INTEGRATED PETROPHYSICAL AND SEISMIC INTERPRETATION OF OFFSHORE INDUS BASIN, PAKISTAN

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This dissertation is submitted for the degree of "Master of Philosophy in Geology"

by

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DEDICATION

I dedicate this research work to my parents who always loved and appreciated me. I thank them for providing me support and encouragement. I am also grateful to my teachers and class fellows who assisted, cooperated and guided me throughout my research work.

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I would like to thank Almighty Allah Whose kind and courteous blessings enable me to receive and reward my ambitions and objectives.

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ABSTRACT

Seismic data interpretations has been used to identify parasequences, faults, stratigraphic lithologies, stratigraphic features (Channels, truncations and progradational patterns). Time and depth map used to locate the subsurface structures and horizons for petroleum exploration. Parasequences has also been marked by GR log which are confirmed by sonic log. Based on the results, reservoir rock of Miocene age is present in the study area. Shales of Miocene age having high GR readings have the potential for acting as a seal rock. Parasequences have been marked on the basis of GR readings. In IndusMarine 1-A, the lower part of Miocene encountered from 2300m to around 2470m consists of progradation (funnel shape) and aggradation (cylindrical shape) pattern. It is mainly sandstone dominated since the GR values are on the lower side and represents channel fills of Miocene age. Middle Miocene section, from 2300m upwards to around 800m has all three parasequences sets with multiple sequence boundaries. This segment is majorly dominated by shale since GR values are on the higher side (bell shape) with some portions encountering interbedded sandstone and shales. The retrogradational pattern from 1430m to 1500m represents shelf deposits. The symmetrical pattern of GR values encountered from 780m to 570m is of Late Pliocene age and indicates delta fronts. In PakG2-01 and PakCan-01wells Miocene Sands acted as reservoir. Neutron-density and neutron-sonic cross were used for lithology and mineral identification for PakG2-01 well. It was found that log values spotted on calcite and dolomite region, which confirmed the lithology as Carbonates. Many values also spotted sandstone beds.

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CHAPTER 1

INTRODUCTION

1.1 The Study of the Hydrocarbons:

Hydrocarbons are one of many crucial energy assets also having a significant impact on the state economy. Currently, the energy sector is in charge of the economy. These energy sectors ensure the political and economic permanence of the country. The study and accessibility of hydrocarbons is relatively associated with the success and evolution of the country (Alger, 1980).

The principle interest in the study and research of oil is the recognition of porosity and permeability in formation, geometry, size, thickness and the degree of the reservoir. Well logging is such a method which obtains this data by determining the physical, chemical and lithological properties of the formation of the reservoir (Alger, 1980).

When this data is augmented with other information obtained from core analysis, it gives further information about its depth, nature, fluid type and extent. It also gives accurate information about its properties such as porosity, permeability, mobility, flow rate and pressure with great accuracy. The advancement of technology has influenced the importance of well logging. The extent of recording information in abundance is acquired in data acquisition by measuring down-the-hole data using a wire line cable. Hence, advanced well logging technology for data interpretation and acquisition has expanded the horizon for the utilization of hydrocarbons. Therefore, geophysical well logging played a key role in the breakthrough and evolution of hydrocarbons. Furthermore, it gives characteristic information about the essence of the rock being infiltrated by the drill. Rock cutting gives us useful information about which lithology exists but doesn't give information about where it takes place in nature. Core drilling is a useful method but it is exceptionally extortionate and doesn't provide complete information about the formation fluids. That being the case, well logging is mandatory for the absolute analysis of formation.

The efficiency of wells in oil and gas bearing reservoirs relies upon the petro-physical properties of formation. It comprises of two constituents, rock matrix and interconnected porosity. The diversity in dimension of pores is as such that its dimensions can vary anywhere from micrometers to centimeters for sandstones and carbonate rocks respectively (Levorsen, 1967).

Porosity, permeability, saturation and capillarity are the petro-physical properties of formation in which, porosity determines the capability of rocks to store hydrocarbons and permeability examines the flow of fluids in rock. The small part of porosity that is inhabited by a fluid is called saturation. And the determination of production of available hydrocarbons is called capillarity.

It is mandatory to precisely evaluate the petro-physical properties for the economic and commercial expansion of the reservoir. Recently, the data acquisition and interpretation system has made progress by leaps and bounds due to the advancements made in this field by new and improved well logging technology. In more developed countries, well logging companies are facilitated with logging systems having groundbreaking technology.

A quality being possessed at a time can be evaluated by the petro-physical examination of rock samples. This characterization of the rock layer possessed by the reservoir can determine factors such as the volume of hydrocarbons, drill plan and production technique. The reservoir capacity calculation has a direct relation with porosity and the extent of producing reservoir is estimated by the permeability. Issues such as salt precipitation in the production line can be determined by lithology. Moreover, lithology also identifies the difference between a reservoir and non-reservoir. And the calculation of resources in the potential phase (gas coning, erratic flow regime, and water-cut etc) is directly impacted by the fluid saturation.

1.2 Study Area

The study area is located in Offshore Indus Basin. The location of study wells are shown in Fig.1.1 and the geographical coordinates of study wells are shown in table 1.1. The Indus offshore Basin of Pakistan is the southern extension of the Indus Basin, covering approximately 2,000 km2. It reaches a depth of two hundred meters from the Indus delta through the Miocene to the recent platform. It's far placed on the western edge of the Indian plate, in particular near Murray Ridge (to the northwest) and close to the prism of the triple intersection/accumulation of the Indian, Eurasian, and Arabian plates (Ellouz-Zimmermann et al., 2007). The study area can be accessed by boat or helicopter from Karachi.

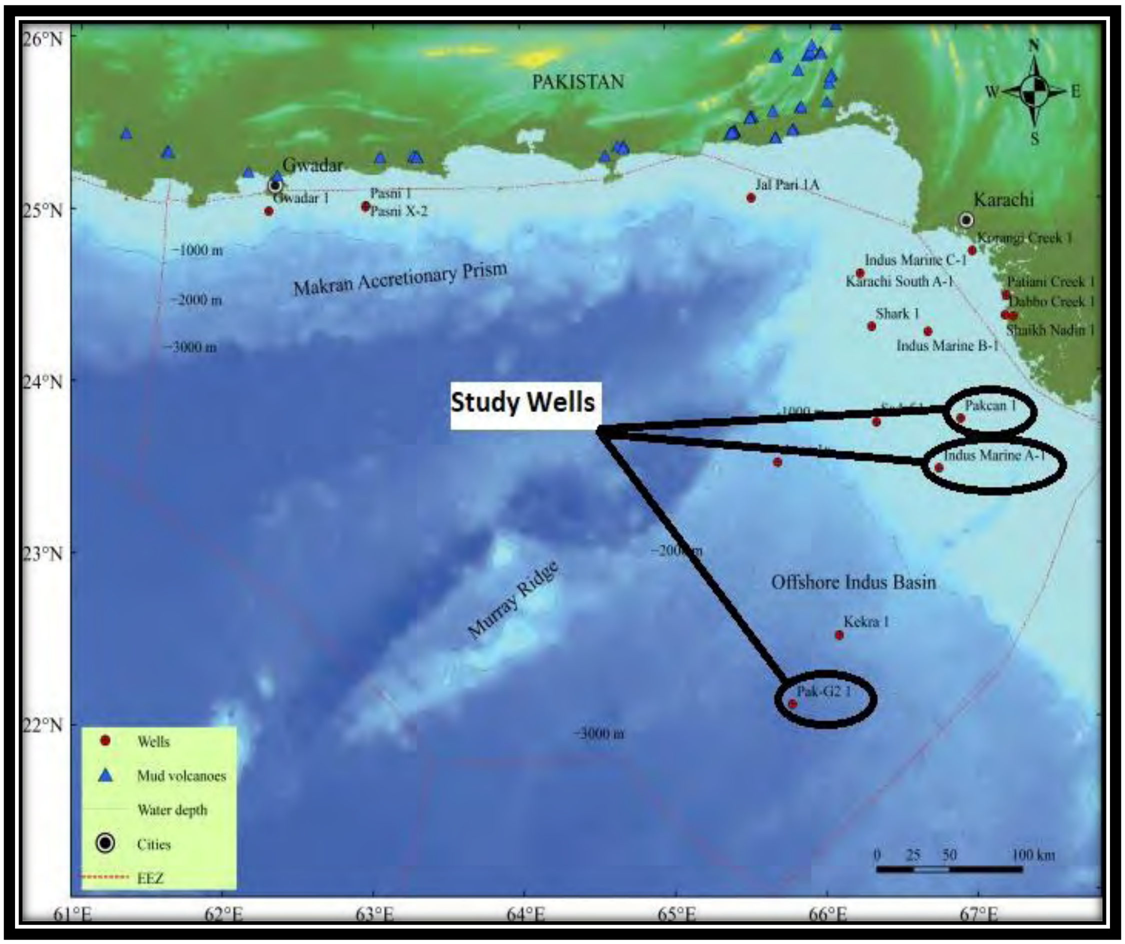

Figure 1.1. Study area location map.

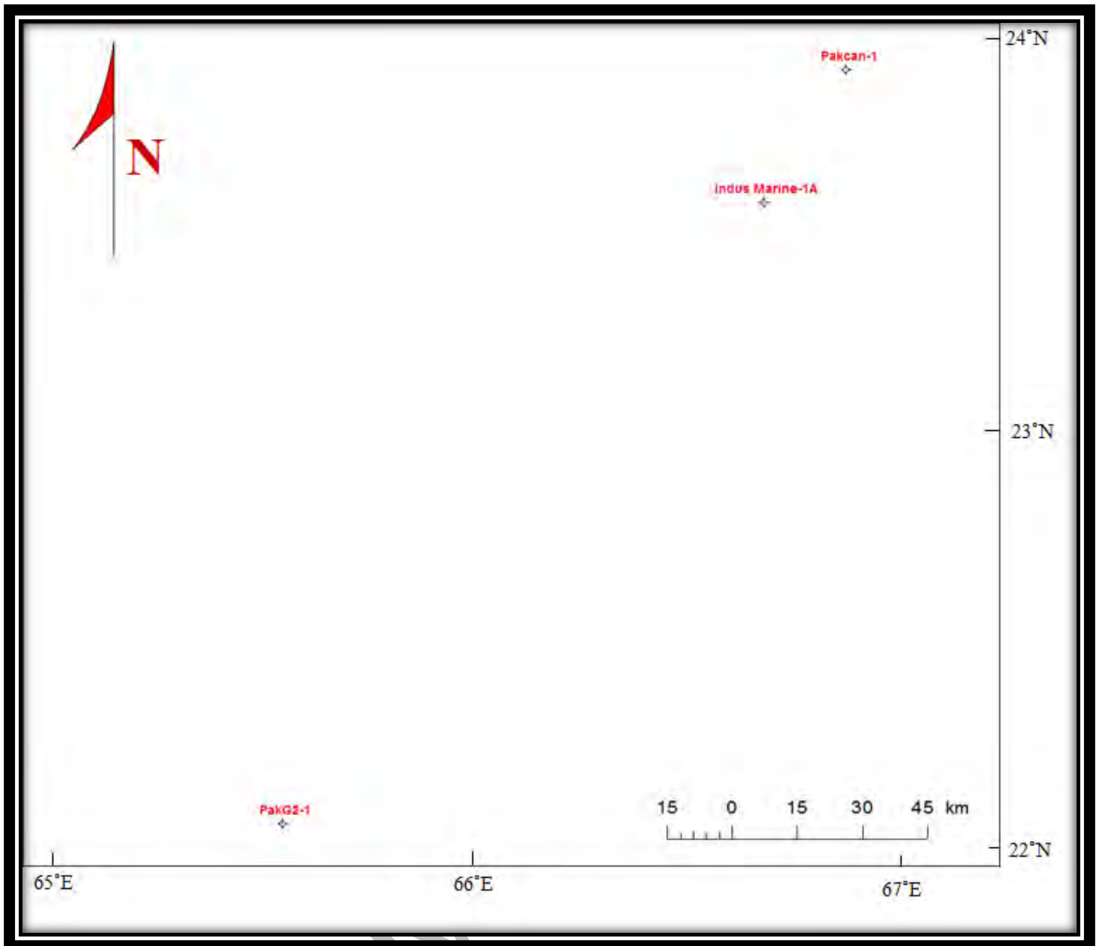

Figure 1.2. Base map of study wells.

Table1.1. Geographic coordinates of study wells.

WELL	LATITUDE	LONGITUDE
PakG2-01	22˚ 06′ 24.42″	65˚ 47′ 34.03″
PakCan-01	23˚ 44′ 33.47″	66˚ 57′ 35.98″
IndusMarine-1A	23˚ 27′ 26″	66˚ 48′ 25″

1.3 Exploration History

Because of the restricted admittance and no openness in the sea, the examination and the exploration work is rely just upon seismic studies. Offshores Indus Basin is a high danger, significant expense region with various play types, each having its own level of dangers and prizes. Different public and worldwide organizations have been effectively engaged with blast exercises. Until so far in excess of 28000 lines km 2D and 2000sq.km 3D seismic facts were procured in Indus seaward (Daley and Alam, 2002).

Table 1.2: Summary of wells drilled in Indus Offshore

S.No.	Well Name	Company/Year	TD (M)	Formation Age	Remarks
1	Indus Marine 1A	WINTERSHALL/ 1972	2841	Middle Miocene	Plugged & Abandoned
2	Pak Can-01	OGDCL/1985-86	3701	Lower Miocene	Plugged & Abandoned
3	Pak G2-01	TOTAL/2004	4750	Paleocene	Plugged & Abandoned

In offshore Pakistan, total of 13 wells have been drilled out of which summary of three wells is shown in Table 1.2. There are three different target horizons for hydrocarbons which deepens towards the sea as water depth increases. The target of hydrocarbons are Cretaceous clastics, Miocene age channel fills, and Carbonate buildups. Out of 13 wells, a few wells had hydrocarbons shows while one very much streamed non-business amounts of gas which is PakCan-01 well.

The TOC value of Ranikot and Mughal kot formations ranges from 1.0% to 1.22%, have mixed type of kerogen with potential of both oil and gas. Miocene Gaj formation has fair to good TOC values. Samples of PakCan-01 well indicated type III kerogen. However, maturity analysis indicated that there is an immature zone down to 2800m and from 2800m to TD 3701m there is an early mature to mature zone. Samples of Sadaf-1 well indicate an immature kerogen of type III with very lean source. Most values of TOC are below 0.5% and some are 0.5% to 0.6%.

1.4 Objectives of study

The Indus Offshore Pakistan is almost unexplored. Lowest number of wells have been drilled in Indus Offshore due to high cost and risk. Only seismic data (2D and 3D) has been acquired mostly in Indus Offshore. There are several risk factors, but the most important include complicated tectonics, basin filling during the Miocene epoch, and channel bypass of sand to deeper settings, and lower sandstone quality and TOC levels.

The current study is being carried out to modernize workflow and to integrate the petrophysical and seismic analysis to better perspective of future exploration and drilling.

Following are the main objectives of the research:

(1) To evaluate petrophysical parameters.

(2) Seismic data interpretation

(3) To find Parasequence using well log

(4) To distinguish the lithology and mineralogical composition.

(5) To delineate the hydrocarbon potential.

(6) Structural correlation of wells

CHAPTER 2
STRATIGRAPHY, GEOLOGY AND TECTONICS

2.1 Background of tectonic and regional geology

The river Indus passes through semi-arid and arid plain and its source-to-sink system drains the Karakorum and western Himalaya ranges to the Arabian Sea. (Gombos et al, 1995). Likewise, the Indus collects large alluvial field delta (Milliman and Meade, 1983). It is the most established stream in the Himalayan region, and its upper reaches have been locked inside the Indus join zone since the early Eocene (Clift et al, 2002).

The Indus River carries the world's seventh largest buildup load to the Arabian Sea despite its age. (wells et al,1994) considering the way that it channels unproductive, unconsolidated frostily and fluvial return squander arrowed from high lightening, rapidly hoisting primary segments of the western Tibetan plateau, Karakuram and the Indus fasten zone (Clift et al,2002). Disconnected central area edge contains a part of the critical hydrocarbons regions of the world. In like manner, the examination of the underlying and stratigraphic advancement has great importance to hydrocarbons examination (Gordon and DeMets, 1989). Tectonics and geological map of the study area is shown figure 2.1.

The seaward Indus is disconnected and damaged edge bowl shaped through the frenzied motion of the Indian plate away from Africa with inside the Jurassic (Gombos et al, 1995, Edward et al, 2000, Clift al, 2002). India cut up from Madagascar and started to flow north during the late Cretaceous (c.90 Ma), joined to; Deccan traps are huge quantities of volcanic substance (Carmichael et al, 2009). About 80% of Deccan traps discharges befell below 0.8 Ma, passing by Cretaceous Tertiary (K-T) boundary. India and Eurasia collided during the Eocene epoch. According to the Paleomagnetic speculations, Lippert et al. (2010) estimate a crash age of forty six MA, with a ninety five percentage self-belief variety of 38 MA to 54 MA.

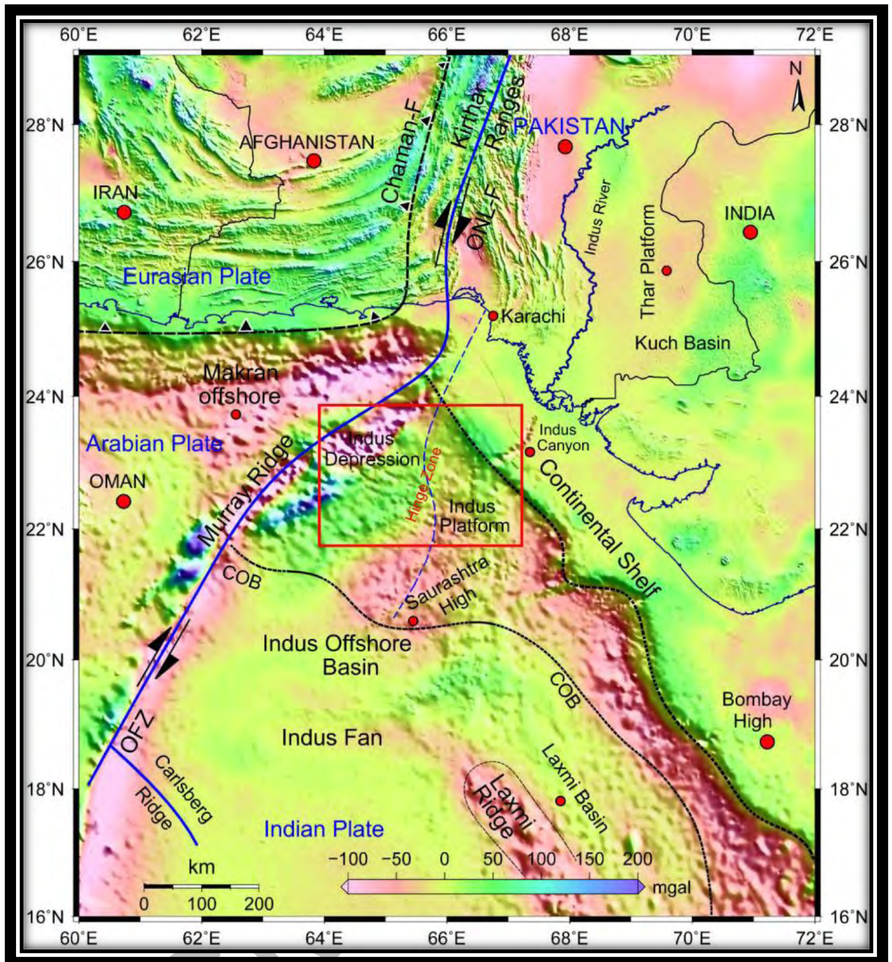

Figure 2.1. Regional geology and tectonic map of study area.

The Murray limit features the northern most advancement of the Owen Fracture Zone. Important region of shelf between Murray ridge and Indo-Pak marine restrict is 120150 km meter wide. The Owen Fracture Zone and Murray edge is limited among Indian and Arabian plate and the Arabian Indian plate improvement is obliging in Owen Fracture Zone. On the southern completion of this plate restriction the sea base spreading vicinity placed aside by way of Sheba and Carlsberg ridges are adjusted of usually 300km along the Owen Fracture Zone (Edward et al, 2000). Global and adjacent plate circles suggest that the Murray Ridge evolves diagonally at a surprisingly drowsy rate of 2 mm per year (Gordon et al., 1989, DeMets et al., 1990). The Murray side can be seen at altitudes from about 22 ° N to about 24 ° N, where the geological formulation of Sill is hidden by the thick debris of the Indus fan (Edward et al. 2000) south of the seamount.

Complement Qullhat Owen Fracture outlines the boundaries between the Arabian and Indian plates.

The Owen fracture more likely to by skip as a deterrent to turbidities of Indus a prolonged way of sea fan and hinders their sedimentation within the course of the west into Owen bowl (Mountain and Prell, 1990, Clift at al 2001). In addition, estimation of the infection tool fuses conveying and controlling bends, pull isolated dishes pleasant on conveying turns, and bowls completing at the shortage form, is solid with a dextral strike slip movement (Fournier et al, 2011).

The Laxmi ridge is big sized extension basement excessive included under the buildup of Indus fan. It is disconnected from the good sized area shelf through the use of Laxmi basin and includes tornado shelter units putting E-W and NW-SE from an issue at 18 ˚ N to 66 ˚ E (Miles et al, 1998) The significant NW-SE appendage of Laxmi Ridge is arranged cycle 300 km sea ward of the Indian mainland rack and it moves corresponding to it for hundred kilometers (Miles et al,1998).The area of the ocean continent transition (OCT) on this side has been as of late proposed at each the southern problem at the Laxmi ridge or the preceding it inside the course of the India-Pakistan shelf.

2.2 Towards Study area of tectonics and general geology:

The Offshore Indus Basin is situated alongside the western fringe of Indian plate. The seaward Indus may be separated into three locales the first is Indus continental shelf then Murray ridge system and the last Indus Submarine Fan.

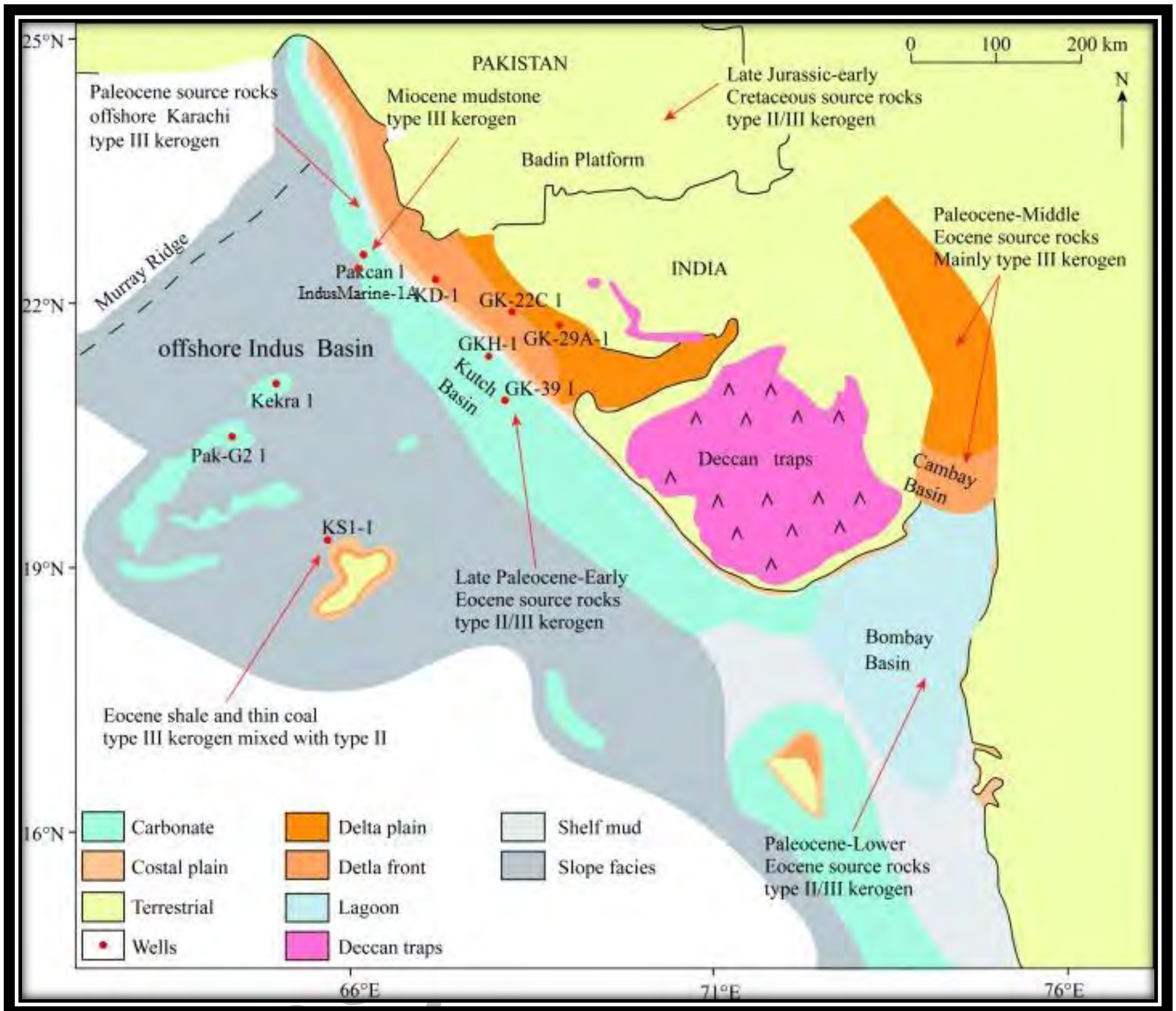

Figure 2.2. Geology of study area.

The Murray Ridge System (fig 2.2) is approximately 750 km from the northern Owen fracture region with inside the south west to the triple junction seaward Karachi with inside the north east. It is comprised of numerous different geology structures which includes three main components that are: southern ridge at water profundity below 1000m profound (peak), The northern scaffold region depicting a subbed structure with water profundity of 2000m (Gaedicke et al., 2002).

The Indus marine fan is the largest two dimensional fan which covers 1,250,000km (500000mi) and is sedimentary and wide physiography detail seaward Indus basin and includes residue more than 7km (23000 ft) thick. The upper Indus fan (1,600-3,600 m) is illustrated with the source of up to a few hundred meters' treatment that happened due to the aggravation of extensive channel-levee complexes and through the usage of unique grained sediments, besides the channels in which route grained substances are surmised (Kolla and Coumes, 1987).

The shelf of Indus delta is limited by means of Murray ridge system withinside the NW and with the useful resource of Gulf of Kutch in SE but it is usually remains unstudied. Its most extensive characteristic is the Indus Canyon or “The Swatch”, a relic detail of which screens water profundity at 3.5 km seaward of the shelf to interior 20 m. At the top of the Karachi platform is a basin infill drilled from the deepest distance between the drill holes PakCan01 and Indus Marine IB, which contain a myriad of Miocene shale. The apparently passive filling of the depot center is surrounded by the use of progressive seismic units. This is clarified by how seismic-scale sigmoid reflectors slide down into the bowl (Daley and Alam, 2002). The Karachi platform is overwhelmed by the mid-Eocene to Oligocene shelf carbonates. This is the same as the coastal development of Raki, Kirdalu and Nari. Especially deep, from the development of the Paleocene Lanikot to the Early Cretaceous Gol Society, there are countless more experienced arrangements in front of parts of the coast (Wandrey and Shah, 2004).

2.3 Stratigraphy study area

The basin's region is tectonically important (Indian, Arabian and Eurasian plates) due to its remote position in the triple junction. The wells drilled in this basin have found out a strong lateral structure from north to south and west to east. In addition, this alteration creates swatch in terms of sedimentation course and rate. The study area's Stratigraphy tiers from Cretaceous to Holocene (Kadri, 1995) Stratigraphic chart of Offshore Indus Basin is depicted in figure 2.3.

2.3.1 Middle-Recent Miocene

Sandstone which is characterized as light grey, friable to medium hard, distinctively grained, silty, often coarse, and quite argillaceous. It is regularly speckled with lignite that is quite glauconitic and micaceous, with pyrite and siltstone and limestone interbeds.

2.3.2 Gaj Formation in Miocene

This improvement can be widely segmented into two components which includes:

a) Collection of earth stone, mild dim to mild brown, sensitive to firm, highly blocky, sometimes evaluating to marl,silty, barely micaceous, and sunstone with lignite,glauconitic, and pyrite are accessible.

b) Sandstone usually grades to siltstone, with tough cryptocrystalline limestone segment that are often detrital.

2.3.3 Oligocene: Nari Formation

Within the Nari configuration, three components may be seen.

a) The upper and lower sections are primarily composed of limestone, but the central segment is primarily granite.

b) Limestone with tremendous interbeds of calcareous earth stone and siltstone. Cream to buff, strong to weak, microcrystalline to cryptocrystalline, porcelaneous at times, few detrital, mostly fossilferous.

c) Darker, smaller to soft sandstone with lignite patches.

d) Limestone is tiny granular at times, slightly argillaceous at others, with sandstone and siltstone interbeds.

2.3.4 kirthar formation in Middle Eocene:

The massive limestone with in dust stone interbeds is available. Two sub-segment, obviously gradational, are perceived interior arrangement.

Limestone, cream-buff, medium hard, fragile, some brittle, generally unadulterated calcific, opaque, rarely or miniature granular, typically extremely fosilliferous. Limestone, dull brown to tawny, marginally spotted, slightly hard to brittle, regularly finely scrap, once in a while white, generally metalliferous.

2.3.5 Laki -Ghazij Formation in Lower Eocene:

Limestone from whitish to tan, hard, natural, microcrystalline to cryptocrystalline, often with traces of coarsely crushed pyrite. Finely scattered pyrite, fading grayish green and gray, medium hardness to crushing, fissile to massive, calcareous to moderate calcareous, silty, fossil-rich slate.

2.3.6 Ranikot Formation in Lower Paleocene:

Light brown, dark, hard, rigid to splintery, can be divided, often moderately chalky, silty, mildly pyrite hints are present on its glauconitic structure .A few skinny sandstones arise as well, which might be generally quartzes, more or less consolidated, extraordinarily high-quality to medium grained, sub-angular, poorly organized, and fairly calcareous. Siltstone is earthy coloured, dim friable, very calcareous, with high-quality brown coal symptoms of pyrite, and a few sensitive chalky dust and dense dust stone with limestone near the pinnacle is likewise present. Limestone is buff to tan in colour, hard, and sometimes detrital in nature.

2.3.7 Pab Formation in Maestrichtian:

Limestone is darkish brown, hard, angular, and cryptocrystalline, with crumbly calcarenite, clay, and siltstone. Off white sandstone grading to sandy limestone, exceptionally friable, satisfactory to very satisfactory grained, and really calcareous. Limestone is darkish brown, hard, angular, and cryptocrystalline, with crumbly calcarenite, clay, and siltstone.

2.3.8 Mughalkot Formation in Uppercretaceous

Grey-green Clay, grey brown, blocky and dense dusty, usually non-calcareous, s grey, hard, typically lignite with some limestone. The appearance of carbonate faces during the tertiary implies a prolonged length of sustained shelf depositional situation. The Paleocene shales and siltstone reflect a more profound water bowl rack part natural surroundings.

2.3.9 Parh & Goru Formation in Middle Cretaceous

Porcellaneous Parh limestone is a ramp deposit and is gradationally connected with higher Goru Maris and lower Goru siltstone and shale out from the Thar platform closer to the shelf.

2.3.10 Sembar Formation in Lower Cretaceous:

The lower cretaceous Sembar formation is a good source rock in the lower and middle Indus Basin, although it is accessible in Earth and mud stone, dark green and faint brown, blocky silty, regularly non-calcareous, silty and siltstone, dark, firm, somewhat lignite with uncommon limestone gatherings. The carbonate faces seen all through the tertiary period address a significant range of consistent rack depositional conditions. The basic Paleocene shales and siltstone suggest additional water bowl rack edge climate, but the lower Eocene Ghazij-Laki development's exchanging sequence of limestone and shale suggests a short external littoral pivot line condition. The Indus offshore shelf region is made up of metamorphosed shales and igneous intrusions, which were discovered while drilling in well Dabbed Creek-01.

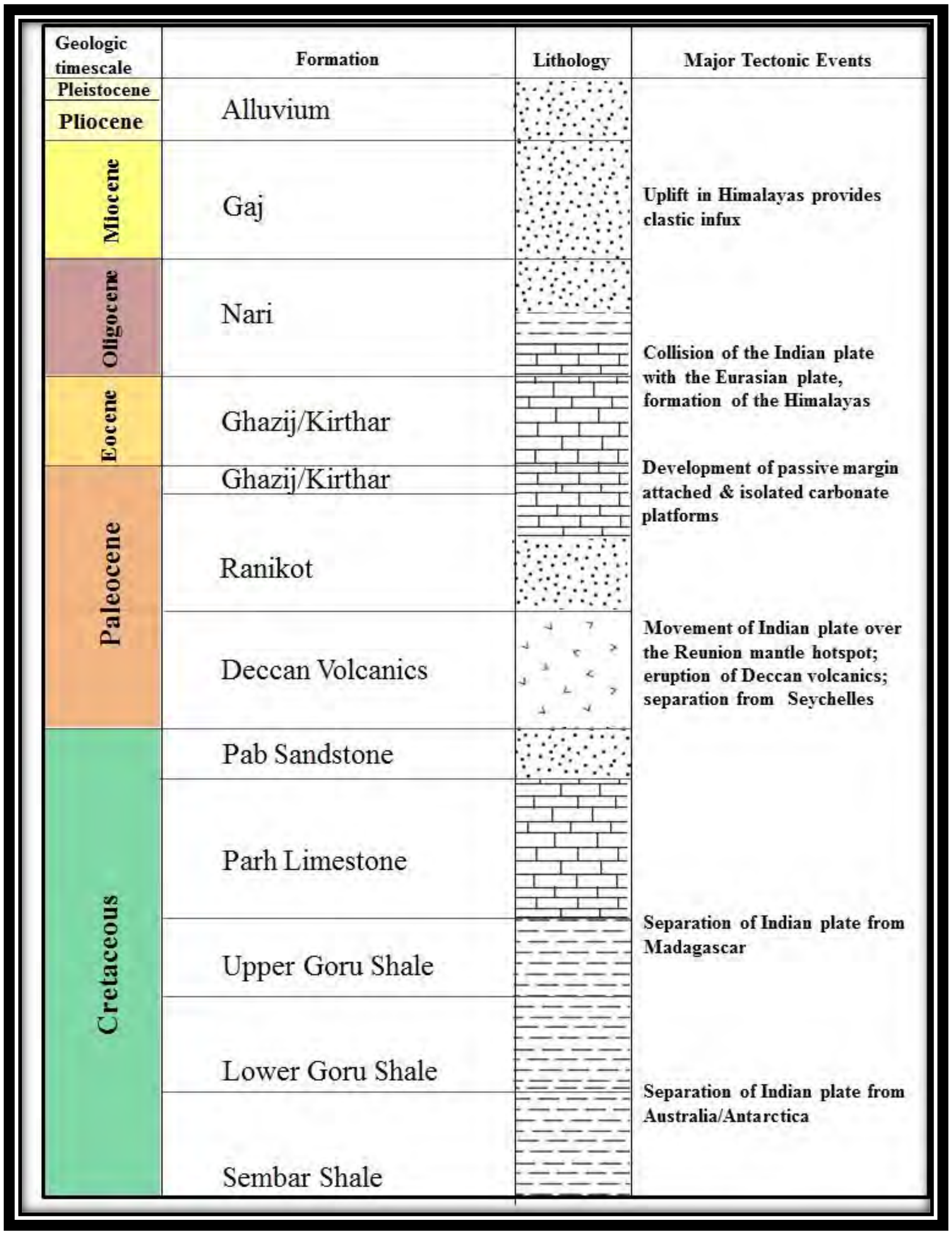

Figure 2.3. Stratigraphic chart of Offshore Indus Basin.

2.4 Petroleum Geology

The offshore Indus is a doubtlessly wealthy hydrocarbon area that has yet to be discovered. Following Reliance`s discovery of the huge Dhirubhai fueloline area (11.2x10x12 SCF reserves) in Pliocene generation turbidities inside the Krishna Godavari Basin offshore East India, business interest in South Asian offshore land has multiplied in current years. (Carmichael et al, 2009).

2.4.1 Source Rocks

The geothermal gradient withinside the seaward Indus tiers from 3-five levels Celsius each one hundred metres. The common warm temperature circulation is 30-50 m (W/m2) (Ashen et al, 2011). Fig 2. five summarises the supply rock traits of Cretaceous to Pleistocene rocks. The TOC values vary from 0.1 to 0.22 percent. They get as high as 2.21 percent every now and again. These projects are fully developed for condensate and gas. PakCan-01 had type III kerogen in all of its specimens. TOC readings indicate that the Miocene Gag setup has a sufficient supply of TOC. Analysis of development suggests a juvenile zone down to 2800m and early develops to develop from 2800m to TD 3,701m. In any event, no link exists between the DST's aftereffects and the source rock. The condensate and gases obtained during DST testing are nearing completion. As a result, these hydrocarbons have been transported from a deeper source. Sadaf-1 TOC values suggest an extremely thin source. Throughout the well, TOC levels are less than 0.5 percent. There are just 0.5-0.6% of characteristics. The kerogen is a kind III kerogen that is thermally immature.

2.4.2 Reservoir Rocks

It is known to be rich in Miocene sandstone (PakCan01). The individual sandstone units are 2-50 meters thick and have a porosity of 1520 percent. Eocene-Oligocene deep sea, coral reefs, or sandbar limestone with porosity of over 20% (PakG21). The placement of Late Cretaceous Pab / Mughal Kot and Paleocene Ranikot could be an additional supply center in the coastal area (Ahsan et al., 2011).

2.4.3 Seal Rocks

Potential reservoirs will be sealed by mud-ruled silt bundles. Eocene and Oligocene reservoirs are sealed by transgressive mudstone. Miocene intra-formational shale would seal the Miocene sands.

2.4.4 Trapping Mechanism

The research area has both underlying and stratigraphic traps. Seismic markings address reef progression along the borders of the Oligocene, Paleocene, and Cretaceous periods independently, with superimposed/equal top off abnormalities of younger ages. In the rack edge bowl, rollover anticlines are used to counteract development faults.

Anticlines and problem structures should be wrenched. Designs for the circulation and advancement of sandstone supplies, as well as channel sands turbidities associated with a subsurface ravine fan framework.

CHAPTER 3

SEISMIC DATA INTERPRETATION

3.1 Introduction

Transformation of seismic reflection data into a structural and stratigraphic picture by going through processing procedure and finally the time and depth contouring of subsurface horizons by applying suitable velocities is called seismic interpretation. Seismic interpretation consists in identifying geologically hidden interfaces or sharp transition zones of reflected seismic impulses towards the ground. The effects of various geologic conditions along the profile are projected to convert the irregular travel time into an acceptable subsurface pattern. This is very important for reliable estimation of depth, foundation geometry and target horizons (Dobrin and Savit,1988).

There are two types of the interpretation of seismic sections.

(1) Structural interpretation

(2) Stratigraphic interpretation

3.1.1 Structural interpretion

It is a study of reflector geometry as a function of reflection time. Structural interpretation or analysis mainly used to identify structural traps containing hydrocarbons. Two-way travel time is used by structural interpretation mostly. Seismic intersections are analyzed to delineate structural traps such as folds, faults, and anticlines. In this modern era of science and technology, software packages offer great help in analyzing seismic data both structurally and stratigraphically. The software supports the interpreter by automatically recognizing error areas and subsequently marking them throughout the project area. However, for this, the seismic data must be of high resolution (Dobrin and Savit, 1988).

3.1.2 Stratigraphic interpretation

Stratigraphic analysis divides the seismic profile into reflection sequences and interprets them as seismic plots of deposit-associated sedimentary sequences. According to Dobrin and Savit (1988), throughout the history of reflection methods, finding hydrocarbons in structural traps has been much worse than looking for hydrocarbons in stratigraphic traps.

Formation oil traps may arise from coral reefs, pinch-out or erosion cuts, facies, transitions and other features associated with sand lenses associated with buried channels, lex or similar resources. Various software not only helps with stratigraphic analysis, but also overlays seismic profiles with different seismic attributes, detects pinch-outs, truncations, etc.

3.2 Work flow

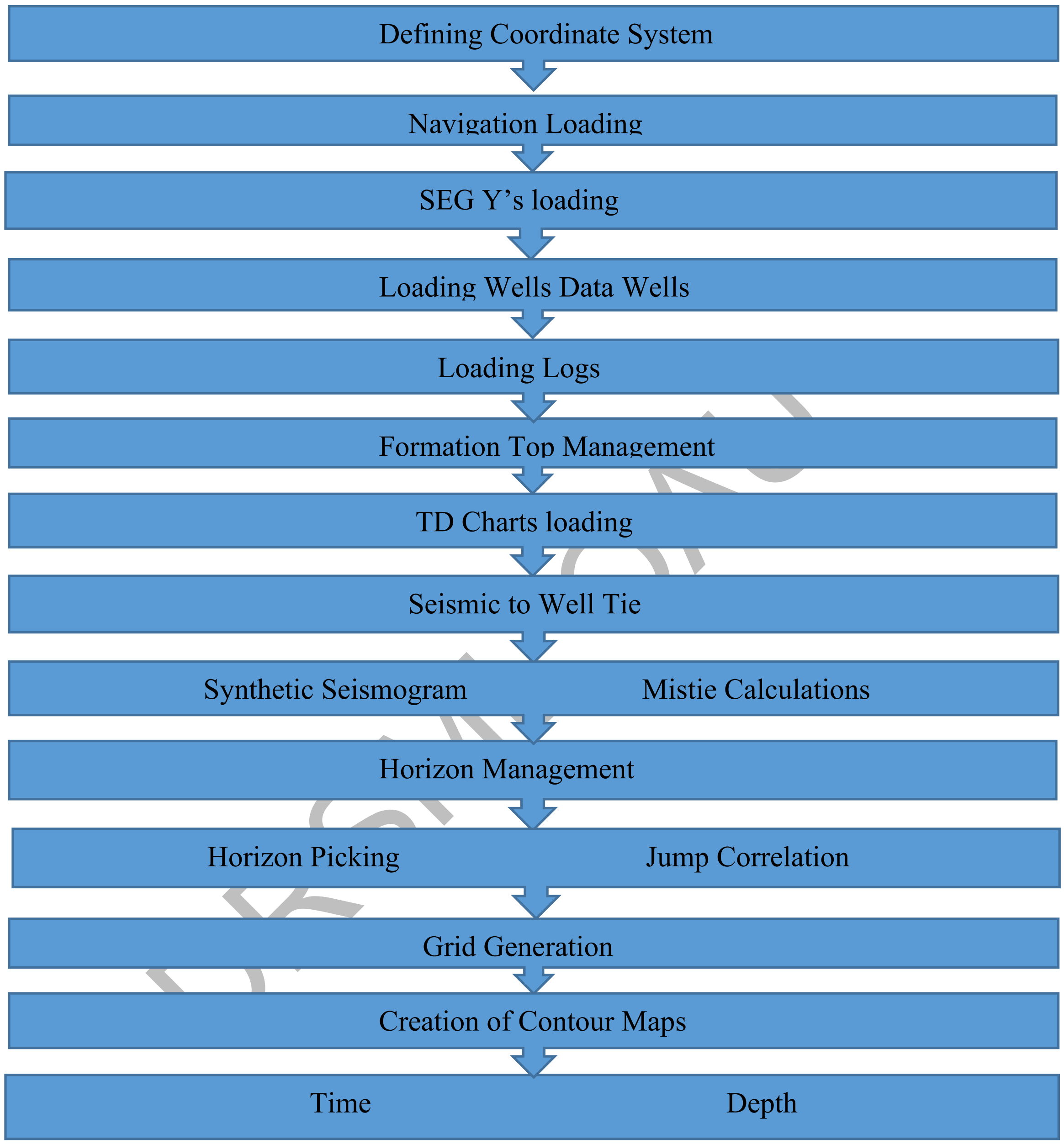

Figure 3.1. Work flow followed while doing seismic interpretation.

3.3 Identification of horizons

In horizons identification the first step is to judge the reflections and unconformaties that are present in the seismic section. Real reflectors probably will always show good continuity and character and can be straggled throughout the area are chosen. Velocity window is solved by multiplying time and velocity through which depth is found. This depth is then converted into seismic reference datum (SRD) through which the depth of each formation is calculated. Time-depth charts were created which were used to find the time of each formation. The calculated time was then used to mark reflectors on the seismic line which was closest to the well. This line was then tied with other seismic lines to mark the next reflectors.

The importance of marking basement Eocene on the seismic lines is because there is a carbonate build-up immediately on top of the basement and while drilling an exploratary well the depth of the basement is identified in order to decide the total depth of the well.

3.4 Identification of faults

Faults identification is the next step of seismic interpretation. Broken reflectors indicate faults which continues after slight distortion in the pattern. The detection of faults on seismic section can be quite easy under favorable circumstance. There are no prominent fault with a reasonable throw except a few, hence faults are not marked on the seismic line.

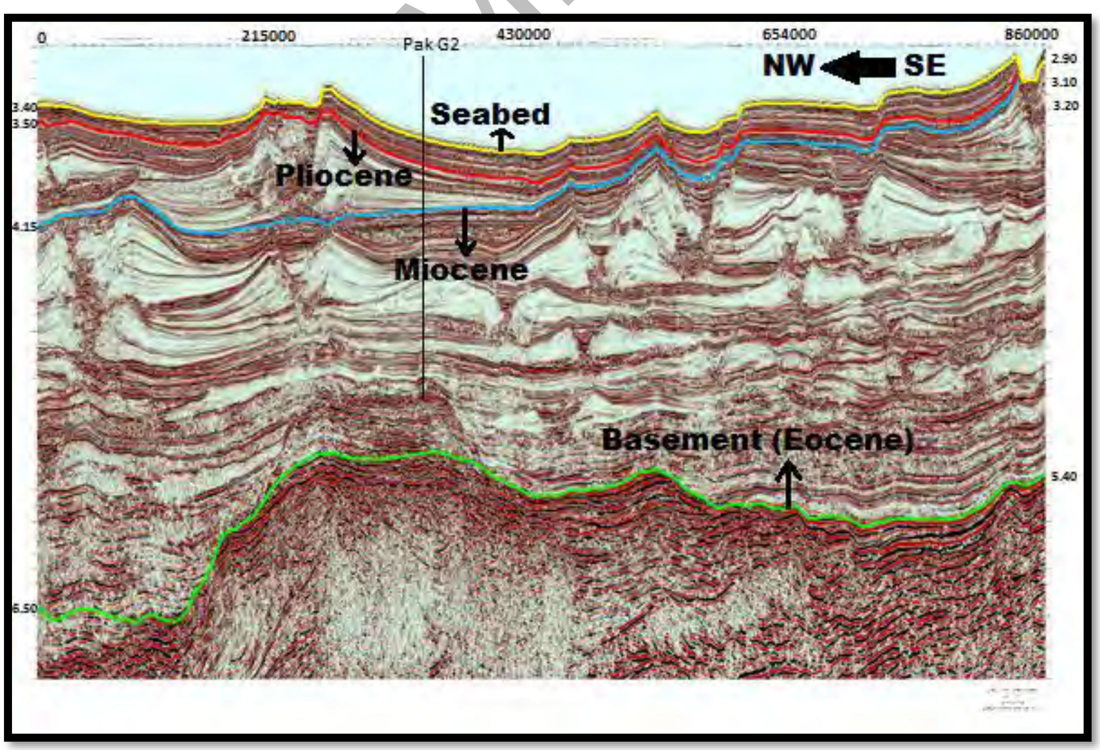

Figure 3.2. Interpreted section of line TEPPOO-117

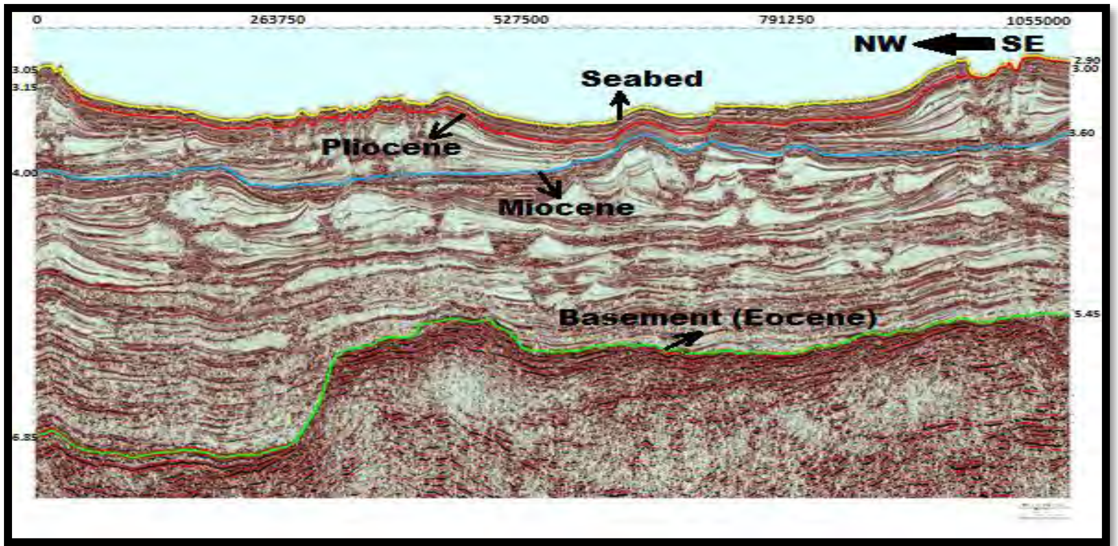

Figure 3.3. Interpreted section of line TEPPOO-115.

Line TEPPOO- 115 and TEPPOO-117 with SE-NW orientation and a length of 1072 Km and 871 Km respectively are the strike lines. Four horizons have been marked in these sections. A carbonate build-up can be seen on top of the basement high. A number of channel fills can be seen showing high amplitude reflections.

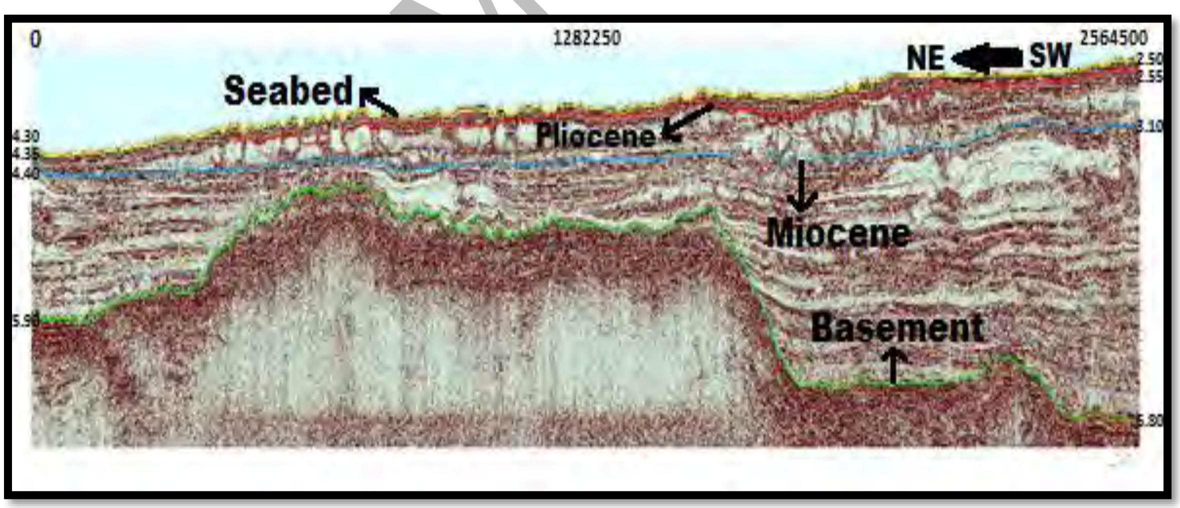

Figure 3.4. Interpreted section of line TEPPOO-205.

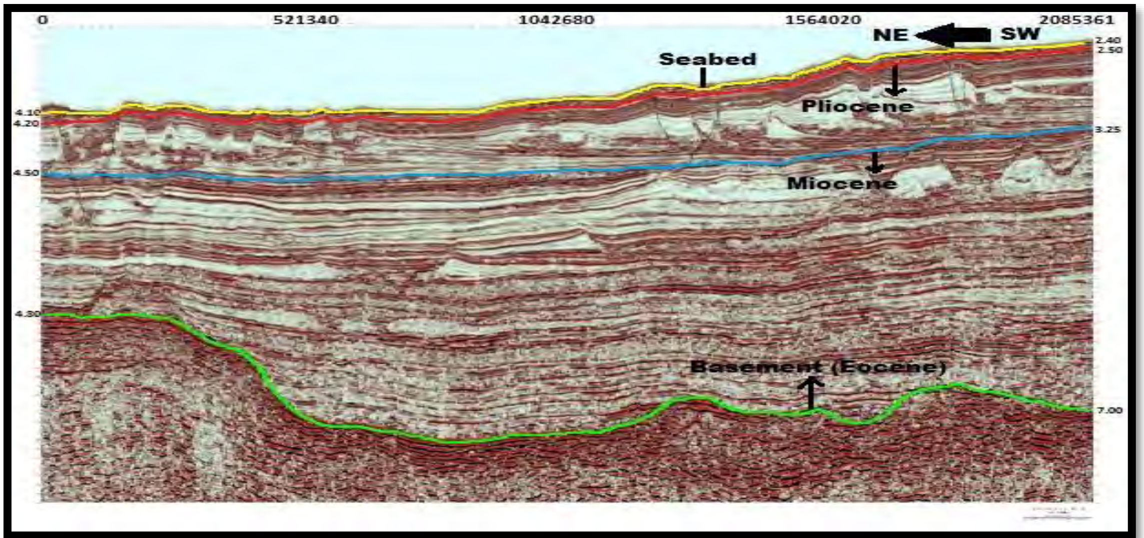

Figure 3.5. Interpreted section of line TEPPOO-206.

Line TEPPOO-205 and TEPPOO-206 are dip lines with SW to NE orientation and the length of these seismic lines is 2576 Km and 2114 Km respectively. These lines are showing different stratigrafical features like channel fills and trucations along with structural featues like faults.

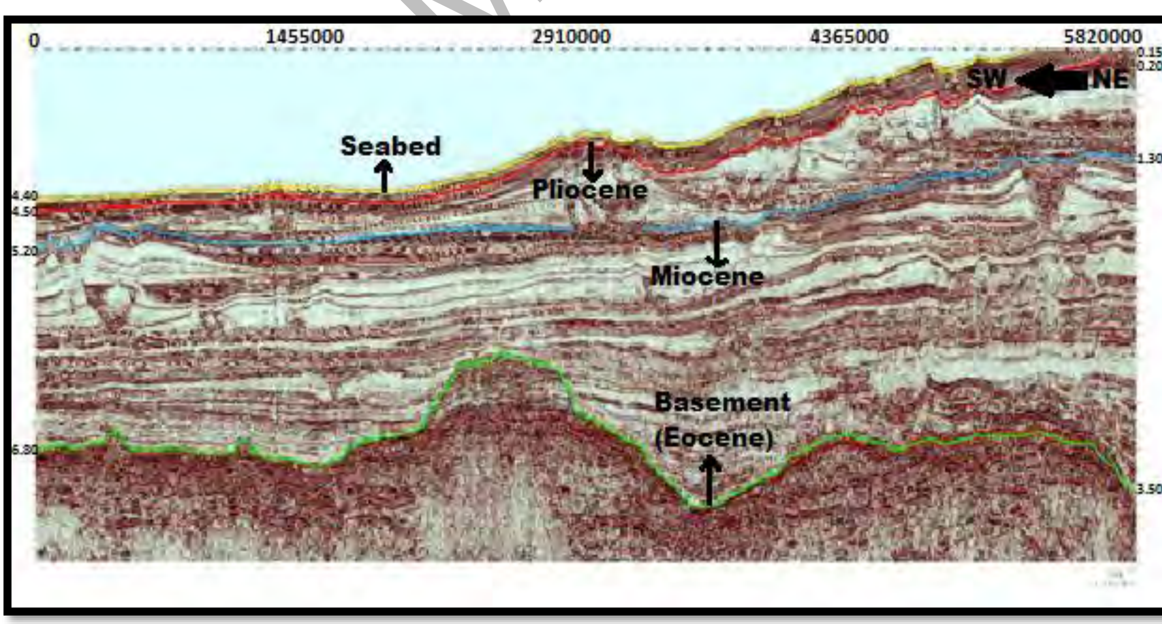

Figure 3.6. Interpreted section of line TEPPOO-207.

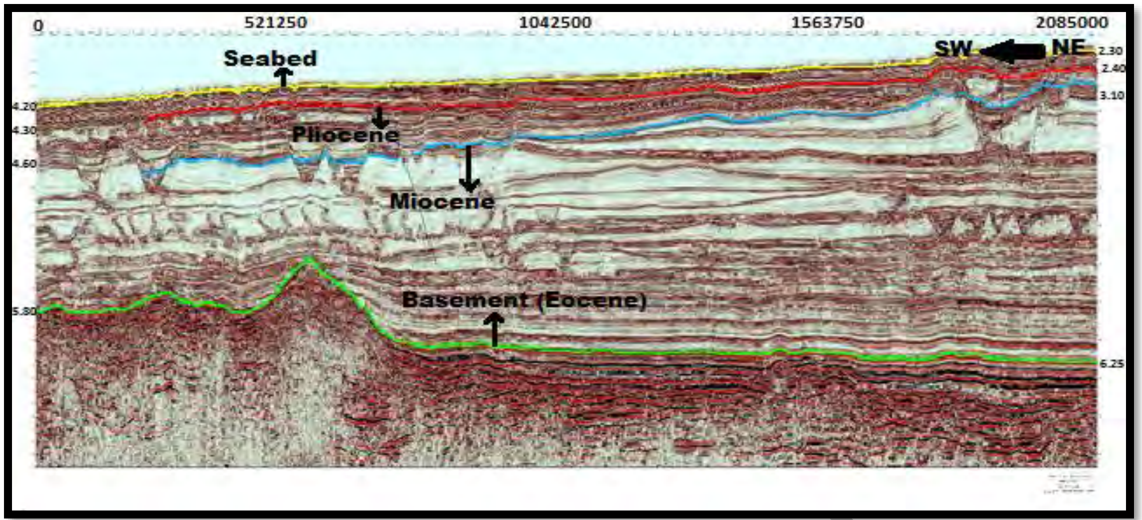

Figure 3.7. Interpreted section of line TEPPOO-208.

Line TEPPOO- 208 and Line TEPPOO-209 with lengths of 2120 Km and 2572 Km respectively with NE to SW orientation shows stratigraphic features as mentioned above in section 3.7. A series of faults with minute throw can be seen in these sections. A progradational patteren of sand from Miocene can also been seen in line TEPPOO-209. This progradational sequence of sand is sandwiched between shale which can be identified by low amplitude reflections around it.

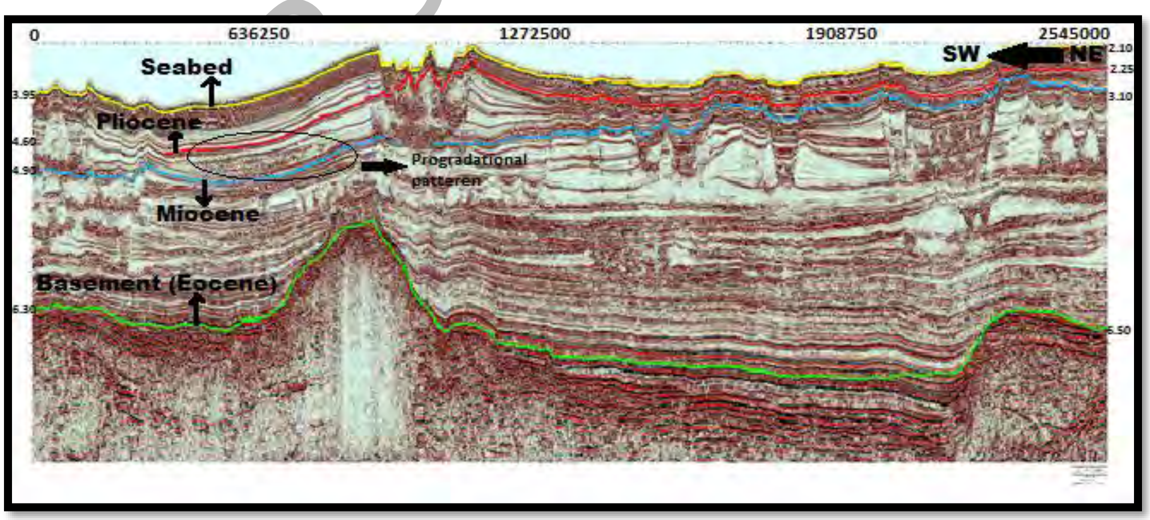

Figure 3.8. Interpreted section of line TEPPOO-209.

3.5 Stratigraphic features

Following are a few stratigraphic features encounted in the seismic line.

(a) Channels: A commonly concave-based, linear depression through which water and sediments can flow and can be deposited in distinctive, often elongated bodies. Some morphologies in which channel can occur in are straight, meandering or braided (Schlumberger, 2000).

The high amplitude inside the channel relative to the surroundings indicate the presence of sands in channel due to the high reflectivity encountered in the seismic section. Channel filled sands mostly has good reservoir quality. If the channel sands are enclosed by shale, it can be a good stratigraphic trap to find hydrocarbon. The low amplitude on top of the channel may be due to the presence of shales which shows low reflectivity on the seismic section. The channels in seismic line 208 seems to be isolated from each other due to the presence of shale in between them which shows a low amplitude.

No attributes have been applied on the seismic data to identify channel sands. These channel sands are marked enterily on the basis of reflectivity.

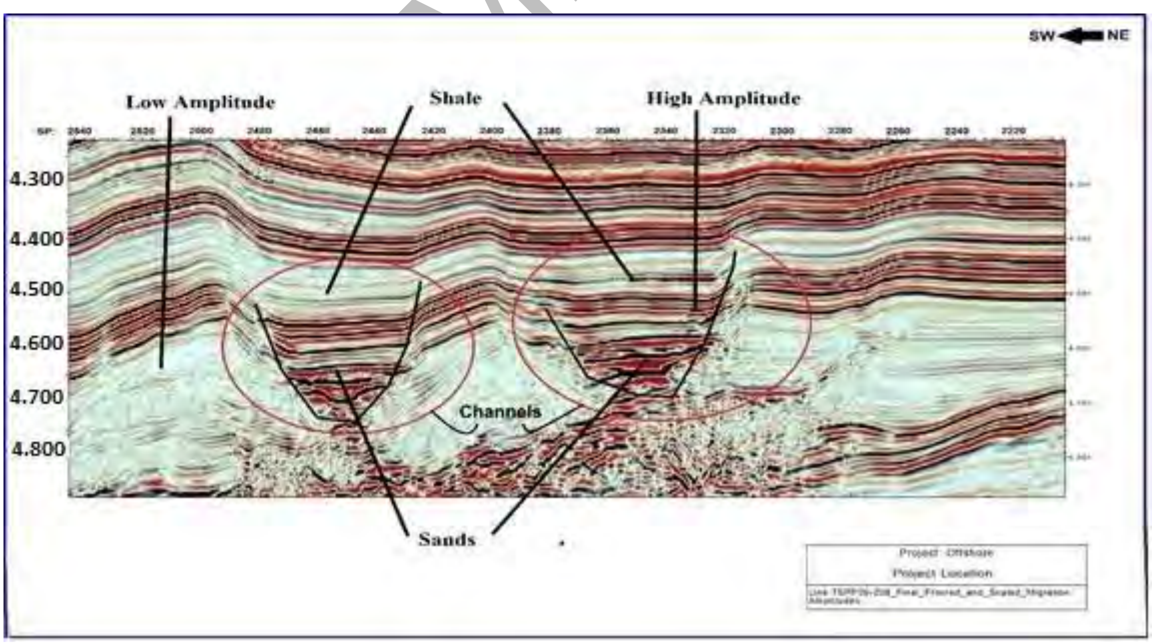

Figure 3.9. Channels encountered in line TEPPOO-208.

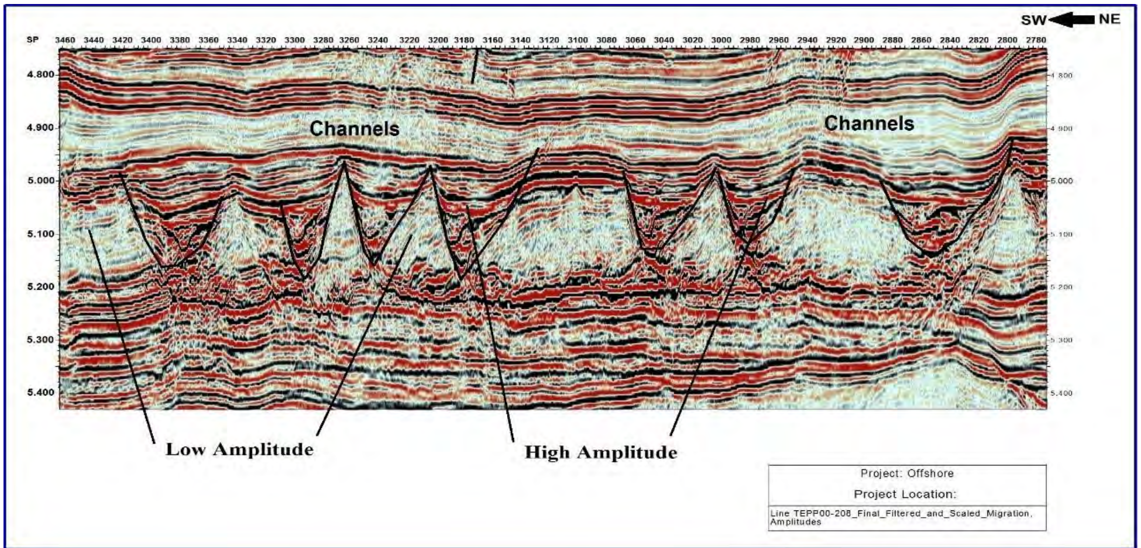

Figure 3.10. Series of channels encountered in line TEPPOO-208

(b) Truncation: Truncation is a termination of strata or seismic reflections along an unconformable surface due to post-depositional or structural effects is called truncation. It occurs along the upper limit of stratigraphic sequences. Deposition of strata and their subsequent removal along an unconformity surface indicates erosional truncation whereas structural truncation is quite different from erosional truncation. Indeed a structural truncation is a lateral termination of a stratum by structural disruption, produced by faulting, gravity sliding, salt flowage, or igneous intrusion.

A localised basement high can be seen in Line 208. In between this basement high, Eocene sequence has been deposited. This basement high is rising in NE direction which shows that the trucations along this side can be a hydrocarbon trap if it has a top and bottom seal. Wells drilled in Eocene shows shale beds which could provide seal for Eocene reservoirs. Laterally, basement rocks juxtawpositioning against Eocene basement of salts are excellent seals for sedimentary rocks.

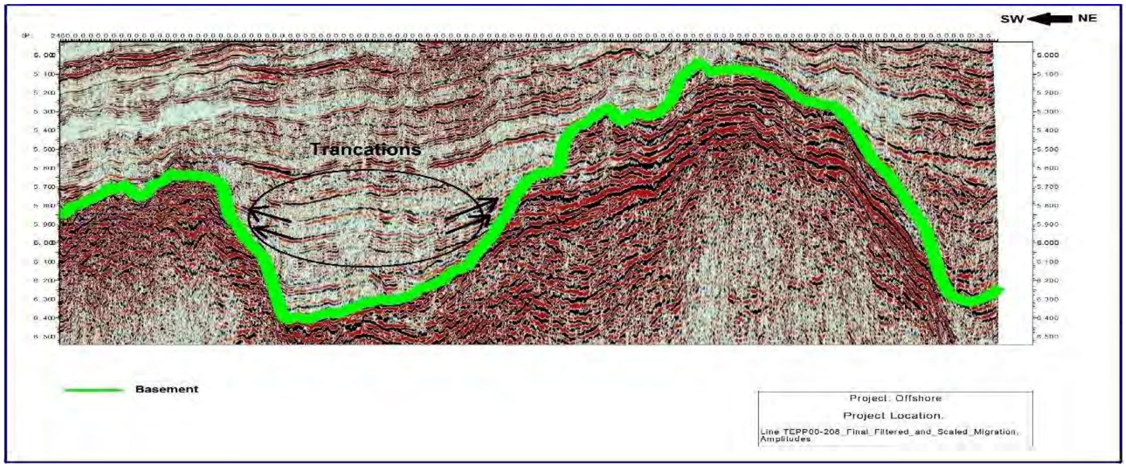

Figure 3.11. Strtigraphic truncations along basement rocks in TEPPOO-208.

(c) Progradational patteren: Progradational Patteren in Miocene can be seen in figure 3.12. In Miocene there is sand and shale sequence. Miocene was the time when a localised influx resulted in the formation of channel prograding sequence etc. in this prograding sequence it shows mainly sands which can be seen due to high amplitude on seismic. This prograding sequence is present in structuraly low position with a rising trend on NE and SW direction. Unfortunately, no wells has been drilled in this sequence so the existance and quality of reservoir in this sequnce is questionable. If this progradational sequence are sand rich and have a top and bottom seal, it can be a potential prospect in the future exploration activities.

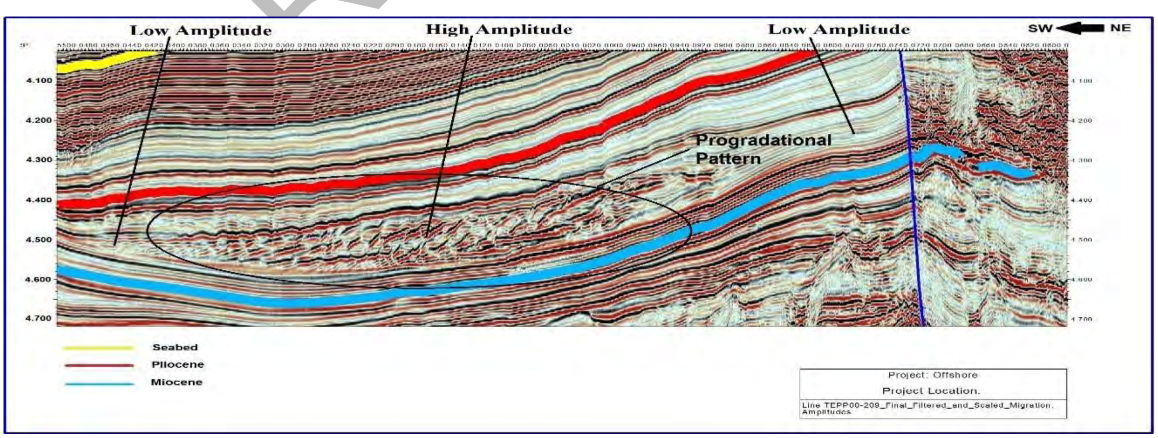

Figure 3.12. Progradational patteren in TEPPOO-209.

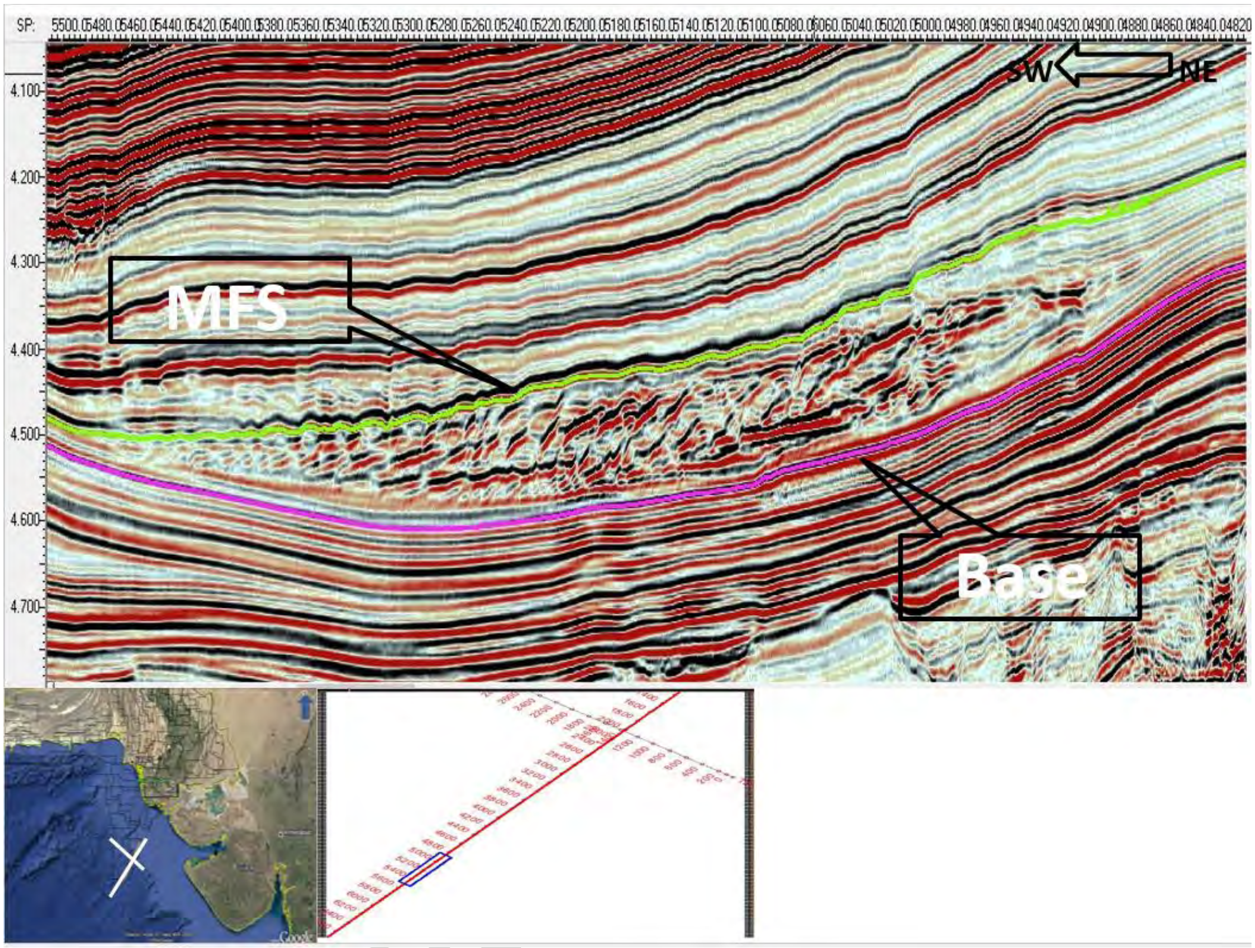

Figure 3.13. Progradational patteren in TEPPOO-209.

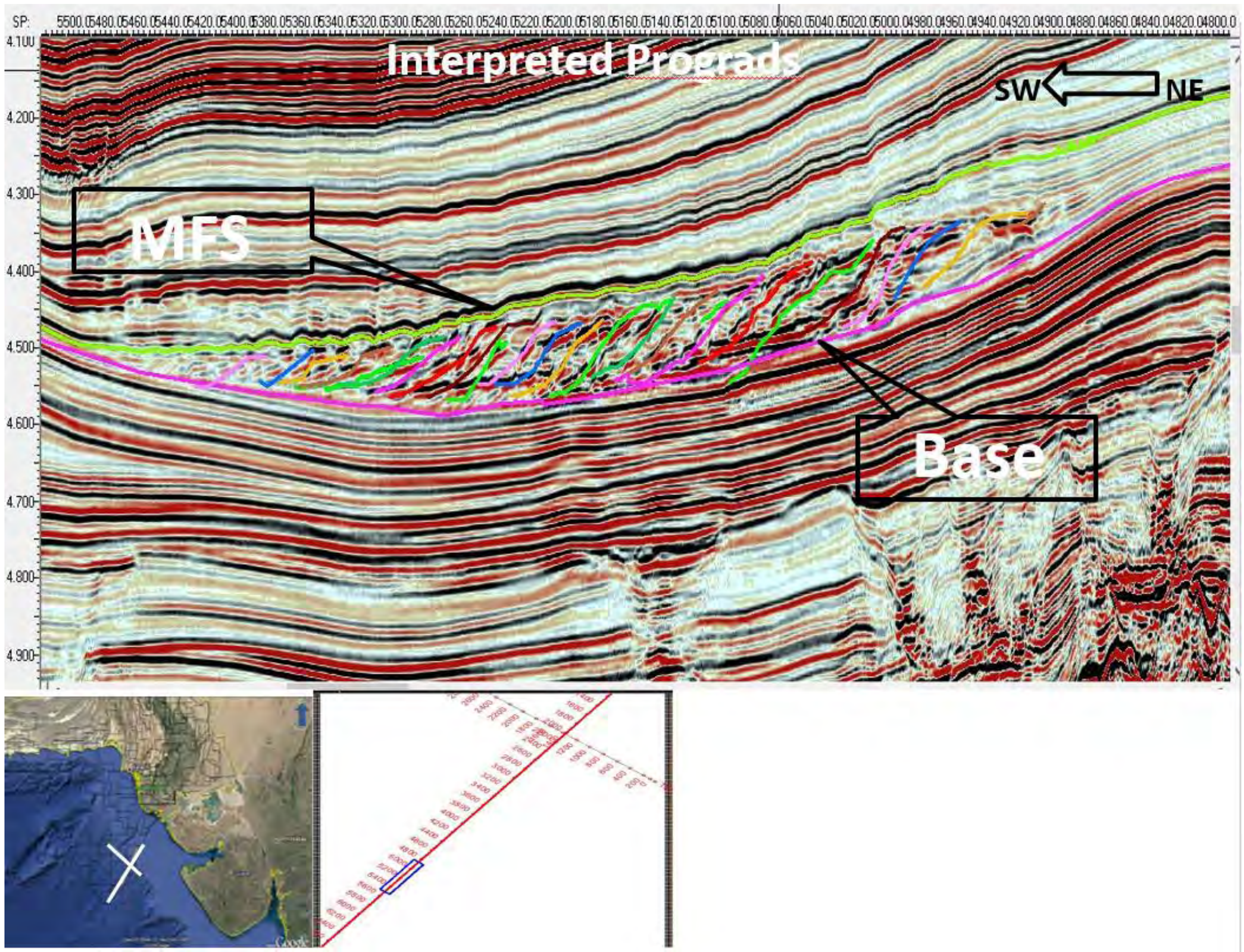

Figure 3.14. Progradational patteren in TEPPOO-209.

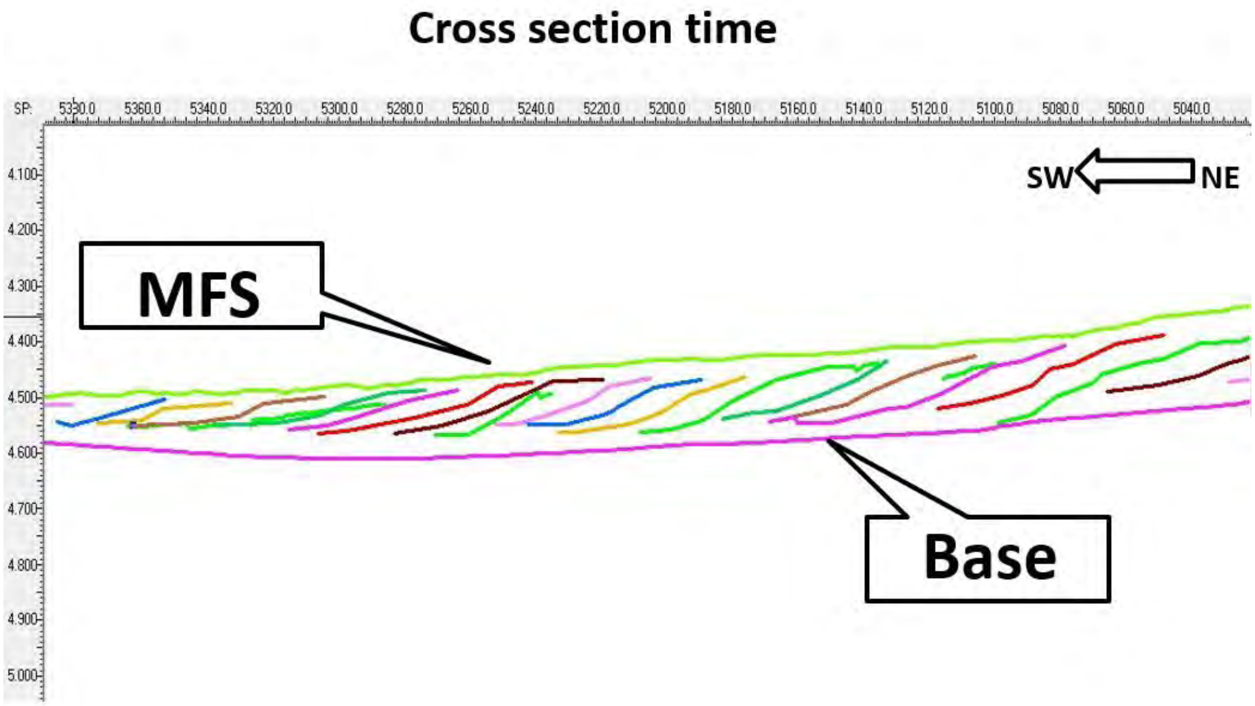

Figure 3.15. Progradational patteren in TEPPOO-209.

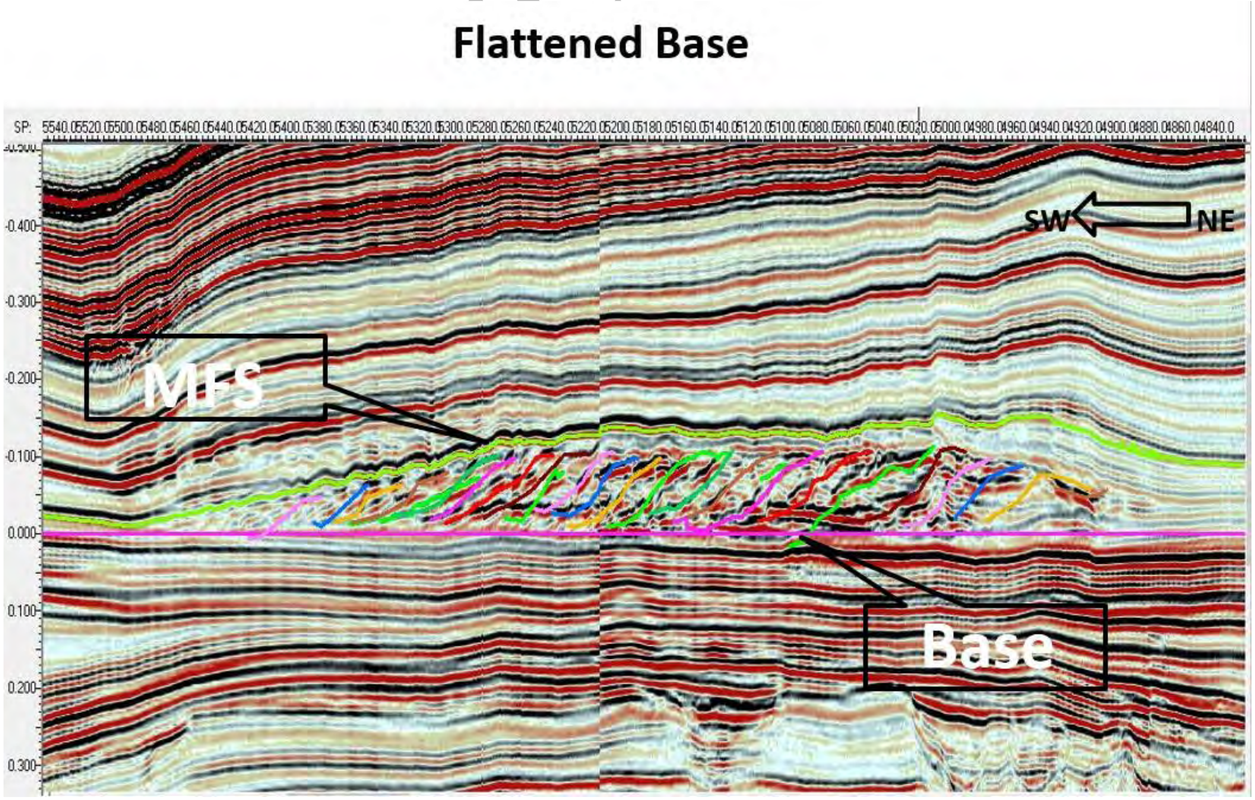

Figure 3.16. Progradational patteren in TEPPOO-209.

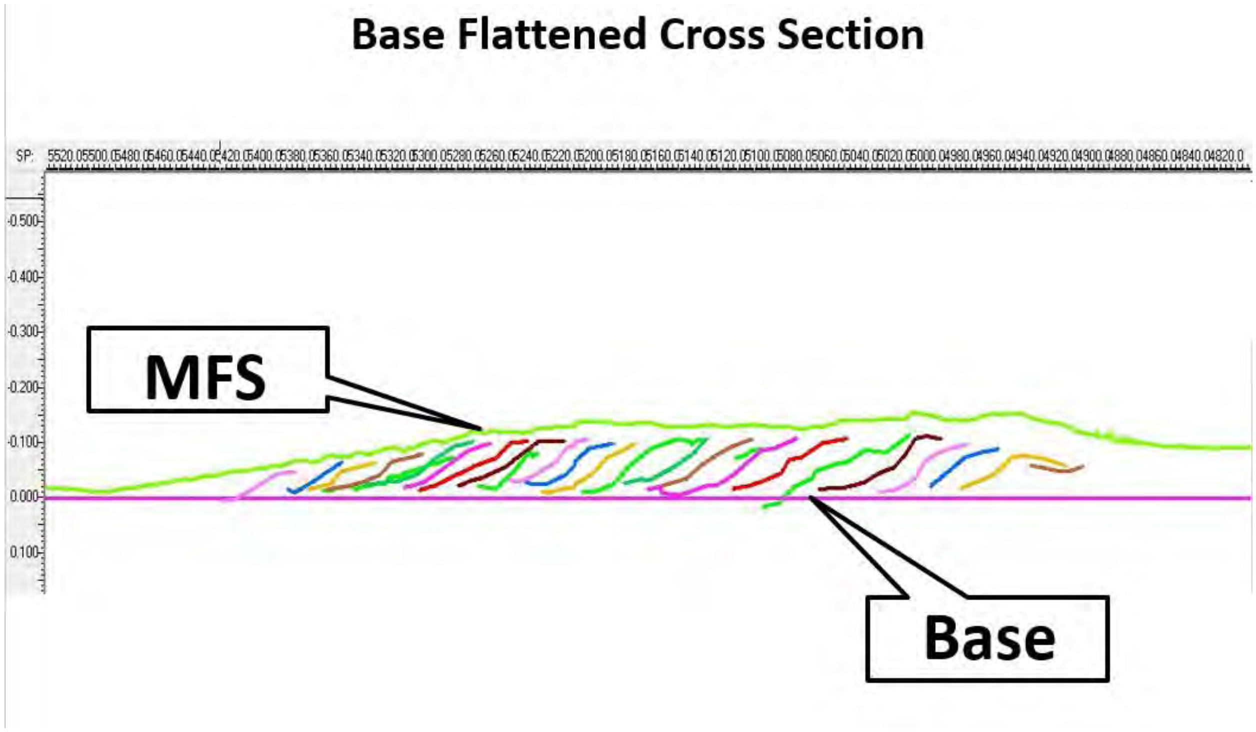

Figure 3.17. Progradational patteren in TEPPOO-209.

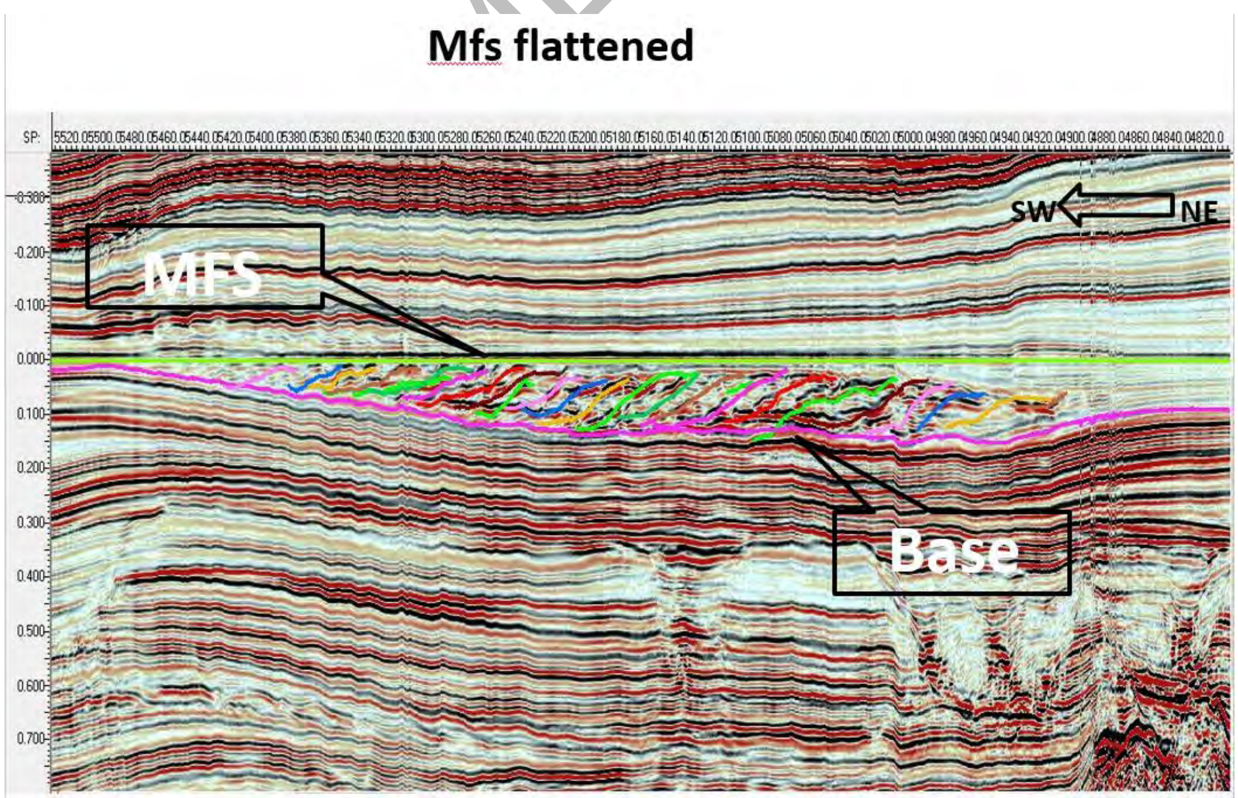

Figure 3.18. Progradational patteren in TEPPOO-209.

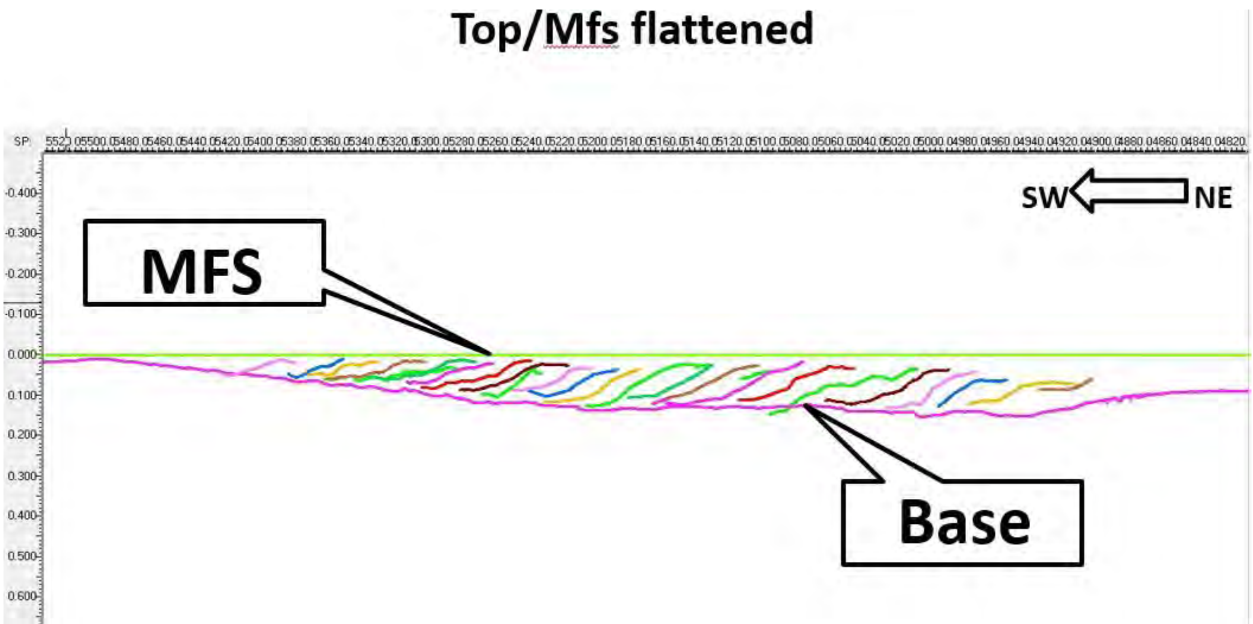

Figure 3.19. Progradational patteren in TEPPOO-209.

3.6 Time maps

A map identifying the seismic image times at which subsurface structure is located. It can be converted into depth-structure maps. Time structure map of Miocene is shown in figure 3.20. The color bar shows the trend of values in the map with yellow being the shallowest whereas blue being the deepest. The unit of the color bar is seconds (secs). The contour interval is 0.2 as mentioned with in the maps. The time values in the area shows low values in north-east direction, which later starts to increase as we go in the south-west direction. A four way dip structure can also been seen on the Miocene level.

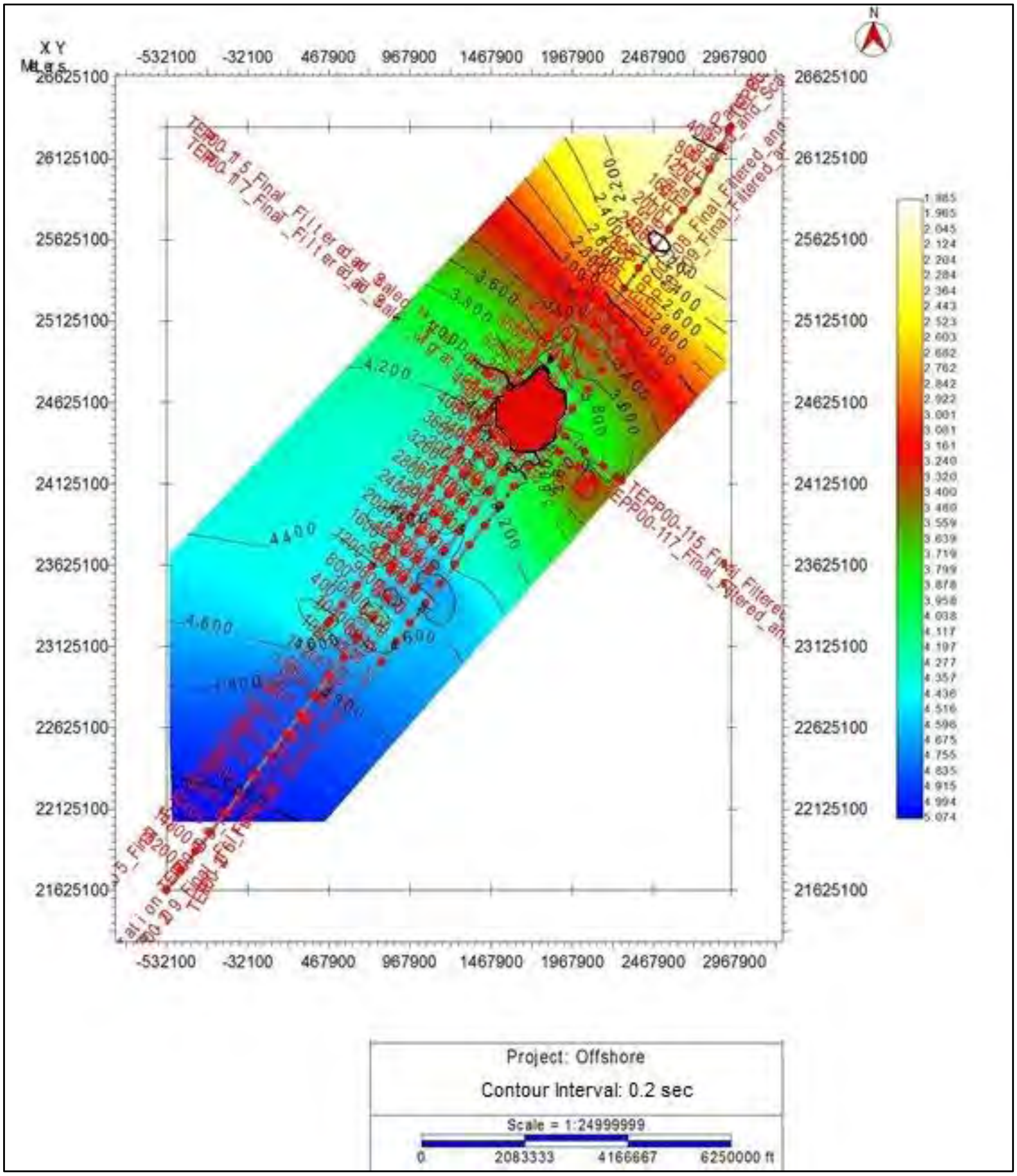

Figure 3.20. Time map of Miocene.

3.7 Depth maps

The depth contour maps specify the horizon location in subsurface with respect to depth which characterize more accurate place of horizons lying with in the surface therefore making these maps vital for seismic data interpretation.

Depth contour maps characterize the precise geological depiction of structures lying in the subsurface. The two way time (TWT) of formations were converted into depth by using average velocity values and then depth contour maps are generated for three horizons. The formula used is as follow:

$$V_{avg} = S/T$$

Where,

S is the depth value,

T is one way time value i.e. two way time (TWT) divided by 2

This information was used to get the depth of horizons. The formula used is as follow:

$$S = V_{avg} * T/2$$

Where

S is depth value of horizon,

Vavg is the average velocity

T is two-way time (TWT) of the horizon marked

Depth contour map of Miocene is shown in figure 3.21. The shallower depths are shown by yellow to red color while green color is showing the medium depth events. Deeper depth events are shown by light blue to dark blue color. The contour interval is set to be 200 meters (m). The depth contour shows a deepening trend when moving from north-east side towards south western side.

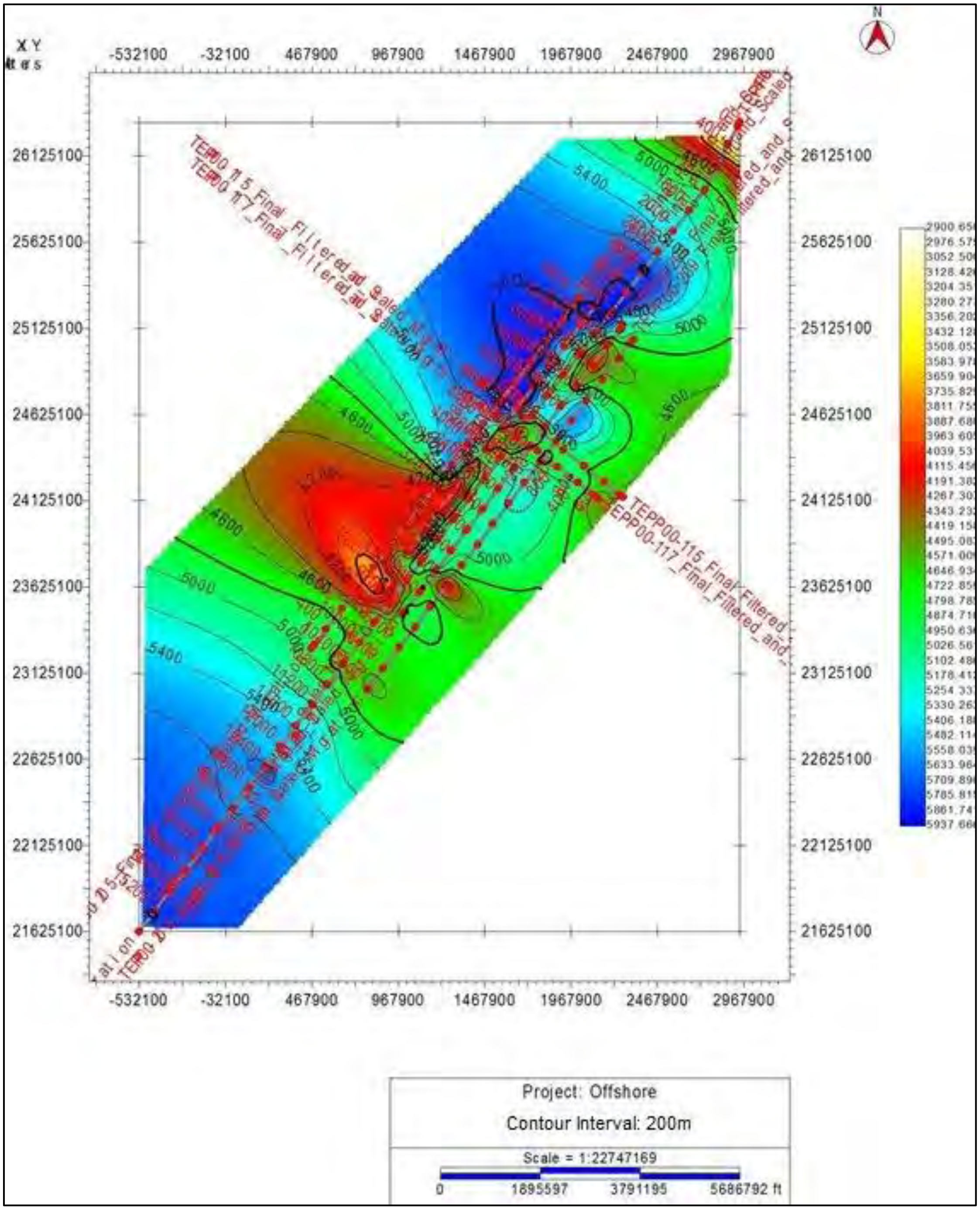

Figure 3.21. Depth map of Miocene.

CHAPTER 4
SEQUENCE STRATIGRAPHY

4.1 Intrduction

The study of rocks or genetically related strata bounded by unconformities or their correlative conformities is called sequence stratigraphy. The study of sequence stratigraphy is key to understand reservoir and source rocks (petroleum system). Seismic interpretations are used to find sequence stratigraphy but well loging in which GR log specially used to predict sequence stratigraphy.

GR log records the intensity of radioactive materials. High GR log value shows high shale content and fine lithology whereas low GR log value show clean and coarse lithology. There different shapes formed on GR log which shows finning upward, coarsening upward and consistent sequence.

4.2 Log curve shape: predictive tools for facies interpretation

According to Selley (1978) the shape of well-log curves are the basic tool to interpret depositional facies since, the shape of logs is directly related to the grain size of rock successions.

There are five types of shapes which can be observe on well log specially GR log.

(1) Cylindrical/boxcar shape
(2) Funnel shape
(3) Bell shape
(4) Bow shape
(5) Irregular shape

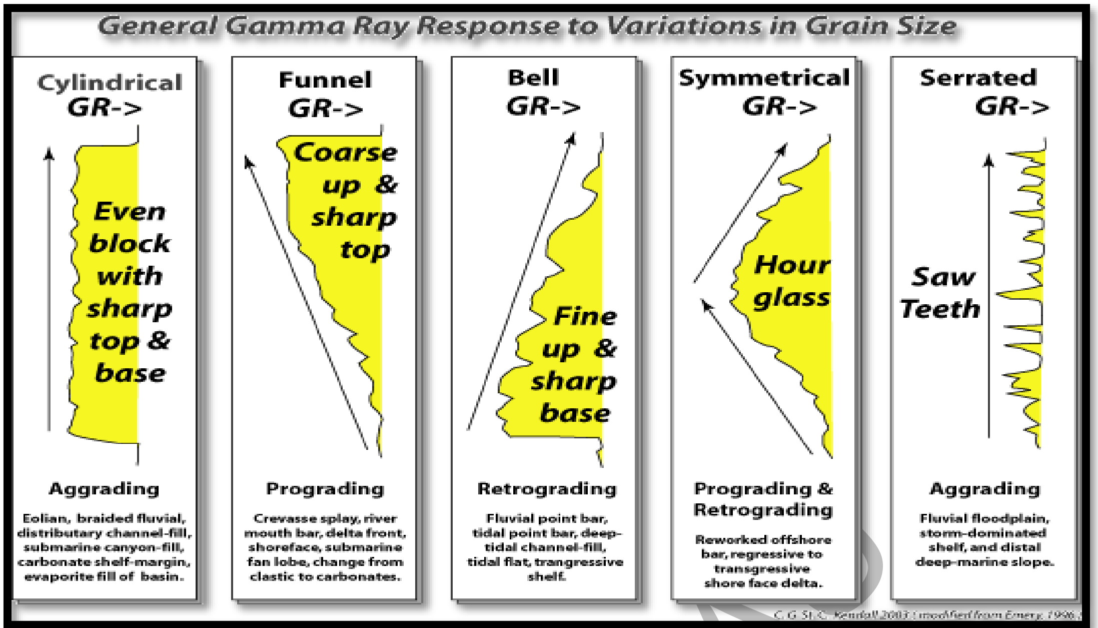

Figure 4.1. Direct corelation between facies and log shapes relative to the sedimentological relationship (Nazeer et al., 2016).

4.2.1 Cylindrical/boxcar shape

This is the type of shape which is characterized by block with sharp top and base. GR log values are consistent which indicates consistent or uniform lithology.

4.2.2 Funnel Shape

Funnel shape shows coarsening upward or finning downward sequence, because from botton to top GR log values increases which forms the funnel shape. It shows coarsening upward pattern with abrupt top.

4.2.3 Bell shape

Bell shape is reverse of funnel shape in which from botton to top GR log values decreases which forms the bell shape. It shows finning upward pattern with abrupt bottom (Nazeer et al., 2016).

4.2.4 Bow shape

Bow shape is formed when from bottom to top GR values first gradually decreases and the increases without any sharp breaks. It can be said high low high GR values or low high low energy where this sequence formed. The opposite of this shape is right bow shape (Nazeer et al., 2016).

4.2.5 Irregular shape

Irregular shape is formed by vertical GR values with high and low readings in very short interval. This shape trend shows laminated beds of sand and shale. Such deposits may formed by turbidities, debris flow or slope deposits.

4.3 Parasequence stacking patterns

Parasequences stack into three basic patterns as a result of the interaction of accommodation and rate of sediment supply (figure 4.3 and 4.4):

1. Progradational
2. Retrogradational
3. Aggradational

4.3.1 Progradational

When rate of sediment supply is greater than topset accommodation space creation progradational geometries are formed. Offlap break and facies belt move towards basinward (Emery and Myers, 2009). Over the logs, it shows a gradual decrease in the GR values which indicates the decrease in shale content. Hence a coarsening upward trend.

4.3.2 Retrogradational

Rectrogradational geometries occur when sediment supply is less than the rate of creation of topset accommodation volume. Facies belts migrate landward and the former depositional offlap break beomes a relict feature (Emery and Myers, 2009). Over the logs, it shows a gradual increase in GR values from minimum values. Which indicates an increase in shale content, hence forming a fining upward trend.

4.3.3 Aggradational

Aggradational geometries is occuer when rate of sediment supply and topset accommodation space creation are balanced or equal. Offlap break do not moves toward seaward or landward and facies tend to be vertical (Emery and Myers, 2009). Over the logs it shows sharp boundaries at the upper and lower boundaries with relatively consistent GR values indicating consistent lithology.

4.4 Sequence boundary

A sequence boundary is an erosional surface that separates older sequences from younger sequence, which is called unconformity. On seismic data it is recognized from a downward shift in coastal onlap which implies a fall in relative sea level (Emery and Myers, 2009). Whereas a sharp break in GR values also conforms a sequence boundary (figure 4.3 and 4.4).

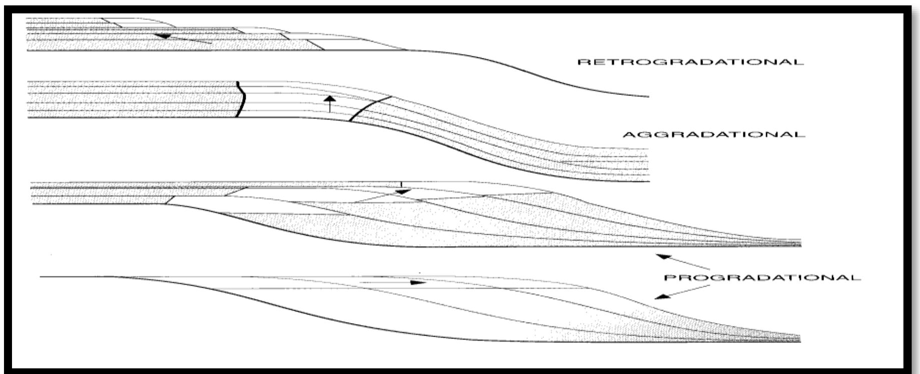

Figure 4.2. Different types of parasequence stacking pattern (Emery and Myers, 2009)

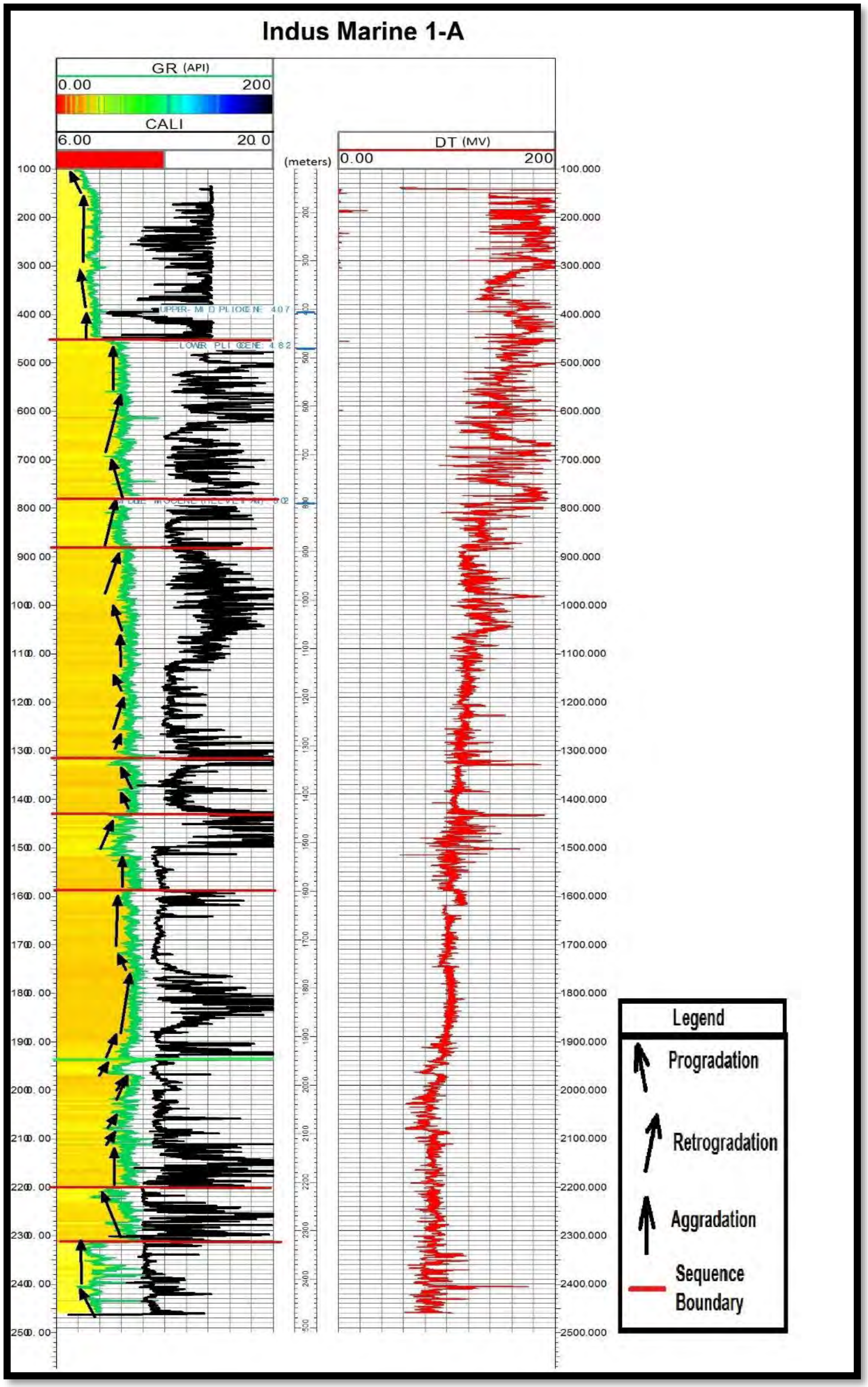

Figure 4.3. Sedimentary facies interpretation using gamma ray and sonic logs of Indus Marine 1-A well.

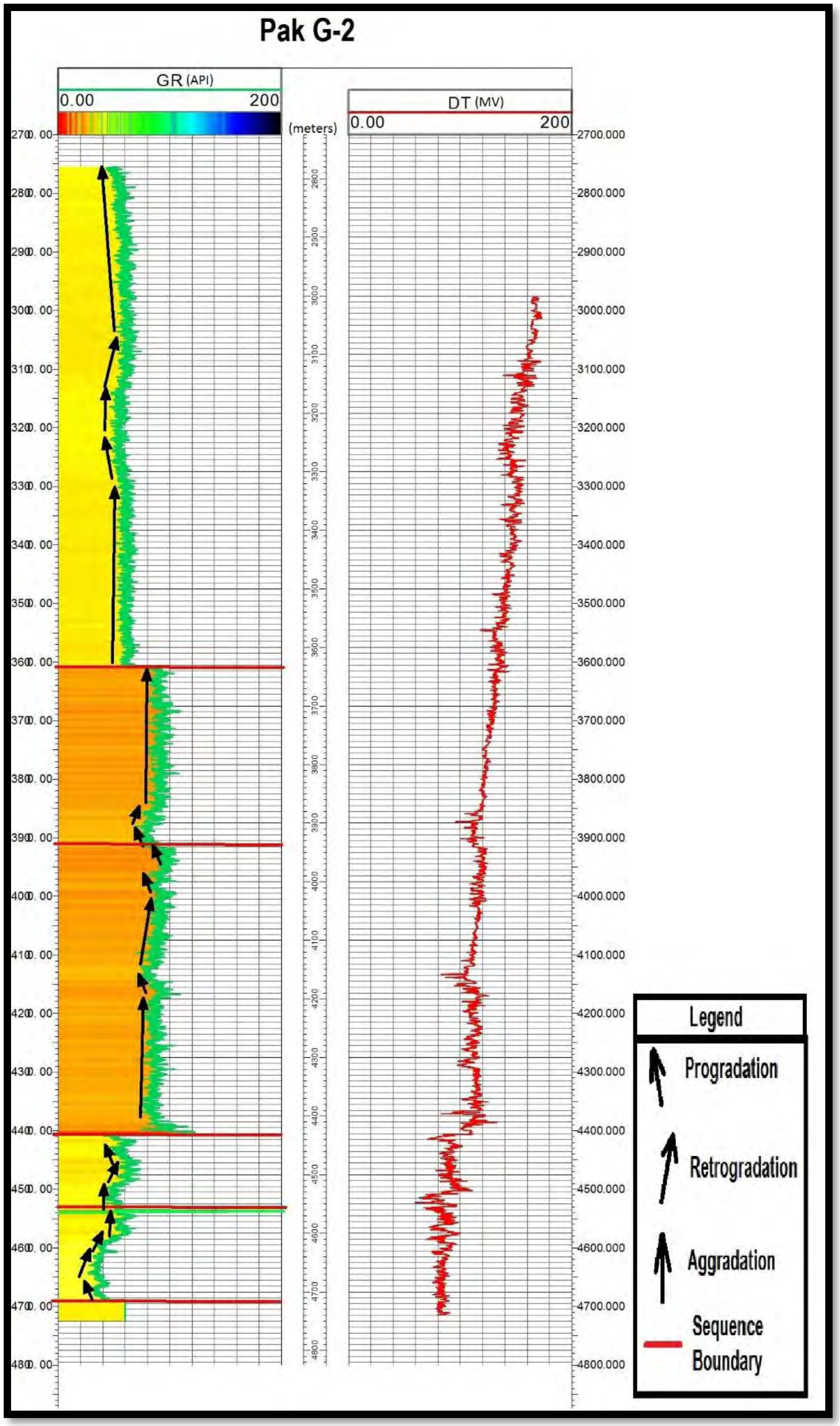

Figure 4.4. Sedimentary facies interpretation using gamma ray and sonic logs of Pak G-2 well.

4.5 Disscussion

Parasequences have been marked on the basis of GR readings. In IndusMarine 1-A, the lower part of Miocene encountered from 2300m to around 2470m consists of progradation (funnel shape) and aggradation (cylindrical shape) pattern. It is mainly sandstone dominated since the GR values are on the lower side and represents channel fills of Miocene age. Middle Miocene section, from 2300m upwards to around 800m has all 3 parasequences sets with multiple sequence boundaries. This segment is majorly dominated by shale since GR values are on the higher side (bell shape) with some portions encountering interbedded sandstone and shales. The retrogradational pattern from 1430m to 1500m represents shelf deposits. The symmetrical pattern of GR values encountered from 780m to 570m is of Late Pliocene age and indicates delta fronts.

The response of GR log in these parasequence sets can also be confirmed by checking the corresponding DT log. DT log shows the transit time of acoustic wave to travel from the source to the receiver. If there is pore space in the rock, and it is fluid-filled, the acoustic energy will take longer to get from the transmitter to the receiver (i.e., low velocity indicates high porosity). The zones where GR values are low the corresponding DT values are also less.

Based on the results, reservoir rock of Miocene age is present in the study area. Shales of Miocene age having high GR readings have the potential for acting as a seal rock.

CHAPTER 5
PETROPHYSICAL ANALYSIS

In order to specify the interest zone in a borehole, petrophysical analysis is executed. The execution takes place by utilizing various log curves that are obtained by wire line logging. After the logs have been obtained, the marking of the interest zones is determined by the conditions possessed by the boreholes, the neutron density cross-over and the resistivity log trends. To evaluate the hydrocarbon potential, calculation of porosity, water saturation, hydrocarbons saturation, volume of sand and volume of shale are made for the zone of interest. Workflow of the methodology is illustrated in figure below.

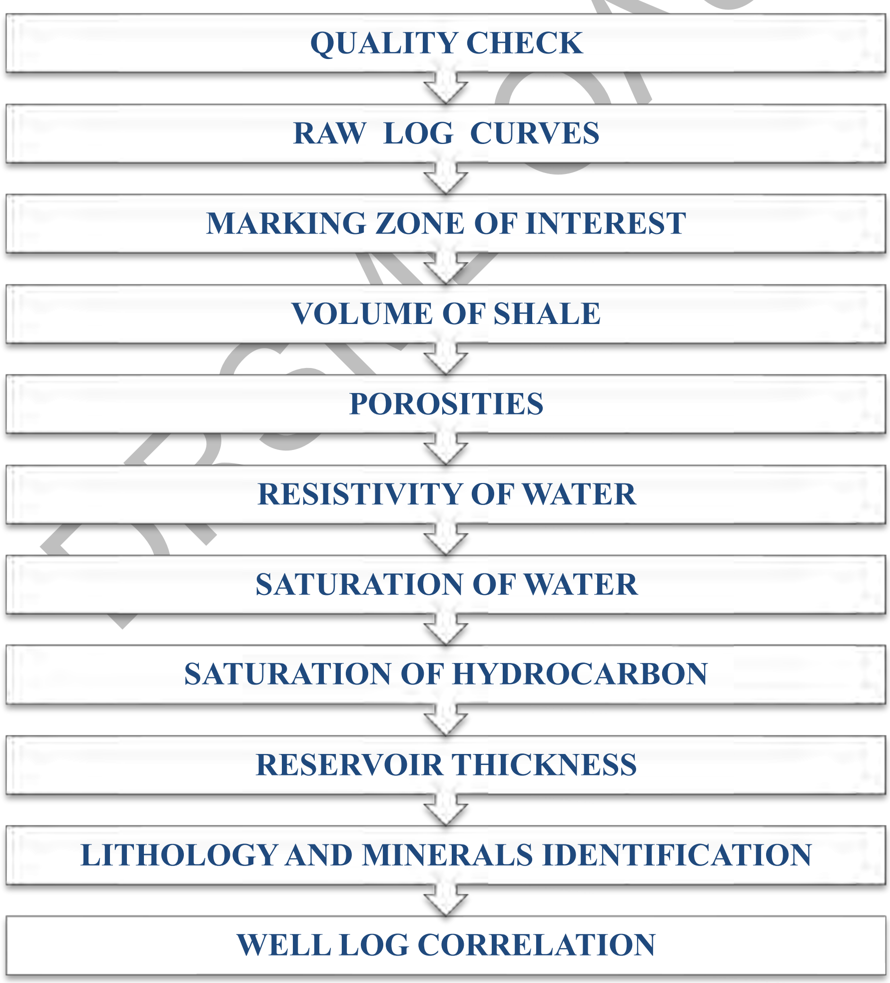

Figure 5.1. Flow chart of methodology for petrophysical analysis.

5.1 Quality check of logs

Quality of logs is about whether logs are readable and understandable or not. What is the behavior of caliper log which shows borehole conditions. Wether borehole is ongauge, overgauge or undergauge.

5.2 Log trend

The caliper, bit size, GR (Gamma Ray) and SP (Spontaneous Potential) are presented in track 01. The resistivity log readings are represented on a logarithmic scale in track 02. And the sonic, neutron and density logs are regulated in the track 03.

5.3 Zone of interest

The marking of the zone of interest is determined by the premise of low GR values, LLD and LLs separation and stable borehole conditions

5.4 Volume of shale (Vsh)

The volumetric analysis of dirt in the targeted zone is called the Volume of shale (Vsh). The analysis is executed by gamma ray logs. High radioactive content is represented by the increasing value of GR log which shows the extent of dirt in the lithology. Whereas, clean lithology is represented by the decreasing value of GR log which in turn, shows the lack thereof or the low concentration of radioactive content.

The estimation of Vsh is evaluated by the use of CGR (Computer Gamma Ray). The calculation is done by using the following equation.

$$V_{sh} = \frac{CGR_{log} - CGR_{\min}}{CGR_{max} - CGR_{min}}$$

Where

Vsh = Volume of shale

CGRlog = CGR reading of the formation

CGRmin = Minimum CGR

CGRmax = Maximum CGR

5.5 Average porosity

The percentage of pore space in a given volume of rock gives the amount of fluid contained by the rock. Usually, this calculation is made by collecting the information gathered by an instrument that evaluates the ration between the reaction of the rock and the bombardment of neutrons of gamma rays. But this information can also be extracted from sonic or neutron and density log as well as NMR logging.

5.6 Effective porosity

The all out porosity not exactly the small amount of pore space moved by either the dirt or shale is called the effective porosity. It depicts the pore space that consists of non-clay water and hydrocarbon. Total porosity becomes equal to effective porosity in dirt-free sand.

5.7 Resistivity of Water

In the evaluation of water saturation, the most sensitive parameter is called the resistivity of water.

5.8 Saturation of water and hydrocarbons

Water saturation is the fraction of pore space that consists of water and is represented by Sw. Similarly, saturation of hydrocarbon is the fraction of pore space that consists of hydrocarbons and is represented by Sh. 100% water saturation hints at the fact that hydrocarbons are non-existent in the interval while high hydrocarbon saturation is the indication of low water saturation. Amidst evaluation, the study of well water saturation was evaluated with the aid of Archie Equation.

$$Sw = \sqrt{((Rw/Rt) * (1/Ø_e\hat{}2))}$$

Rw = Resistivity of water

Rt = True resistivity

$Ø_e$ = Effective porosity

Hydrocarbon saturation are calculated by the formula.

Sh = 1-Sw

Where

Sh= hydrocarbon saturation

Sw=water saturation

5.9 Reservoir thickness

Net reservoir and net pay thickness are marked on the basis of average porosity, effective porosity and hydrocarbon saturation.

5.10 Identification of lithology and mineralogical composition

The mineralogical configuration and recognition of lithology is determined by the use of SGR and Neutron-density cross plot. To recognize the lithology and mineralogical configuration, the log data is charted on cross plots.

5.11 Quality check of logs

Well log data of PakG2-01, PakCan-01 and Indus Marine-1A is of bad quality. Most of logs are not readable and some data is missing through various depths. Neutron log data is missing in Indus Marine-1A well. Whereas sonic log is missing in PakCan-01 well. Moreover in certain zones due to poor borehole conditions the log data is found to be affected.

5.12 Log trend

In track 01 caliper, bit size, GR (Gamma Ray) and SP (Spontaneous Potential) logs are run. Caliper log displays that in all three wells the hole remained almost over gauged for most of the depth. GR log curves were found undulating, and gradual peaks were observed. In certain depths very high values were observed. The scale of GR log was 150 API. SP log curve showed little deflections in PakG2-01 whereas high and undulating deflection in PakCan-01 and Indus Marine-1A. Overall negative SP log trend was observed.

Track 02 consist of resistivity log and logarithmic scale used for this log. There was no to little deviations in resistivity curves and no separation was present between LLD (Deep Lateral Log), LLS (Shallow Lateral Log) and MSFL (Microspherically Focused Log) curves and showed low values.

Track 03 consists of sonic, neutron and density logs. In Indus Marine-1A neutron log is not present.

5.13 Results

The most dependable indicator of reservoir rock will be from the behavior of the density/neutron logs. Where the density will move to the left (lower density) and will touch or cross the neutron curve. The greater the crossover between the density and neutron logs, the better the quality of the reservoir and vice versa (Darling.T, 2005). However, gas zones will display a greater crossover for a given porosity than oil or water zones. On the other hand the corresponding values on the GR log will also be low showing the formation having less shale content. The resistivity readings in a hydrocarbon bearing formation will show low values of MSFL in the logarithmic scale as compared to LLS and LLD which are strongly influenced by the non-invaded zone. The above mentioned log trends can be seen in the reservoir zone of PakG2-01 and PakCan-01 marked in figure 5.2 and 5.3 respectively. The cutoff parameters used during the petrophysical analysis were V_{shale} 55%, Porosity 8% because reservoir with less than 8% porosity does not produce hydrocarbon, S_w 40% because above this percentage, the water does not allow hydrocarbon to flow because its density is higher. The zone of interest marked with figure is of Miocene age. Since the stratigraphy of Offshore Indus is not established, the name of the formation is unknown. Petrophysical analysis of Indus Marine 1-A cannot be performed due to the incomplete log data.

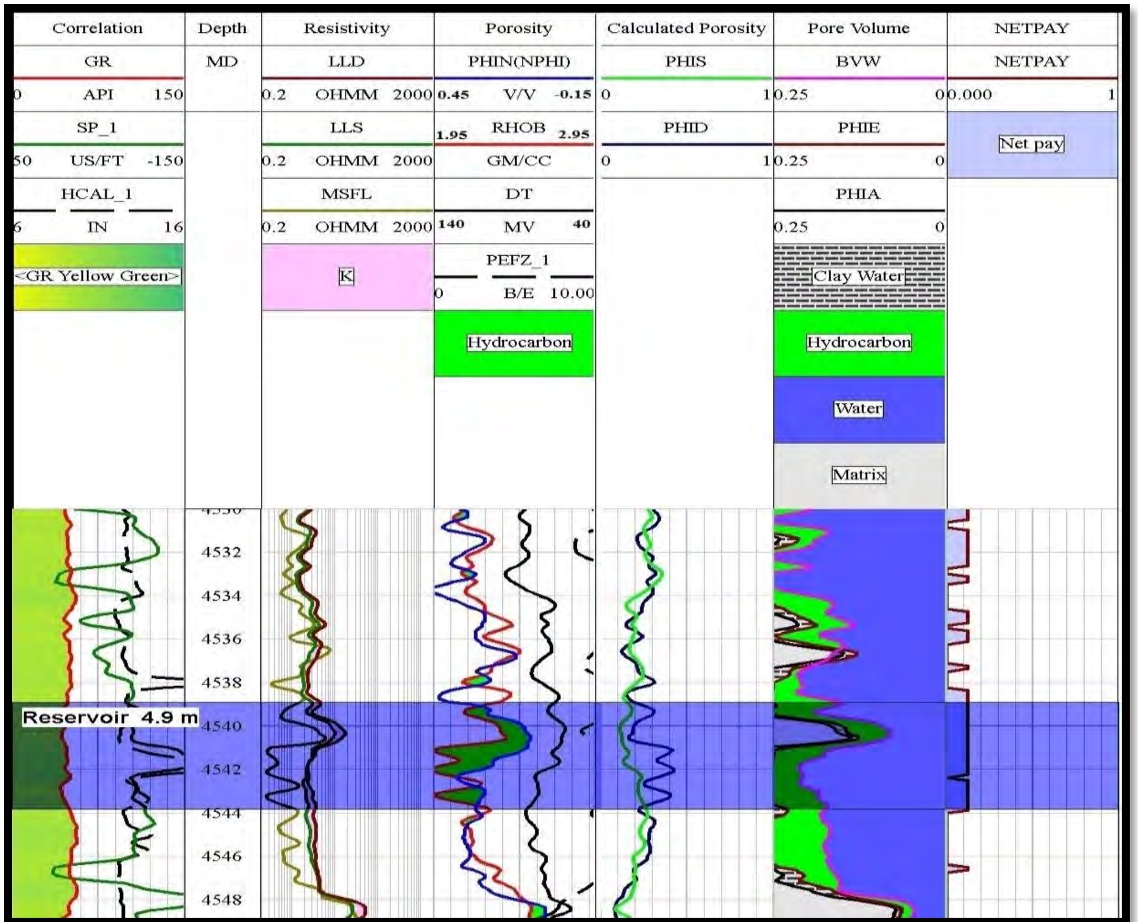

Figure 5.2. Petrophysical analysis of Pak G2-01.

Table 5.1. Final results of the calculations carried out on PAK G2-01 well.

Volume Of Shale (%)	Average Porosity (%)	Effective Porosity (%)	Avg. Water Saturation (%)	Avg. Hydrocarbon Saturation (%)
10.3%	18%	12%	59.9%	40.1%

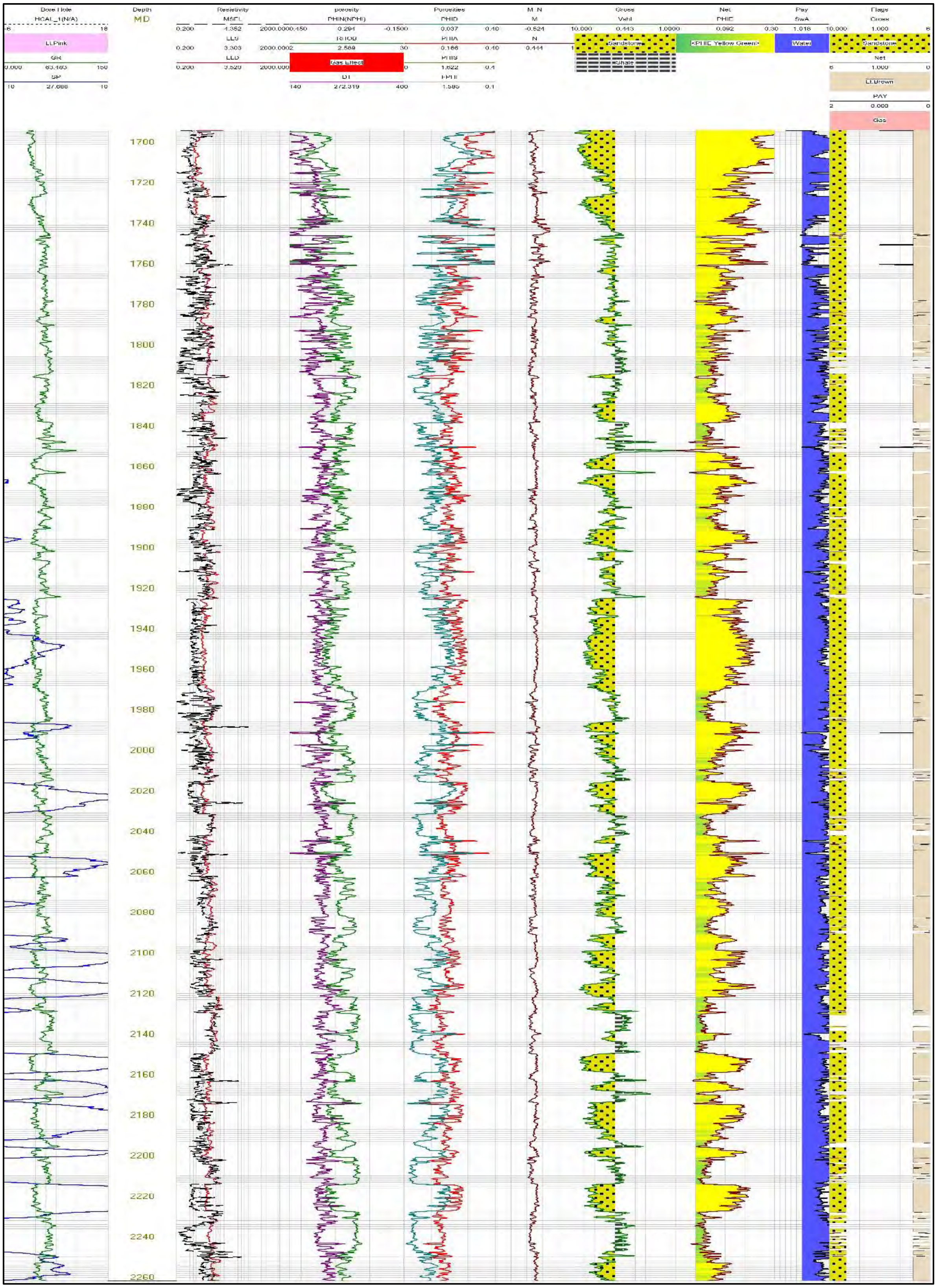

Figure 5.3. Snapshot of log showing zone 1 (1694-2262m) in Late Miocene Sands of PakCan-01 well.

Table 5.2. Various parameters calculated for the zone of interest.

Formation	Thickness of zone of interest (m)	Volume of shale (%)	Average porosity (%)	Effective porosity (%)	Saturation of hydrocarbons (%)
Late Miocene	568	33	21	14	6

5.14 Identification of lithology and mineralogical composition of PakG2-01

The lithology and mineralogical composition were identified using neutron-density and neutron-sonic cross plots. Well log values were plotted on cross plots to identify lithology and mineralogical composition.

5.14.1 Neutron-Density cross plot

Neutron and density log value are plotted on x-axis and y-axis respectively, which is used to identify the lithology of formation.

The neutron-density cross plot of the PakG2-01 well over the depth interval of 4432 m to 4712 m is shown in Figure 5.4. The majority of the Neutron and density log values are found in the calcite and dolomite regions, indicating that the carbonate deposit, which is Carbonates.

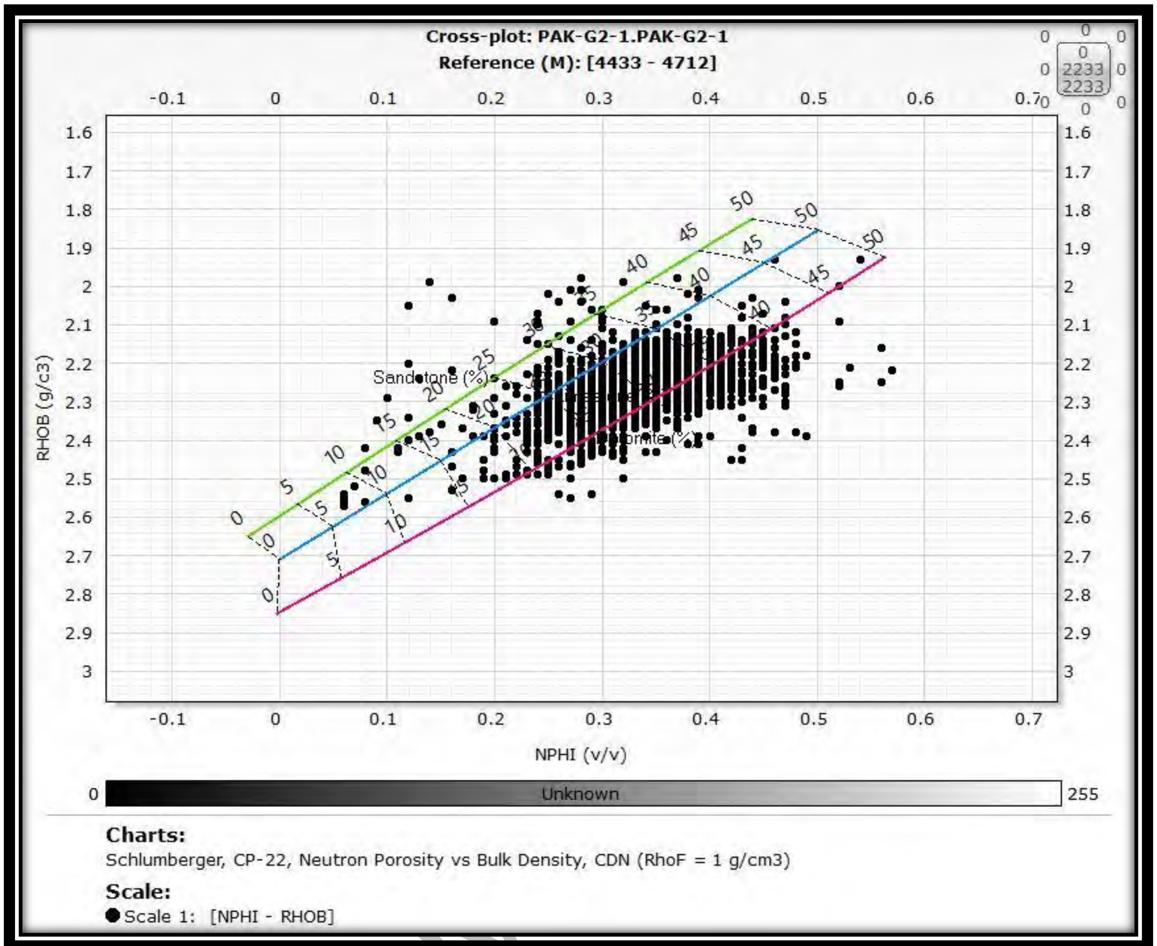

Figure 5.4. Neutron-density cross plot for lithology and minerals identification (Schlumberger log interpretation charts, 1997).

5.14.2 Neutron-Sonic cross plot

Neutron and sonic log value are plotted on x-axis and y-axis respectively, which is used to identify the lithology of formation.

The neutron-sonic cross plot of the PakG2-01 well for the depth interval of 4432 m to 4712 m is shown in Figure 5.5. The majority of the neutron and acoustic log values are found in the calcite and dolomite regions, indicating that the carbonate deposits, which is Carbonates.

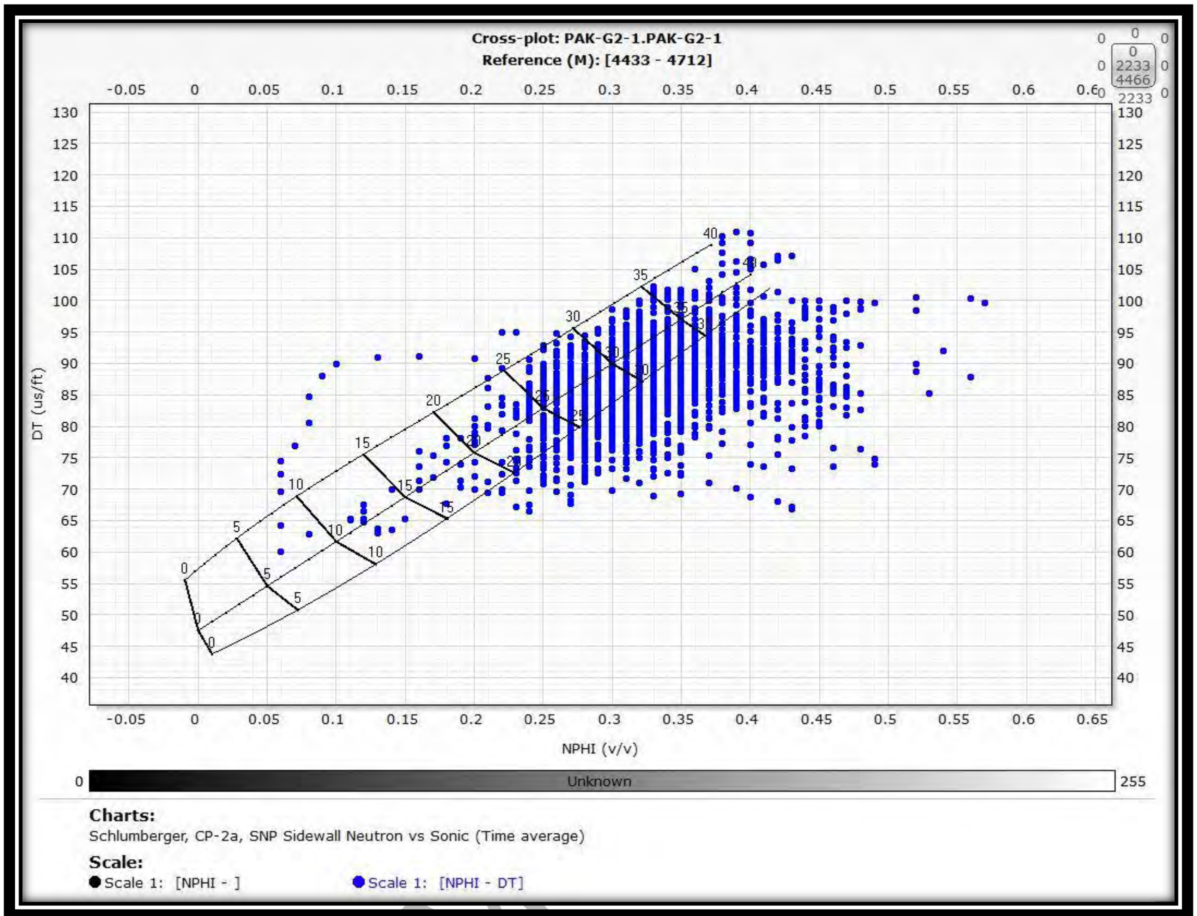

Figure 5.5. Neutron-density cross plot for lithology and minerals identification (Schlumberger log interpretation charts, 1997).

5.15 Well log Correlation

Well log correlation of three wells PakG2-01, PakCan-01, IndusMarine-1A has been done by using two logs GR log and Sonic log. PakCan-01 has been drilled 36km NE from IndusMarine-1A. Whereas, IndusMarine-1A has been drilled 181km NE of PakG2-01. All three wells are drilled far away from each other especially PakG2-01 from other wells. Petrophysical analysis of Indus Marine 1-A cannot be performed due to the incomplete log data. Overall quality of petrophysical parameters were good in all wells. The reason of it can be timing of petroleum system. The early generation of hydrocarbons and late structure formation or there can be absence of source which mean there is no source rock which generates the hydrocarbons.

Table 5.3. Correlation of various parameters calculated for wells.

Petrophysical Parameters	PakG2-01	PakCan-01
Volume of shale (%)	10.3	33
Average porosity (%)	18	21
Effective porosity (%)	12	14
Saturation of hydrocarbons (%)	40.1	6

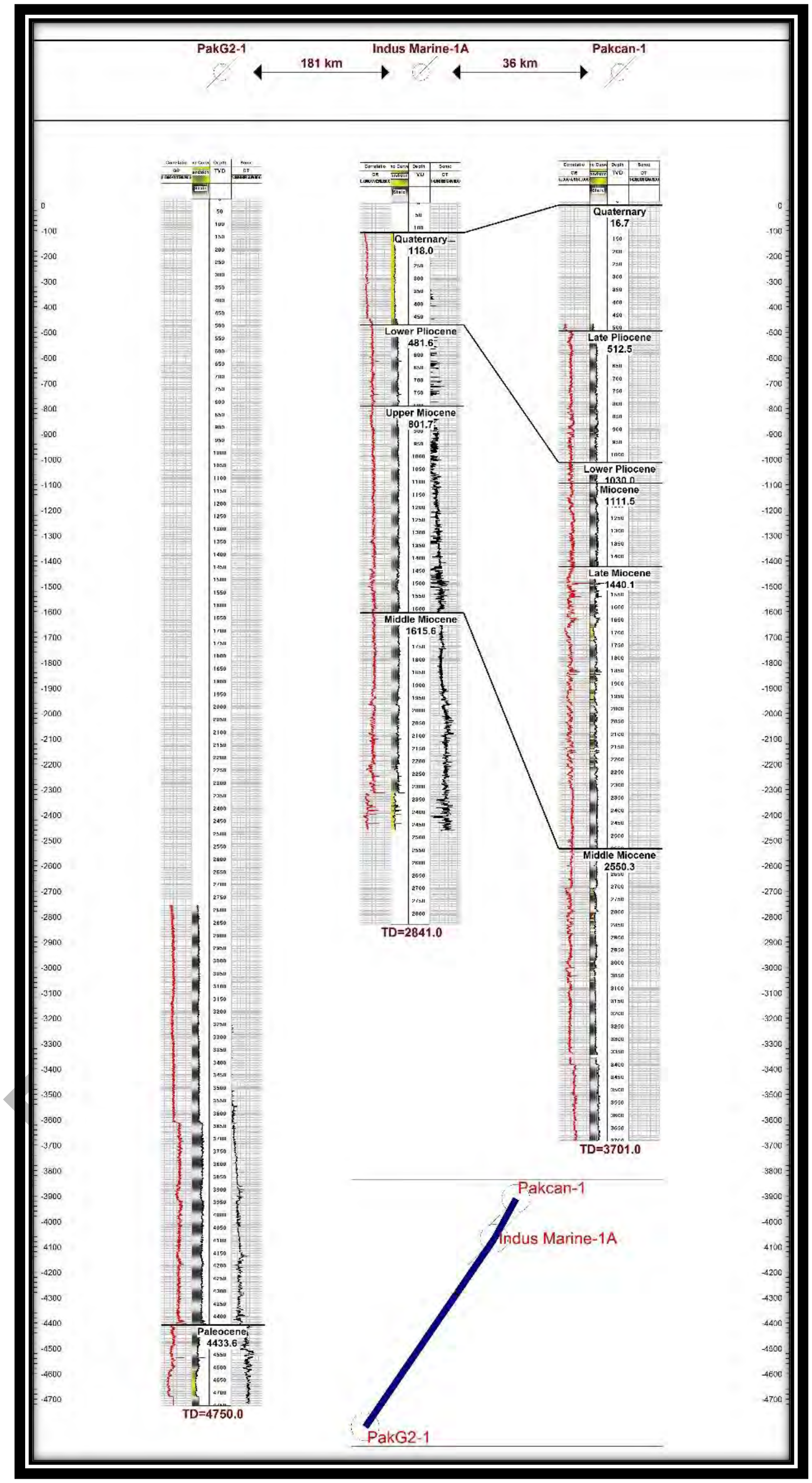

Figure 5.6. Structural well log correlation.

CONCLUSIONS

1) Seismic data interpretations has been used to identify parasequences, faults, stratigraphic lithologies, stratigraphic features (Channels, truncations and progradational patterns). Time and depth map used to locate the subsurface structures and horizons for petroleum exploration.

2) Parasequences has also been marked by GR log which has confirmed by sonic log. Based on the results, reservoir rock of Miocene age is present in the study area. Shales of Miocene age having high GR readings have the potential for acting as a seal rock.

3) In PakG2-01 and PakCan-01wells Miocene Sands acted as reservoir. Petrophysical analysis of Indus Marine-1A could not be performed due to incomplete log data.

4) Neutron-density and neutron-sonic cross were used for lithology and mineral identification for PakG2-01 well. It was found that log values spotted on calcite and dolomite region, which confirmed the lithology as Carbonates. Many values also spotted sandstone beds.

5) Well log correlation of PakG2-01, PakCan-01 and IndusMarine-1A has been done by using GR and sonic logs. Results tell that PakCan-01 has been drilled 36km NE from IndusMarine-1A. Whereas, IndusMarine-1A has been drilled 181km NE of PakG2-01.

6) Based on research integrated study of well logging and seismic enable us to interpret data in a better manner which helps for precise and truthful exploration of hydrocarbons.

RECOMMENDATIONS

1. Logging data should be plotted on per feet scale so that precise evaluation of the formations can be done and it will be easy to mark sweet spots, where further testing can be conducted.

2. Drilling practices should be modified so that borehole enlargement is minimum. Gauged borehole bears good quality data and requires low amount of cement after casing, further more interpretation and decision making is easy on good data as it truly represents the formation parameters. Slight washing out of the borehole wall can cause deterioration of the quality of formation density and neutron logs measurements. In the worst cases, borehole size enlargement can affect the accuracy of all logging measurements.

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