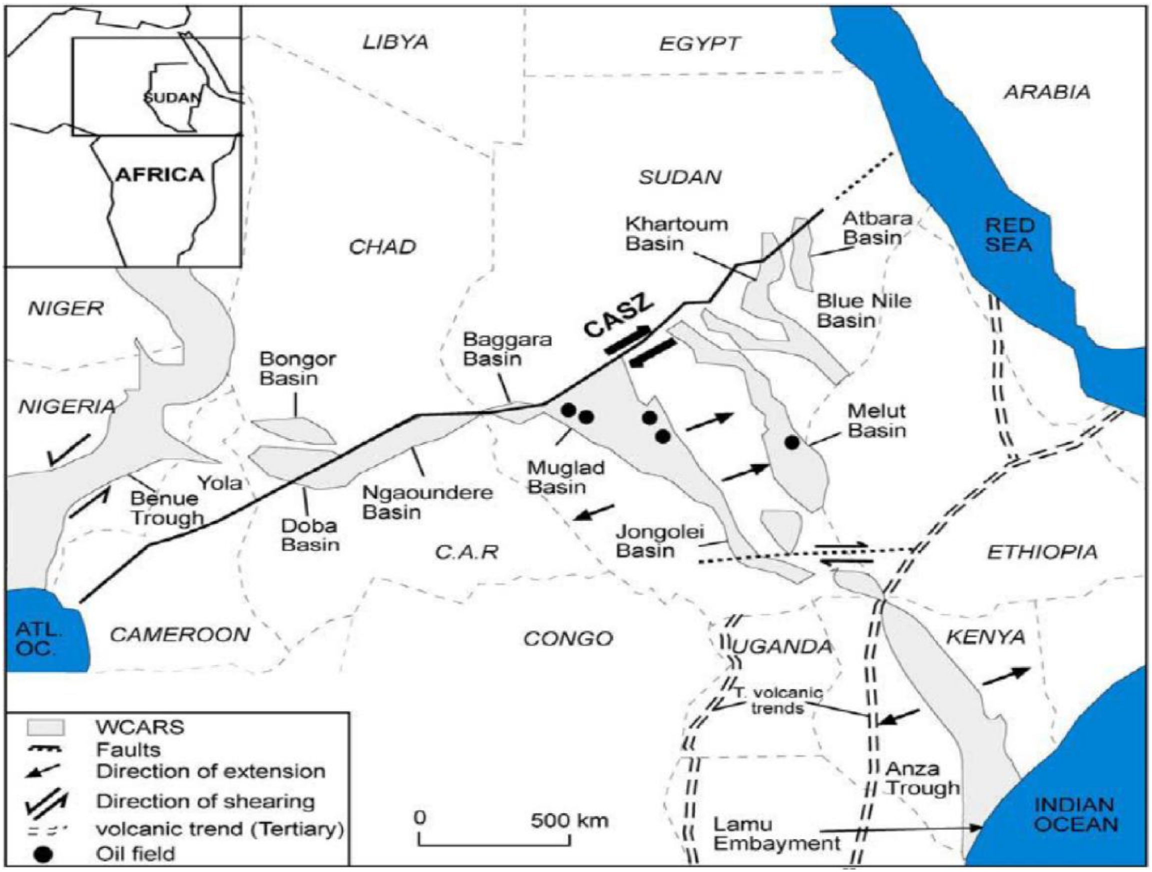

Fig (2.1): Location of the principal basins of the Central and Southern Sudan in relation to the Central African Shear Zone (from Robertson Research Int., 1991).

2.2. Regional Tectonic:

Rifting in Sudan began in the Late Jurassic and continued up to the Middle of the Miocene. 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 up to the Late Jurassic, the near subsiding areas of the region have been supplied by poorly sorted and various types of sediments.

2.2.2 Rifting phase:

Rifting is thought to have begun during Jurassic (?) to Early Cretaceous time (130 – 160 Ma). Three distinct periods of rifting have occurred in response to crustal extension, which provided the isostatic mechanism for subsidence. These three rifting phases can be described as follows:

2.2.2.1 The primary rifting phase:

It had begun in the Jurassic (?) – Early Cretaceous up to near the end of the Albian, Some basins developed within and in the immediate vicinity of the Cretaceous shear zones in the period from 120 – 90 Ma, due to shear movements. Moreover, Fairhead and Green (1989) suggested that the movements of the Central African Shear Zone were translated into the extensional basins of the Sudan interior. However, no volcanism is known to be associated with this early rifting phase in Sudan. The termination of the initial rifting is stratigraphically marked by the basin wide deposition of thick sandstones of the Bentiu Formation (Schull 1988).

2.2.2.2 The second rifting phase:

`It occurred during the Turonian – Late Senonian. Stratigraphically, this phase is documented in the widespread deposition of lacustrine and floodplain claystones and siltstones, which abruptly terminated the deposition of the Bentiu Formation (Schull 1988). This rifting phase was accompanied by minor volcanism. The end of this phase is marked by the deposition of an increasingly sand-rich sequence which ended with the Paleocene sandstone of the Amal Formation (Schull, 1988).

2.2.2.3 The final rifting phase:

It began in the Late Eocene – Oligocene. The initiation of this phase was occurring simultaneously with the initial opening of the Red Sea (Lowell & Genik 1972). This final phase is reflected in the sediments by a thick sequence of lacustrine and floodplain claystones and siltstones. After this period of rifting throughout the Late Oligocene – Miocene, deposition became more sand-rich.

2.2.3. Sag Phase:

The intracratonic sag phase was first identified by Schull (1988). In the Middle Miocene, the basinal areas entered an intracratonic sag phase of very gentle subsidence accompanied by little or no faulting. During that time the sedimentation in the Central and Southern Sudan Interior Rift Basins was essentially controlled by subsidence due to differential compaction of sediments. In Muglad Basin the Eocene - Oligocene sedimentation has continued across the Oligocene/Miocene boundary with the deposition of basinwide fluvial and floodplain sediments of the upper members of the Kordofan Group.

2.3. Sedimentary Setting:

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 fig (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 Formations:

It is early syn-rift sediments of the first cycle deposited during the Neocomian – Barremian. It consists mainly of claystones and shales with interbeds of fine sandstone and siltstone deposited in lacustrine and fluvial environments, is relatively thick and has good source rock potential (Mohamed et al., 2001).

2.3.2. AbuGabra Formation:

It is the Albian – Aptian time, which consists mainly of thick shales and claystones with fine sandstones and siltstone, the sedimentation was continued in lacustrine and deltaic fan environments. 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 (IRR, 1991).

2.3.3 Bentiu Formation:

It is end syn-rift sediments of the first cycle deposited during the late Albian – Cenomanian, which consists predominantly of thick sandstone beds, deposits of braided and meandering streams. The top of Bentiu formation is marked by an unconformity, and typically shows good reservoir quality.

2.3.4 Darfur Group:

It represents a coarsening-upward cycle, contain late Cretaceous Early Tertiary sediment. In the Muglad area the Darfur Group was subdivided into four formations. From bottom to top, these are Aradeiba, Zarga, Ghazal and Baraka Formations (Fig 2.2 and Table 2.1). The first three represent the principal reservoir intervals in the SE Muglad Basin.

Aradeiba and Zarga Formations are the thick sandstone-clay with interbeds of siltstones and sandstones, deposits of Floodplain/lacustrine with fluvial/deltaic channel sands. Aradeiba formation acts as a major reservoir horizon and as a seal as well. Ghazal and Baraka Formations are lithologically similar to the underlying Zarga formation; they contain sandstones with minor shales and claystones interbeds (Abdelhakam and Ali Sayed, 2008).

2.3.5 Amal Formation:

The Darfur Group is overlined by marked unconformity separate it from thick sediment of Amal formation, which predominantly massive medium to coarse sandstones sequences. The major sediment deposited in braided streams and alluvial fans (RRI, 1991).

2.3.6 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 lower Adok formations contain claystone/shale interbedded with 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 braided streams and alluvial fans (RRI, 1991; Mohamed et al., 2001).

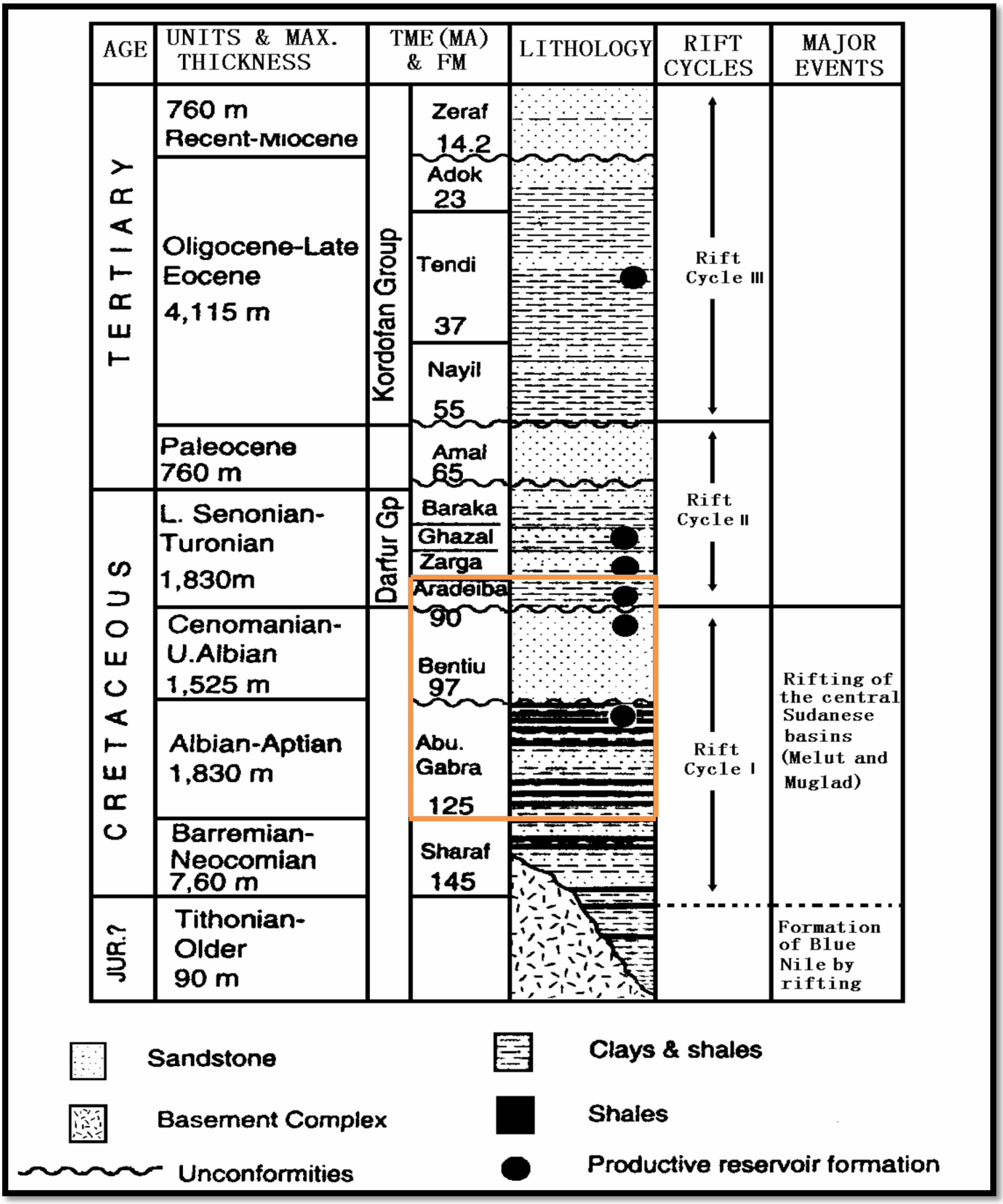

Fig (2.2): the sedimentary sequence of the Muglad basin with the depositional cycles from Mohamed et al., (2001).

FORMATION		LITHOLOGY AND ENVIRONMENTS	AGE	
KORDOFAN DARFUR GROUP	Zeraf Fm.	Predominantly iron-stained sands and silts with minor claystones interbeds.	Recent-middle Miocene	TERTIARY
	Adik Fm.	Braided streams/alluvial fans.	Oligocene- Late Ecocene	
	Tendi Fm.	Predominantly claystone/shale, interbedded with sandstones		
	Nayil Fm.	Fluvial/floodplain & lacustrine		
	Amal Fm.	Predominantly massive medium to coarse sandstones sequences. Braided streams/alluvial fans.	Paleocene	
	Baraka Fm.	Predominantly sandstones with minor shales and claystones interbeds.	Late Senonian Turonian	CRETACEOUS
	Ghazal Fm.	Fluvial/alluvial fans.		
	Zarga Fm.	Predominantly sandstones shales with interbedsof siltstones and sandstones.		
	Aradeiba Fm.	Floodpain/lacustrine with fluvial/deltaic channel sands.		
Bentiu Fm.		Predominantly thick sandstones sequences. Braided/meandering streams.	Cenomanian Late Albian	
Abu Gabra Fm.		Predominantly claystones and shales with fine sandstones and siltstones. Lacustrine/deltaic.	Albian-Aption	
Sharef Fm.		Claystones, shales with interbeds of fine sandstones and siltstones. Lacustrine/fluvial floodplain.	Barremian Neocomian	

Table (2.1): Stratigraphic units of the Muglad rift basin, SW Sudan, their lithology and depositional environment (adapted from Schull 1988).

Chapter 3

3. Methodology

3.1 Introduction

Seismic reflection surveying is the most widely used and well-known geophysical technique. The current state of sophistication of the technique is largely a result of the enormous investment in its development made by the hydrocarbon industry, coupled with the development of advanced electronic and computing technology. Seismic sections can now be produced to reveal details of geological structures on scales from the top Dozens of meters of drift to the whole lithosphere (Philip Kearey et al, 2002).

3.2. Reflection Seismic Method:

Seismic reflection surveying is the most widely used and well-known geophysical technique. Seismic sections can now be produced to reveal details of geological structures on scales from the top ten of meters of drift to the whole lithosphere. Part of the spectacular success of the method lies in the fact that the raw data are processed to produce a seismic section which is an image of the subsurface structure. This also provides a trap for the unwary, since the seismic section is similar to, but fundamentally different from, a depth section of the geology.

3.2.1 Basic Principles

The first step in seismic exploration is to acquire data, which in most cases is carried out from the surface. To understand the seismic data, a review of the physical principles that govern the movement of seismic waves through layered media is necessary (Nazmul Haque Mondol, 2010).

3.2.1.1 Seismic waves:

A seismic source at any point on the Earth generates four types of seismic waves: compressional (P-wave), shear (S-wave), Rayleigh (ground roll) and Love, that travel through the layers fig (3.1). Each layer will have a specific density and velocity. Rayleigh and Love waves are surface waves and propagate approximately parallel to the Earth's surface. Although surface waves penetrate to significant depth in the Earth, these types of waves do not propagate directly through the Earth's interior and have limited significance in oil and gas exploration. On the other hand, P- and S-waves are often called body waves because they propagate outward in all directions from the source and travel through the interior of the

Earth and have great significance in seismic exploration. P-waves move faster than S-waves. The P-wave is a longitudinal wave, the force applied in the direction that the P-wave is travelling. In the S-wave, the medium is displaced in a transverse way (up and down – compared to the line of travel), and the medium must move away from the material right next to it to cause the shear and transmit the wave. This takes more time, which is why the S-wave moves more slowly than the P-wave in seismic events. S-waves do not travel through fluids as fluid has no shearing capacity.

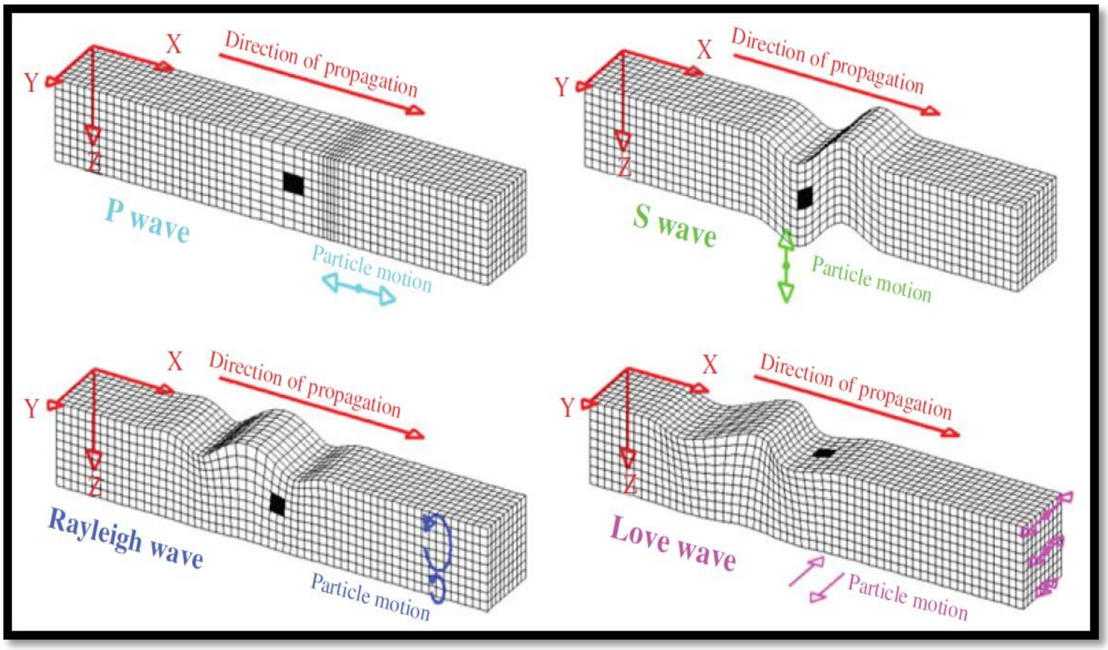

Fig (3.1): Propagation of body (P- and S-) and surface (Rayleigh and Love) waves as a function of particle motions.

3.2.1.2 Reflection and Rock Properties:

Acoustic energy traveling through the subsurface will be reflected from interfaces associated with a change in physical properties from one layer to the next. Physical properties of interest are bulk density (ρ_B) and p-wave velocity (Vp). Density a function of mineralogy, porosity and pore-filling fluids, Velocity a function of mineralogy, porosity, pore-filling fluids, cementation, pressure, temperature, etc (Bruce S. Hart et al, 2004).

Acoustic energy responds to the product of density and velocity (ρ*Vp) – known as the acoustic impedance (Z). A range of acoustic impedance values may characterize a single lithology; different lithologies may have identical acoustic impedance. When a seismic source emits a pulse that propagates through the sedimentary layers, the sound waves travel between the layers with different velocities and will be refracted according to Snell's law:

$$\frac{\sin\ \theta 1}{\sin\ \theta 2} = \frac{V2}{V1} \qquad (3.1)$$

The angle between the normal to the interface of two media and an incident P-wave is the angle of incidence (θ_1), and is equal to the angle of reflection (θ_3) in isotropic media. The angle of refraction (θ_2) depends on the velocity of the wave in that medium (Nazmul Haque Mondol).

The total energy of the transmitted and reflected rays must equal the energy of the incident ray. The relative proportions of energy transmitted and reflected are determined by the contrast in acoustic impedance Z across the interface (Philip Kearey et al, 2002). The Reflection- and Transmission coefficient give the ratio between the incident amplitude A_0, and the reflected (A_R) and transmitted (A_T) amplitude, respectively. In the special case of an incident wave perpendicular at an interface for a P-wave, a simple expressions for the reflection and transmission coefficient is obtained (Jan van der Kruk, 2001). Where there is a change in Z, some of the incident acoustic energy will be reflected at the interface and some will be transmitted. Amount reflected (amplitude of reflection) will depend on the relative difference in physical properties across the interface define reflection coefficient (R_C). Not all changes in lithology associated with change in Z. Changes in fluid content in a single lithology can give rise to reflections. Different combinations of layers lithologies can have the same RC (Bruce S. Hart et al, 2004).

3.2.2 Seismic data acquisition systems:

The fundamental purpose of seismic surveys is accurately to record the ground motion caused by a known source in a known location. The record of ground motion with time constitutes a seismogram and is the basic information used for interpretation through either modeling or imaging (Philip Kearey et al, 2002). 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.

The shot points and the receivers may be arranged in many ways. Many groups of geophones are commonly used on a line with shot points at the end or in the middle of the receiver array. The shot points are gradually moved along a line of geophones. The variations in ground elevation in land acquisition causes sound waves to reach the recording geophones with different travel time. 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, fig (3.2) 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.

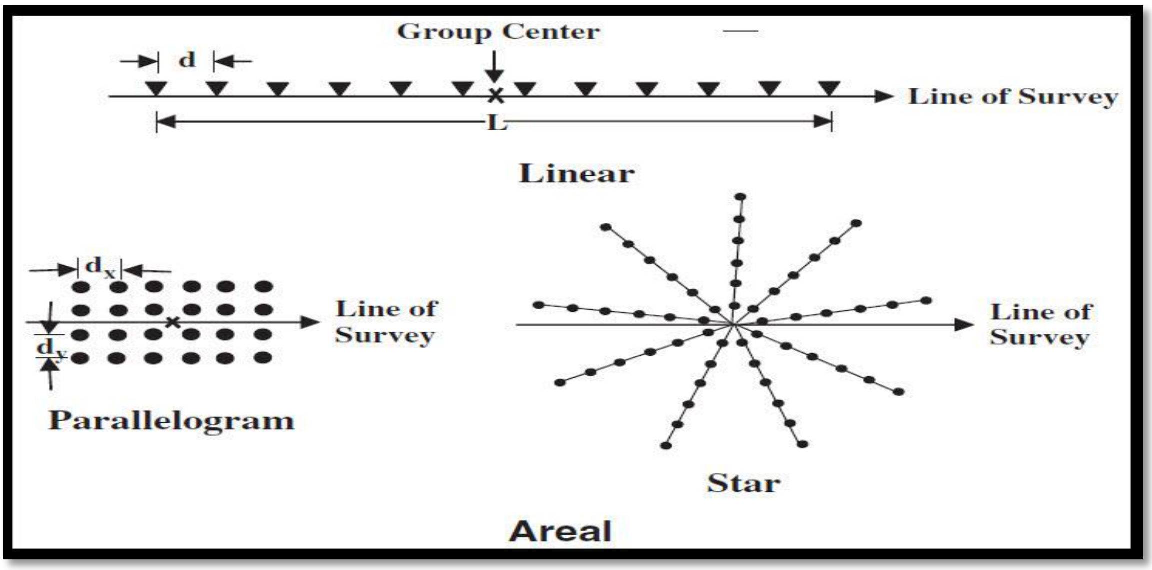

Fig (3.2): the different types of receiver and shot point arrays.

3.2.2.1 Seismic Sources and receivers:

Different seismic sources are usually used in acquisitions. Seismic energy is normally generated using arrays of air-guns, explosives or vibrators. Hydrophones and geophones serve as receivers for seismic signals. The hydrophone is a device designed for use in detecting seismic energy in the form of pressure changes in water during marine seismic acquisition. The geophone is a device that detects ground velocity produced by seismic waves and transforms the motion into electrical impulses. Geophones, unlike hydrophones, detect motion rather than pressure.

3.2.2.2 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.

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 recorders.
- 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.

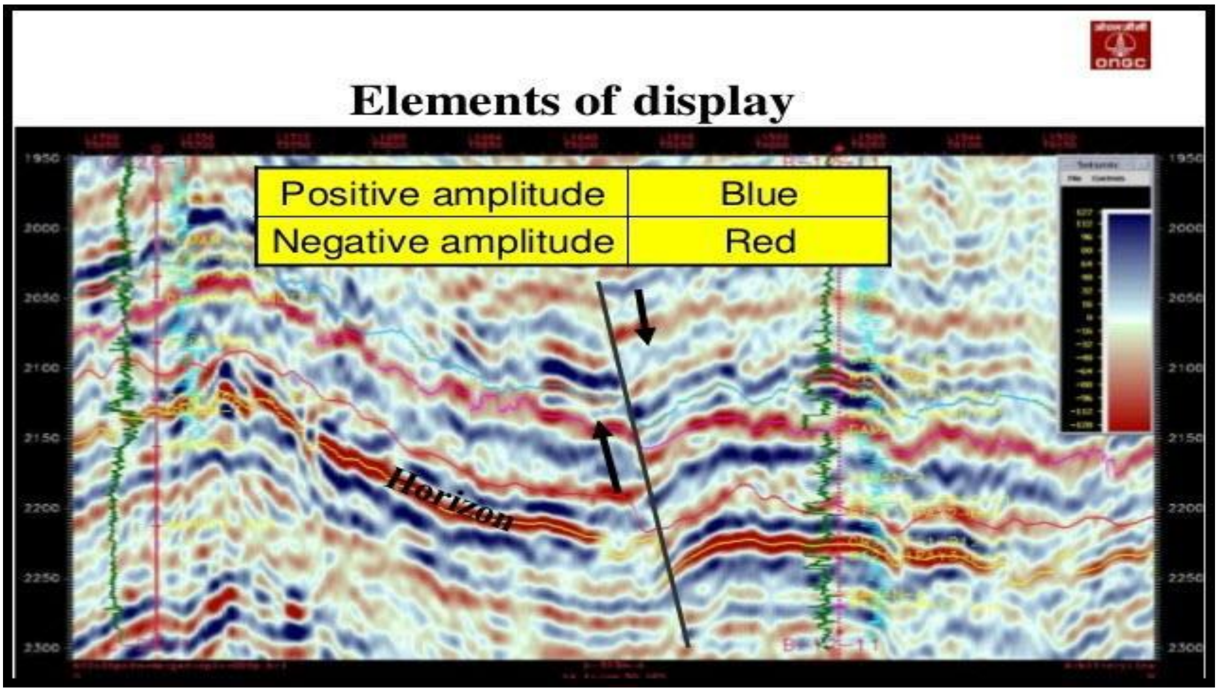

Fig (3.3): seismic record section as end products of the process of data acquisition and processing.

3.2.2.3 Seismic trace and seismogram:

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 move out correction and.
- Traces can be combined by CMPs stacking into CMP trace that enhances signal to noise ratio and attenuate multiple reflections.

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.

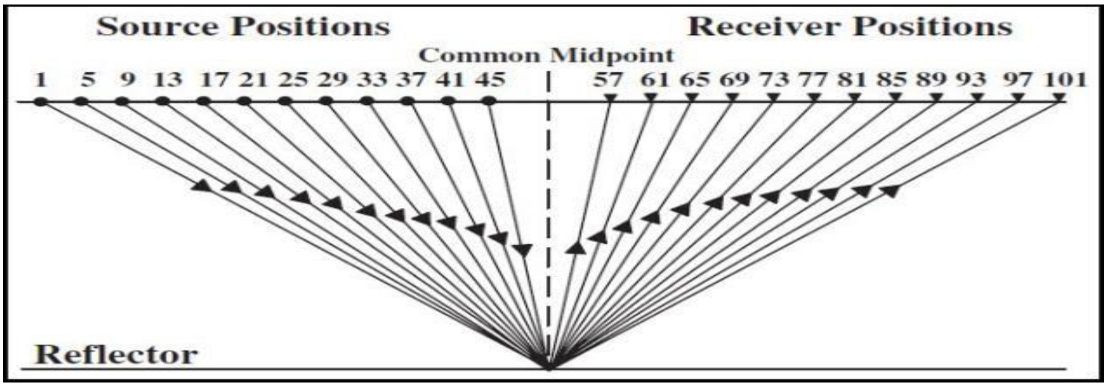

Fig (3.4): common midpoint CMP.

3.2.2.4 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).

3.2.2.5 Seismic display:

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

- **Wiggle display:** this 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, fig (3.5) show modes of display.

3.2.2.6 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.

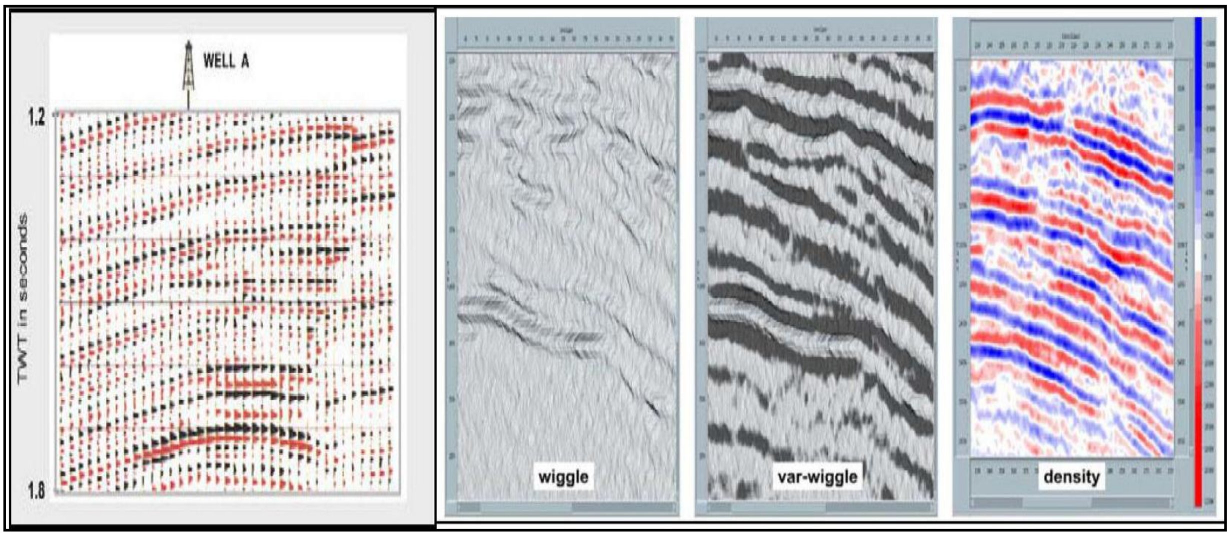

Fig (3.5): dual polarity, wiggle, var-wiggle and variable display of seismic data.

3.2.2.7 Seismic wavelet:

There are two shapes of seismic wavelets presented on (fig: 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.

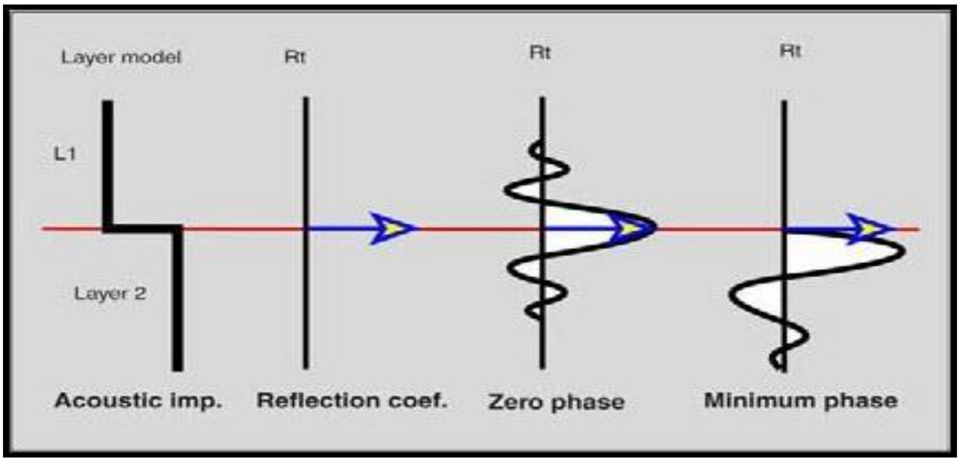

Fig (3.6): the zero-phase wavelet, whereby the maximum amplitude of the wavelet is coinciding with the lithological interface the minimum-phase wavelet, whereby the start of the wavelet is coinciding with the exact position of the subsurface interface.

3.2.2.8 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 is resolved (Veeken, 2007).

3.2.3 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:

(1) To improve the signal to noise ratio: e.g. by measuring of several channels and stacking of the data (white noise is suppressed)

(2) To obtain a higher resolution by adapting the waveform of the signals

(3) Isolation of the wanted signals (Reflections isolated from multiples and surface waves).

(4) Realistic image by geometrical correction (Conversion from travel time into depth and correction from dips and diffractions).

(5) To obtain information about the subsurface velocities, reflectivity etc.

There are three primary steps in processing seismic data:

- Deconvolution.
- Stacking.
- Migration.

3.2.3.1 Deconvolution:

It is a process that improves the vertical resolution of seismic data by compressing the basic wavelet and 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 deconvolution is to remove the effect of the Convolution of the basic wavelet with the reflectivity, output seismic trace to be the reflectivity series.

3.2.3.2 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. Before final stacking, normal move out (NMO) correction are applied to correct for the horizontal component of reflection ray paths. The normal move out correction, 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.

3.2.3.3 Migration:

It is a process of moving the reflections to their proper places with their correct amount of dip. 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.

3.2.4 Seismic Data Interpretation:

3.2.4.1 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. Seismic data have been interpreted in two modes, with gradations between the modes. The first is in areas of substantial well control, in which the well information is first tied to the seismic information, and the seismic then supplies the continuity between the wells for the zones of interest. The second mode is in areas of no well control ("frontier areas"), in which the seismic data provide both definition of structure and estimates of depositional environments (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.

3.2.4.2 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.

3.2.4.3 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.

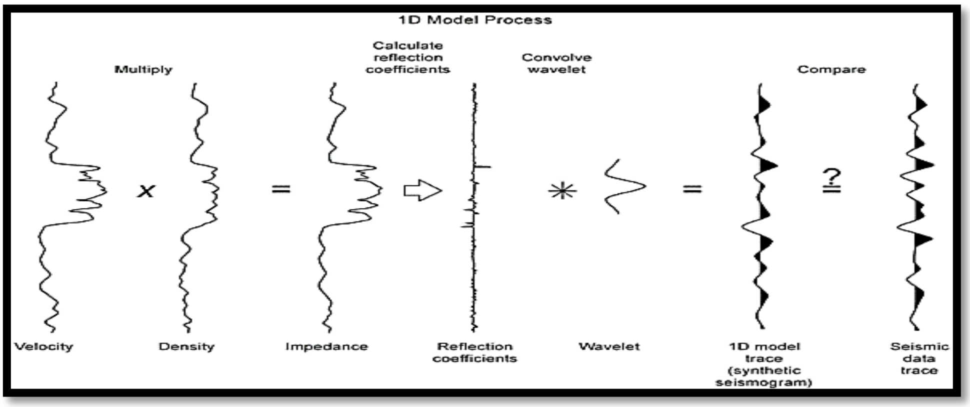

Fig (3.7) the reflection seismogram viewed as the convolved output of a reflectivity function with an input pulse.

3.2.4.4 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 Cause 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.

3.2.4.5 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.

3.2.4.6 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., 2011) 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.

3.2.4.7 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, 2017).

3.2.4.8 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 is 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 non obvious 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.

3.3 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 Gibson, 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 wire line 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 fig (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.

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 shale formations, which give high GR reading, where the radioactive elements tend to concentrate in clays and shales.

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.

3.3.4 Velocity survey:

It 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.

3.4 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).

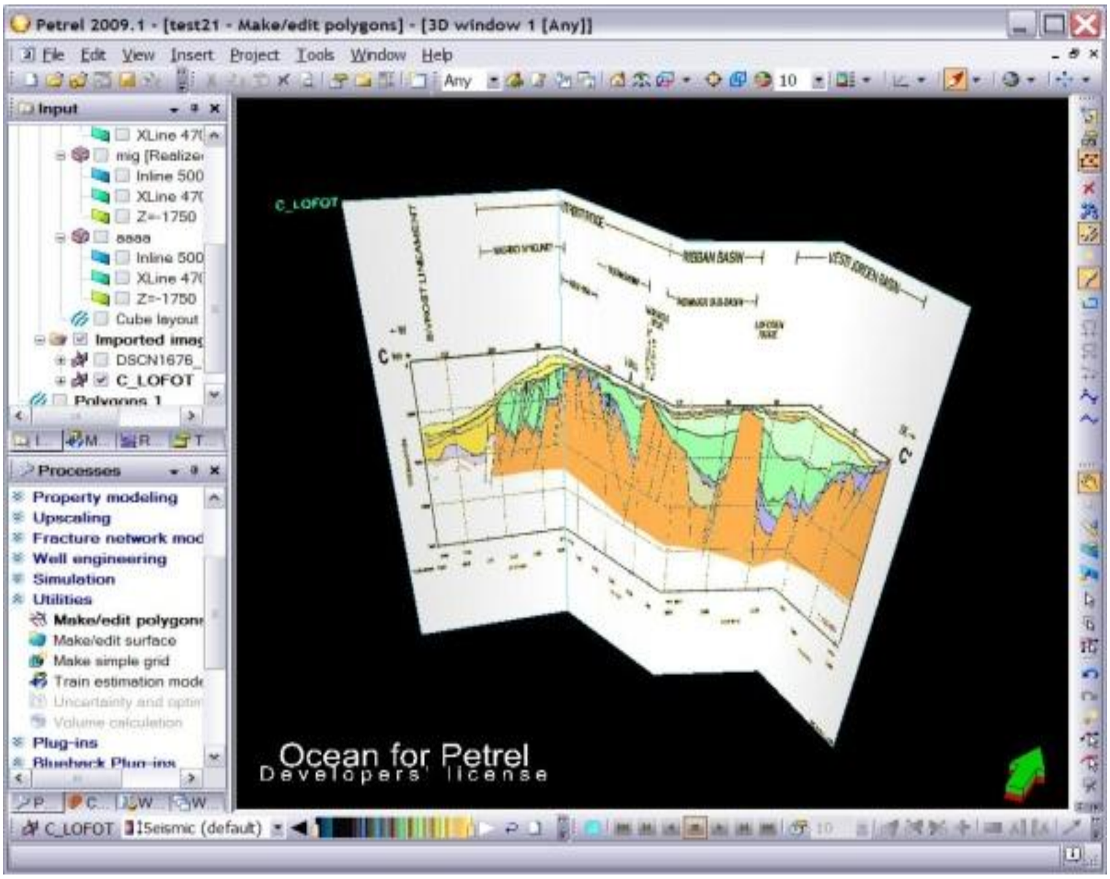

Fig (3.8): the desktop of petrel 2009.1 program.

3.3.7.2 Interactive petrophysics (IP version 3.5)

Interactive petrophysics (IP V3.5) is one of the best petrophysical software in the industry. It helps to determine the amount of hydrocarbons in the reservoir by calculating the porosity and water saturation using well logging data, and more than that Interactive petrophysics is also a tool for geologists and reservoir engineers who want to take control of their analysis and interpretation. It is easy to learn so that can get going quickly, able to focus on accurate calculations that get the most out of the reservoir. Its intuitive interface runs on robust algorithms and provides these benefits:

- Diminished uncertainty in your interpretation
- Fast results due to the ease of learning IP™
- Flexibility so that you work the way you want to work

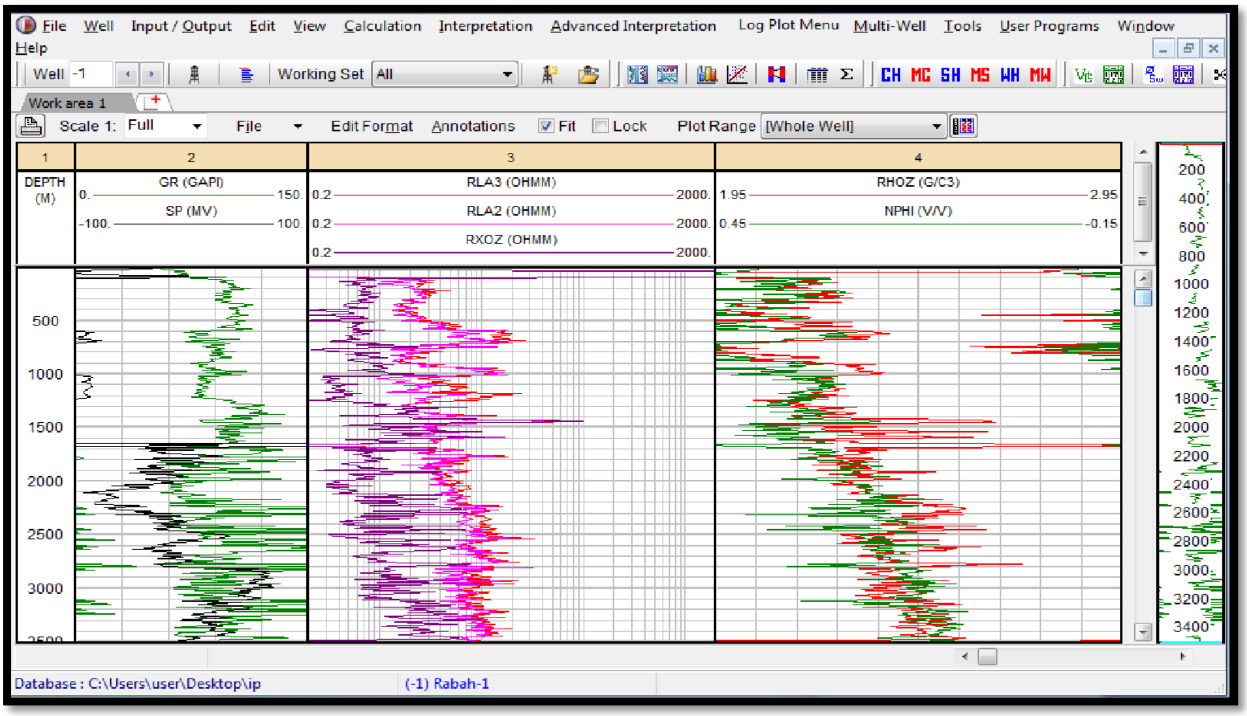

Fig (3.9): the desktop of IP V3.5 program.

Chapter 4

4. Integrated Data Interpretation

4.1 Introduction:

Seismic data interpretation of two 2D seismic lines was integrated with well data (Rabah-1_spliced) to delineate the dominant structures of study area and its influences on the hydrocarbon accumulation. Software that provides an Environment of multi points of view at them fig (4.1), where:

a) Line SD 79-094, of 60.5481 Km length and strikes NW -SE, shows generally medium data quality.

b) Line SD79-091, of 46.8328 Km length and strikes NE-SW, shows medium data quality.

Tying between Line SD 79-094 and Line SD79-091 shows small shift as shown in fig (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 SD79-094 to well (Rabah-1_spliced), unfortunately the software failed in matching correctly the synthetic seismogram to the line fig (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.

Three horizons were selected: top Aradieba, top Bentiu, and top AbuGabra formations, as they were picked and Interpreted on the two seismic lines. Each horizon is described based on its quality, continuity, reflectivity and the picked TWT range. Later, a TWT structural map for the three horizons was created to delineate its dip trend and the dominant fault network.

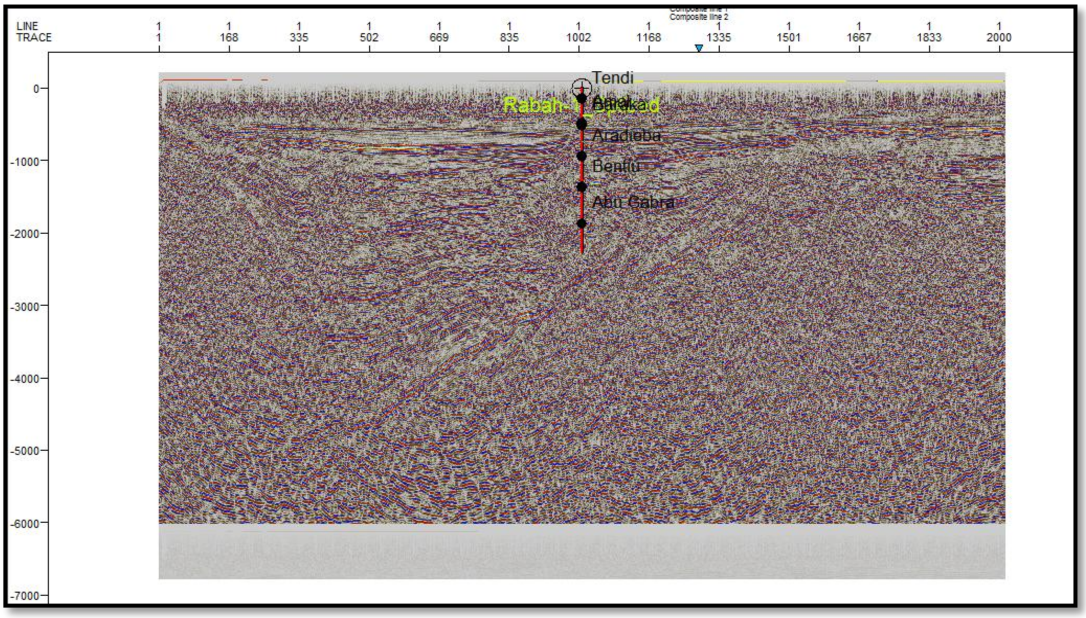

Fig (4.1a): Line SD79-094 of 60.5481 Km length and strikes NW-SE, shows medium data quality.

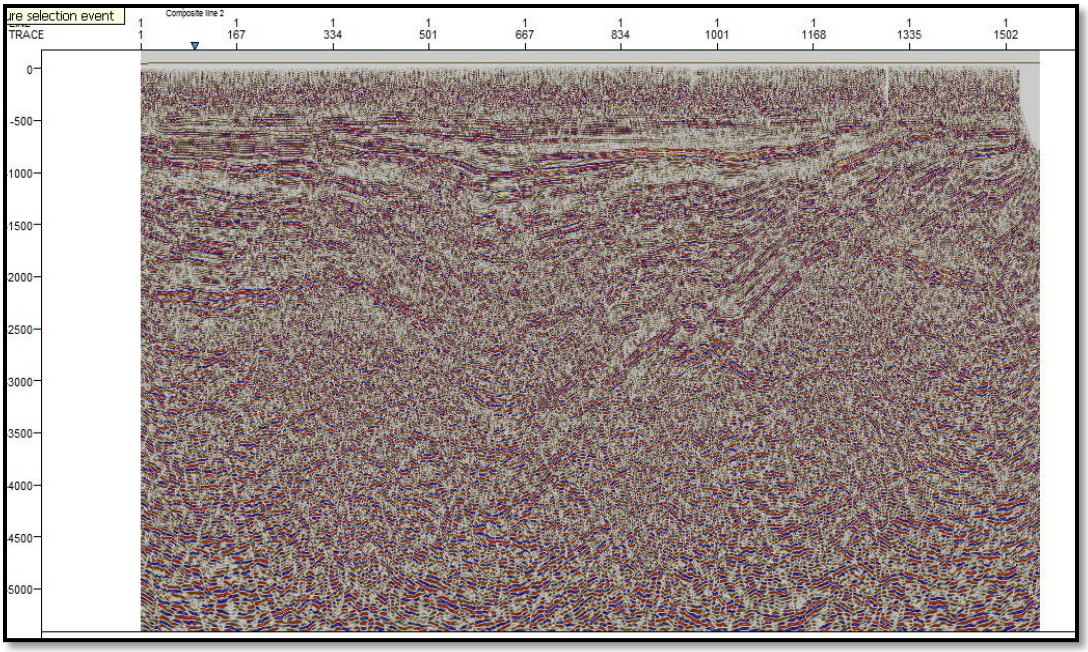

Fig (4.1b): Line SD79-091 of 46.8328 Km length and strikes NE-SW, shows generally medium data quality.

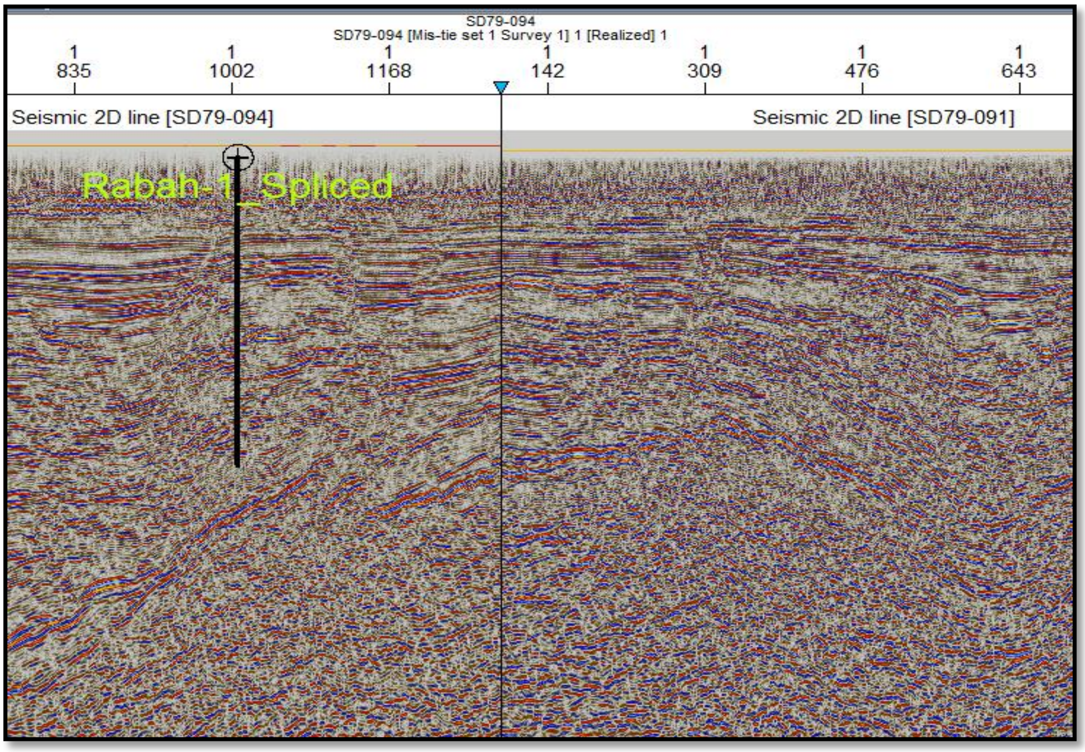

Fig (4.2): shows the shift of tying both Line SD 79-091 and Line SD 79-094.there is a few shifting between two lines therefore there is no large difference before and after a mis-tie process.

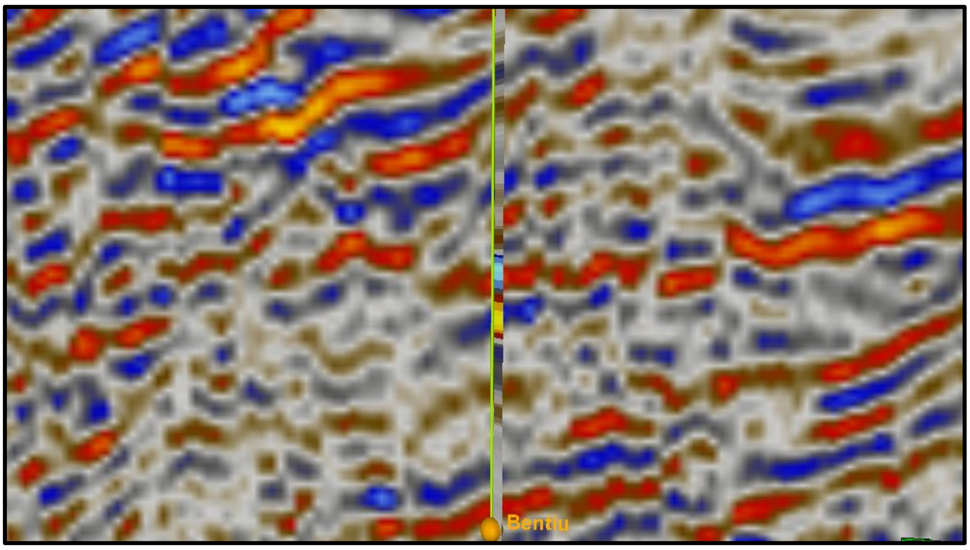

Fig (4.3): synthetic seismogram was generated to tie Line SD79-094 to well (Rabah-1_spliced) which was difficult to be adjusted correctly.

4.2 Interpreted Horizons:

4.2.1 Top of AbuGabra Formation:

Top of AbuGabra formation as shown in fig (4.4) shows low data quality, hard to be picked, clear discontinuity and has strong to medium reflectivity. It ranges in two way time from 733.52 to 2661.78ms.

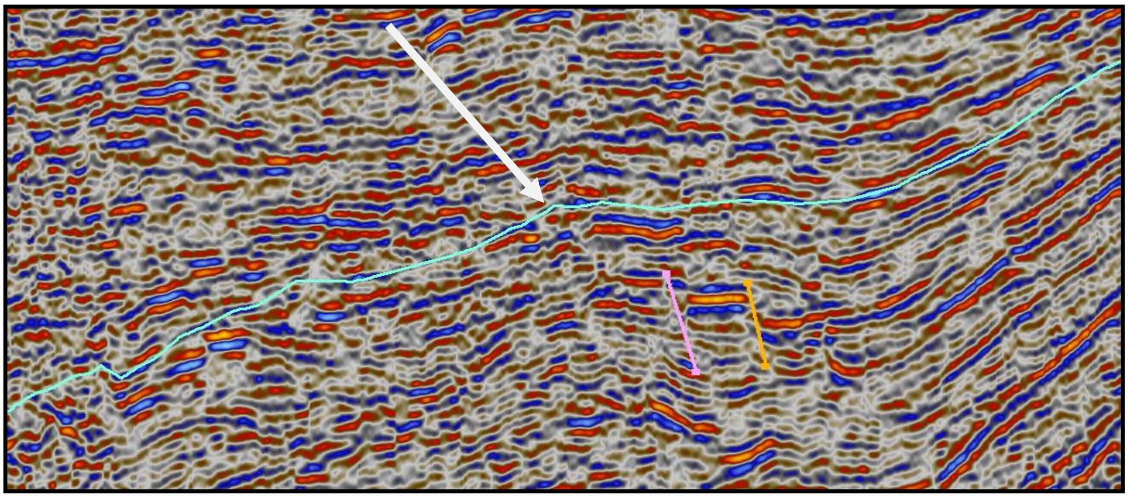

Fig (4.4): top of AbuGabra formation.

4.2.2 Top Bentiu Formation:

Top of Bentiu as shown in fig (4.5) varies in its quality along the composite line but generally it is fair but can be picked. The reflected amplitude from top Aradeiba is medium that ranges in two-way time from 1187.4–1913.49ms.

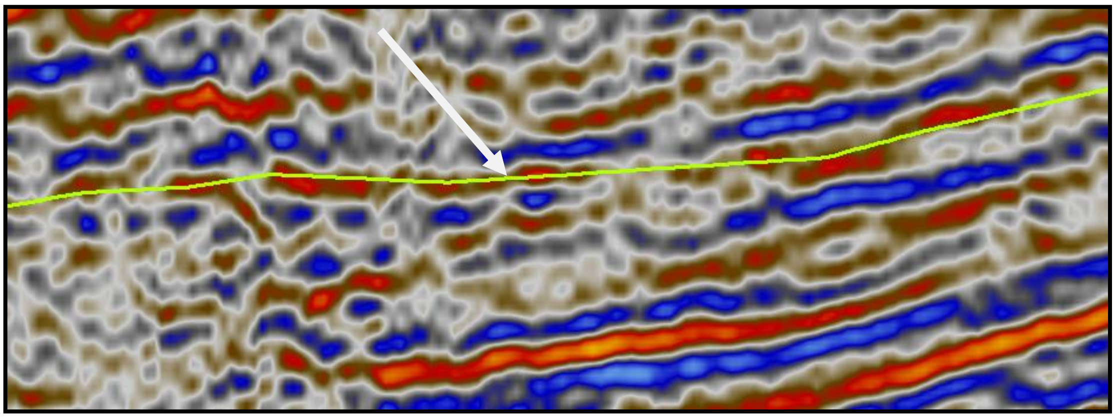

Fig (4.5): top of Bentiu formation.

4.2.3 Top Aradieba Formation:

The reflector of top Aradieba formation as shown in fig (4.6) demonstrates a good quality, easy to pick. Besides strong and continuous reflectivity along the horizon. The picked two-way time of top Aradieba ranges from 380.26 to 1162.49ms.

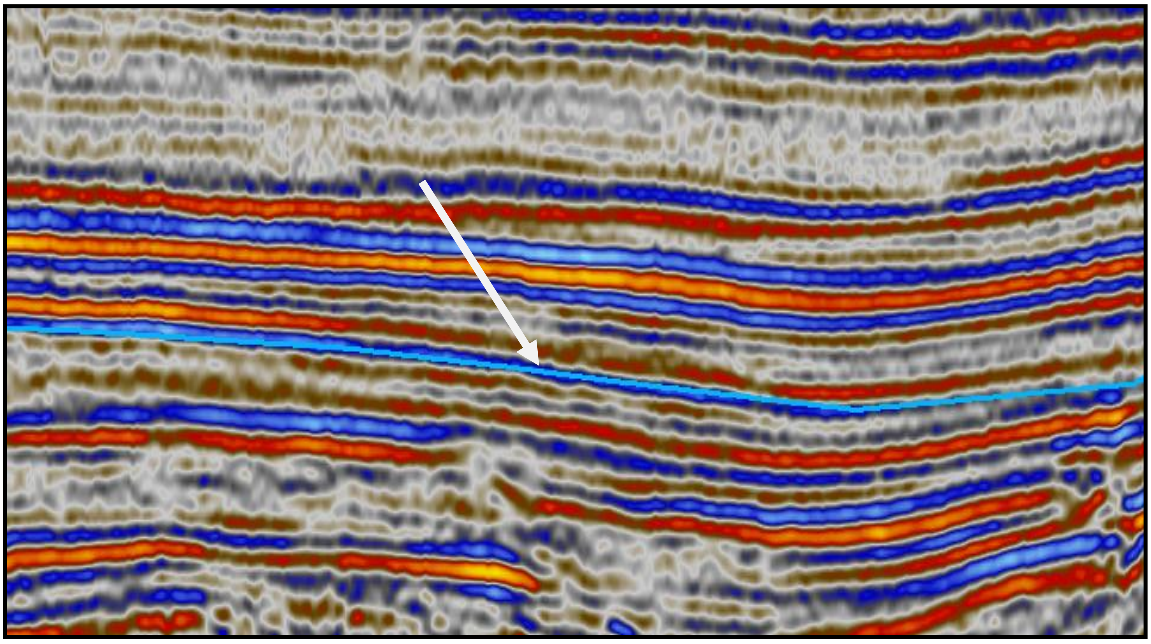

Fig (4.6): the interpreted top Aradieba formation.

4.3. 2D Seismic Lines Interpretation:

4.3.1 Line (SD79-094):

It is strike line as shown in fig (4.7), located at southern west side of study area and oriented NW-SE. The line is approximately crossing Rabah-1_spliced exploratory well, of 3495 m depth drilled by (APCO) and was calibrated to the other seismic lines. Generally, the line shows the formation thickness are LARGE varying, because of the large accommodation in the center of section hence high sedimentation rate than edge's of it, the line shows relatively a little deformation compared with line SD79-091 because it's a parallel to sufyan sub basin The next figure represent that line:

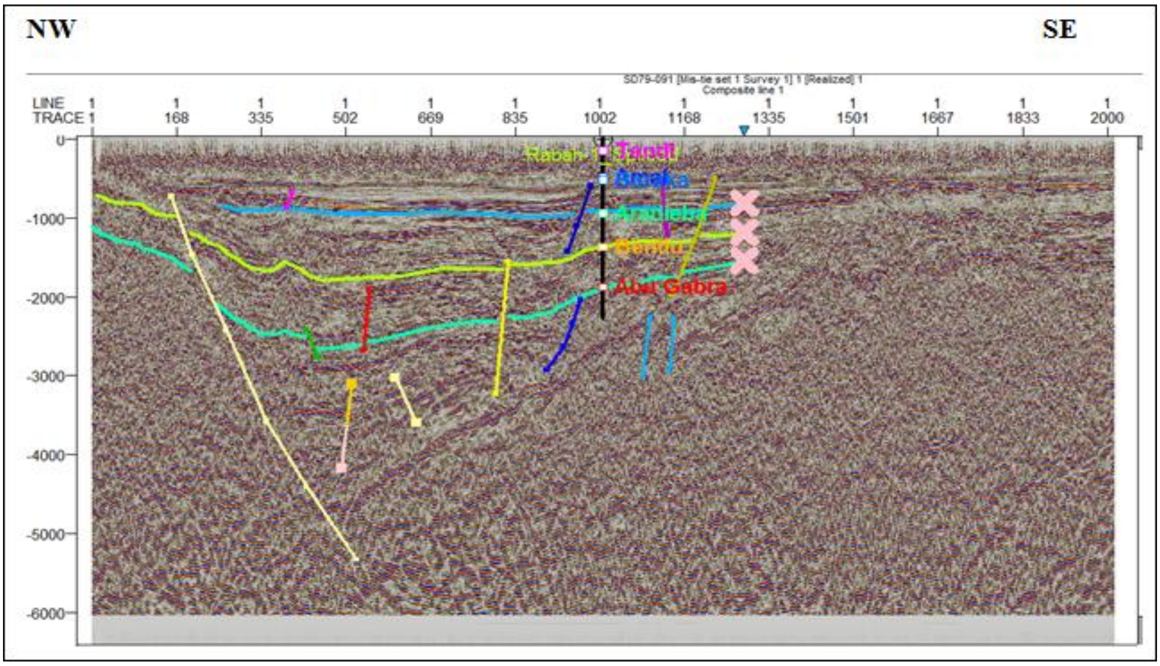

Fig (4.7): shows line SD79-094 located in Sufyan sub basin as a half graben and it parallel to its strike.

4.3.2 Line (SD79-091):

It’s a dip line as shown in fig (4.8) located in the northern east part of study area, oriented NE-SW and perpendicular to strike direction of Sufyan sub-basin. This line shows a structural pattern of an extensional rift basin.

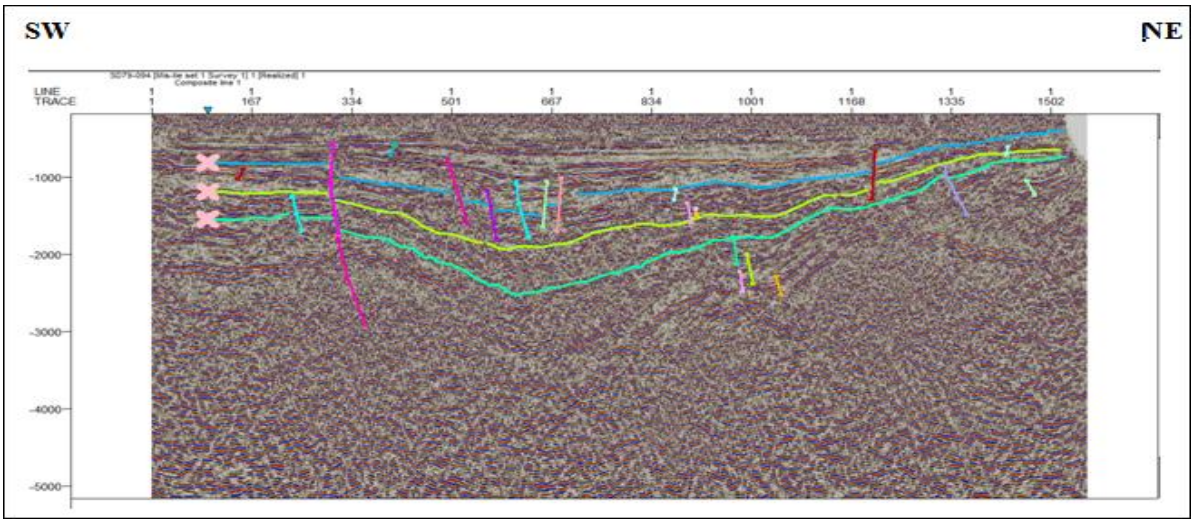

Fig (4.8): Line SD79-091, a dip line that perpendicular to the strike direction of Sufyan sub-basin.

The middle part of the section represents subsidence 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, as well as the section shows the thickness of formation are decrease gradually in the edges compared to center and the basement is shallower in NE direction.

4.4. Structural Maps Interpretation:

4.4.1. AbuGabra Structural Map:

Two-way time structural maps were created for top Aradieba, top Bentiu and top AbuGabra formations. There are two trends are delineated in this horizon: the dominant NW-SE which reflected the major rifting structures of sufyan sub-basin in north and central part of the area, secondary NE-SW that observed mainly in the northwestern part of the area suggesting a NW extension of Abu sufyan sub-basin. Structural map of the top AbuGabra fig (4.9) shows a shallower basement when we trend to NE or SW, moreover extend of basin in northern part is not accurate because missing of data compared with NW part. The eastern part of the area may be affected by Tomat high (this required more data and seismic lines). As observed results that the western side shows the deepest values in term of two ways time, and it is dipping in NW direction.

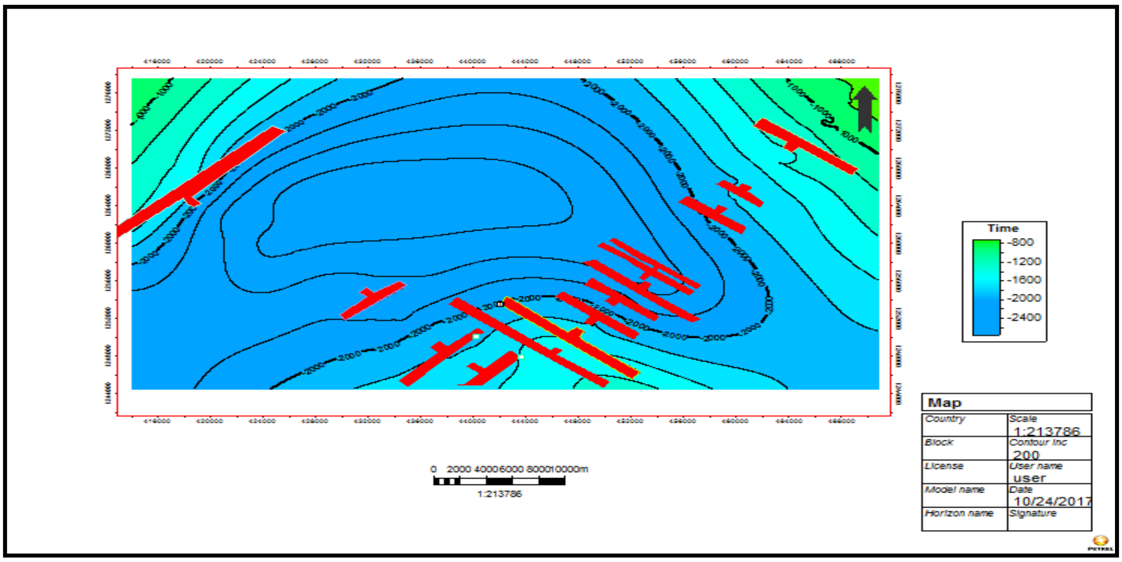

Fig (4.9): Two-way structure map of top AbuGabra horizon.

4.4.2. Bentiu structural map:

Bentiu structural map as displayed in fig (4.10), similarly to top AbuGabra maps, two faults trends are observed in Bentiu map: the dominant NW-SE which reflected the major rifting structures of sufyan sub-basin in north and central part of the area, NE-SW that are parallel to Tomat high and suggest a graben extension of Sufyan sub-basin. The map shows shallow depths to top Bentiu at flank of the basin (northeastern), and the extension of basin in northern part it's not clear, hence more seismic data in this part are required.

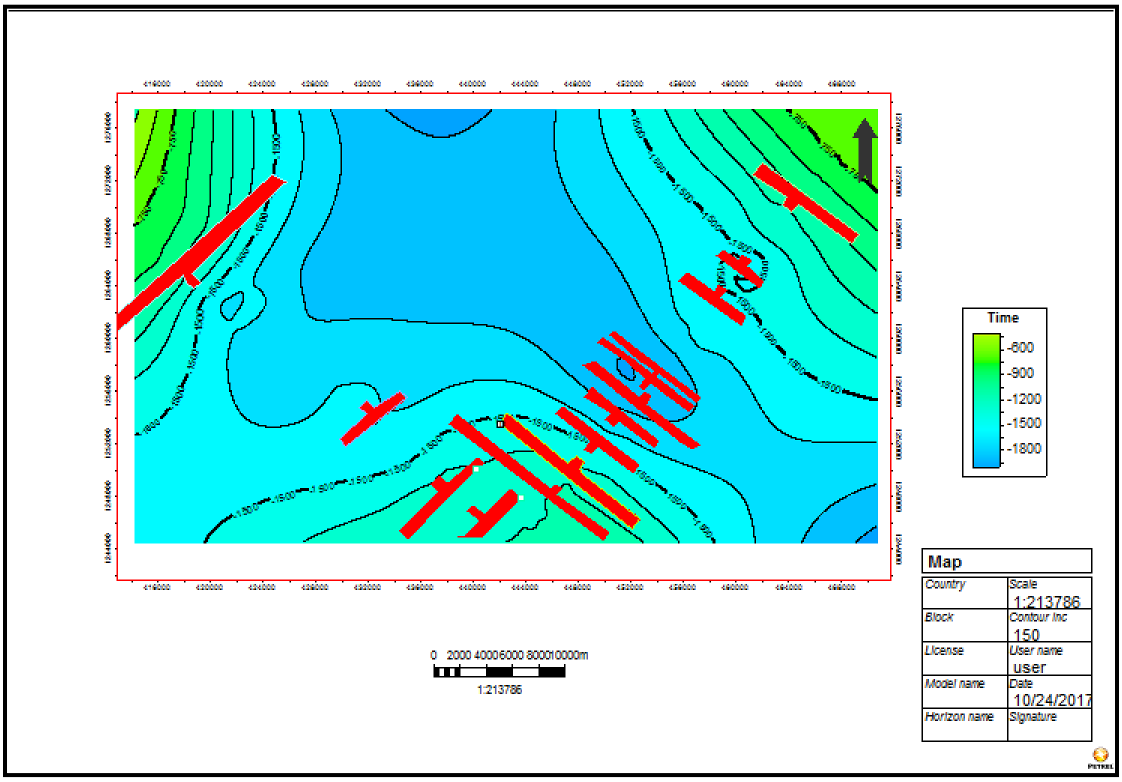

Fig (4.10): Two-way structure map of top Bentiu horizon.

4.4.3. Aradieba structural map:

Bentiu structural map as displayed in fig (4.11). its shows conformable with Bentiu formation in thickness term and it's consider a seal rocks(clay) and shows very clear thinning at northeastern flank.

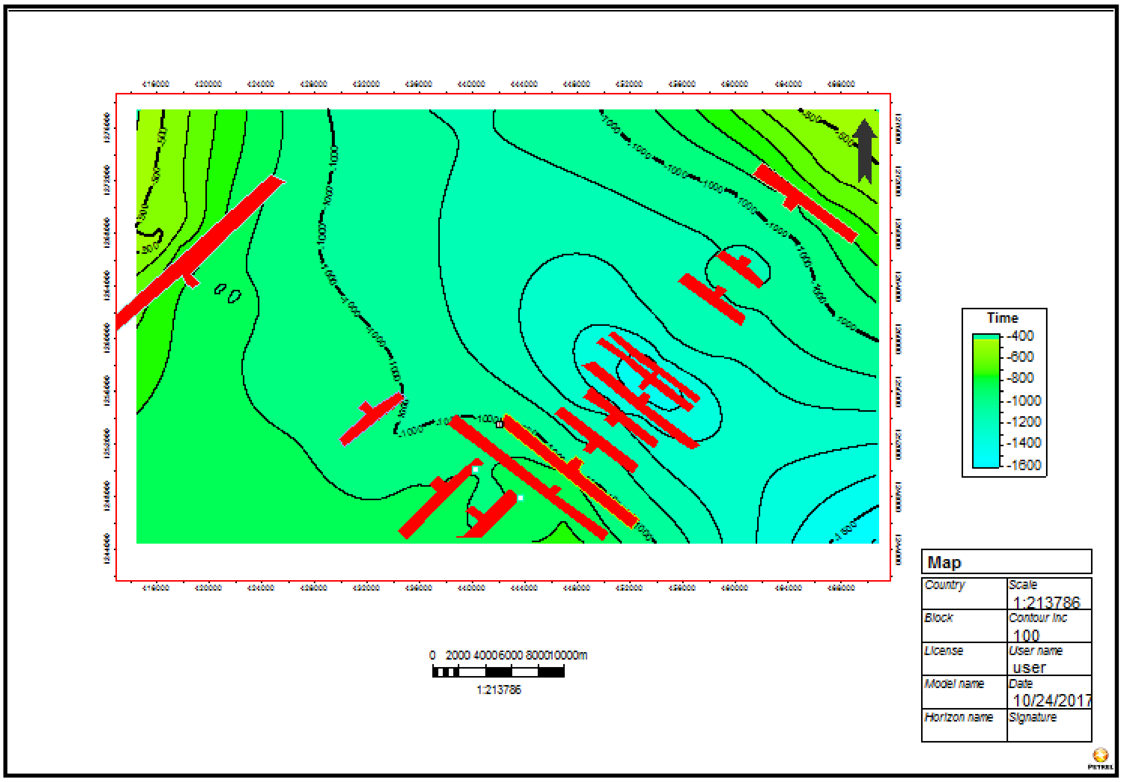

Fig (4.11): Two-way structure map of top Aradieba horizon.

Chapter 5

5. Results and comparative study

5.1 The Hydrocarbon Potentiality:

5.1.1 Introduction:

The occurrence of hydrocarbon accumulations on the subsurface requires several geological elements, these elements are the following (Izz al-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 in to an accumulation.

5.1.2 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 fig (5.1). The illustrated figure displayed the lithological units that composed AbuGabra, Bentiu, Darfur group, and Amal formations.

5.1.3 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 fig (5.1) (Sheriff and Geldart, 1995).

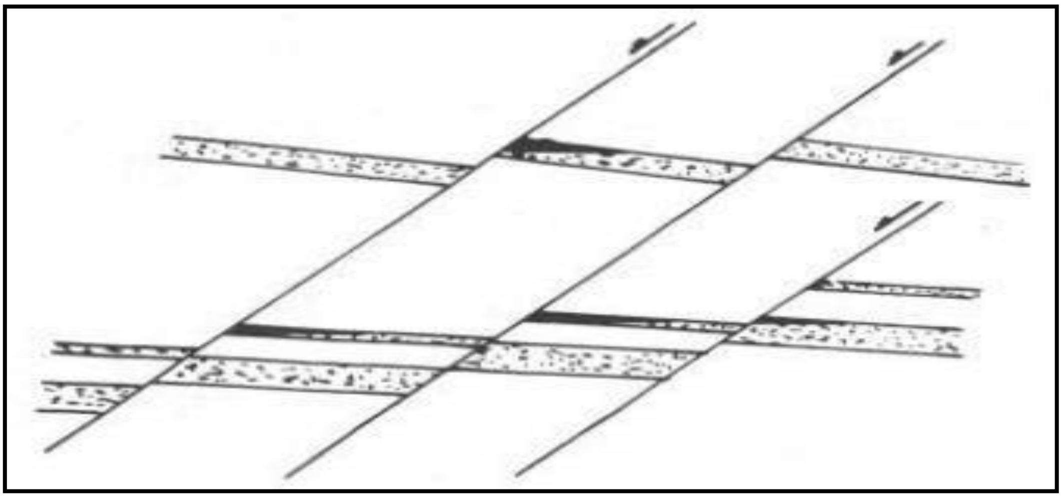

Fig (5.1): developed traps where faults cause to juxtapose the permeable beds on the fault plane against impermeable beds.

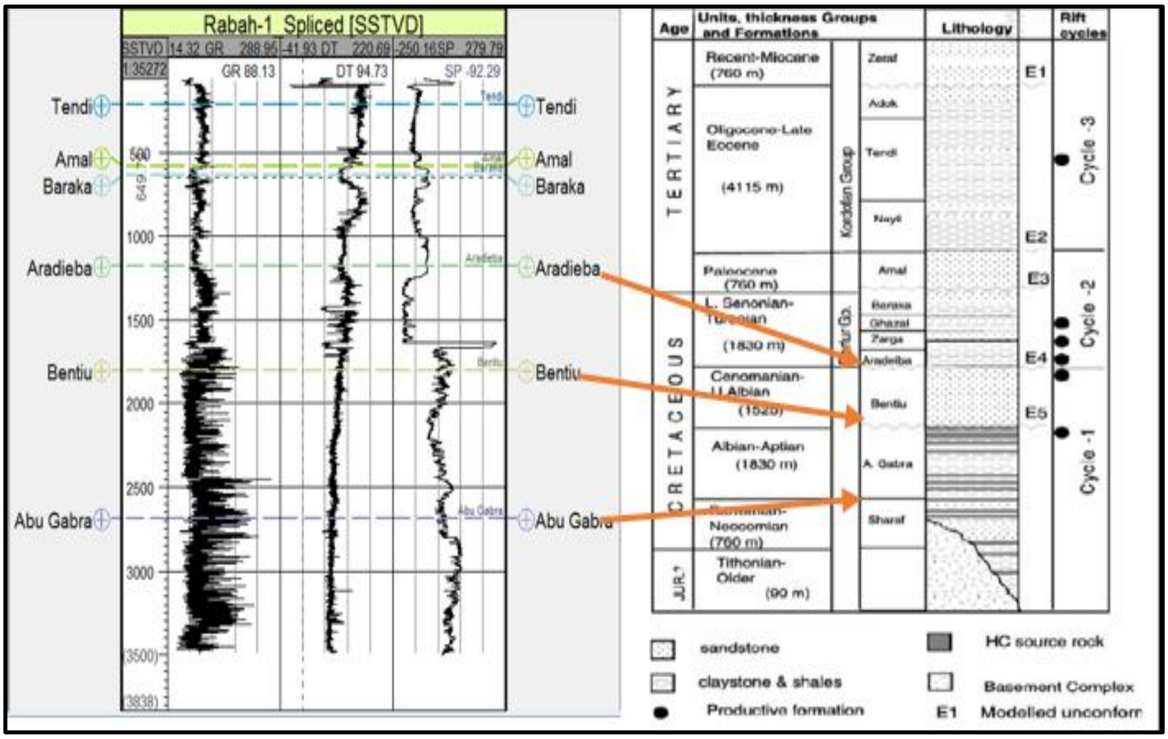

Fig (5.2): calibrated log data of Rabah-1_spliced well with the stratigraphic column of Muglad basin for the interpreted three tops horizons (Top Aradieba, Bentiu, and AbuGabra formations).

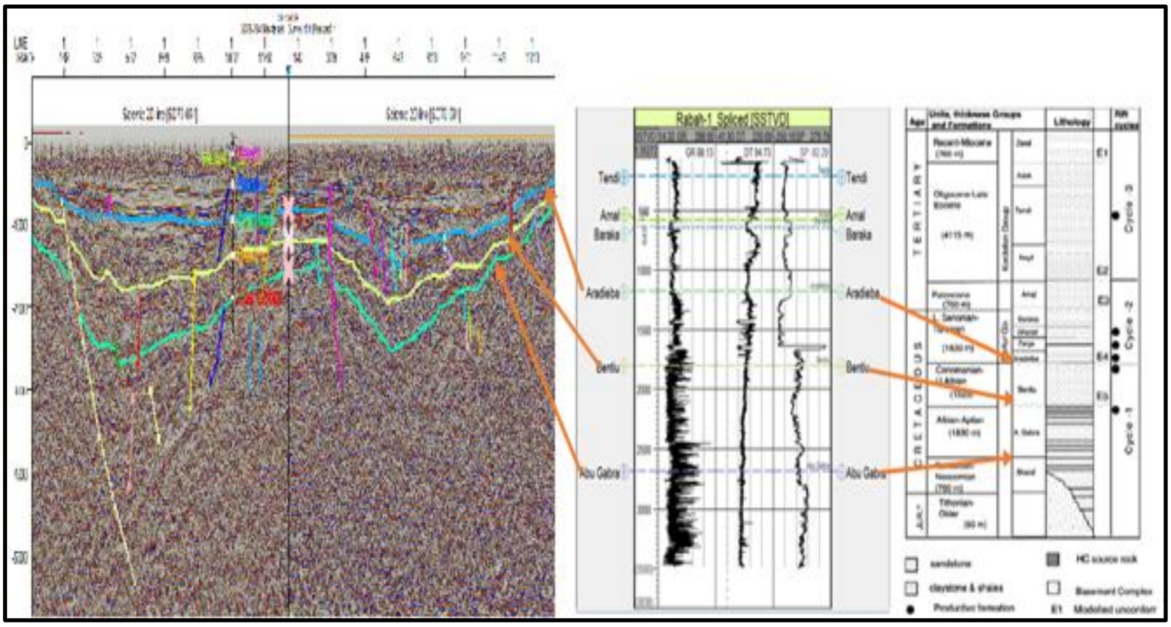

Fig (5.3): presents the Rabah -1_spliced logs (Gamma ray) which reveals the AbuGabra formation as shale stone, Bentiu formation grossly as sandstone and the Aradieba formation within Darfur group is shale that emphasize the integration of hydrocarbon system elements in seismic line SD79-094.

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. One zone (A) was identified as having good hydrocarbon potentiality as shown in fig (5.4).

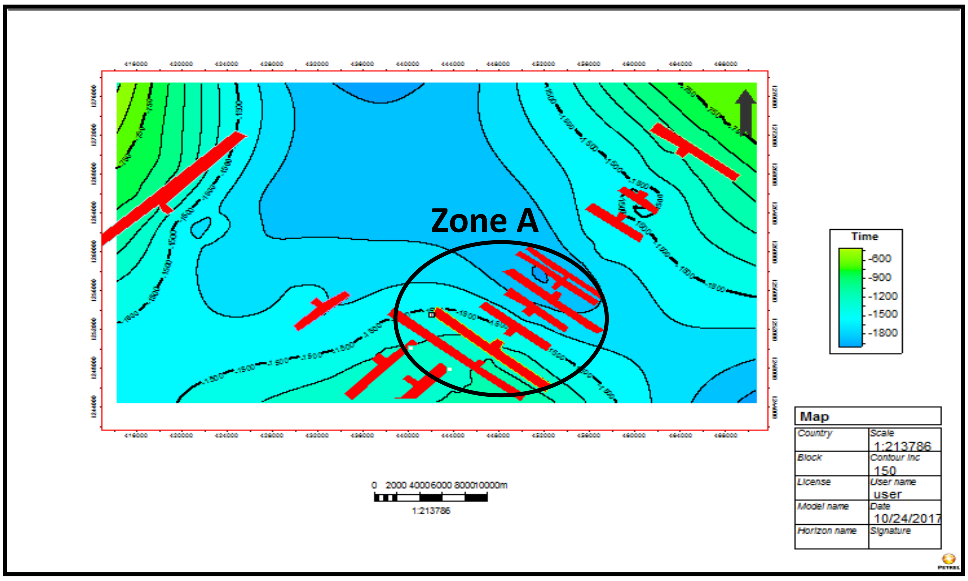

Fig (5.4): TWT structural map of top Bentiu, in which zone (A) represents the good potentiality of hydrocarbon accumulation in sub-basin.

5.2 Comparative study:

5.2.1 Introduction:

Due to the lack of seismic lines and log data in this research, and to improve the reliability of the concluded results, the current interpretation was compared to a previous study that was done by CPET-SUST graduation project in 2016 in Rakuba sub basin, especially that the used seismic lines were having similar trend NW-SE and NE-SW dip lines fig (5.5).

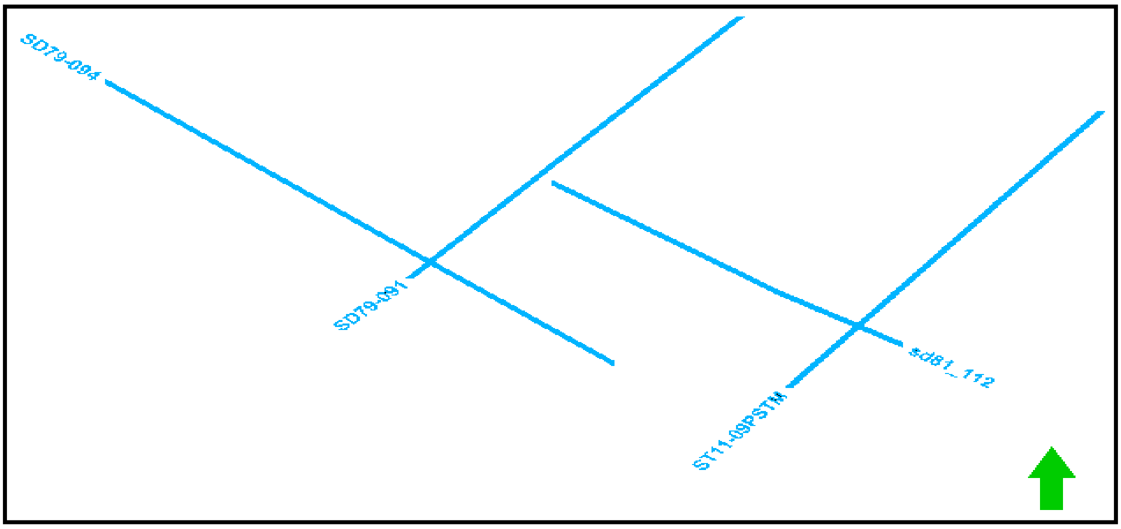

Fig (5.5): shows location of lines which represent recent study in Sufyan sub basin (line SD79-091 and line SD79-094) and late study performed in Rakuba sub basin.

5.2.2 Outputs of Comparative study:

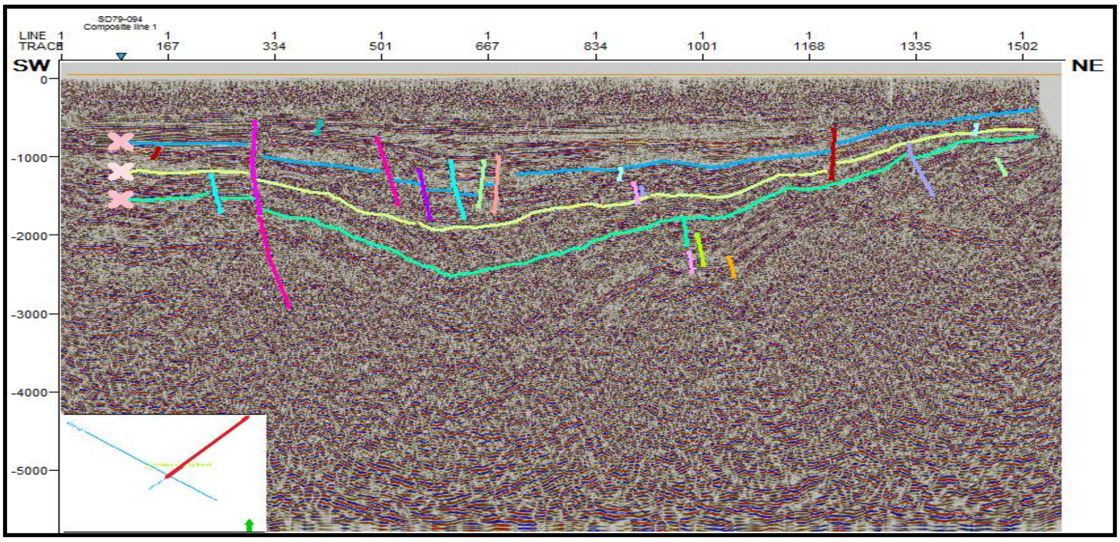

Fig (5.6a): shows line SD79-091 which located in Sufyan sub basin.

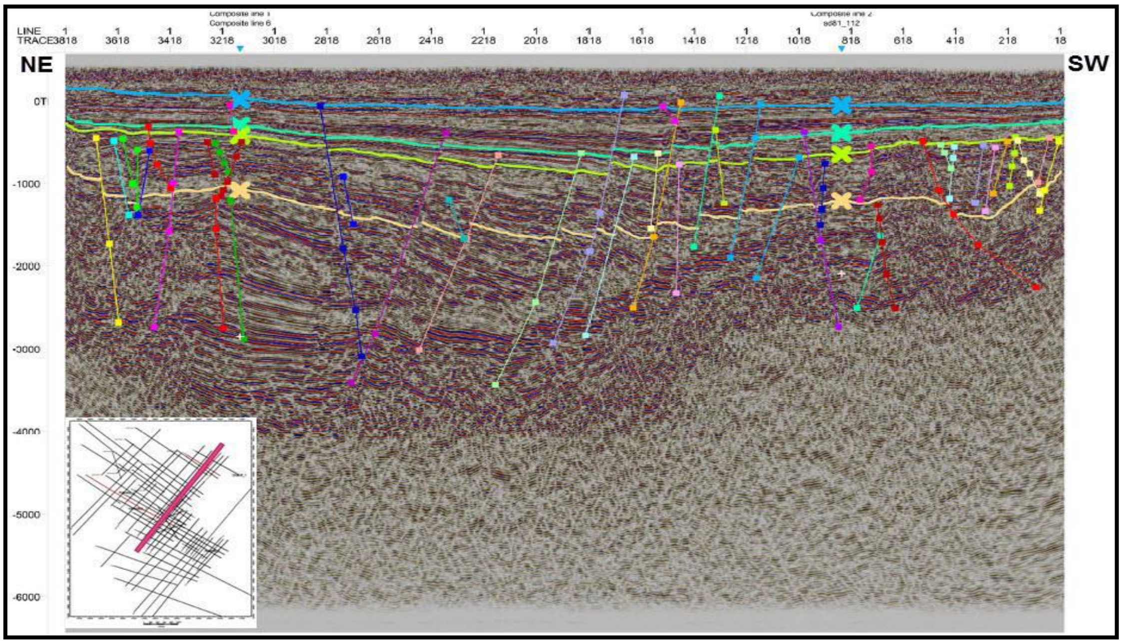

Fig (5.6b): shows line ST11-09 PSTM which located in Rakuba sub basin.

As observed result, there is clearly differences in thickness between packages of strata in Rakuba sub basin and Sufyan sub basin, where line ST11-09 PSTM, shows uniforms thickness of formations (top Bentiu, Darfur group and top AbuGabra), contrariwise line SD79-091 which shows a large variation in thickness from center to flank considered area. As well as line ST11-09 PSTM observed rotate faults phenomena which create rotate blocks fig (5.6b), on the other hand line SD79-091 doesn’t reflect any foundation of this rotate faults phenomena fig (5.6a). Moreover, as observed results the thickness of Aradieba formation in Sufyan sub basin is larger than thickness of Darfur group. Moreover, both line SD79-091 and line ST11-09 PSTM, shows high deformation level because which are perpendiculars to Sufyan and Rakuba sub basins respectively.

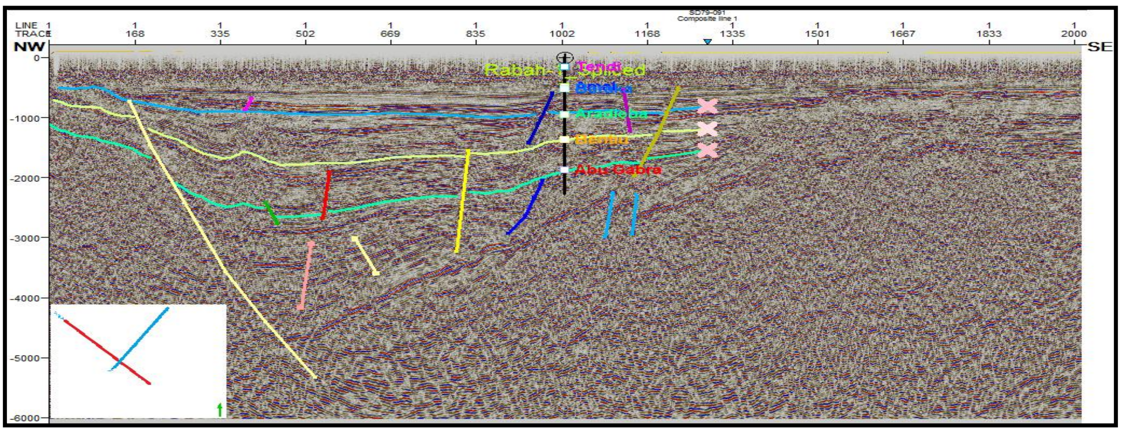

Fig (5.7a): shows line SD79-094 strike in NW-SE which located in Sufyan sub basin.

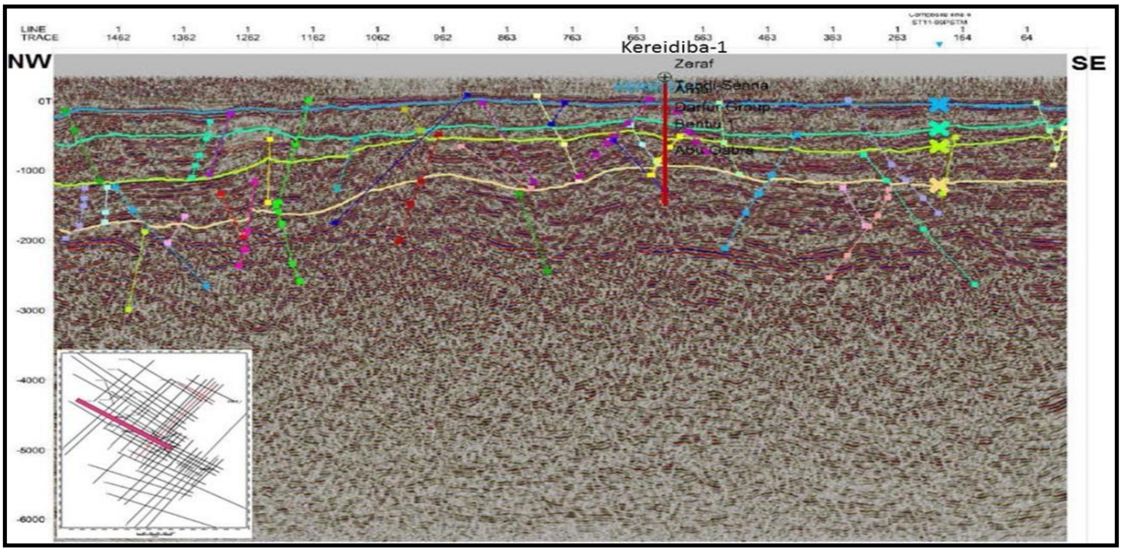

Fig (5.7b): shows line Sd81-112 also strike in NE-SE which located in Rakuba sub basin.

On the other hand, both line SD79-094 in Sufyan sub basin and line Sd81-112 in Rakuba sub basin show relatively low deformation because they are parallel to the sub basins, however there are difference in strata thickness that Sufyan sub basin encounters high thickness variation along this line while Rakuba sub basin strata appeared a uniform thickness.

Line SD79-094 fig (5.7a) shows a large accommodation closely to major fault, on other hand this was not founded in Rakuba line Sd81-112 fig (5.7b). The eastern part of the section associated to line SD79-094 did not observed Tomat high in its mapped subsurface thus to delineate whether Tomat high extends downwards or not more interpreted seismic data is required.

As observed result, that the top of AbuGabra in Sufyan sub basin fig (5.8a) is deeper than the same top in Rakuba sub basin in term of TWT values. The top of AbuGabra in Rakuba sub basin fig (5.8b) was delineated from western to northeast, and the same top is dipping in northeast in Sufyan sub basin where more seismic data is required in particularly in the northern part. The northwest part of the TWT structural map of Rakuba sub basin shows a depression which represents an extension to Sufyan sub basin.

As observed result that the gradient depth of top of Bentiu in Rakuba sub basin fig (5.9b) is uniform, but in Sufyan sub basin fig (5.9a) there is a high gradient variation in depth of the same top from western part to northeast, in addition that the northwestern part of TWT structural map in Rakuba sub basin indicating possible tectonic movement and that Rakuba is an extension to Sufyan sub basin.

Therefore, from comparing above sections it is possible to consider Sufyan sub basin is an extension to Rakuba sub basin, and because the re-activated dextral strike slip fault (as lateral movement), Sufyan sub basin was separated from Rakuba sub basin, and to approve such question more integrated data is needed.

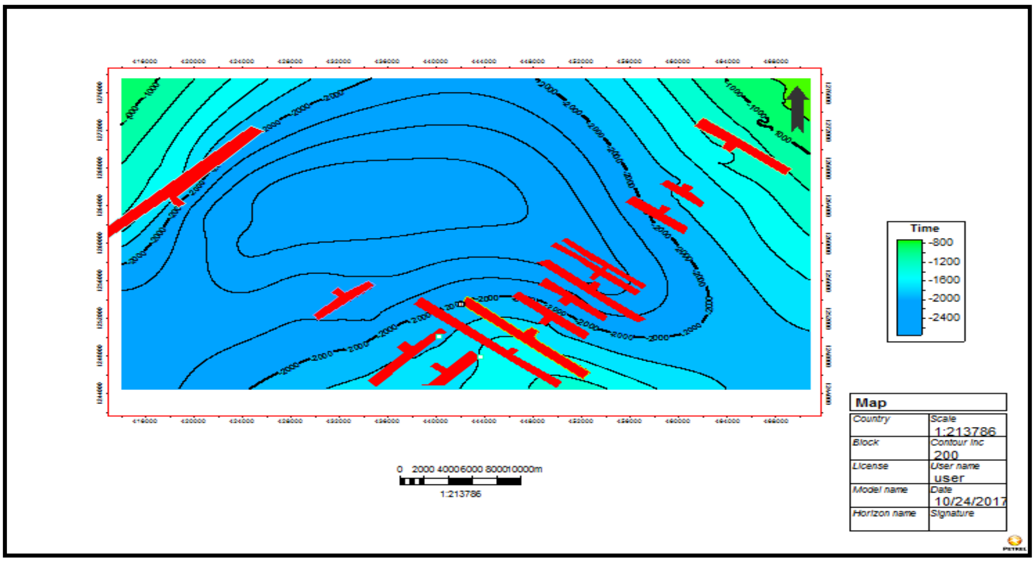

Fig (5.8a): shows TWT structural map of AbuGabra in Sufyan sub basin.

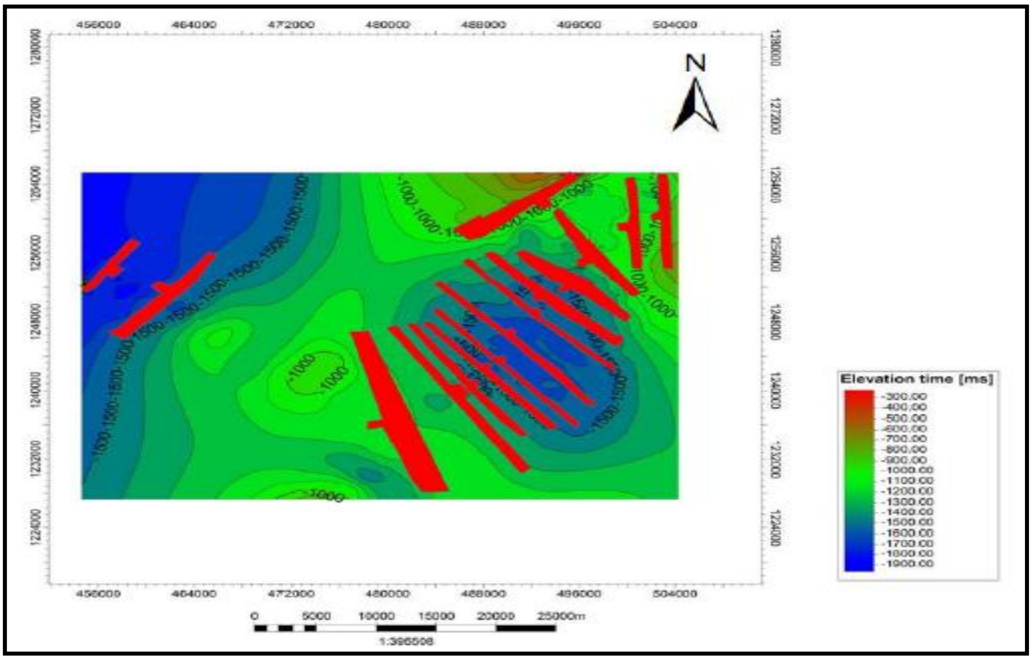

Fig (5.8b): shows TWT structural map of AbuGabra in Rakuba sub basin.

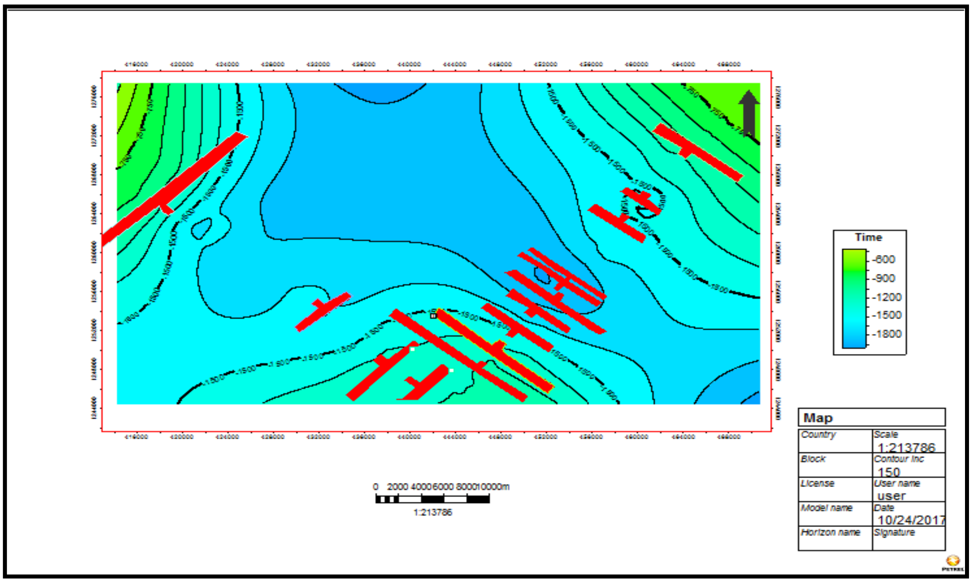

Fig (5.9a): shows the top of Bentiu in Sufyan sub basin.

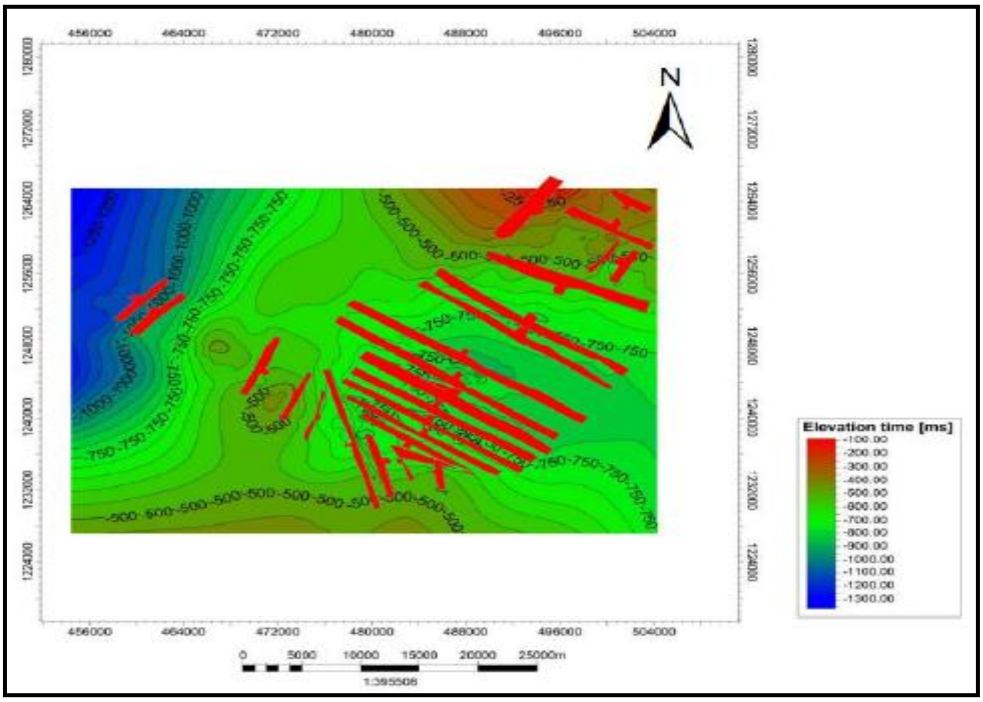

Fig (5.9b): shows the top of Bentiu in Rakuba sub basin.

Chapter 6

6. Conclusion and Recommendation

6.1 Conclusions:

The current study was emphasis on the integration of the structural seismic interpretation with well data in Sufyan sub basin in NW Muglad area, where there is a high structural complexity. The interpretation was done on selected two 2D seismic lines and integrated with (Rabah -1_spliced) well information, in order to describe the structural influence on the subsurface and further identify zones.

Petrel software was used as a mean for interpreting three horizon tops of Aradeiba, Bentiu, and AbuGabra, more over to delineate the controlled faults on the two seismic lines. Then the two-ways time structural 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 sufyan sub-basin was intensively affected by normal faults that generate many horst/graben structural blocks. Also it was observed from the two structural maps a set of two fault trends, NW-SE as dominant faults at the central area which had played important role in basin development, secondary NE-SW trend at the northwestern side of the area.

A comparative study to Rakuba sub basin indicate several outputs including strata thickness variation and intensive observed tectonics in Sufyan sub basin although the selected top horizon have the same seismic characters in both sub basin which indicate that Sufyan sub basin is a potential extension of Rakuba sub basin due to reactivated dextral movement.

Although the limited data, one zone (A) was selected NE of Falah-1 well on the maps as potential prospect based on the integrated interpreted seismic lines, structural maps and the stratigraphic column of the Muglad basin, in which zone (A) shows effective structural deformation to build potential HC trap.

6.2 Recommendations:

- Interpreting more seismic lines calibrated with well logging data and checkshot to improve the vertical and horizontal extension of the sedimentary formations in sufyan sub-basin compared to Rakuba sub basin.
- Vertical seismic profiling data gives accurate and reliable extracted velocity values to convert the two-way times into true depths of these sedimentary formations.
- Conducting quantitative interpretation method using different seismic attributes and amplitude versus offset analysis for top Bentiu horizon.
- Shift location of Falah-1 well in NE direction because it was located in edge of the basin.

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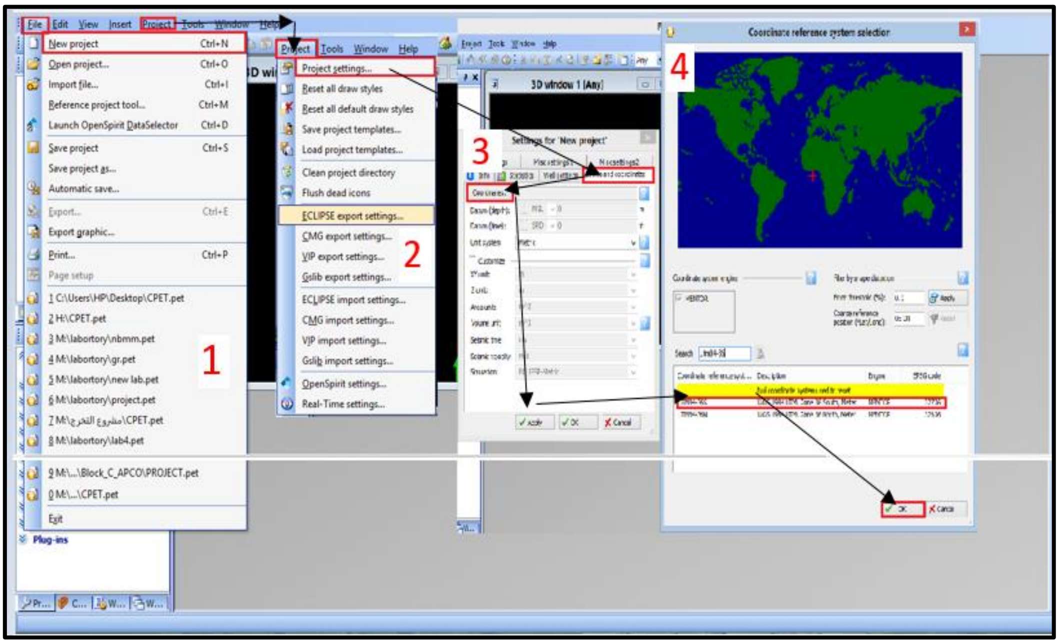
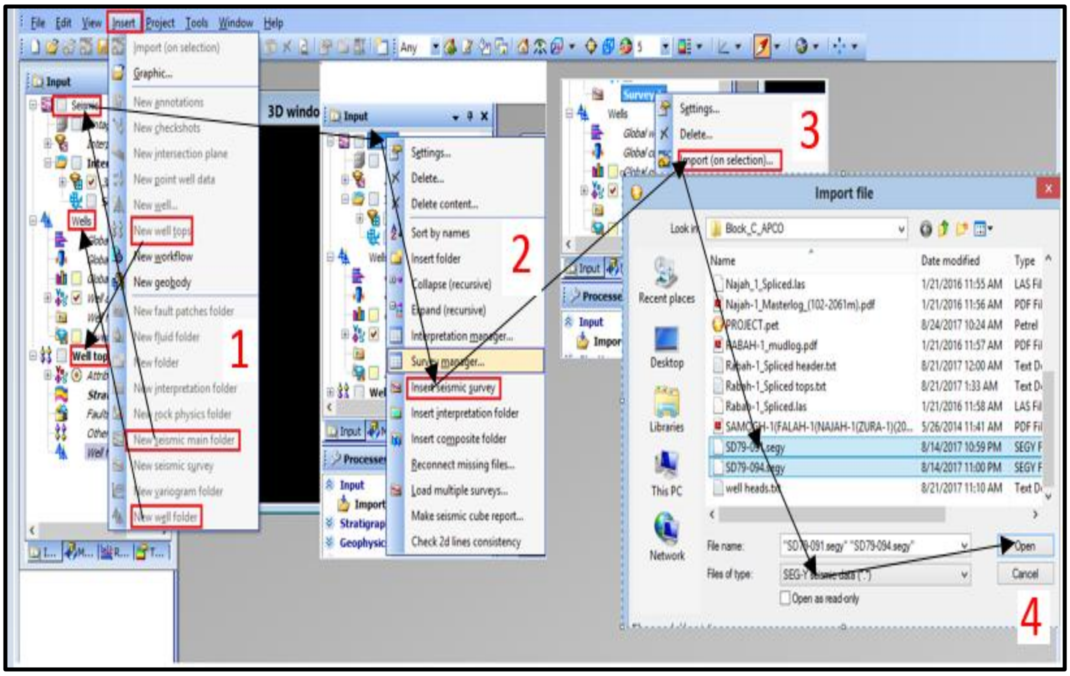
Appendix

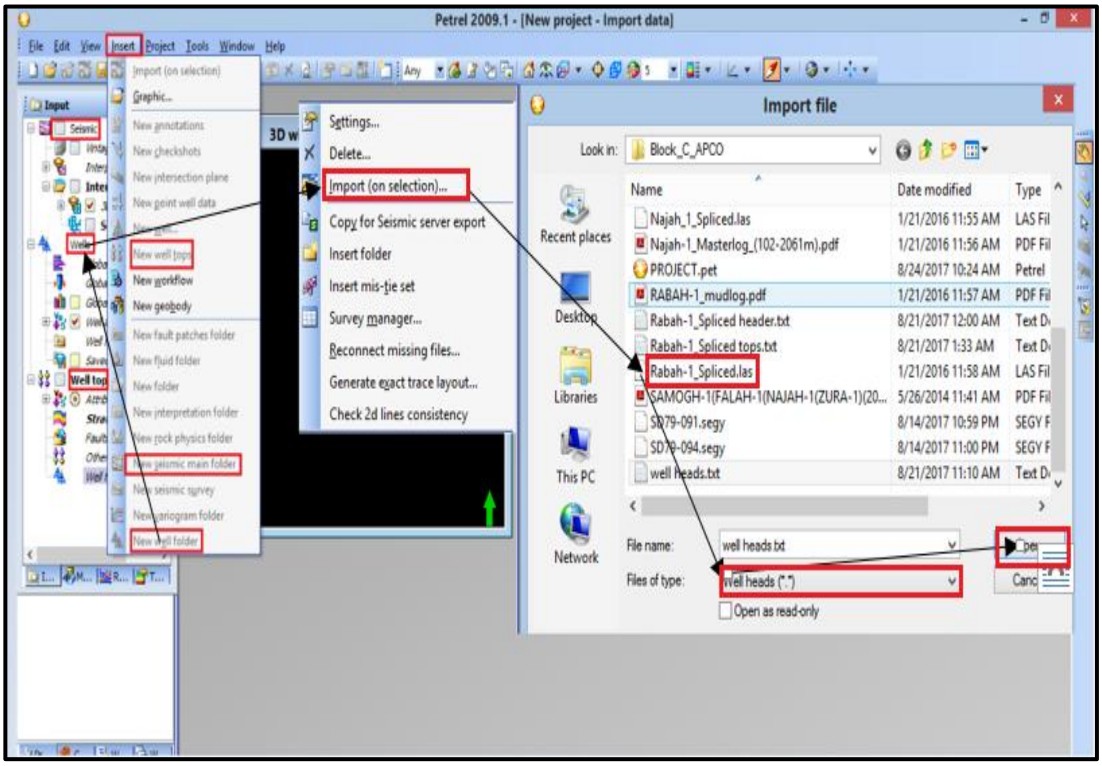
Appendix



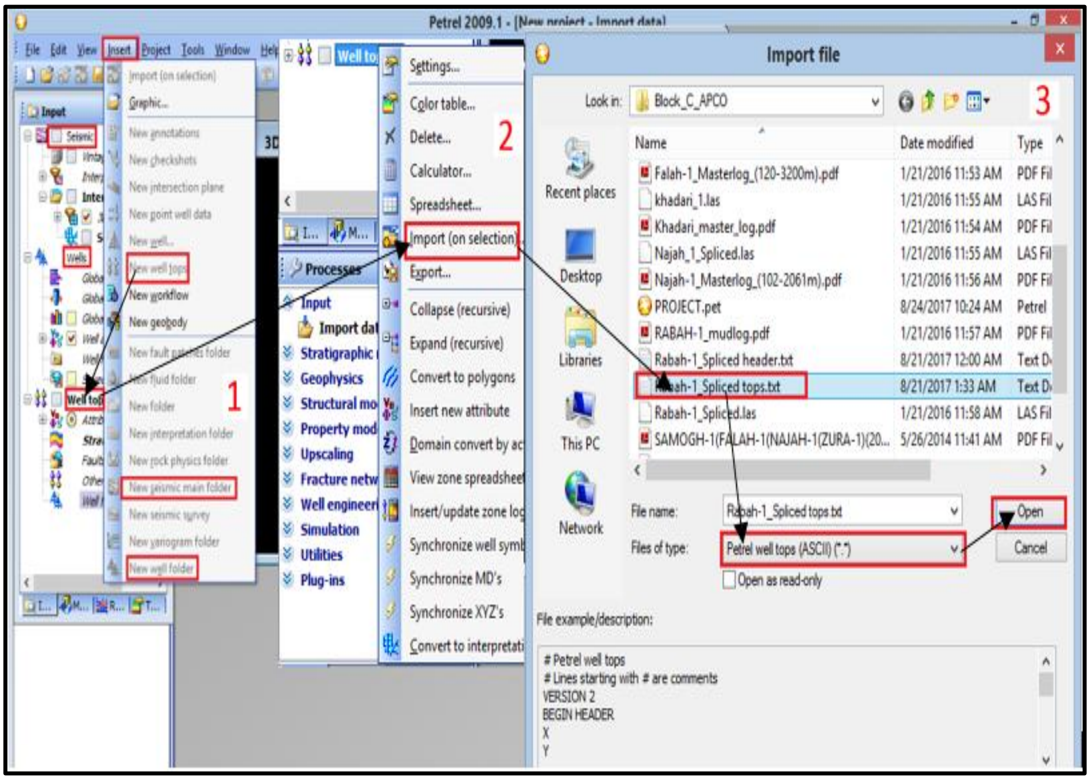
A.1: selection of Coordinate Reference System (CRS) to provide a geodetic reference for project



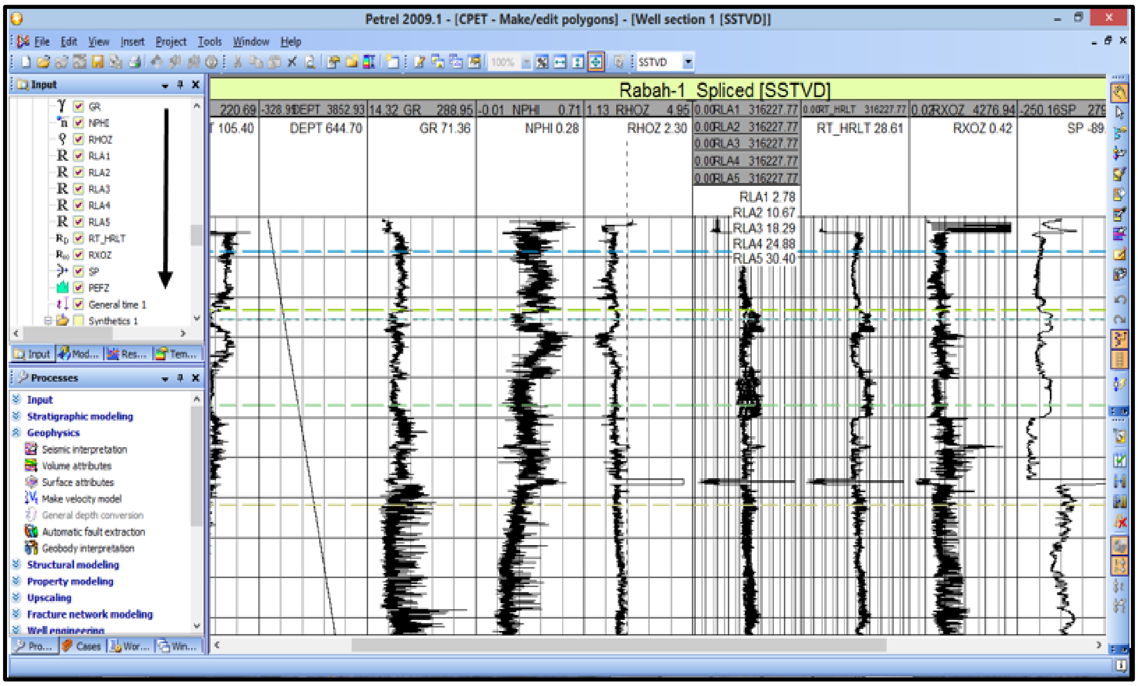
A.2: Loading of new folders of seismic, wells, well tops and seismic sections with their data format.



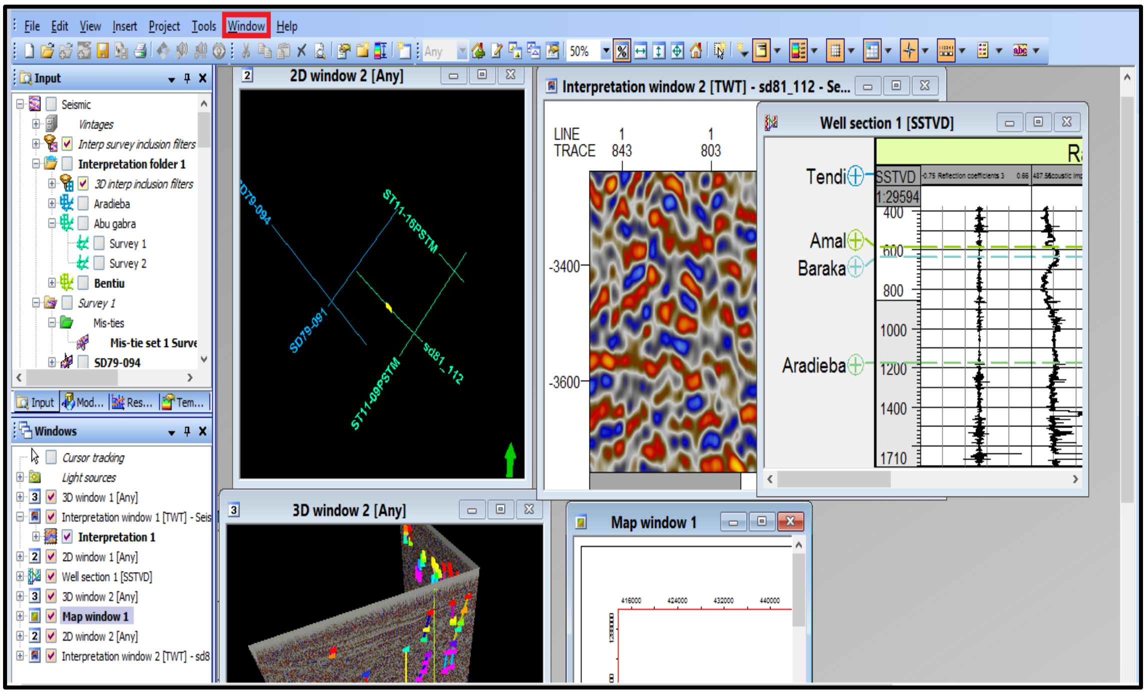
A.3: Loading of well with log data manually without a header info.



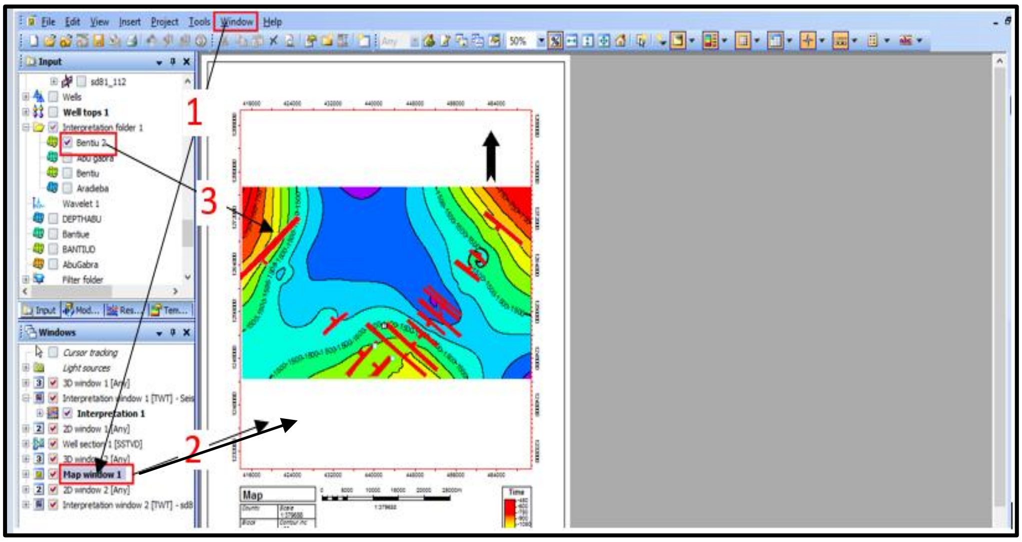
A.4: loading of well tops with well tops format.



A.5: Types of loaded data logs.



A.6: displaying of seismic section, well data and other related data.



A.7: Generated TWT and Depth Maps for Bentiu Top