Sudan University of Science and Technology

College of Petroleum Engineering and Mining

Exploration Engineering Department

Seismic Sequences Stratigraphic in Sufyan Sub-Basin - Muglad Basin, using 2D Seismic Data

دراسة التتابع الزلزالي الطبقي في حوض سفيان الفرعي في حوض المجلد بإستخدام بيانات زلزالية ذات بعدين

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

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الإستـهلال

قال تعالي : (وَلَئِنِ اتَّبَعْتَ أَهْوَاءَهُمْ بَعْدَ الَّذِي جَاءَكَ مِنَ

الْعِلْمِ مَا لَكَ مِنَ اللَّهِ مِنْ وَلِيٍّ وَلَا نَصِيرٍ)

صدق الله العظيم

سورة البقرة أية 120

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.

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

stratigraphic interpretation process of the reflective seismic data which was done in Sufyan sub-basin in NW Muglad basin in East Darfour State, Seismic data represented by seven 2-dimensional seismic lines which include inlines and crosslines, the study area is mainly covers a part of sufyan sub-basin. The study aims to identify the subsurface stratigraphic terminations; the geophysical interpretation involves making geological deductions from the set of data available. the interpretation processes were done using Petrel version 2009 software. interpretation of the seismic sections was calibrated with the stratigraphic column of the Muglad basin. We found stratigraphic bodies such as (top lap, down lap, truncation and concordance).

التجريد

عملية تفسير طبقي للبيانات الزلزالية الإنعكاسية في حقل سفيان الفرعي ؛ حيث يقع في الجزء الشمالي الغربي لحوض المجلد في ولاية شرق دارفور ، مُثلت البيانات الزلزالية بسبعة خطوط زلزالية ذات بعدين متوازية ومتقاطعة و تغطي منطقة الدراسة جزء من حوض سفيان الفرعي ، تهدف الدراسة لتحديد النهايات الطبقية للسطوح التحت سطحية، و يهتم التفسير الجيوفيزيائي بالاستنتاجات الجيولوجية من البيانات المتوفرة.

تمت عملية التفسير باستخدام برنامج petrel 2009 ، و تمت مضاهاة تفسير المقاطع الزلزالية مع عمود الطبقات في حوض المجلد، و تم ايجاد اجسام طبقية مثل (Toplap, downlap, truncation and concordance).

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Chapter One

Introduction

1.1 Introduction

Seismic Stratigraphy is basically a geologic approach to the stratigraphic interpretation of seismic data. Seismic reflections allow the direct application of geologic concepts based on physical stratigraphy. Primary seismic reflections are generated by physical surface in the rocks, consisting mainly of strata surface and unconformities with velocities-density contrasts.

Therefore, primary seismic reflections parallel strata surface and unconformities.

A seismic section is a record of chronostratigraphic (time-stratigraphic) depositional and structural patterns and not a record of the time-transgressive lithostratigraphy (rock-stratigraphy). Seismic sequence analysis is based on the identification of stratigraphic units composed of a relatively conformable succession of genetically related starta termed *depositional sequence.* The upper and lower boundaries of depositional sequences are unconformities or their correlative conformities.

Rift basins of interior Sudan represent one of the major rift systems of the world. The deep Cretaceous–Tertiary basins form part of a regionally linked intra - continental rift system that crosses Central AfricaThe Sufyan filed is located in the northwest of the Muglad Basin in the southern area of Sudan (Fig. 1). It is a relatively independent structural unit in the Muglad Basin. The exploration activities in the Sufyan filed began in the 1970's. From 1975 to 1985, Chevron had carried out aeromagnetic and gravity surveys in the whole area. In 1982, Chevron drilled the first well named S-16 in the east of Sufyan filed (Fig. 1) with a depth of 3341.5 m. Only some oil stain and spot shows were found in this well. Since 1996, China National Petroleum Corporation (CNPC) has taken over the exploration work in the Sufyan filed. CNPC had promoted 2D seismic survey line density for two times in 1997 and 2003 for seismic prospecting. In 2003, CNPC drilled the preliminary exploratory well named S-5 in the central Sufiyan.

1.2Study area:

The Sufyan filed is one of the low-exploration areas in the Muglad Basin (Sudan), and hydrocarbon potential evaluation of source rocks is the basis for its further exploration. The Abu Gabra Formation consisting of three members (AG3, AG2 and AG1 from bottom to top) was thought to be the main source rock formation, but detailed studies on its petroleum geology and geochemical characteristics are still insufficient. Through systematic analysis on distribution, organic matter abundance, organic matter type, organic matter maturity and characteristics of hydrocarbon generation and expulsion of the source rocks from the Abu Gabra Formation, the main source rock members were determined and the petroleum resource extent was estimated in the study area. The results show that dark mudstones are the thickest in the AG2 member while the thinnest in the AG1 member, and the thickness of the AG3 dark mudstone is not small either. The AG3 member have developed good-excellent source rock mainly with Type I kerogen. In the Southern Sub-sag, the AG3 source rock began to generate hydrocarbons in the middle period of Bentiu. In the early period of Darfur, it reached the hydrocarbon generation and expulsion peak.

It is in late mature stage currently. The AG2 member developed good-excellent source rock mainly with Types II1 and I kerogen, and has lower organic matter abundance than the AG3 member. In the Southern Sub-sag, the AG2 source rock began to generate hydrocarbons in the late period of Bentiu. In the late period of Darfur, it reached the peak of hydrocarbon generation and its expulsion. It is in middle mature stage currently. The AG1 member developed fair-good source rock mainly with Types II and III kerogen.

Throughout the geological evolution history, the AG1 source rock has no effective hydrocarbon generation or expulsion processes. Combined with basin modeling results, we have concluded that the AG3and AG2 members are the main source rock layers and the Southern Sub-sag is the main source kitchen in the study area. The AG3 and AG2 source rocks have supplied 58.1% and 41.9% of the total hydrocarbon generation, respectively, and 54.9% and 45.1% of the total hydrocarbon expulsion, respectively. Their hydrocarbon expulsion efficiency ratios are 71.0% and 62.3%, respectively. The Southern Sub-sag has supplied more than 90% of the total amounts of hydrocarbon generation and its expulsion.

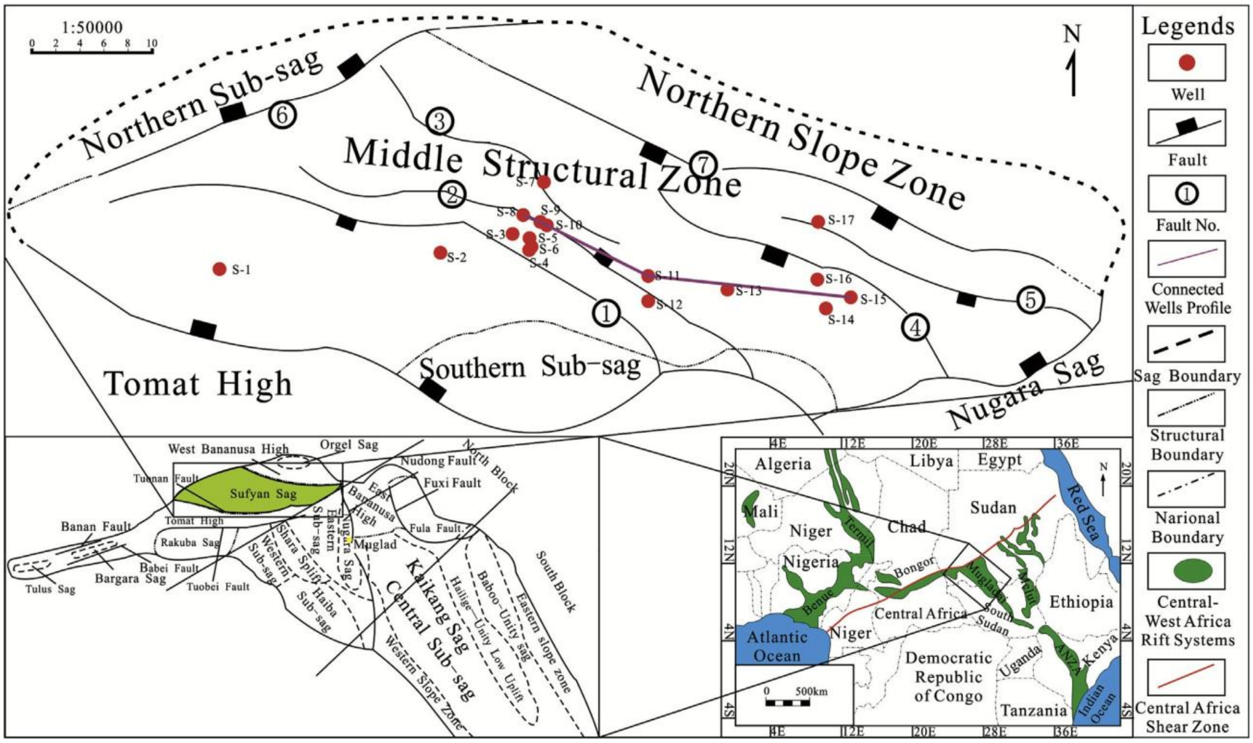

Fig (1). Tectonic units and location of the Sufyan field in the Muglad Basin, Sudan (according to Shi et al., 2014; Zhang and Qin, 2009; having modification).

The Sufyan field is located in the northwest of the Muglad Basin, in east darfuor (N 11 55 38.2 \ E 26 22 42.2).

It is about 100 km long from east to west and 50 km wide from south to north with a total area of 5000 km2 . Its formation evolution and stratigraphic characteristics are roughly similar to the whole Muglad Basin. Since the Cretaceous period, controlled by the shearing motion of the Central African Shear Zone, the Sufyan field began to enter the fault depression stage. The large “diamond” pull-apart sag mainly containing the Cretaceous strata was formed The southern boundary connects to the Tomat High with a Z-shape fault, and the fault throw is more than ten thousand meters. The eastern boundary connects with the Nugara Sag. To the north, the sag overlaps the Babanusa High in the form of fault terrace uplifts (Schandelmeier and Pudlo, 1900). As a whole, the Sufyan field is a half graben-like tectonic unit, which faulted in the south and overlapped in the north. The Sufyan field has experienced three fault-depression stages and three depression stages. The subsidence center was located in the Southern Sub-sag with an area of 350 km .The favorable source rocks were buried more than 3500 m and gradually became thinner to the west and to the north. From the view of tectonic evolution, three large deposition cycles can be divided for the Sufyan field, and each cycle contains a fault depression stage and a depression stage. The first deposition cycle includes the Abu Gabra and Bentiu formations. The Abu Gabra Formation deposited lacustrine shale, mudstone and fine grain sandstone as the main source rock layer in the study area. The Bentiu Formation deposited white, yellow and brown gray sandstone , and particle size is highly variable.

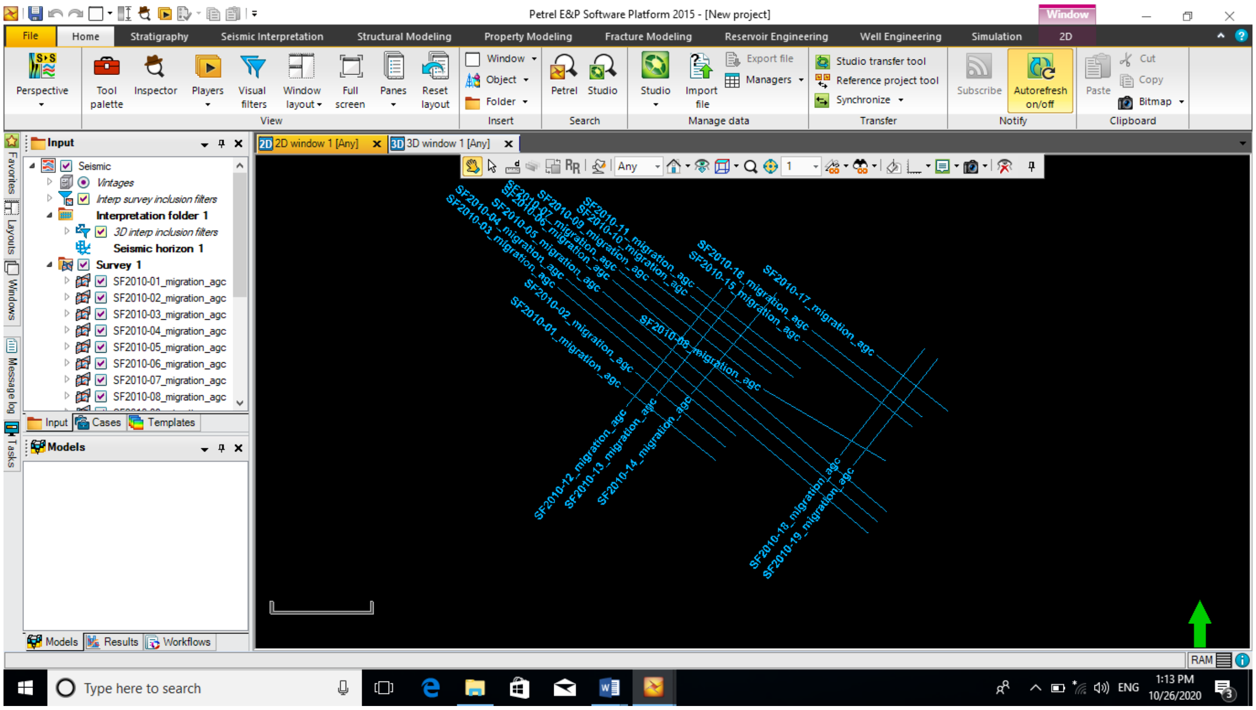

Fig (2): 2D seismic lines form seismic migration sag-y

1.3 Well log data processing

Combined with the core observation and logging data analyses, we have conducted the fine stratigraphic classification on the Abu Gabra Formation in the Sufyan Sag. A total of 14 wells logging curves including the S-1, S-3, S-4, S-5, S-7, S-8, S-9, S-10, S-11, S-12, S-13, S-14, S-15 and S-19 wells logging curves (Fig. 2) were processed by standardization. Based on the standardized logging curves, the dark mudstone thickness for each interval was calculated. The connected wells profile was draw from west to east through the S-8, S-10, S-11 and S-19 wells in the sag (Figs. 1 and 3), which was applied to the analysis of the vertical and horizonal distributions of source rocks of the Abu Gabra Formation.

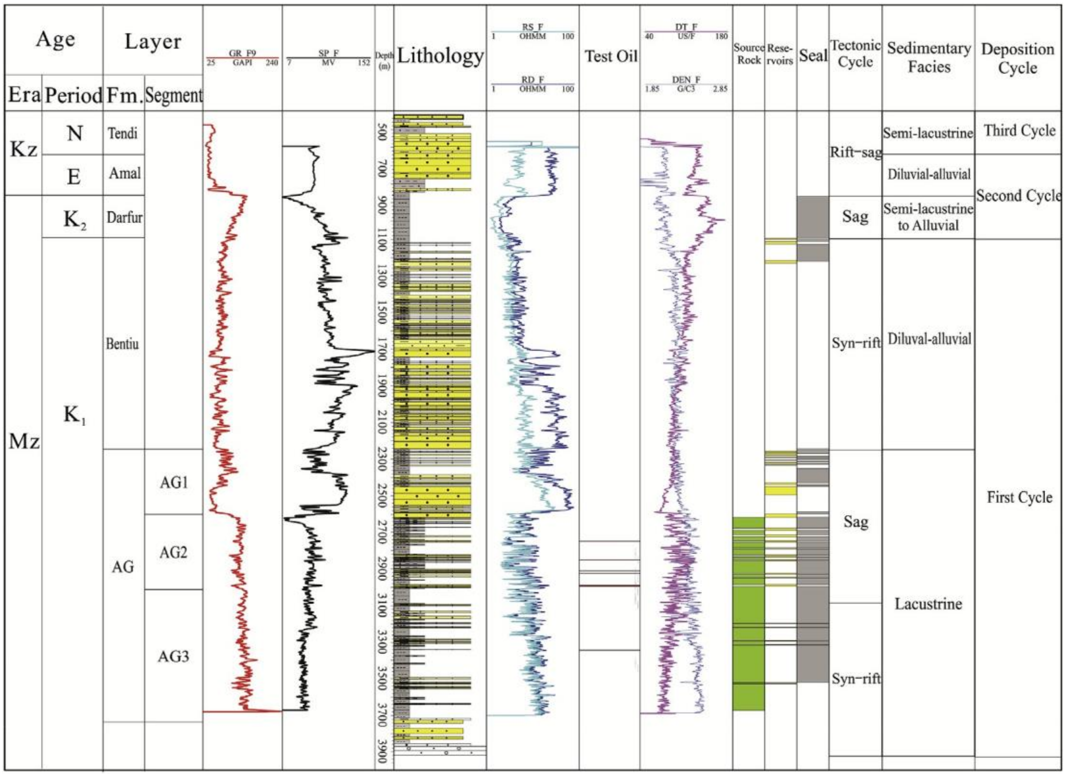

Fig (3) : Comprehensive stratigraphic column of the S-10 well in the Sufyan filed.

1.4Previous studies:

Previous studies have been focused on the petroleum systems and reservoir fluids in the Sufyan field (Luo et al., 2003a, 2003b, 2006; Zhang and Qin, 2009). Two sub-petroleum systems were divided in the study area. One consists of the Abu Gabra source, the Bentiu channel sandstone reservoir and the Darfur shale seal; the other is self-generation, self-reservoir and self-seal system within the Abu Gabra Formation (Fig. 2). Therefore, no matter which sub petroleum system is, oil and gas are both from the Abu Gabra source rocks. Meanwhile, the Abu Gabra Formation is very thick, which can be divided into three members from bottom to top, including the AG3, AG2 and AG1 (Fig. 2). Each member has different structural evolution and sedimentary characteristics, which can influence the geology and geochemical characteristics of source rocks. In this study, we have analyzed the hydrocarbon potential of the source rocks for each member, and then, the main source rock members can be confirmed. Furthermore, combined with the basin modeling results, we have estimated the hydrocarbon generation and expulsion potential of the Abu Gabra source rocks and determined the main source kitchen.by tension effect under the background of the dextral shear stress field of the Central African Shear Zone (Schull, 1988; Allen and Allen, 1990). From bottom to top, it can be divided into three rift-sag deposition cycles (Fig. 2). In the Lower Cretaceous, the sediments are thicker in the east than in the west; in the Upper Cretaceous, the sedimentary thickness in the east is smaller than in the west (Fan et al., 2002).

1.5Predicted results:

1. Detected termination in any sections.
2. Detected the faults in any sections.
3. Identified the main source rock from seismic sequence.
4. Used this termination to correlated between the sections.
5. Presented termination in base map.

Chapter Two

Geology of Study Area

2.1. Introduction:

Muglad Basin represents a major part of the West and Central African Rift Systems and is mainly composed of discrete half and full grabens (Genik,1993). The origin of the WCARS is believed to be related to the opening of the Atlantic Ocean (Fig (2) Binks and Fairhead, 1992; Fairhead and Binks, 1991; Guiraud and Maurin, 1992

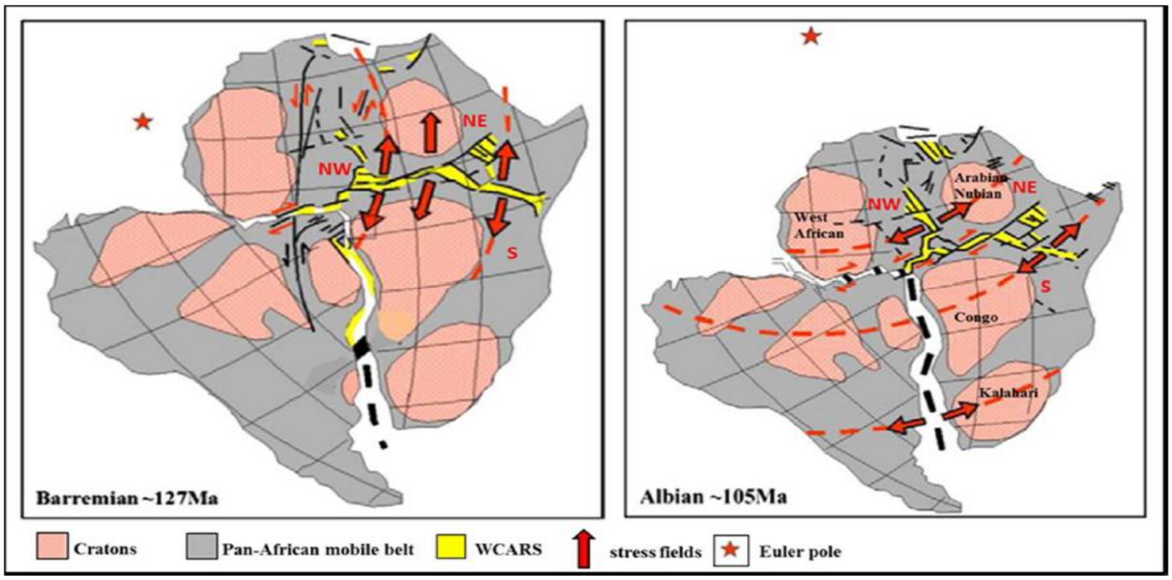

Fig (4): Shown the origin of the WCARS

Muglad Basin is the largest rift basin discovered in Sudan. It trends northwest-southeast and consists of a thick Mesozoic and Tertiary continental syn-rift sequence buried by a Miocene - Recent post-rift sedimentary cover. These continental sediments comprise fluvial and lacustrine facies. The Muglad Basin is the most extensively explored and proved to contain as much as 13 km of sediment. An extension of 32% for the southern Muglad Basin was estimated from the amount of basin infill, and a depth of 12-16 km was estimated for detachment within the crust Rifting began in the Late Jurassic-Early Cretaceous and continued up to the end of the Oligocene The rifting occurred in three episodes giving three cycles of sediment deposition, all of continental facies. Each cycle gave rise to a coarsening-upward sedimentary sequence and the three cycles have been dated as Late Jurassic-Early Cretaceous (140-95 Ma), Late Cretaceous (95-65 Ma) and Paleocene (65-30 Ma). (Schull, 1988; Bosworth, 1992; McHargue et al., 1992).

2.2 Rift system in Sudan

The interior rift basins in Sudan were NW-SE trending continental rifts known as:

1-The Atbara rift.

2 - The Blue Nile Rift.

3 - The White Nile Rift.

4 - The Muglad-Abu Gabra Rift.

5 - The Bagarra Basin.

The most important one is the Muglad basin, which extends along its length up to 800 km, and is connected with the Anza rift in the North Kenya (Bosworth, 1992). The basins are isolated by highs consisting of Precambrian basement rocks or magmatic rocks, and internally cut by some transcurrent faults, probably as a result of differential extension of different portions. Basement fabrics presumably control the basin initiation and development.Stratigraphic sequences are divided into different formations , although the thickness and completeness of the formations are variable from basin to basin. There exist several unconformities or hiatus within the sequences, which separate the Abu Gabra from the Bentiu Formations, the Bentiu Formation from the Darfur Group, the Amal from the Nayil and Tendi Formations, and the Tendi from the Adak and Zeraf Formations. 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. Although

Sufyan Sub-basin is a part of Muglad Basin Fig (5) it is relatively independent structural unit in the Muglad Basin, the trend of the Sufyan Sub-basin (E-W) is different from the general trend of Muglad Basin (NW-SE) and similar to that Baggara basin in west of Sudan and other basins in east Chad

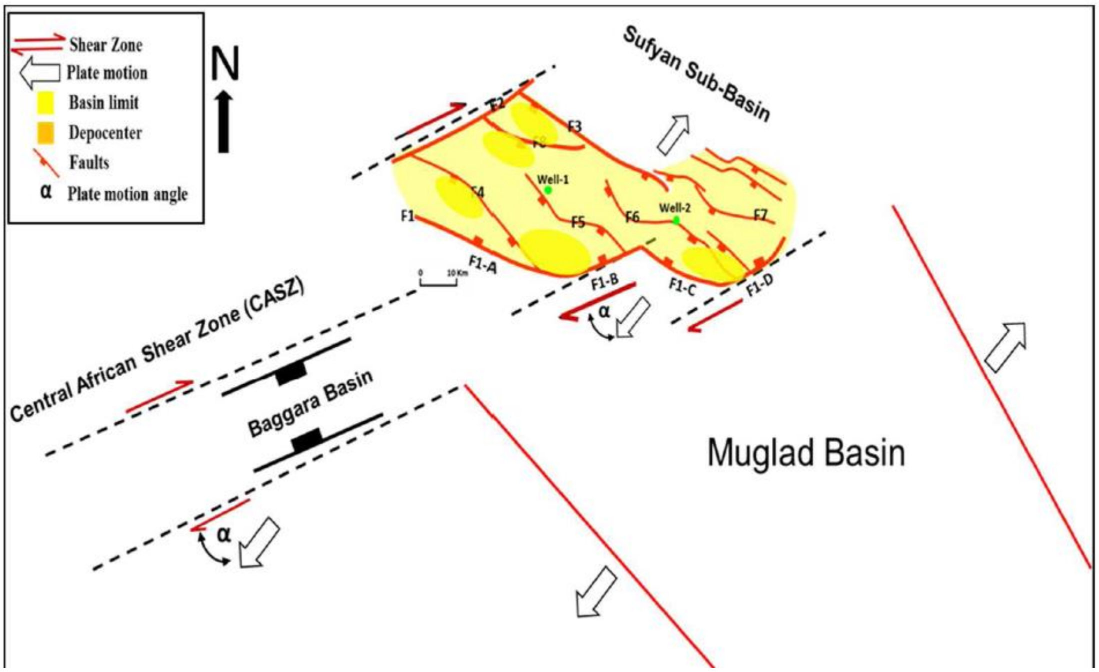

Fig (5) the trend of the SufyanSub-basin (E-W) (yassen 2016)

2.3 Lithostratigraphic Units of Muglad Basin

Hydrocarbon exploration in the Muglad Basin commenced in the early 1970s. Chevron and partners delineated a large basin area, which extends about 800km in length and 200km in width. Several sub-basin have been recognized, whereas half-graben structures dominate the tectonic style. The maximum sediment thickness in the Muglad Basin, which was determined seismically, reaches about 15 km thick in the deepest troughs comprising the three depositional cycles related to the three rift phases.

The main stratigraphic units in the Muglad area are:

1. The Precambrian Basement Complex.

2. Late Jurassic / Early Cretaceous–Tertiary strata.

3. The Tertiary–Quaternary sediments of Umm Rawaba Formation.

4. Holocene to recent.

The Precambrian Basement Complex

The basement rocks bordering towards the NE and SW constitute the elevated shoulders of the Muglad basin, these rocks are part of the Sudanese shield and comprise of a metamorphic terrain intruded by localized igneous bodies The Basement rocks were penetrated and cored in two wells within the NW Muglad area, in Baraka-1 and Adila-1 wells. At these localities the primary composition is granitic and gneisses which has been dated as 540 ±40 Ma (Schull, 1988). The Late Jurassic / Early Cretaceous–Tertiary strata. The lower strata (Late Jurassic / Early Cretaceous to Tertiary) in the Muglad Basin are no marine sediments deposited in lakes, deltas, alluvial fans and fluvial environments.

2.4 Cycles of coarsening upward

Based on the cyclic subdivision of the "Nubian Sandstone" of NW Sudan, the sedimentary rocks of the Muglad Basin belong to the upper or the Nubian Cycle. The following accounts, which are on the stratigraphy and sedimentology of the Late Jurassic/Early Cretaceous–Tertiary strata were summarized after (Schull, 1988 &Kaska, as a result to the repeated rifting, subsidence and sedimentation, three coarsening upward cycles have formed

2.4.1 First Cycle Strata

2.4.1.1Abu Gabra Formations

Abu Gabra Formation comprise the first sedimentary units that were deposited during the early rift phases in the new graben like developing structures,it comprises clay-stones, siltstone, and fine-grained sandstones,The maximum thickness of this unit is approximately 370 m in the NW of the Muglad Basin (Schull, 1988).

2.4.1.2Bentiu Formation

The first depositional cycle ended with deposition of the predominantly sandy sequence of the Bentiu Formation, the deposition of the Bentiu Formation most probably represents a period of ceasing of the initial active rifting. This period constitutes the sag phase of the basin development that followed the rapid initial tectonic subsidence. This formation consists predominantly of thick sandstone beds, deposits of braided and meandering streams, intercalated with thin claystone beds. The Bentiu Formation represents a change in the depositional style from an internal to an external drainage system. The Bentiu Formation may reach up to over 1500 m thickness in some localities (Table 1), and typically shows good reservoir quality (Schull, 1988).

2.4.2Second Cycle Strata

2.4.2.1Darfur Group:

The deposition of the Darfur Group represents the second rift phase. It is characterized by a coarsening upward sequence comprising five formations from bottom to top; these are Aradeiba, Zarga, Ghazal, Baraka Formations and Amal formation (Table 1). Darfur Group, the Baraka Formation does not contribute to the reservoir zones in the Unity and Heglig Fields; this is because of the absence of adequate sealing. The Amal Formation declared the onset of depositional processes during the Tertiary period, however this Formation represents the closure of the second depositional cycle in the Muglad basin. During the Paleocene the massive sandstones sequence of the Amal Formation up to 762 m thick (Table 1) was deposited in high-energy environments comprising regionally extensive alluvial plains with coalescing braided streams and alluvial fans. The Amal sandstone is composed dominantly of coarse to medium grained quartz arenite, which forms potentially excellent reservoirs (Schull, 1988). This group constitutes the final depositional cycle in the Muglad Basin (Table 1). The third rifting phase was created by the reactivation of extensional tectonism during Late Eocene – Oligocene time (Schull, 1988). The syn-rift sediments of this cycle consist of the Nayil and Tendi Formations, which represent the middle part of the Kordofan Group (Table. 1). These formations are dominated by claystones deposited in fluvial/ floodplain and lacustrine environments. The lacustrine facies of the Nayil and Tendi formations appear to have only minor oil source potential, however they offer an excellent seal for the underlying massive sandstones of the Amal Formation. On top of the section of the Kordofan Group the Adok Formation was deposited during the Late Miocene. It comprises medium to coarse-grained sandstone, rarely interbedded with thin beds of claystones (Schull, 1988).

Table 1: Stratigraphic units of the Muglad rift basin, SW Sudan, their lithology and depositional environment (adapted from Schull 1988).

FORMATION		LITHOLOGY AND ENVIRONMENTS	AGE	
KORDOFAN GROUP	Zeraf Fm.	predominantly iron - stained sands and silts with minor claystones interbeds. braided streams / alluvial fans.	Recent - Middle Miocene	TERTIARY
	Adok Fm.		Oligocene - Late Ecocene	
	Tendi Fm.	predominantly claystone / shale interbedded with sandstones. fluvial / floodplain & lacustrine.		
	Nayil Fm.			
	Amal Fm.	predominantly massive medium to coarse sandstones sequences. braided streams / alluvial fans.	Paleocene	
DARFUR GROUP	Baraka Fm.	predominantly sandstones with minor shales and claystones interbeds. fluvial / alluvial fans.	Late Senonian Turonian	CRETACEOUS
	Ghazal Fm.			
	Zarga Fm.	predominantly sandstones, shales with interbeds of siltstones and sandstones. floodplain / lacustrine with fluvial / deltaic channel sands.		
	Aradeiba Fm.			
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	
Sharaf Fm.		claystones, shales with interbeds of fine sandstones and siltstones. lacustrine / fluvial - floodplain.	Barremian - Neocomian	

Source rocks (dark shading: Abu Gabra Fm., Sharaf Fm.)   Reservoir rocks (dotted shading: Ghazal Fm., Zarga Fm., Aradeiba Fm., Bentiu Fm.)

Chapter Three

Methodology

3.1Introduction

Seismic stratigraphy, the science of interpreting or modeling stratigraphy, sedimentary facies, and geologic history from seismic reflection data, has been practiced for at least three decades. However, the term seismic stratigraphy became common place in the vocabulary of geologists and seismic interpreters only after publication in 1977 of authoritative AAPG Memoir 26, seismic stratigraphy --- Applications to Hydrocarbon Exploration (payton 1977). Subsequently, seismic stratigraphic studies have increased significantly in number, establishing the importance of the discipline to geological interpretation of sedimentary rocks Sequence stratigraphic units: Sequences.

Definition a sequence was originally defined as an unconformity-bounded stratigraphic unit (Slossetal1949; Sloss1963). The concept of sequence was subsequently revised to include "a relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities" (Mitchum1977). The continued development of the sequence stratigraphic paradigm in the 1980s and 1990s resulted in a diversification of approaches and the definition of several types of sequence : depositional sequences, bounded by subaerial unconformities and their marine correlative conformities (e.g., Vail 1987; Posamentieretal.1988; Van Wagoner et al. 1988, 1990; Vail et al. 1991; Hunt and Tucker 1992); genetic stratigraphic sequences, bounded by maximum flooding surfaces (Galloway 1989); and transgressive regressive (T-R) sequences, also referred to as T-R cycles, bounded by maximum regressive surfaces (Johnson and Murphy 1984; Johnson et al. 1985). The T-R sequence was subsequently redefined by Embry and Johannsson (1992) as a unit bounded by composite surfaces that include the subaerial unconformity and the marine portion of the maximum regressive surface.

3.2Types of sequence:

Depositional sequences A depositional sequence forms during a full cycle of change in accommodation, which involves both an increase (positive) and decrease (negative) in the space available for sediments to fill. The formation of depositional sequence boundaries requires periods of negative accommodation. The dependency of depositional sequences on negative accommodation (whether in continental or marine settings), in addition to the nature of bounding surfaces, separates depositional sequences from other types of sequence stratigraphic unit, the formation of which may not require negative accommodation (i.e., parasequences, genetic stratigraphic sequences, T-R sequences in the sense of Johnson and Murphy (1984), and systems tracts that form during positive accommodation).

3.3 Genetic stratigraphic sequence:

The formation of genetic stratigraphic sequences depends on the development of maximum flooding surfaces, which form during times of positive accommodation. A genetic stratigraphic sequence may form during a full cycle of change in accommodation, as in the case of a depositional sequence, but it may also form during periods of positive accommodation in response to fluctuations in the rates of accommodation creation and/or sediment supply. Consequently, a genetic stratigraphic sequence may or may not include an internal subaerial unconformity, depending on whether or not the corresponding cycle includes a stage of negative accommodation. Maximum flooding surfaces may include unconformable portions expressed as “hiatal surfaces preserved as marine unconformities” (Galloway 1989). Such unconformities may develop on the shelf and slope because of sediment starvation, shelf-edge instability and erosion during transgression. Where present, unconformable maximum flooding surfaces are included within but do not constitute the bounding surfaces defining depositional sequences and T-R sequences.

3.4 Transgressive-regressive (T-R) sequences

The original T-R sequence of Johnson and Murphy (1984) depends on the development of maximum regressive surfaces, which form during times of positive accommodation. As in the case of genetic stratigraphic sequences, this type of sequence may form during a full cycle of change in accommodation, but it may also form during periods of positive accommodation as a result of fluctuations in the rates of accommodation and/or sediment supply. By contrast, the T-R sequence of Embry and Johannessen (1992) is dependent on negative accommodation, as it requires a subaerial unconformity at the sequence boundary. As the maximum regressive surface is younger than the subaerial unconformity, the marine portion of the maximum regressive surface may or may not meet with the basin ward termination of the subaerial unconformity (Embry and Johannessen 1992). The temporal and spatial offset between the two portions of the sequence boundary is increasingly evident at larger scales of observation (Catuneanu et al. 2009).

3.5 Sequence stratigraphic units: Para sequences

Definition a para sequence in its original definition (Van Wagoner et al. 1988, 1990) is an upward-shallowing succession of facies bounded by marine flooding surfaces. A marine flooding surface is a lithological discontinuity across which there is an abrupt shift of facies that commonly indicates an abrupt increase in water depth. The concept was originally defined, and is commonly applied, within the context of siliciclastic coastal to shallow-water settings, where para sequences correspond to individual prograding sediment bodies. In carbonate settings, a para sequence corresponds to a succession of facies commonly containing a lag deposit or thin deepening interval followed by a thicker shallowing-upward part, as for example in peritid cycles. In contrast to sequences and systems tracts, which may potentially be mapped across an entire sedimentary basin from fluvial into the deep-water setting, para sequences are geographically restricted to the coastal to shallow-water areas where marine flooding surfaces may form (Posamentier and Allen 1999). In the case of carbonate settings, peritidal cycles can in some cases be correlated into slope and basin facies (e.g., Chen and Tucker 2003). For this reason, it has been proposed that ‘ para sequence ’ be expanded to include all regional meter-scale cycles, whether or not they are bounded by flooding surfaces.

3.6 Sequence stratigraphic surfaces

Definition Sequence stratigraphic surfaces mark changes in stratal stacking pattern. They are surfaces that can serve, at least in part, as systems tract boundaries. Sequence stratigraphic surfaces may correspond to ‘conceptual’ horizons (i.e., without a lithological contrast) or physical surfaces, depending on their outcrop expression (e.g., Carter et al. 1998). Unconformable sequence stratigraphic surfaces typically have a physical expression. Any conformable sequence stratigraphic surface may be a conceptual horizon or an observable surface with physical attributes, depending on local conditions of deposition or preservation. A set of seven sequence stratigraphic surfaces, including two types of correlative conformities, is in wide spread use. Criteria for mapping each type of sequence stratigraphic surface are summarized in Catu- neanu (2006).

3.7 Interpretation of seismic reflection data

Seismic interpretation and sub-surface mapping are main key skills that used commonly in oil industry, the geophysical data provide subsurface image and other information. That may be used by geophysicist, geologist and engineers to identify and effectively Drain hydrocarbon reservoirs Both geophysical and Geological expertise need to be included in a complete interpretation. Seismic interpretation is the science and art of inferring the geology at some depth from The processed seismic record. It is important for the interpreter to have basic Understanding of what tectonic influences and depositional systems occur within the Area of the seismic survey to be investigated.

The interpretation of fault styles, structural geometric, and facies patterns must be Consistent with regional tectonic forces and basin infilling. 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. 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. (Dobrin1988)

3.8 Stratigraphic analysis (seismic stratigraphy)

Seismic stratigraphy involves the subdivision of seismic sections into sequences of reflections that are interpreted as the seismic expression of genetically related sedimentary Sequences. The principles behind this seismic sequence analysis are two-fold. Firstly, reflections are taken to define chronostratigraphic units, since the types of rock interface that produce reflections are strata surfaces and unconformities; by contrast, the boundaries of diachrono lithological units tend to be transitional and not to produce reflections. Secondly, genetically related sedimentary sequences normally comprise a set of concordant strata that exhibit discordance with underlying and overlying sequences; that is, they are typically bounded by angular unconformities variously representing onlap, downlap, toplap or erosion

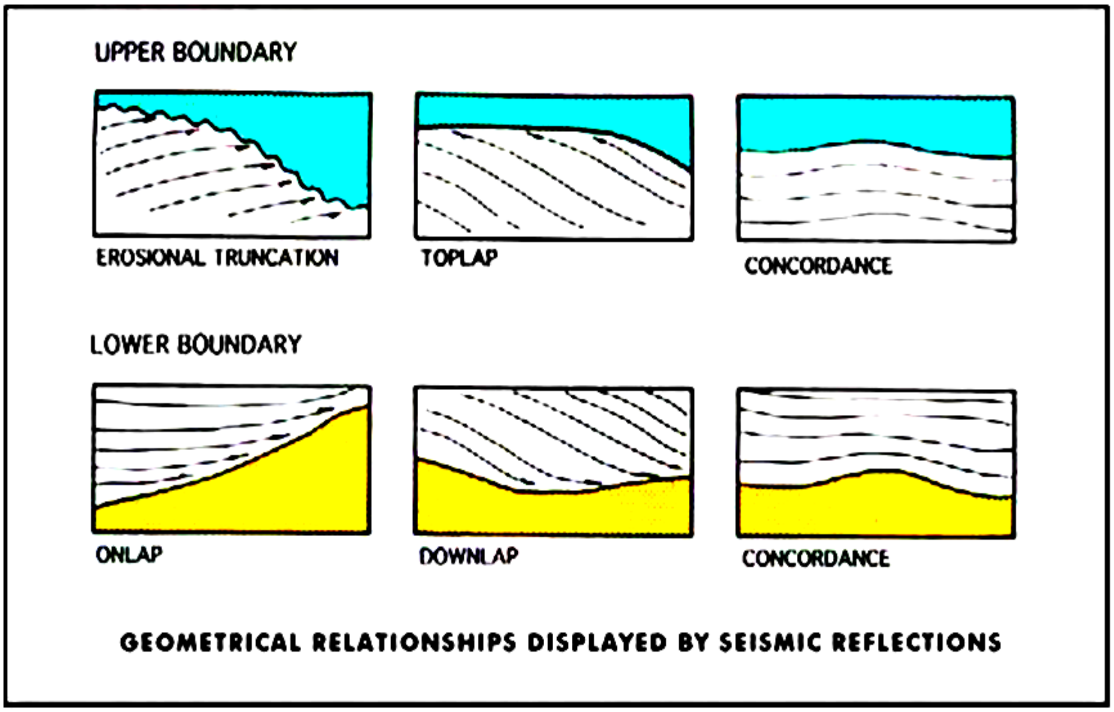

Figure (6): shown geometrical relationships displayed by seismic reflections

Different types of geological boundary defining seismic sequences. Seismic sequence is the representation on a seismic section of a depositional sequence; as such, it is a group of concordant or near-concordant reflection events that terminate against the discordant reflections of adjacent seismic sequences.

Having subdivided a seismic section into its constituent sequences, each sequence may be analyzed in terms of the internal disposition of reflection events band their character, to obtain insight into the depositional environments responsible for the sequence and into the range of lithological facies that may be represented within it. This use of reflection geometry and character to interpret sedimentary facies is known as seismic facies analysis.

3.9 Interpretation techniques:

3.9.1 Picking reflections

Picking reflections is usually based on following the same phase from trace to trace. Usually a peak or a trough; where the reflection character changes because component beds thicken or thin or change their lithological makeup. Routine following of the same phase may introduce errors. And the interpreter should think about what he is trying to map and take appropriate liberties in interpreting the data.

3.9.2 mapping reflecting horizons

The horizons that we draw on seismic sections provide us with a two-dimensional picture only. Three-dimensional picture is necessary. Isopach maps which show the thickness of sediments between two horizons are useful in studying structural growth. They can be prepared by overlaying maps of the two horizons and subtracting the contour values wherever the contours on one map cross the contour on the other.

3.9.3 Petrel Software Technique:

Petrel software version 2009 has been used for this research. This software is window based and assets of Schlumberger. Petrel can perform various operations, including interpretation of seismic data, well correlation; also it can generate reservoir models, calculation of volumes …etc.

The Petrel user has the option to choose between manual and automatic interpretation, for which both act as freely interpretation or with guidelines respectively. If automatic interpretation of horizons is used, one of three functions should be elect; guided auto tracking, 2D auto tracking or 3D auto tracking, which all required an important parameter that defining the degree of the seismic event is to be followed. For “good”, continuous reflectors such as the sea floor, one can have loose constraints, whereas for more chaotic events such as failed slide deposits stricter constraints are suggested. It is possible to choose which part of the signal is to be followed: the lower zero crossing or upper zero crossing, peak or trough …etc.

3.10 Data and Methods:

3.10.1 Data definition:

The available data which used in this study as shown in fig (2) consist of the following:

- Nineteen seismic lines (2D)
- Three Well information of (Suf c-1, Suf 1, Abu Sufyan) include horizon tops of (Amal, Darfur group, Bentiu and Abu Gabra Formations).

3.10.2 Methods of analysis:

The first step in our work is to load the data in the software we, hence the package used in this study is Petrel software 2009 version, the data loaded were 2D seismic lines.

Chapter Four

Integrated Data Interpretation

4.1 Introduction:

Seismic data interpretation of seven selected 2D seismic lines show in fig (7) to delineate the stratigraphic of study area, the lines is:

1. Line SF 2010-05_migration_agc
2. Line SF 2010-06_migration_agc
3. Line SF 2010-13_migration_agc
4. Line SF 2010-14_migration_agc
5. Line SF 2010-16_migration_agc
6. Line SF2010-18_migration_agc
7. Line SF2010-19_migration_agc

All these line already been processing to migration and auto gain control, also All these line have same datum. These lines were loaded on the Petrel TM. software that provides an Environment of multi points of view at them Fig (7), 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 auto tracking.

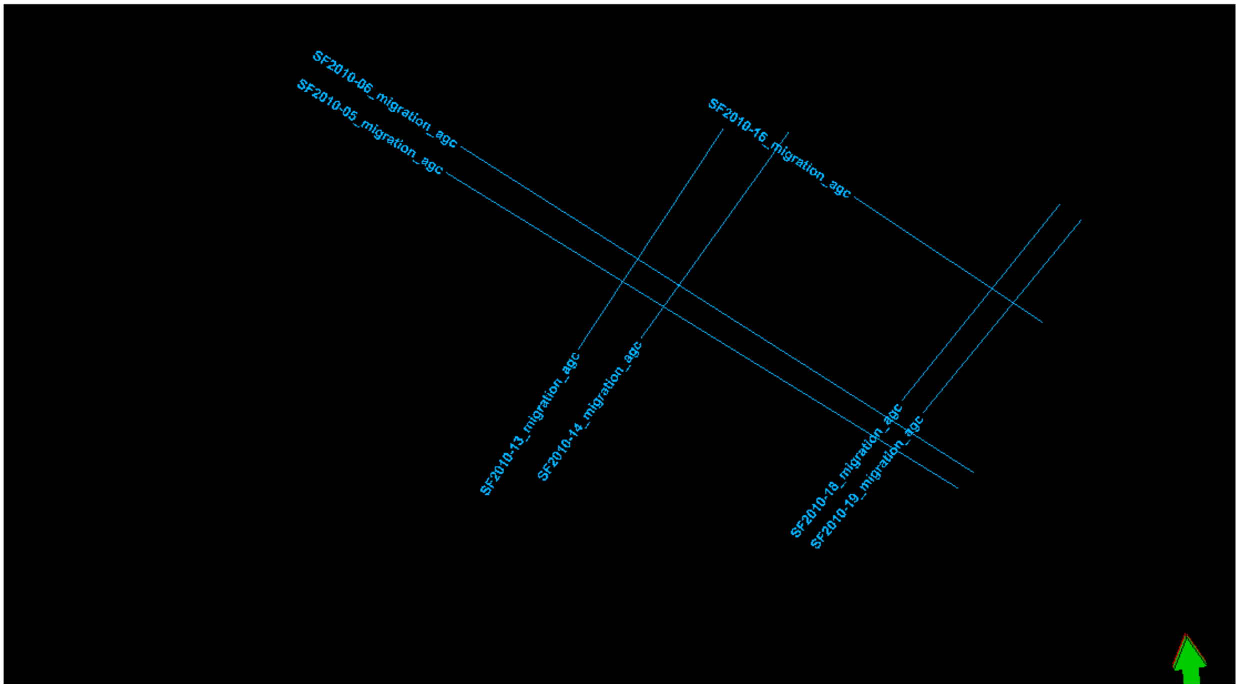

Fig (7): Base map from Petrel TM software

The SF 2010-05_migration_agc is cross with two lines(13,14) we found concordance in shot point 1651, erosion trancation in shot point 3751 and toplap in shot point 4250, shown in fig (8).

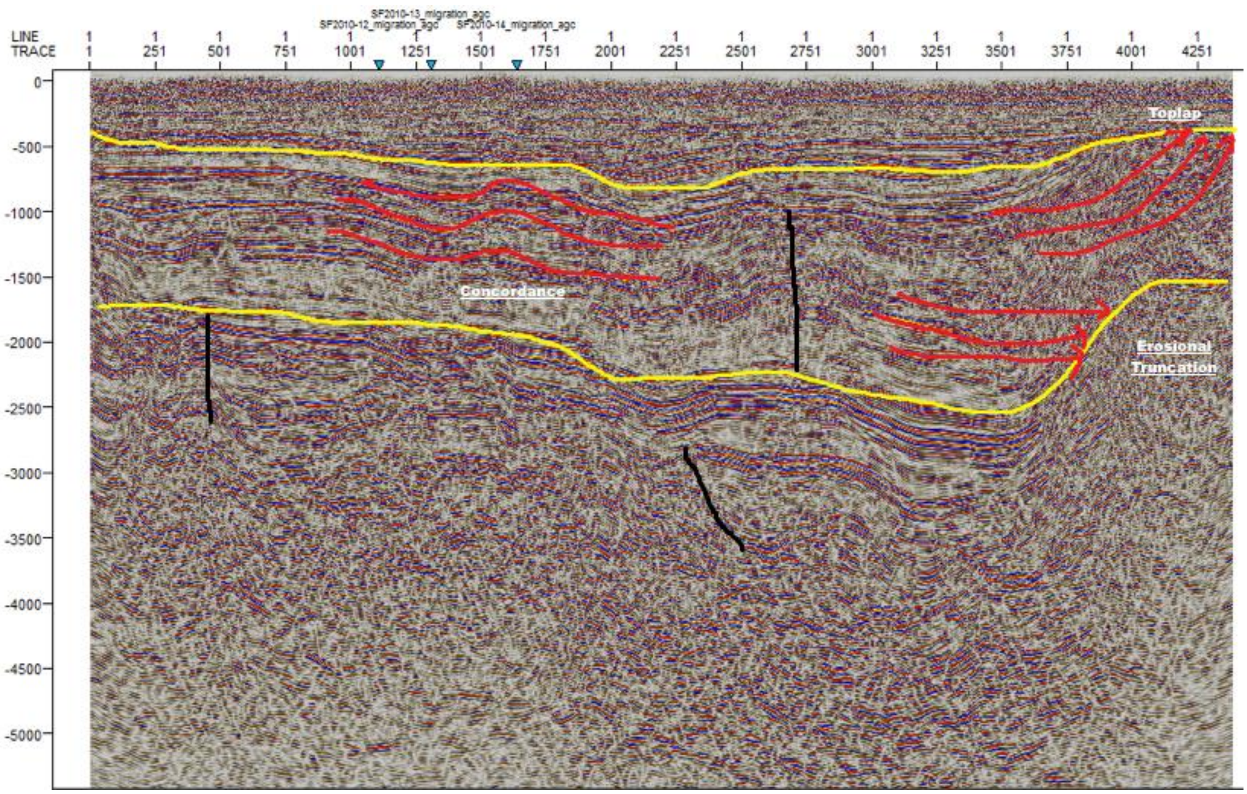

Fig (8) : siesmic section of line (SF 2010-05_migration_ag c)

SF 2010-06_ migration_agc is cross with line 13 we found Erosion Truncation in shot point 3751 in sequence at depth 1500, top lap in shot point 3501 in sequence at depth 500, shown in fig (9).

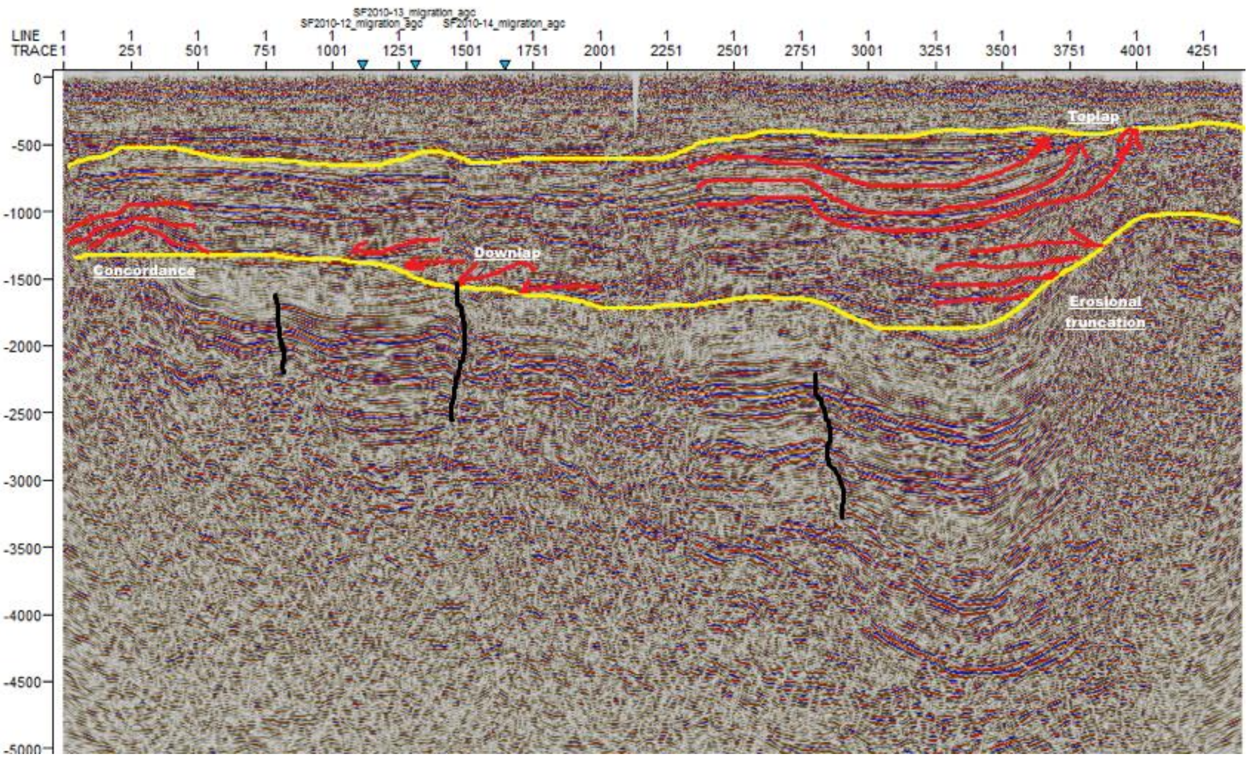

Fig (9) : siesmic section of line (SF 2010-06_migration_agc)

SF 2010-13_ migration_agc is cross with two lines (5,6) we found two Sequence the First Sequence in depth (350-400) Truncation in shot point 1601, Down lap in shot point 1401 and Second Sequence in depth (550-750) and Concordance in two shot point (1 – 401), shown in fig (10).

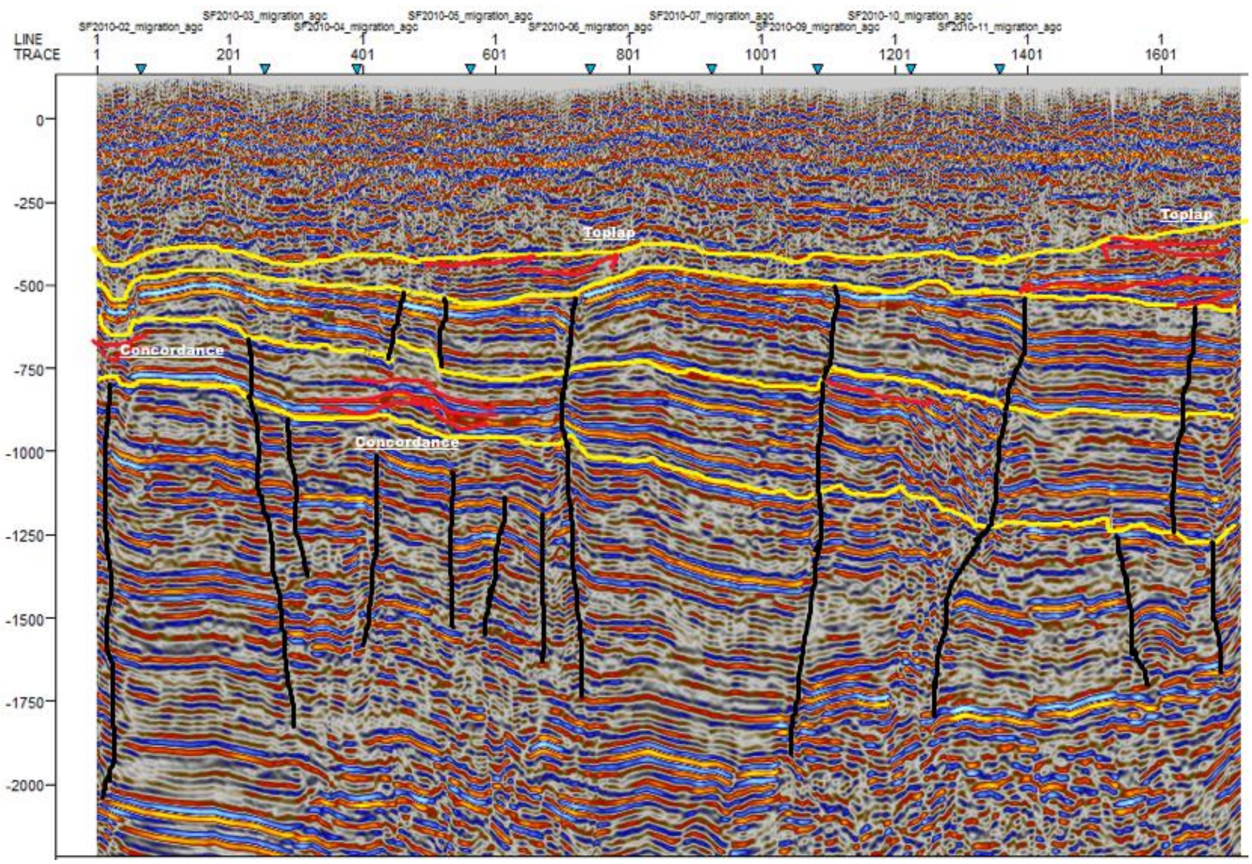

Fig (10) : siesmic section of line (SF 2010-13_migration_agc)

SF 2010-14_ migration_agc is cross with two lines (5,6) we found Down lap in shot point 1601 and Down lap in shot point 1201.shown in fig (11).

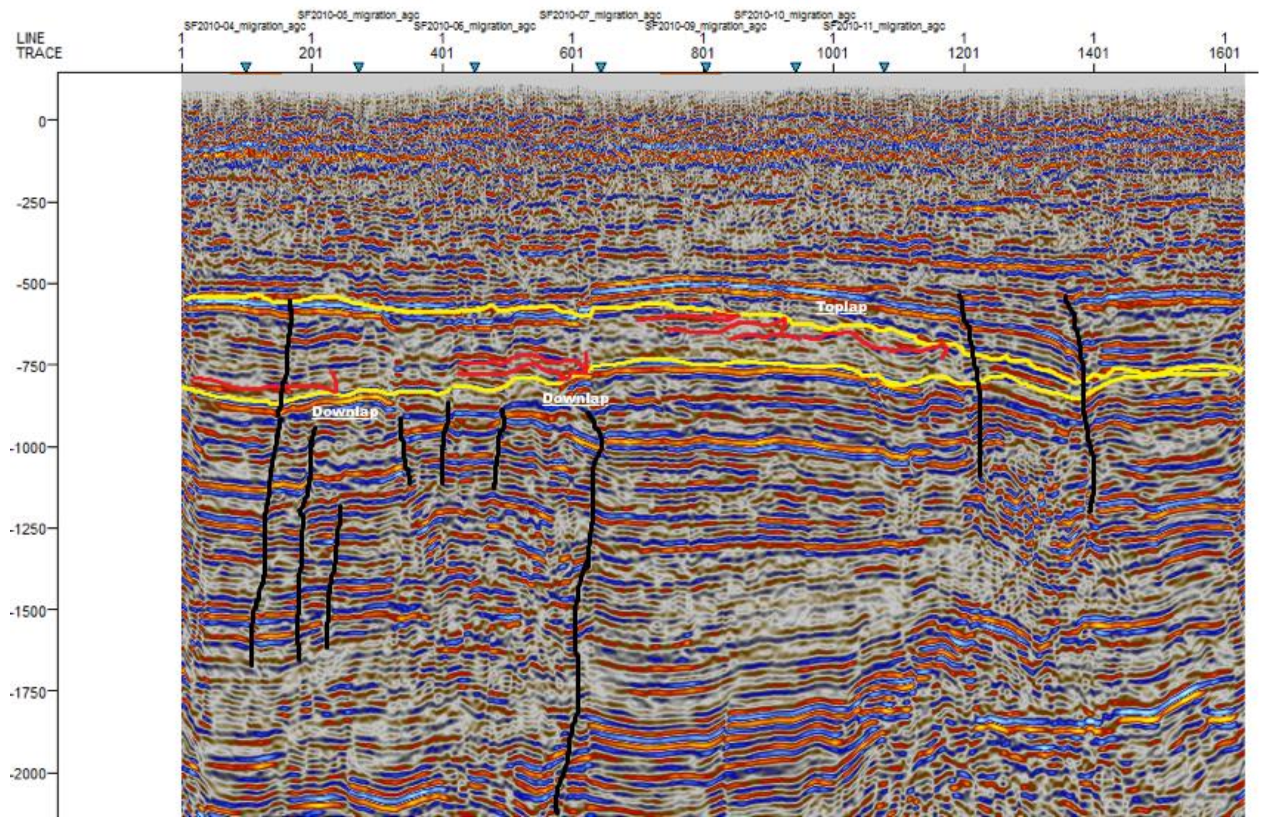

Fig (11) : siesmic section of line (SF 2010-14_migration_agc)

SF 2010-16_ migration_agc is cross with two lines (18,19) we found two Sequence : First Sequence at depth (625-800)Concordance in shot point 401 and Second Sequence at depth (1000-1250) another Concordance in shot point 401.shown in fig (12).

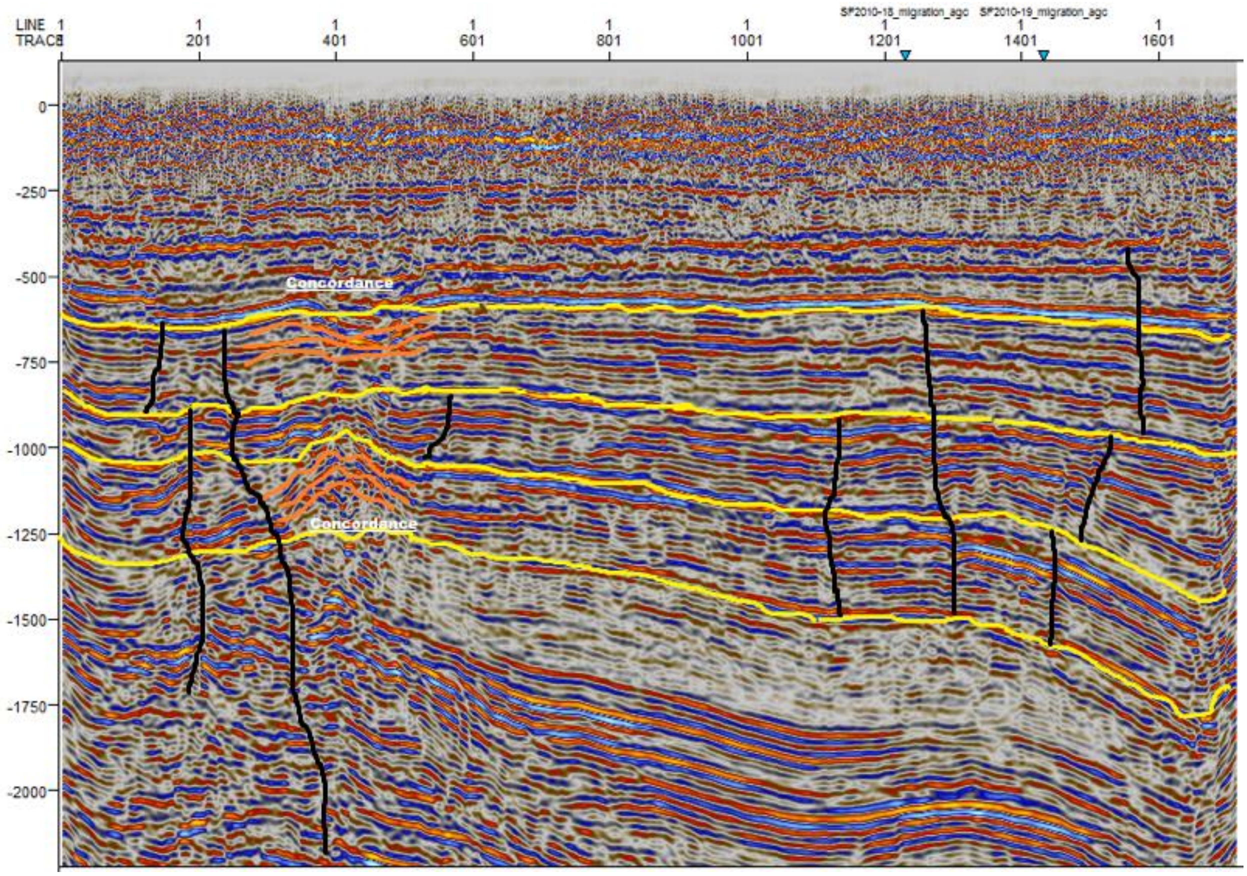

Fig (12) : siesmic section of line (SF 2010-16_migration_agc)

SF 2010-18_ migration_agc is cross with two lines (18,19) we found Down lap in shot point 401,near line 19. Shown in fig (13)

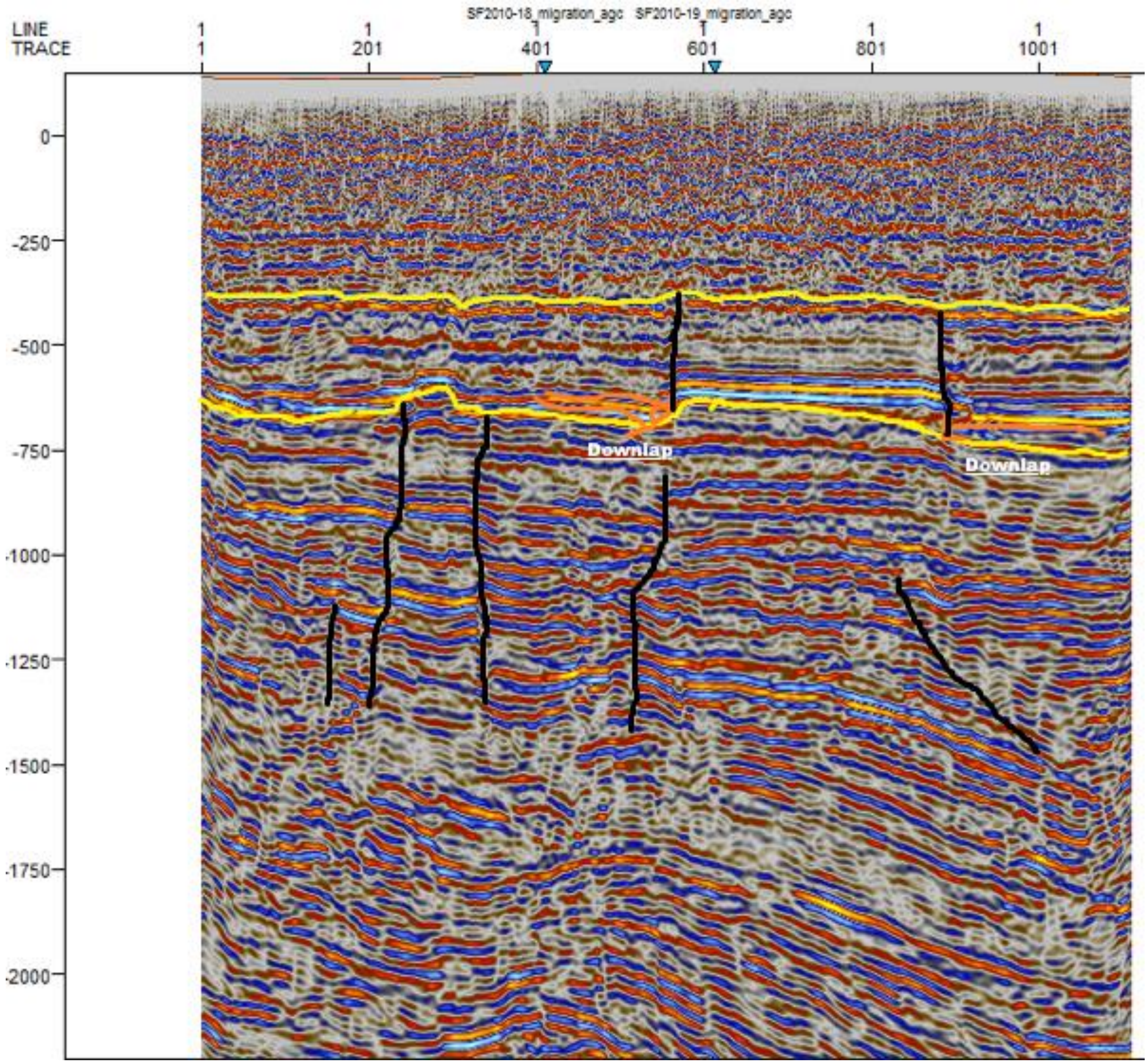

Fig (13) : siesmic section of line (SF 2010-18_migration_agc)

SF 2010-19_ migration_agc is cross with two lines (16,17)we found Top lap in shot point 1601,Down lap in shot point 1201,near line 17.shown in fig (14).

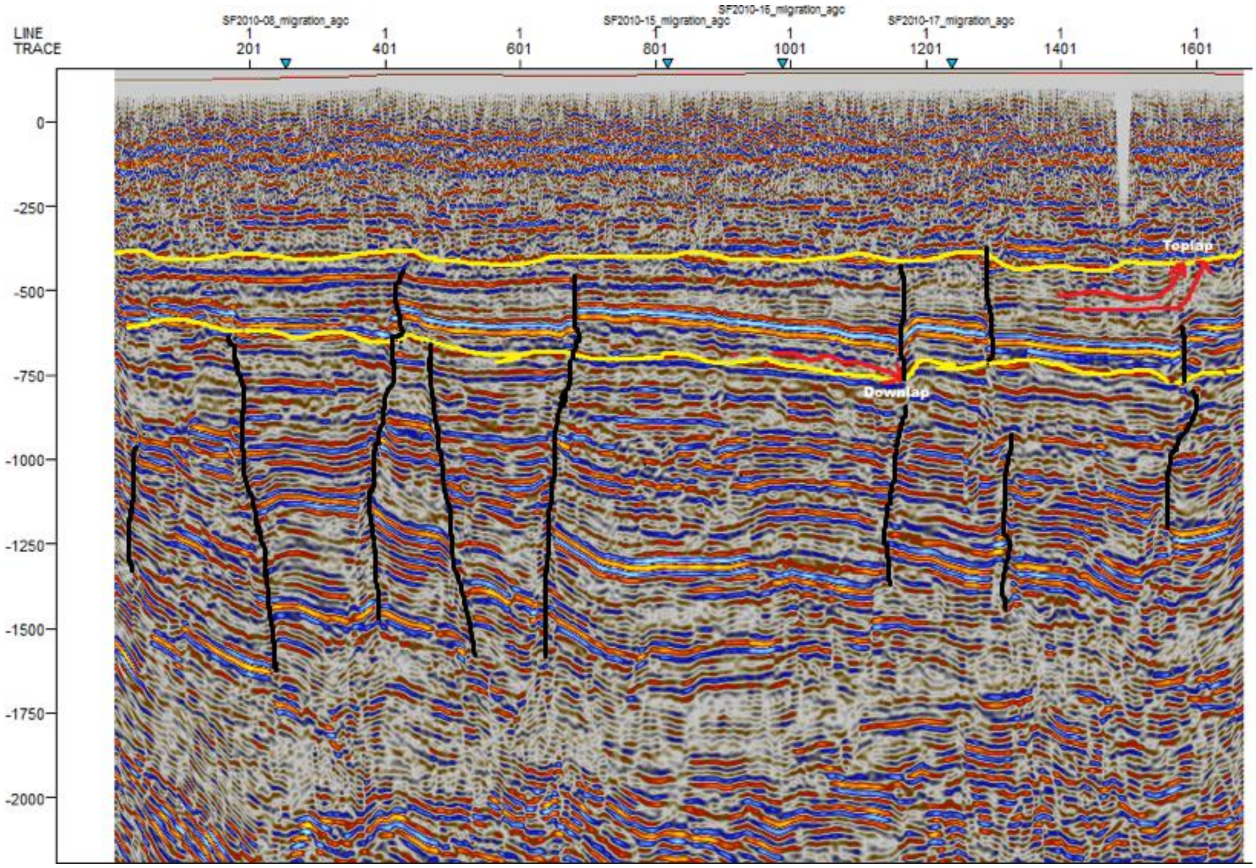

Fig (14) : siesmic section of line (SF 2010-19_migration_agc

After updating the interpretation horizon, 9 horizons were available, such as Top Amal, top Darfur, top Bentiu, intra-Bentiu, top AG, AG-2, AG-3, AG-4 and top Basement.

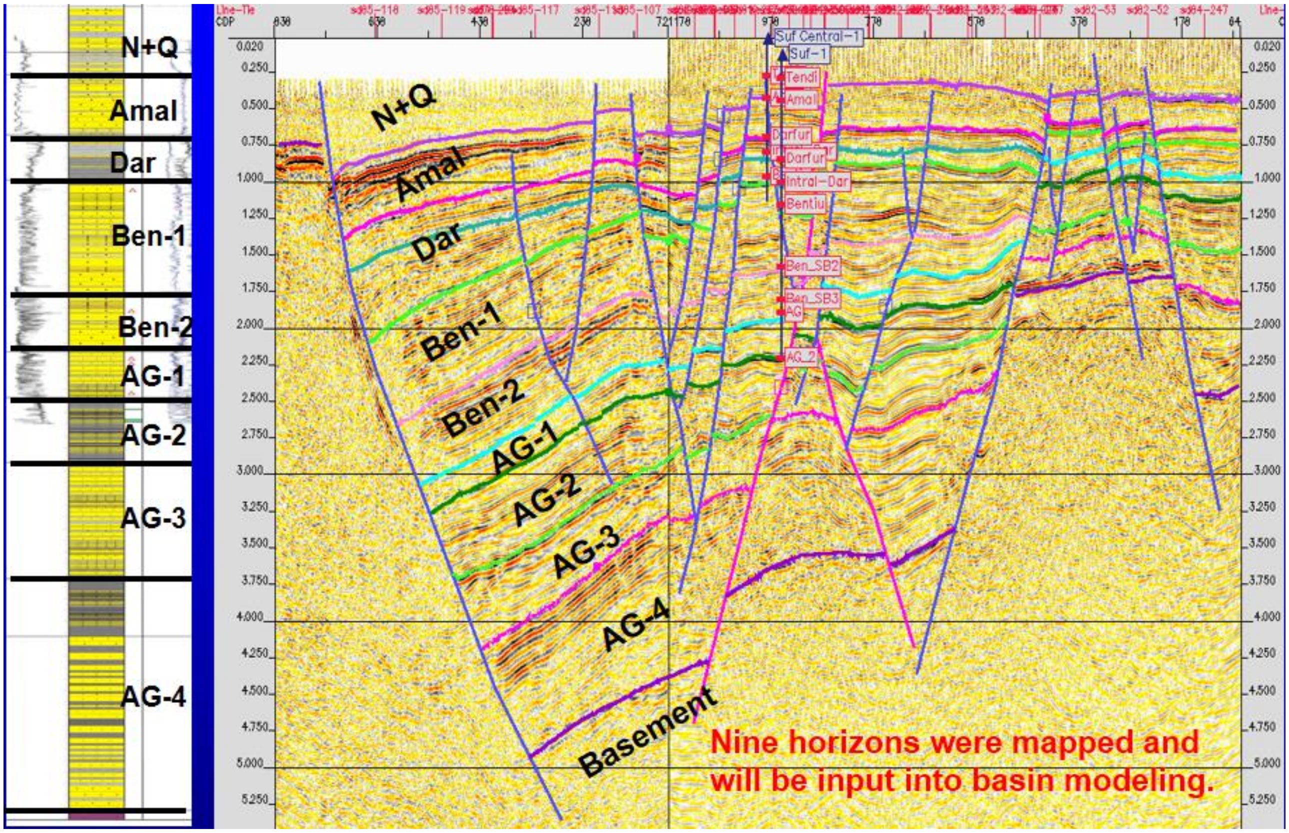

Fig (15): The interpretation horizon after updating and corrleation with geological data from well.

Sequence stratigraphy framework were built and analyzed, From well data

- Darfur: 2 sequences, mainly semi-deep lacustrine;
- Bentiu: 2 sequence, mainly Braided river.
- Abu Gabra: One plus apart another sequence, AG-1 is shore-shallow Lacustrine, AG-2 is semi-deep lacustrine.

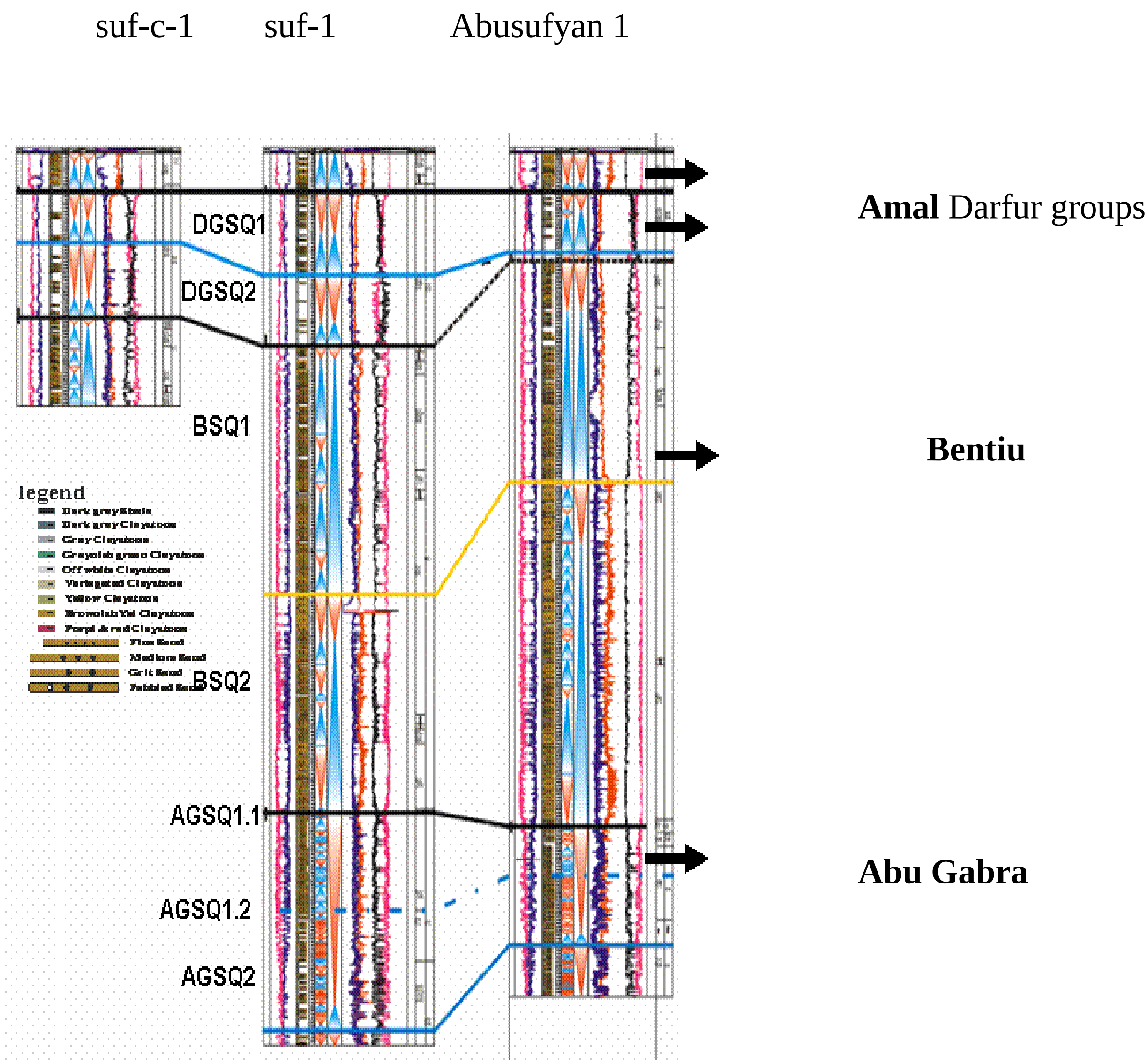

Fig (16) : data from wells (suf-c-1,suf-1 and Abusufyan 1).

Chapter Five

Discussion, Conclusion and Recommndation

5.1 Discussion:

In base map in S-E direction we found top lap in shot point 1601 in depth 450 and down lap in shot point 1201 in depth 750 and also down lap in shot point 401 in depth 750, in N-E direction in shot point 401 we found concordance between depth (625-800) and anothor concordance in that shot point at depth between (1000-1250), in North direction we found in shot point 3751 erosion truncation at depth 1500 and top lap in shot point 3501 at depth 500 and down lap in shot point 1401 between depth (350-400) and concordance in two shot points (1,401) at depth 750, in N-W direction we found concordance in shot point 1501 at depth 1000 and top lap in shot point 4251 at depth 400,in West direction we found truncation in shot point 1601 at depth 300 and concordance in shot point 401 at depth 750.

5.2 Conclusion :

At the end of our study we arrived to stratigraphic bodies in sufyan sub basin in east Darfur after we analysed seismic data by Petrel software technique and detected depth and shot point for these bodies (down lap,top lap,truncation and concordance).

5.3 Recommondation :

Hence we finish our reserch in sufian sub basin we stronglly recommonded that to study these area very well and earn data has high quality and enclode check shot to determined formation top.

5.4 References:

1. Ali Sayed Mohammed Ibrahim 2003, Sedimentology and Reservoir Geology of the Middle-Upper Cretaceous Strata in Unity and Heglig Fields in SE Muglad Rift Basin, Sudan.PP…14.
2. Ben A.VanDgrRluijm and Stephen Marshak, 2004. Earth Structure and Introduction to Structure Geology and Tectonic, 2ndEdition. W.W. Norton and Company, New York, London.
3. Richard H. Groshong, Jr.A 3-D Structural Geology Practical Guide to Quantitative Surface and Subsurface Map Interpretation Second Edition.
4. Fairhead, J. D. (1988) Mesozoic plate tectonic reconstruction of the central south Atlantic Ocean: The role of the west and central African rift system. Tectonophysics.
5. Fairhead, J.D. and Green, C.M., 1989. Controls on rifting in Africa and the regional tectonic model for the Nigeria and East Niger rift basins. In: B. Rosendahl (Editor), African Rifting. J. Afr. Earth Sci. Spec. Publ., 8: 231-249.
6. Fairhead, J.D., 2009, the Mesozoic West and Central African Rift System: Qualitative Evaluation, Search and Discovery Article#30077.
7. Frank Nitsche and Jan van der Kruk, Reflection seismics 1
8. G. Asquith, C. Gibson 1982, Basic Well Log Analysis for Geologist, Oklahoma, The American Association of Petroleum Geologist.
9. GRAS-RRI, 1991. The geology and petroleum potential of southern, central and eastern Sudan. .
10. Izz al-Din, 2016, Principles of Basin Modeling [Interview] (12 may 2016).

11. KeWeili, Zhang Guangya, Liu Aixiang, ZhengYonglin and Yu Yongjun, petroleum exploration potential of Abugabra formation in Fula sub-basin, Muglad basin, Sudan
12. M. A. Sroor, 2010, Geology and Geophysics in Oil Exploration.
13. M. B. Dobren, C. H. Savit, 1976, Introduction to Geophysical Prospecting, USA: MC Grow-Hill.
14. M. Bacon, R. Simm, T. Redshow, 2003, 3-D Seismic interpretation, United Kingdom: Cambridge University Press.
15. M.Gadalla, R. Fisher, 2009, Exploration Geophysics, verlag Berlin Heidelberg: Springer.
16. Mohamed, A.S., 2003, Sedimentology and Reservoir Geology of the Middle-Upper Cretaceous Strata in Unity and Heglig Fields in SE Muglad Rift Basin,
17. Mohamed, A.Y., Pearson, M.J., Ashcroft, W.A., Iliffe, J.E., and Whiteman, A.J., 1999.Petroleum Maturation Modeling, AbuGabra-Sharaf Area Muglad Basin, Sudan. Journal of African Earth Science, 35.
18. P. C. H. Veeken, 2007, Seismic Stratigraphy, Basin Analysis and Reservoir Characterization, Netherland: Elsevier.
19. Paul C.H. VEEKEN, handbook of geophysical exploration; seismic exploration; Volume 37: seismic stratigraphy, basin analysis and reservoir characterization.
20. Philip Kearey, Michael Brooks and Ian Hill, 2002, an introduction to geophysical exploration third edition.
21. R. E. Sheriff, L. P. Geldart, 1995, Exploration Seismology, USA: Cambridge University Press.
22. Schlumberger Co, 2015, Petrel manual.

23. Schlumberger Co, 2016, Petrel Seismic Interpretation, [Online] available from <https://www.software.slb.com/products/petrel/petrel-geophysics/seismic-interpretation> [8. Oct.2017].
24. Schlumberger Co, interactive Petrophysics formation evaluation, [Online] available from<http://www.slb.com/content/contact/sis support.asp>.
25. Schull, T.J., 1988 Rift Basins of Interior Sudan: 7Petroleum Exploration and Discovery, AAPG Bulletin V.72, No.10 (October 1988).
26. USGS, 2011, Assessment of Undiscovered Oil and Reservoir of the Sub-Province: North-Central Africa.
27. W. M. Telford, 1976, Applied Geophysics, Great Britain: Cambridge University Press.
28. Geology of the Muglad Rift Basin of Interior Sudan Hassan A. Ahmed and Maduka Bertram OzumbaIOSR Journal of Applied Geology and Geophysics (IOSR-JAGG).