2D SEISMIC REFLECTION DATA INTERPRETATION, PETRO PHYSICAL ANALYSIS, AND FACIES ANALYSIS, USING SEISMIC AND WELL LOG DATA OF FIMKASSAR AREA UPPER INDUS BASIN, PAKISTAN

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CERTIFICATE OF APPROVAL

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بسم الله الرحمن الرحيم

"*In the Name of Allah, the Most Beneficent, the Most Merciful.*

All the praises and thanks be to Allah, the Lord of the 'Alamin (mankind, jinns and all that exists).

The Most Beneficent, the Most Merciful.

The Only Owner of the Day of Recompense (i.e. the Day of Resurrection)

You (Alone) we worship, and You (Alone) we ask for help.

Guide us to the Straight Way...

The Way of those on whom You have bestowed Your Grace, not (the way) of those who earned Your Anger, nor of those who went astray.

(The Qur'an- Surah Al-Fatihah)"

DEDICATION

I would like to dedicate this thesis work to my parents, whose love, encouragement, guidance and prays make me able to achieve such success and all those who helped me for completing this work.

ACKNOWLEGMENT

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no God but Allah and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

I am indebted to my honorable supervisor **Dr. FAISAL REHMAN** for giving me an initiative to this study. He helped me in all aspects of work, moral and technical support which was very valuable for my work.

I also wish to thank the whole faculty of my department for providing me with an academic base, which has enabled me to take up this study I pay my thanks to the employees of clerical office who helped me a lot and all those their names do not appear here who have contributed to the successful completion of this study.

I specially acknowledge the prayers and efforts of my whole family, especially my parents, my brothers and sister for their encouragement, support and sacrifices throughout the study. I would like to thank all my friends for always being there for me whenever I wanted.

ABSTRACT.

The dissertation work includes seismic data interpretation, Petro physical analysis and facies analysis using well logs data.

Seismic and well log interpretation used for study of structural style, physical properties of rocks and identification of possible petroleum system of Fimkassar area (Upper Indus Basin) Pakistan.

Petrophysical analysis of wells Fimkassar-02 is carried out for Sakesar Formation to depict the probable hydrocarbon producing reservoir. The results suggest that the Sakesar Formation are more producing. The lower part of Sakesar Formation shows indication of maturity or reservoir rock.

Seismic facies results show that there are three lithologies limestone, limestone inter bedded with shale and shale. This is because the values of logs used are obtained only from reservoir. The reservoir is Sakesar and it is limestone it confirms our interpretation as in hydrocarbons resistivity values should be high and the density value should be less.

CHAPTER 1

1.1 INTRODUCTION

Seismic exploration method is used in hydrocarbon exploration; no doubt hydrocarbon exploration is a backbone for economy of any country, especially developing countries like Pakistan. As the energy demand increases, exploration sector catches their eyes over unexplored areas for new energy resources excavation. The dissertation comprises of exploration result in Fimkassar oil field which lies in Chakwal city Punjab province. Geophysicists have been trying for hydrocarbon exploration since a long time ago and developed many techniques in this regard. Seismic method is direct result evaluating and accurate geophysical method used for structural analysis. Seismic Reflection Method most used in hydrocarbon exploration in petroleum geology. Petroleum system mainly comprises of three constituents that are enlisted below. Source rocks (contains organic materials which for responsible for generation of hydrocarbons). Reservoir rocks (migration of hydrocarbons takes place from source rock and reservoir rock offers suitable conditions for their accumulation). Seal or trap rocks (act as a barrier it stops upward movement of hydrocarbons). Investigation of earth through geophysical method involves taking measurement to check the variation in the physical properties of the earth both laterally and horizontally to interpret structure you can say petroleum play more precisely. Petrophysics is one of the most important and reliable technique in the field of the earth sciences. Petrophysics provide the link between the rock properties i.e. lithology, water saturation, porosity, clay content, acoustic impedance, primary and secondary wave velocity, and elastic moduli. After obtaining petrophysics results we get more clear understanding of rock properties and detect more meaningful results.

1.2 EXPLORATION HISTORY OF FIMKASSAR OIL FIELD

Fimkassar oil and gas field is located about 75 kilometers Southwest (SW) of Islamabad, in the northern Pakistan. The field was discovered in 1980 by Gulf Oil Company (GOC), which drilled a well named, the Fimkassar-1X. The Fimkassar field produces, from Eocene limestone of Sakesar and Chorgali Formations. These Formations are deformed in an anticlinal structure known as the Fimkassar Structure. Because of low production, 20 barrels of oil per day, the field was declared non-commercial field and was sold to a National company of Pakistan, Oil and Gas

Development Corporation Limited (OGDCL). OGDCL drilled a well named, Fimkassar-1A but the well was abandoned due to technical problems. The Fimkassar-1X borehole was re-entered and sidetracked; this well was renamed as Fimkassar-1-ST. Fimkassar-1-ST was the highest oil volume producer well and it produced about 4,000 barrels/day. In 1990, well named as Fimkassar-2 was drilled. This well initially produced 1960 barrels of oil per day. Due to decrease in Formation pressure and consequently decrease in production, an injection well named as Fimkassar-3 was drilled. In 2004, a well named as Fimkassar-4 was drilled but it produced very low quantity of oil, therefore the well was plugged and abandoned. Fimkassar is an unusual play as it produces oil and gas from a very stiff limestone that have very low porosity and permeability. Epigenetic process of dolomitization creates porosity values of 25% (Malik et al., 1988), whereas tectonic deformation of the Fimkassar structure has created fractures through which hydrocarbons can migrate. Mianwali (Triassic), Datta (Jurassic), and Patala (Paleocene) Formations are major source of oil at Fimkassar field (Khan et al., 1986). The Shales of Murree Formation provide a seal for hydrocarbon catch for underlying reservoirs of Eocene age.

1.3 GEOGRAPHICAL LOCATION

The Fimkassar field is in the eastern part of the Potwar basin and is approximately 75 kilometers SW of Islamabad. Geographically, Fimkassar field is in Chakwal district of Punjab province (Fig 1.1). Geologically it is in eastern part of Potwar Basin, Upper Indus basin, bounded by Soan syncline in the north, Salt Ranges in the south, Jhelum fault in east and Kalabagh fault in west (Siddiqui et al.,1998).

Fig 1.1 Satellite image of Fimkassar area

1.4 OBJECTIVES OF DISSERTATION

The main objective of dissertation is to present a subsurface model, estimates the reservoir properties. All objectives are stated below in points.

Detailed seismic interpretation for identification of the structures favorable for hydrocarbon accumulation.

Petrophysical analysis for the identification of the reservoir types and various petrophysical properties of reservoir encountered in study area.

Rock physics and facies modelling of the reservoir.

1.5 DATA USED

To carry out this thesis, seismic reflection data and well data was provided by the permission of Directorate General of Petroleum Concessions Government of Pakistan (DGPC).

Seismic Lines	Direction
0884-FMK-106	Strike Line
0884-FMK-103	Dip Line
0884-FMK-107	Dip Line

Table 1.1 Seismic Lines

Well Names	Status of Wells	Discovery
TURKWAL-01	Exploratory	Oil
FIMKASSAR-02	Development	Oil & Gas

Table 1.2 Wells

1.6 SOFTWARE TOOLS USED

To complete project SMT KINGDOM 8.8 software were used.

CHAPTER:2

GEOLOGY AND STRATIGRAPHY

2.1 Introduction

Geological and structural knowledge of the area is a key for interpreter to perform precise interpretation of seismic data. The main reason behind that, in many cases similar signature is obtained from different lithologies and vice versa. To deal with such complexities an interpreter must have background knowledge of geology about the area and its stratification, unconformities, and major structures of area under study (Kazmi & Jan 1997). This chapter deals with a brief description of tectonics settings, structural geology and stratigraphy of area under study.

2.2 Regional Settings and Tectonics of Pakistan

In late Paleozoic, Pangaea split into two parts. The northward drift of Indian plate started in late Mesozoic time (Cretaceous) and continued till late Eocene. When the plate collided with Kohistan Island arc the Island arc formed because of calcium alkaline activity in the subducting oceanic crust during Cretaceous time. This northward drift finally resulted in formation of Himalayas Mountains. Pakistan acquired its structural and stratigraphic features from tectonic events associated with plate movements, which occurred from late Paleozoic time to present (Kazmi & Jan 1997).

From Permian through middle Jurassic time, the area known today as Indus Basin was in the southern hemisphere. Pakistan comprises of the main geological subdivisions referred as Eurasian, Tethyan and Gondwanaland domain. On this scenario Pakistan is unique in as much as it lies at the junction of two convergent Indian and Eurasian plate. The southern part belongs to Gondwanian domain and is sustained by Indo-pak crustal plate. The northern and western regions of Pakistan fall in Tethyans domain and present a complicated geology and complex crustal structure (Kazmi & Jan 1997).

2.3 Tectonic Basins of Pakistan

Basin is an area characterized by regional subsidence and in which sediments are preserved for longer period. Pakistan comprises of three basins.

Indus basin

Baluchistan basin

Pasheeen basin

2.3.1 Indus Basin

The Indus basin belongs to extra continental down wrap. The basin has elongated shape and is oriented in Northeast and Southwest direction. The main tectonic features of Indus basin are the platform, for deep comprising depressions, inner folded zone and outer folded zone (Kazmi & Jan 1997).

Indus basin is divided into Compression regime in upper Indus basin, Basement uplift in central Indus basin and Extensional regime in lower Indus basin. Based on structure Indus basin is subdivided into two parts

Upper Indus Basin (North)

Lower Indus Basin (South)

Upper Indus basin is in Northern Pakistan and separated from lower Indus basin by the Sargodha high. In its North Main Boundary Thrust, while in the East and West strike slip faults Jhelum and Kalabagh are located, respectively. Upper Indus basin is subdivided into two parts.

Potwar basin

Kohat basin

2.4 Potwar Plateau

Topography of potwar plateau is undulating where series of valleys and parallel ridges are present having general trend in E-W direction. According to geology it forms foreland zone of N-W thrust belt and Himalayan fold. Molasses of age Miocene to Pleistocene covered potwar basin. In south along the ranges Precambrian to tertiary sequence is exposed.

2.4.1 Structure of Potwar

The overall structural trend in study area is east to west or northeast to southwest. Anticlines are separated by synclines in East Potwar salt core. Due to strike slip movement these structures are formed. These structures (Anticlines, Synclines) are mostly bounded by hinterland and foreland verging faults, popup zones. The northern part is more intensively deformed called North Potwar Deformed Zone (NPDZ).

NPDZ is followed to the south by soan syncline which is gently northward dipping southern flank along the salt range and steeply dipping northern limb along NPDZ. Several east-west broad and gentle folds are present in its Western part. Strike abruptly changes to North-East in its Eastern part and tightly folded anticline and broad syncline structures are present.

Axial zone of most anticline dip steeply or overturned (Pennock et al., 1989). Thrust wedge has been transported southward as a coherent slab with little internal deformation in the western and central Potwar, and less than 1 Km shortening between NPDZ and salt range (Bakar et al,1988). Deformation has been reduced in size due to increase basal traction and fault cut up section in Eastern Potwar, in contrast, the, producing different structural style characterized by fault-folds, triangles and pop-up zone in this region 24 Km of shortening has occurred (Pennock et al., 1989). Without significant involvement of basement tectonic in the Potwar is thin skinned tectonic (Kazmi & Jan 1997).

2.4.2 GEOLOGICAL BOUNDARY:

The Potwar is bounded by the following two strike-slips and two thrust faults which are.

Kalabagh Fault.

Jhelum Fault.

Salt Range Thrust.

Main Boundary Thrust.

KALABAGH FAULT:

It is right lateral strike-slip fault, and its direction is from north to west 150 km which is faulted block. It lies in the north of the Kalabagh City, Mianwali and is the TransIndus extension of Western Salt Range (McDougal & Khan, 1990).

JHELUM FAULT:

Extending from Kohala to Azad Pattan the Murree is hanging while Kamlial, Chingi and Nagri Formations are footwall. Starting from the Indus-Kohistan to Ravi it is the active aspect of the Indian Shield. It is seen also in the map that MBT, Panjal Thrust and HFT cut shortened by left-lateral reverse Jhelum Fault in west.

SALT RANGE THRUST:

It is also known as Himalayan Frontal Thrust. Salt range and Trans-Indus Himalayan ranges are the foothills.

MAIN BOUNDARY THRUST:

The MBT which lies in the north of the Islamabad is called as Murree fault. The western part of this fault is orienting to north east forming non-striking fault in its western part i.e. Hazara Kashmir-Syntaxes (Latif, 1970; Yeats and Lawrence, 1984: Greco, 1991) also this fault strike the direction of east moving in the direction of Southern side of Kalachitta Range and North of Kohat plateau (Meissner et at, 1974).In Potwar the structure trend is east to west or northeast to south west end mostly large surface anticlines are bounded by the thrust or reverse faults. The structure of Potwar basin is affected by compressional forces, basement slope, and variable thickness of Pre-Cambrian salt over the basement, and deposition of very thick molasses and tectonic events. In Potwar basin some surface features mismatch subsurface structures due to decollements at different levels. In such circumstances, it is necessary to integrate seismic data with surface geological information for precise delineation of sub-surface configuration of various structures (Moghal et al, 2003).

Tectonic of the potwar plateau is controlled mainly by the following factors:

1. Slope of the basement (steeper in western Potwar Plateau).

2. Thickness of the Eocambrian evaporates beneath the cover.

3. Reactivation of basement brittle tectonics (more enhanced in the eastern Potwar Plateau).

In Potwar, the EoCambrian evaporate sequence is overlain by Cambrian rocks of Jhelum Group which comprises Khewra Sandstone, Kussak, Jutana, and Bhaganwala Formations. From middle Cambrian to Early Permian the Jhelum group consist of limited deposition or erosion and the strata from these periods are missing in Potwar sub-basin. The continental depositional environmental of Nilawahan group of early

Permian is bounded to the eastern part of Potwar/Salt Range. According to the interpretation of seismic in structures in Potwar region may be divided into. Pop-up anticlines Snake head anticlines Salt cored anticlines.

2.5 Structural Features

The following structural features are found in study area (Pennock et al., 1989).

Tanwin Anticline

Domeli Thrust

Adhi-Gungril Anticline

Chak-Naurang Anticline

Soan Syncline

Jhelum fault

The Salt Range Thrust

Popup anticline

Triangle zone

Salt cored anticline

2.6 STRATIGRAPHY OF THE AREA:

The stratigraphic column is divided into three unconformity-bounded sequences. These unconformities in the study area are Ordovician to Carboniferous, Mesozoic to Late Permian, and Oligocene in age. These unconformities are difficult to identify in the seismic profiles due to complicated thrusting. The Potwar sub-basin is filled with thick infra-Cambrian evaporite deposits overlain by relatively thin Cambrian to Eocene age platform deposits followed by thick Miocene-Pliocene molasse deposits. This whole section has been severely deformed by intense tectonic activity during the Himalayan orogeny in Pliocene to middle Pleistocene time. The oldest Formation penetrated in this area is the Infra- Cambrian Salt Range Formation which is dominantly composed of halite with subordinate marl, dolomite, and shale. The Salt Range Formation is best developed in the Eastern Salt Range. The salt lies unconformably on the Precambrian basement. The overlying platform sequence consists of Cambrian to Eocene shallow water sediments with major unconformities at the base of Permian and Paleocene. The Potwar basin was raised during Ordovician to Carboniferous; therefore, no sediments of this time interval were deposited in the basin. The second sudden alteration to the sedimentary system is represented by the complete lack of the Mesozoic sedimentary sequence, including late Permian to Cretaceous, throughout the eastern Potwar area. In Mesozoic time the depocenter was in central Potwar, whereas thick Mesozoic sedimentary section is present. A major unconformity is also found between the platform sequence and overlying molasses section where the entire Oligocene sedimentary record is missing. The molasses deposits include the Murree, Kamlial, Chinji, Nagri, and Dhok Pathan Formations Rock units ranging in age from Infra - Cambrian to Cambrian are exposed in the Potwar Province of the Indus basin where the Salt Range Formation with salt, marl salt seams and dolomite is the oldest recognized unit through surface and subsurface geological information and forms the basement for the fossiliferous Cambrian sequence. Since the complete section of Salt Range Formation has not been observed in any of the wells of Potwar sub-basin and the Formation is not completely exposed along the Salt Range, it was therefore, assumed in the past that the Salt Range Formation is the oldest rock unit overlying the Pre-Cambrian basement. Extent of these Formations toward north and examination of seismic data indicate that the mentioned Formations may also be present in the eastern Potwar region.

2.7 PETROLEUM PROSPECT:

The petroleum prospect of the Area tells us about the Source Reservoir and seal Mechanism. The Stratigraphic column of the area shows different rocks act as Source, reservoir and Cap rock in the area.

2.7.1 SOURCE ROCKS:

Source rock is the productive rocks for hydrocarbons; these rocks also initiate the conversion of organic compound into oil and gas. The Formations which act as source rocks in the study area are as follow.

PATALA FORMATION:

The Patala Formation overlies the Lockhart Formation conformably and its type of section is in the Patala Nala in the Western Salt Range. It consists largely of shale with sub-ordinate marl, limestone and sandstone. Marcasite nodules are found in the shale. The sandstone is in the upper part. The Formation also contains coal and its thickness ranges from 27m to over 200m (Warwick, 1990). It contains abundant foraminifera, molluscs and ostracods. The age of the Patala Formation is Late Paleocene.

2.7.2 RESORVOIR ROCKS:

The main reservoir rocks in the study area are lower Chorgali and Sakesar Formations.

SAKESAR FORMATION (EOCENE):

With increase in limestone beds, the Nammal Formation transitionally passes into the overlying Sakesar Formation, the type locality of which is the Sakesar Peak (Pennock & Yousaf, M. (1989)). It consists of grey, nodular to massive limestone, which is cherty in the upper part. Near Daudkhel, the Sakesar Formation laterally grades into massive gypsum. Its thickness ranges from 70m to about 450m. Its age is early Eocene.

CHORGALI FORMATION:

The Chorgali Formation rests conformably over the Sakesar Formation (type locality Chorgali Pass) (fatmi, 1984). It consists largely, in the lower part, of thin bedded grey, partly dolomitized and argillaceous limestone with bituminous odor, and in the upper part, of greenish, soft calcareous shale with inter beds of limestone. It contains molluscs, ostracods and foraminifera.

2.7.3 TRAP OR SEAL ROCKS:

In potwar basin both structural and stratigraphic traps are available. In study area the associated structures are pop up anticlines and snaked head structures. The seal is provided by Murree Formation.

MURREE FORMATION:

The Murree Formation of Miocene age provides a lateral and effective seal to reservoir rocks. The Murree Formation consists of clay and shale both lithologies act as a good seal rock.

Fig 2.1

Geological-framework-and-generalized-oil-and-gas-field-of-Potwar-Basin-in-northern.

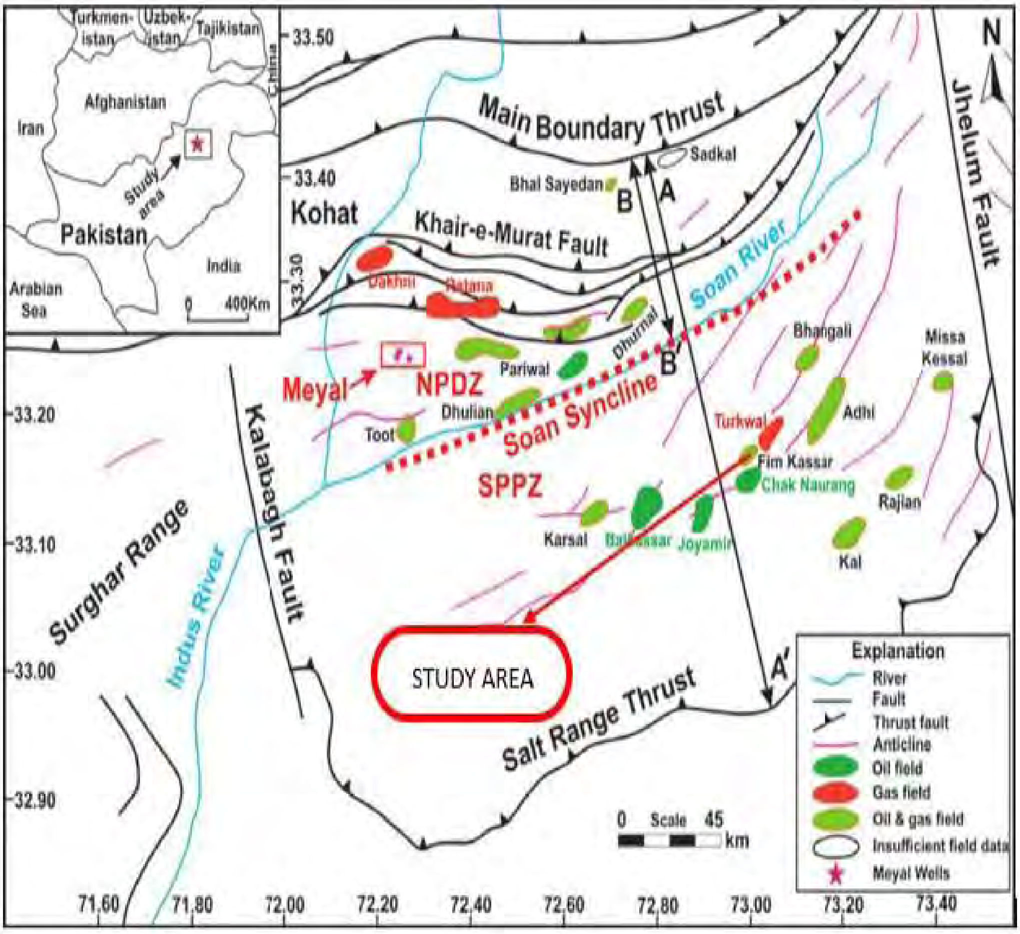
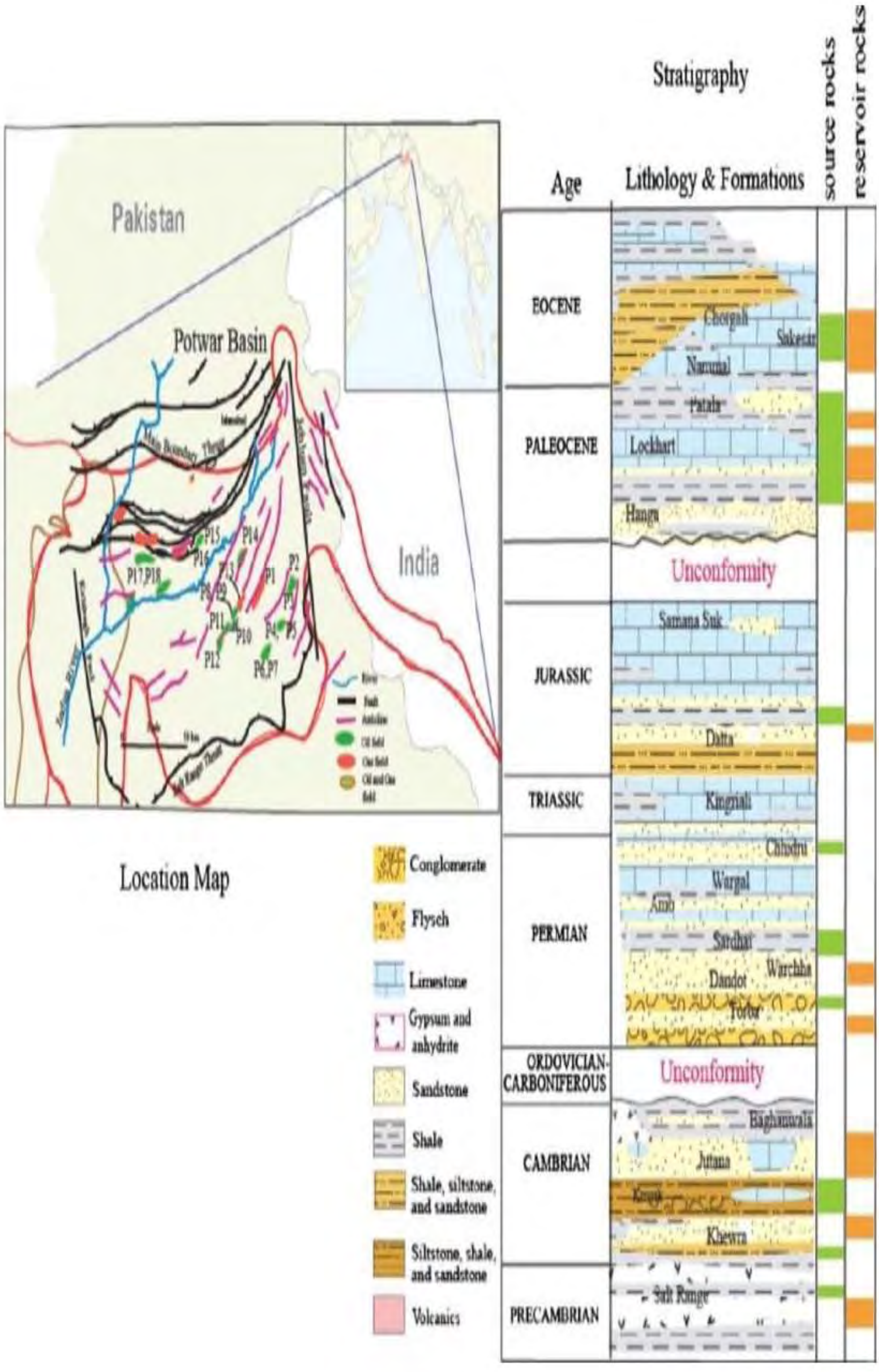


Fig 2.2

General-Stratigraphy-of-Potwar-Sub-Basin



CHAPTER 3

Seismic interpretation

3.1 Introduction

Seismic interpretation implies picking and tracking seismic reflectors on basis of lateral continuity for the purpose of identifying geologic structures, stratigraphy, and petroleum play. The goal is to portray hydrocarbon accumulation and their extent by keeping economic factor in mind also calculates their volume as well. Conventional seismic interpretation is an art that requires skill and experience in geophysics and geology. (Badley 1985).

The Seismic data interpretation is the method of determining information about the subsurface of earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells or guide development of an already discovered field (Coffeen, 1986). According to (Badley 1985), such reflections and unconformities are to be mapped on seismic section, which fully describe the geology and hydrocarbon potential of the area. If the horizon of interest is not prominent and it is difficult in tracing it over the whole area, it is advisable to pick additional horizons above and or below the target horizon. This helps in understanding the trend and behavior of the target horizon in the zones where its quality is not good enough to be picked with confidence.

Final objective of interpretation is conversion of seismic section into a geological section which provides a somewhat realistic subsurface picture of that area, both structurally as well as strati graphically. (Badley, 1985).

In this dissertation seismic interpretation technique for subsurface structural analysis has been used. Seismic interpretation has been done with the help of IHS Kingdom 8.8.

3.2 Seismic Interpretation

Transformation of seismic reflected data into a structural picture by the application of corrections, migration and time depth conversion is called Seismic Interpretation. (Dobrin and Savit, 1988) Seismic Interpretation is very complex process. It includes many problems and difficulties. These problems and difficulties vary from area to area every area so the approach used for an area would not work on other areas.

Because of this reason an interpreter must be familiar with an area on which he is working. Due to its extensive application Seismic work is very important in the exploration for petroleum. Almost all the major oil and gas companies rely on seismic work for selecting the sites for oil wells. (Telford and Geldart, 1999).

3.3 Methods of Interpretation

There are two main approaches for the interpretation of the seismic reflection data.

Qualitative Interpretation

Quantitative Interpretation

3.3.1 Qualitative interpretation

Mapping the subsurface geology is the primary objective of the qualitative interpretation of the seismic data. Qualitative interpretation is seismic technique that includes the marking of horizontally consistent reflectors and discontinues and their mapping on different scales (space and travel time). The geometry on the seismic section is accurately interpreted according to geological concept to find out hydrocarbon's accumulation.

The structure and stratigraphic structure of the petroleum is determined and on base of the geometric features the location of the well is established. Stratigraphy analysis is used to delineating the seismic sequences, which tell us about different depositional units, find out the seismic facies characteristic with gave us information about depositional environment and analysis the reflection feature variation to locate the stratigraphy changes and hydrocarbon depositional environment (Sheriff, 1999).

In structural analysis focus is on the structural traps. Tectonic plays an important role in traps. Tectonic setting usually tells us, which types of the structure are present and how the structural features are correlated with each other's, so tectonic setting of the area is helpful for locating the traps. Structural traps include the faults, folds anticline, pop up, duplex, horsts and graben structures, etc. (Sheriff, 1999).

3.3.2 Quantitative interpretation

Seismic quantitative interpretation technique as compared to the traditional seismic interpretation technique is more useful. One advantage of these unconventional techniques is that they make prospect generation easier by widening the exploration area. Various alterations in these techniques have contributed to the better prospect's evaluation and reservoir characterization.

The most important of these techniques include post-stack amplitude analysis (bright-spot and dim-spot analysis), off-set dependent amplitude analysis (AVO analysis), Acoustic impedance inversion, and forward seismic modeling. Base map is prepared by loading navigation data and seismic data (seg Y). Horizons are marked in zone of interest manually. In this process faults are identified and marked. Faults polygons are generated, and horizons are contoured to find out structural highs and lows. Then time and depth contours are plotted.

3.4 Steps of Interpretation

The following steps were followed for interpretation purpose.

Preparation of base map

Generation of synthetic seismogram

Fault identification and marking

Horizon marking

Contour map generation

Interpretation

3.5 Base map:

Base map is a map which shows orientation and location of the seismic lines and wells (TURKWAL-01 in green and FIMKASSAR-02 in pink color). The map consists of dip and strike lines as shown in figure 3.1.

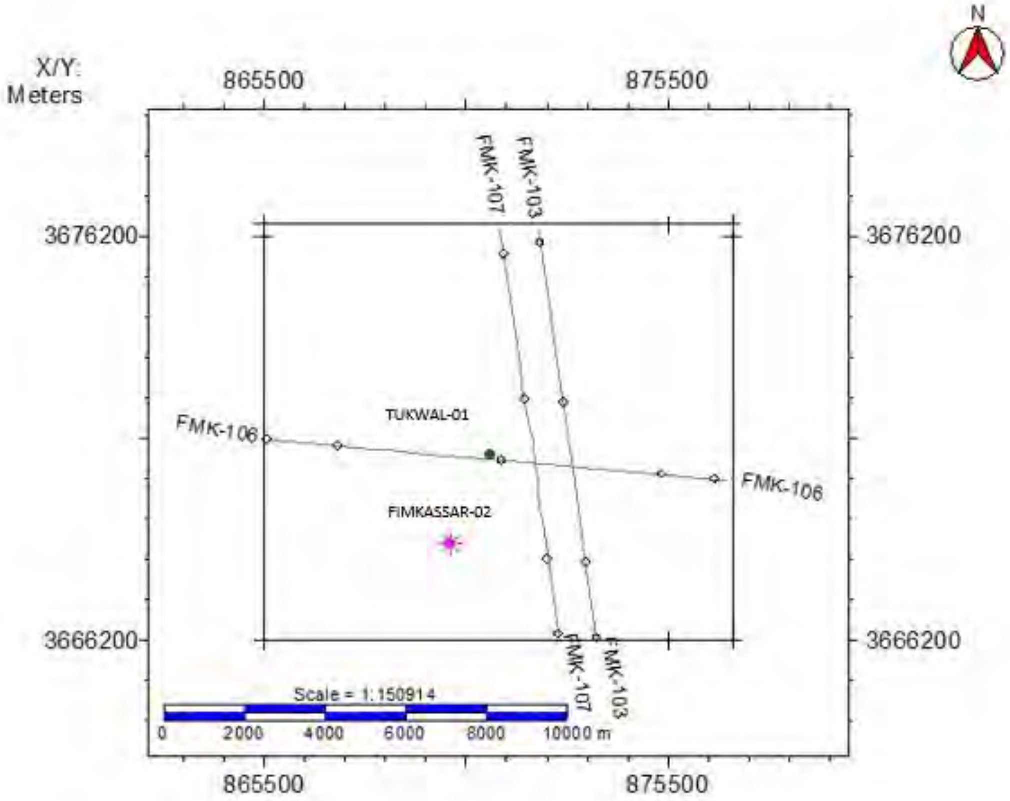


Fig 3.1 Base Map

3.6 Generation of Synthetic Seismogram

The more control the geoscientist has in mapping the subsurface, the greater the accuracy of the maps. Control can be increased by the correlation of seismic data with borehole data. The synthetic seismogram is the primary means of obtaining this correlation. Velocity data from the sonic log (and the density log if available) are used to create a synthetic seismic trace. This trace closely approximates a trace from a seismic line that passes close to the well in which the logs were acquired. The synthetic then correlates with both the seismic data and the well log from which it was generated.

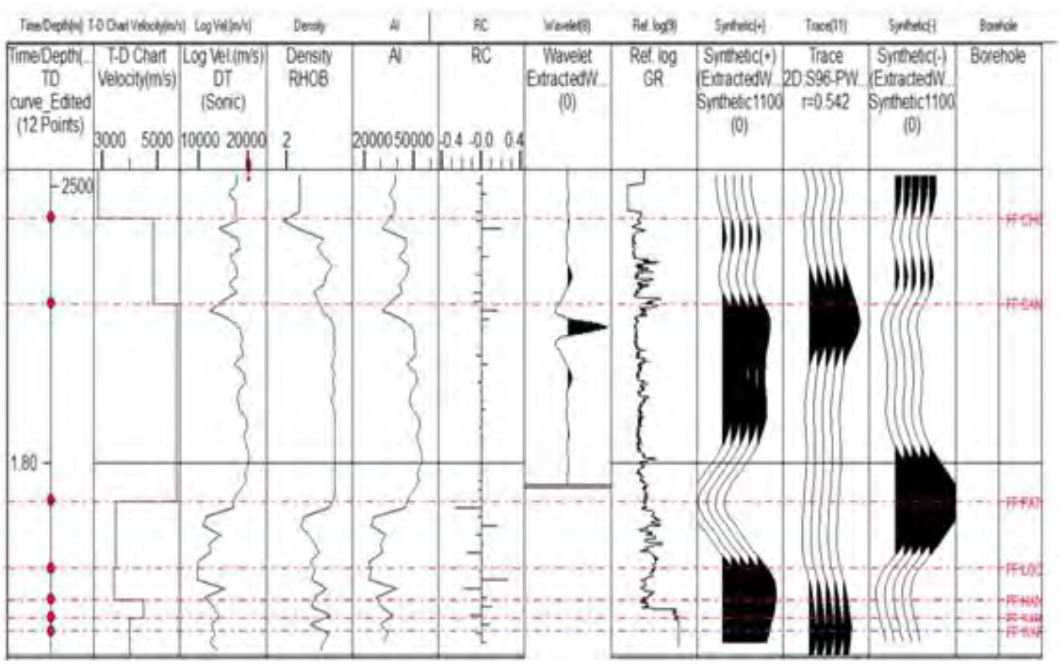


Fig 3.2 Synthetic Seismogram of Turkwal-01

3.7 Interpretation of seismic lines:

It includes following steps.

3.7.1 Marking of Seismic Horizons:

Primary task of interpretation is the identification of various horizons as an interface between geological Formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required (McQuillin, et al., 1984). Thus, during interpretation process; I mark both, the horizons and faults on the seismic section. Three horizons are picked based on available information (well data and generalized stratigraphic map). The horizons picked are named on basis of well top of the Turkwal-01 the Chorgali, Patala and hangu showing high reflections on a seismic section making it easier to be picked.

3.7.2 Fault and folds Identification:

To identify faults and folds it is important to have background knowledge about the geology of the area. Geology of the Area: Based on the geology of the area, it is evident that the area under study lies in compressional regime. This background knowledge helps us to identify that reverse and thrust faults should be marked on the seismic section.

3.8 Interpreted Seismic Sections:

The two dip lines i.e., 884-FMK-103, 884-FMK-107 are interpreted are shown in figure 3.3and figure 3.4, respectively. Three seismic horizons namely, Chorgali, Patala and Hangu based on well tops are marked. Along these seismic horizons one fault is also picked shown in figures.

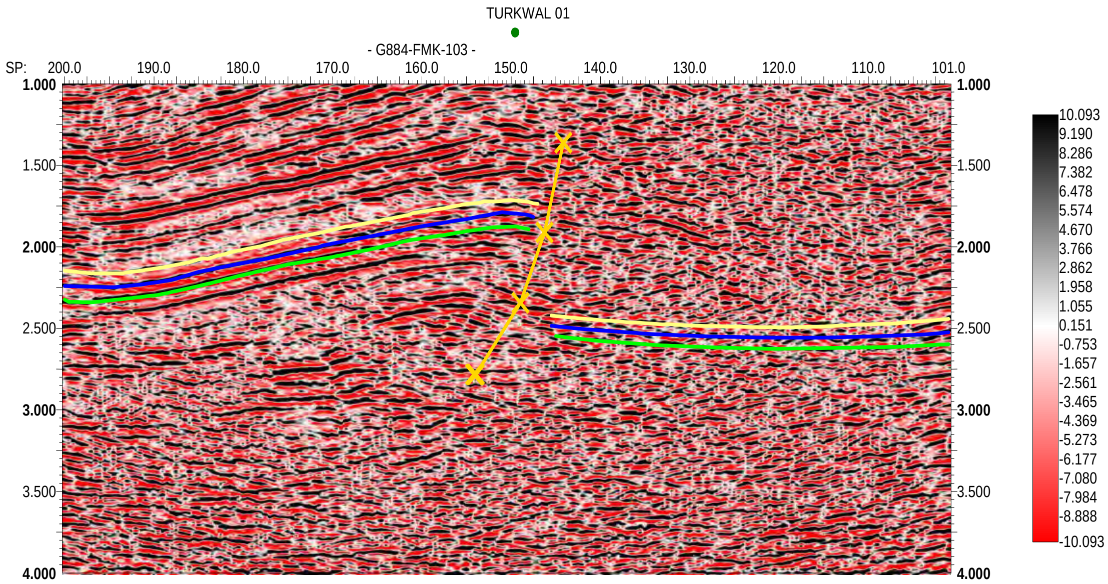


Fig 3.3 Interpretation of seismic line G884-FMK-103

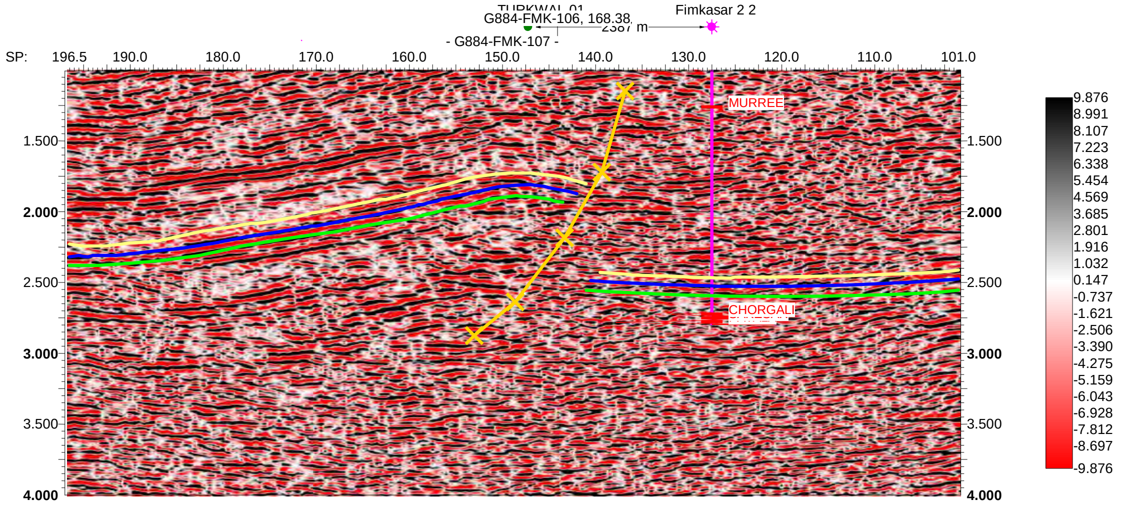


Fig 3.4 Interpretation of seismic line G884-FMK-107

3.9 Contour maps:

The results of seismic interpretation are usually displayed in the form of maps. Mapping is part of the interpretation of the data. The seismic map is usually the final product of seismic exploration, the one on which the entire operation depends for its usefulness. The contours are the lines of equal time or depth wandering around the map as dictated by the data (Coffeen, 1986).

In constructing a subsurface map from seismic data, a reference datum must first be selected. The datum may be sea level or any other depth above or below sea level. Frequently, another datum above sea level is selected to image a shallow marker on the seismic cross-section, which may have a great impact on the interpretation of the zone of interest (Gadallah & Fisher, 2009).

Contouring represents the 3D earth on a 2D surface. The spacing of the contour lines is a measure of the steepness of the slope i.e., closer the spacing, steeper the slope. A subsurface structural map shows relief on a subsurface horizon with contour lines that represent equal depth below a reference datum or two-way time (TWT) from the surface. These contour maps reveal the slope of the Formation, structural relief of the Formation, its dip, and any faulting or folding. The interpreted seismic data is contoured for producing seismic maps which provide a 3D picture of the various layers within an area which is limited by intersecting shooting lines. The picked times for each reflector are exported along with the navigation data in the form of an XYZ file to be used for contouring.

3.9.1 Time and Depth Contour Maps of Chorgali Formation:

The time and depth map of Chorgali Formation are generated on the base map along with wells and their corresponding fault polygons shown in figures. The polygon F1, shows dipping in NE-SW direction.

3.9.1.1 Time Contour Map

The TWT contour map of Chorgali Formation is shown in figure. The structural variation in these contours can be interpreted by using color bar and legends. The light orange color from (1.696-1.920s) shows the shallowest part and light blue color approaches from (2.272-2.496s) shows the deepest part. The time contour map is shown in figure 3.5.

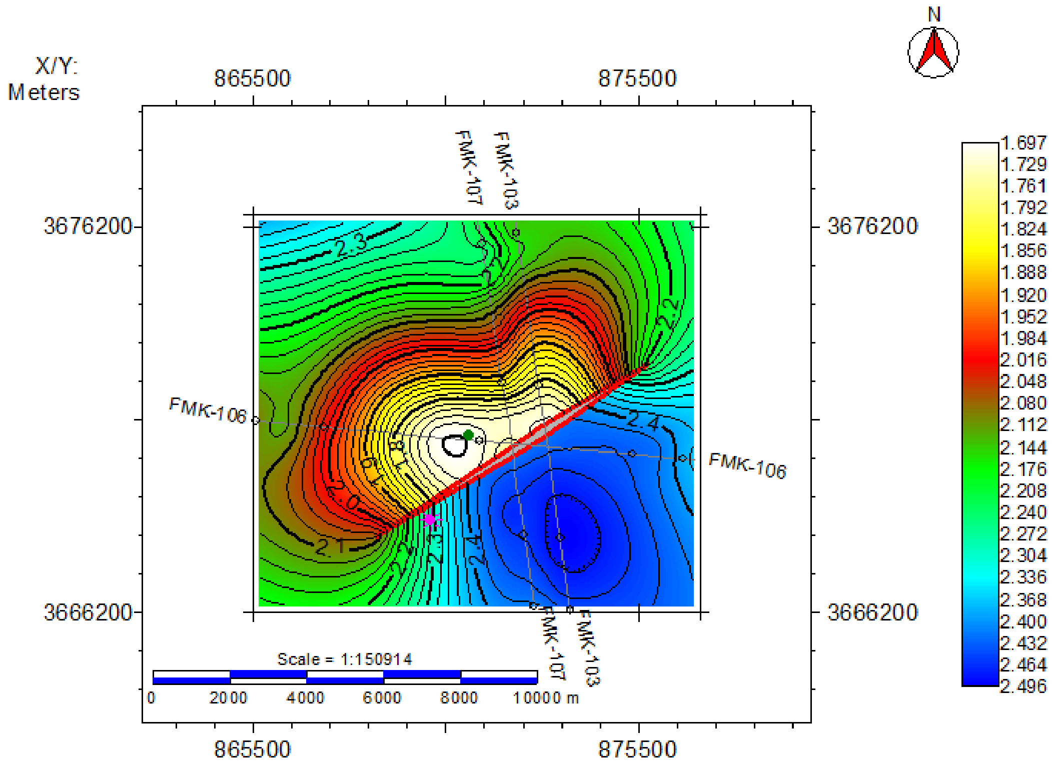


Fig 3.5 Time contour map of chorgali formation

3.9.1.2 Depth Contour Map

The depth contour map of Chorgali Formation was calculated from the time contour map by using velocity obtained from DT-log run in Chorgali Formation using formula S=VT/2. The depth variation in contour map is interpreted by using color bar shown in figure. The orange color from (3007.9-3291.638m) shows the shallowest part while light blue color from (4029.29-4426.50m). The depth contour map is shown in figure 3.6.

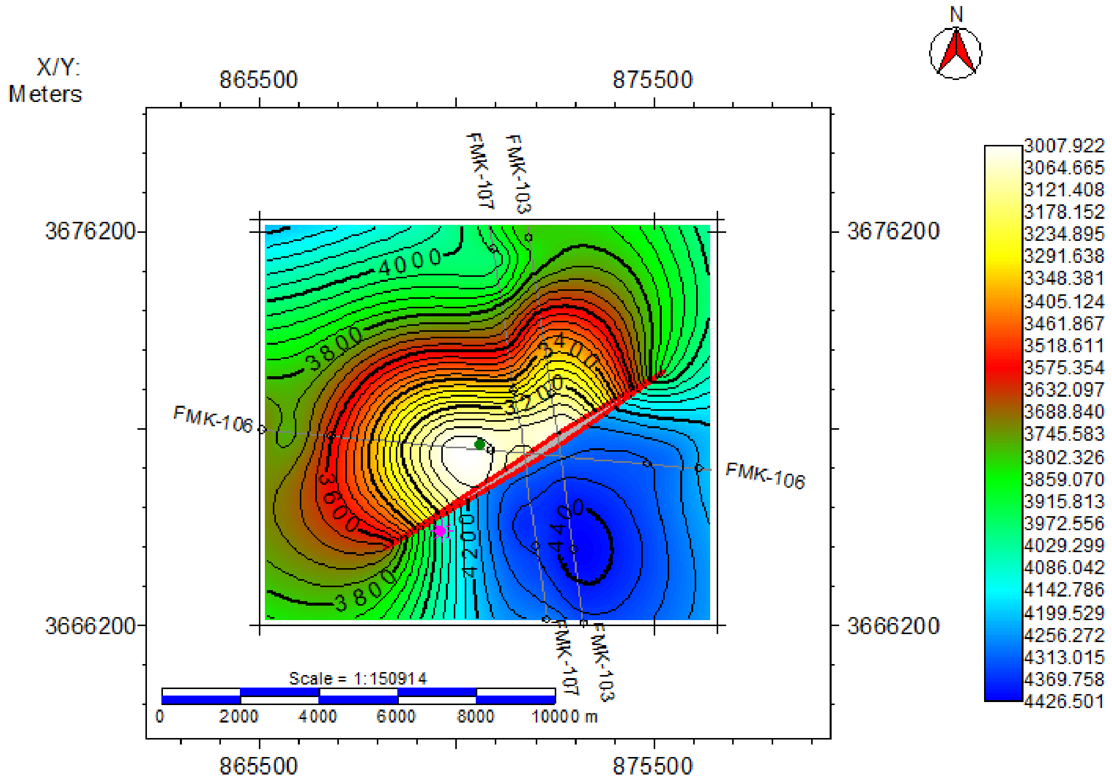


Fig 3.6 Depth contour map of chorgali formation

3.9.2 Time and depth contour of Patala Formation:

Patala Formation can act as both reservoir as well as source rock.

The time and depth maps can be interpreted by using same techniques as we have done in previous Formations.

The contour map shown in figure almost gives same structure interpretation as of previous Formation discussed above.

The time and depth map of patala Formation are generated on the base map along with wells and their corresponding fault polygons shown in figures.

The polygon F1, shows dipping in NE-SW direction.

3.9.2.1 Time Contour Map

The TWT contour map of Patala Formation is shown in figure. The structural variation in these contours can be interpreted by using color bar and legends. The light orange color from (1.760-1.984s) shows the shallowest part and light blue color approaches from (2.360-2.559s) shows the deepest part. The time contour map is shown in figure 3.7.

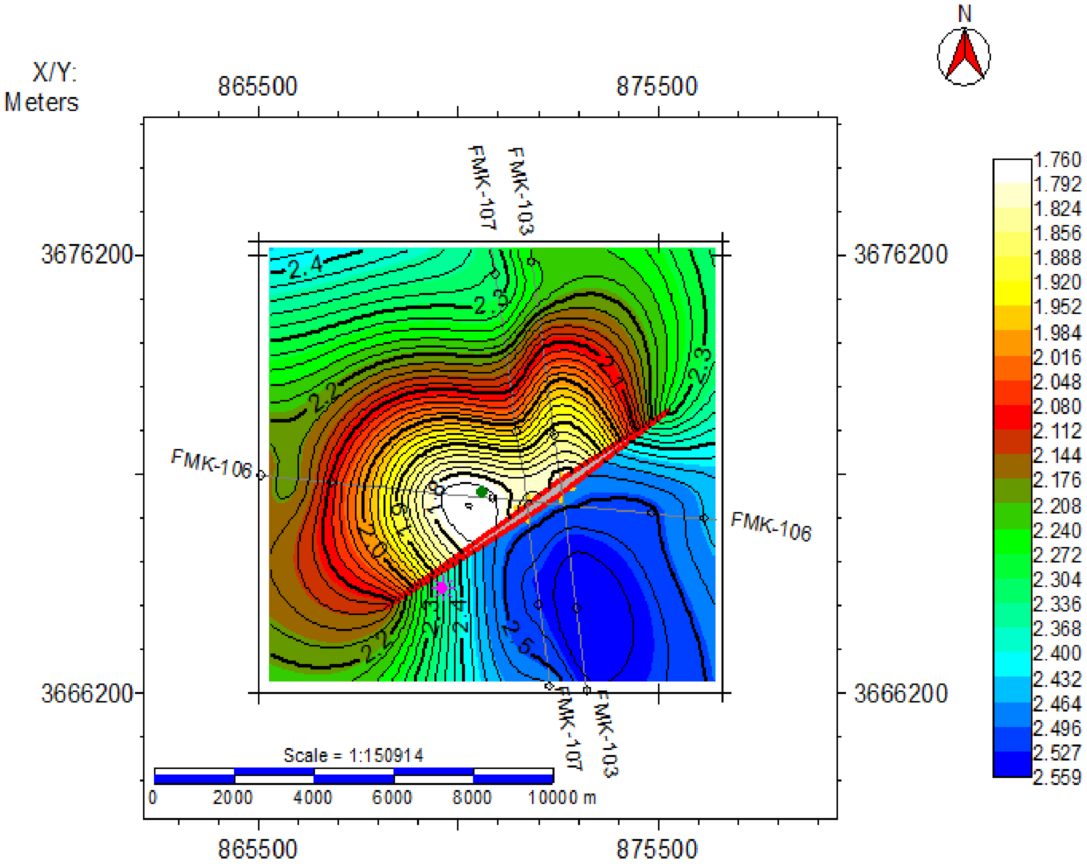


Fig 3.7 Time contour of Patala Formation

3.9.2.2 Depth Contour Map

The depth contour map of patala Formation was calculated from the time contour map by using velocity obtained from DT-log run in patala Formation using formula S=VT/2.

The depth map of patala Formation is generated on the base map along with wells and their corresponding fault polygons shown in figures.

The polygon F1, shows dipping in NE-SW direction.

The depth map of Patala Formation is also constructed by same procedure that we have discussed above.

The depth map of Patala Formation can also interpret by using color bar. The orange color from (3167.59-3513.07m) shows the shallowest part while light blue color from (4261.59-4607.06m) shows deepest part.The depth contour map is shown in figure 3.8

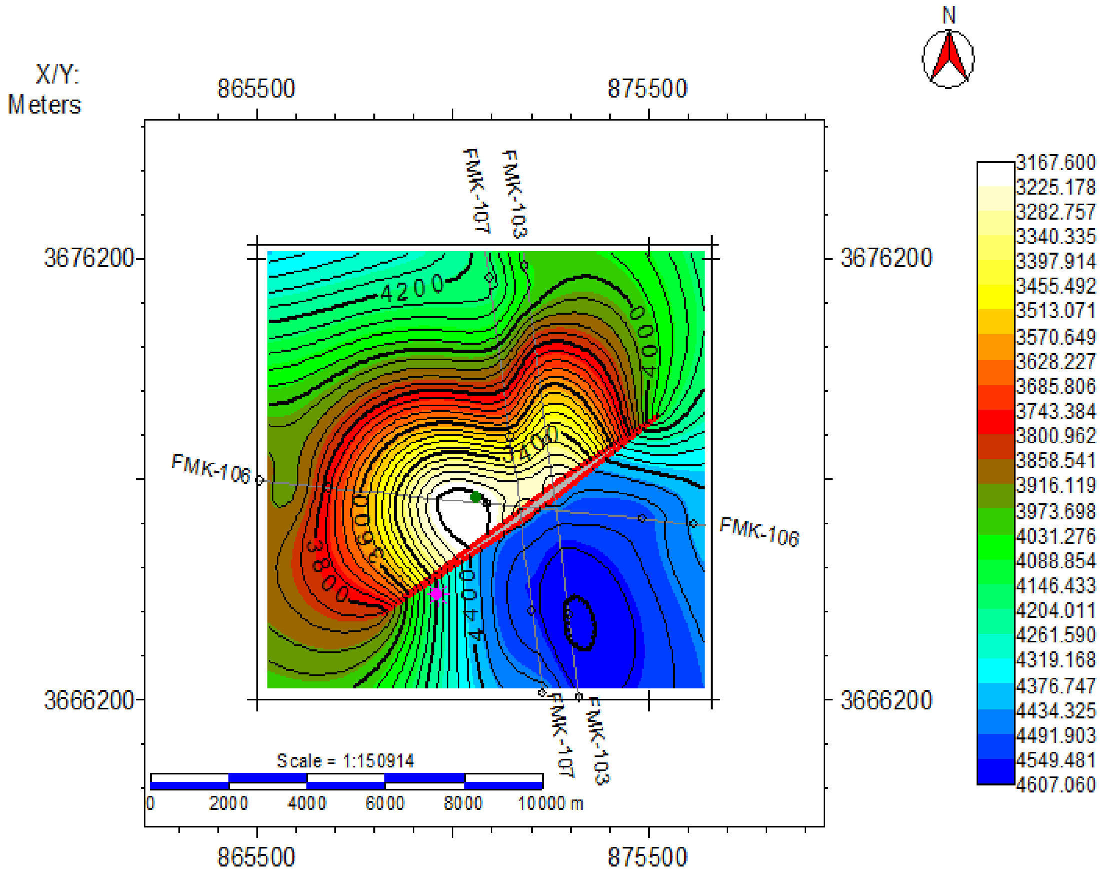


Fig 3.8 Depth contour of Patala Formation

3.9.3 Time and Depth Contour Maps of Hangu Formation:

The time and depth map of hangu Formation are generated on the base map along with wells and their corresponding fault polygons shown in figures.

The polygon F1, shows dipping in NE-SW direction.

3.9.3.1 Time Contour Map

The TWT contour map of Hangu Formation is shown in figure.

The structural variation in these contours can be interpreted by using color bar and legends. The light orange color from (1.854s-2.067s) shows the shallowest part and light blue color approaches from (2.402-2.615s) shows the deepest part. The time contour map is shown in figure 3.9.

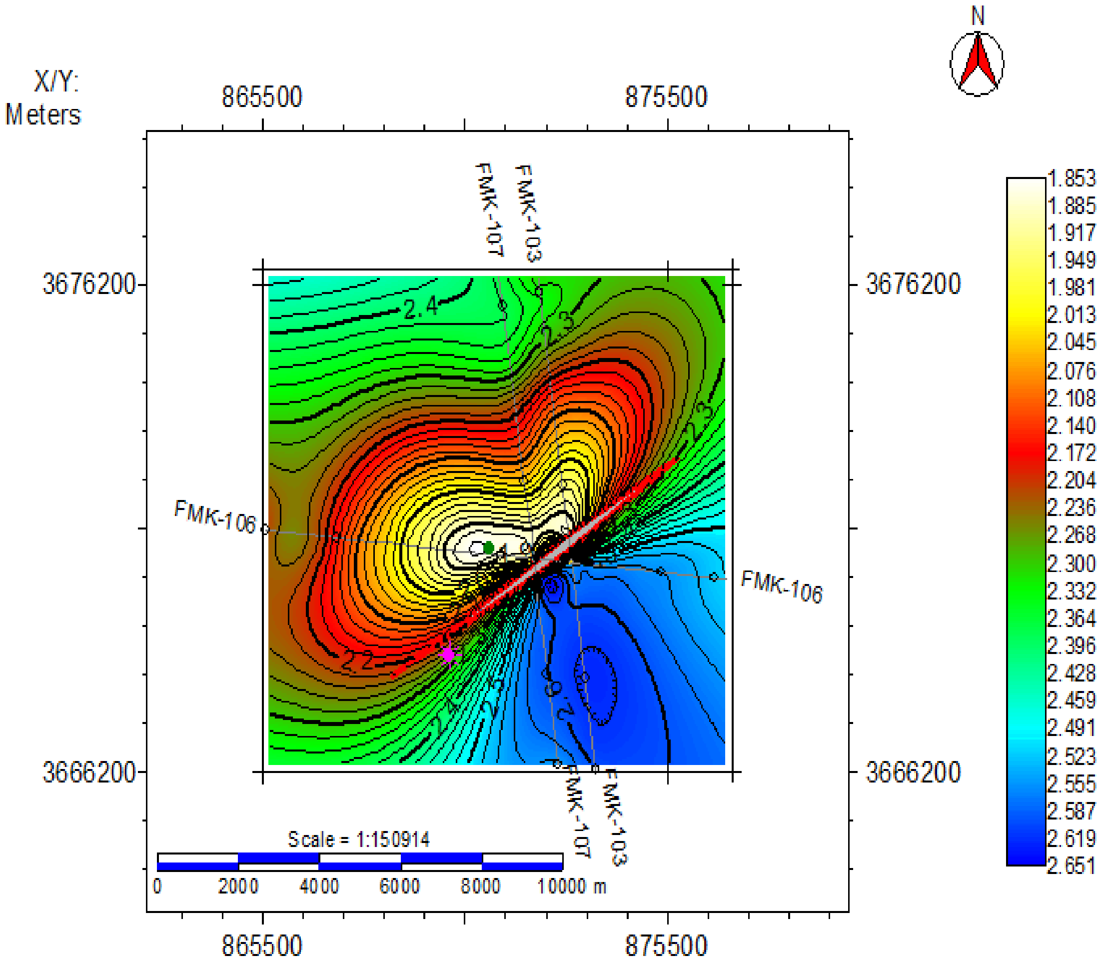


Fig 3.9 Time contour of Hangu Formation

3.9.3.2 Depth Contour Map

The depth contour map of hangu Formation was calculated from the time contour map by using velocity obtained from DT-log run in hangu Formation using formula.

$$S=VT/2$$

The time and depth map of hangu Formation are generated on the base map along with wells and their corresponding fault polygons shown in figures.The polygon F1, shows dipping in NE-SW direction.The depth variation in contour map is interpreted by using color bar shown in figure.The orange color from (3215.09-3347.33m) shows the shallowest part while light blue color from (4322.56-4599.43m) shows deepest part. The depth contour map is shown in figure 3.10.

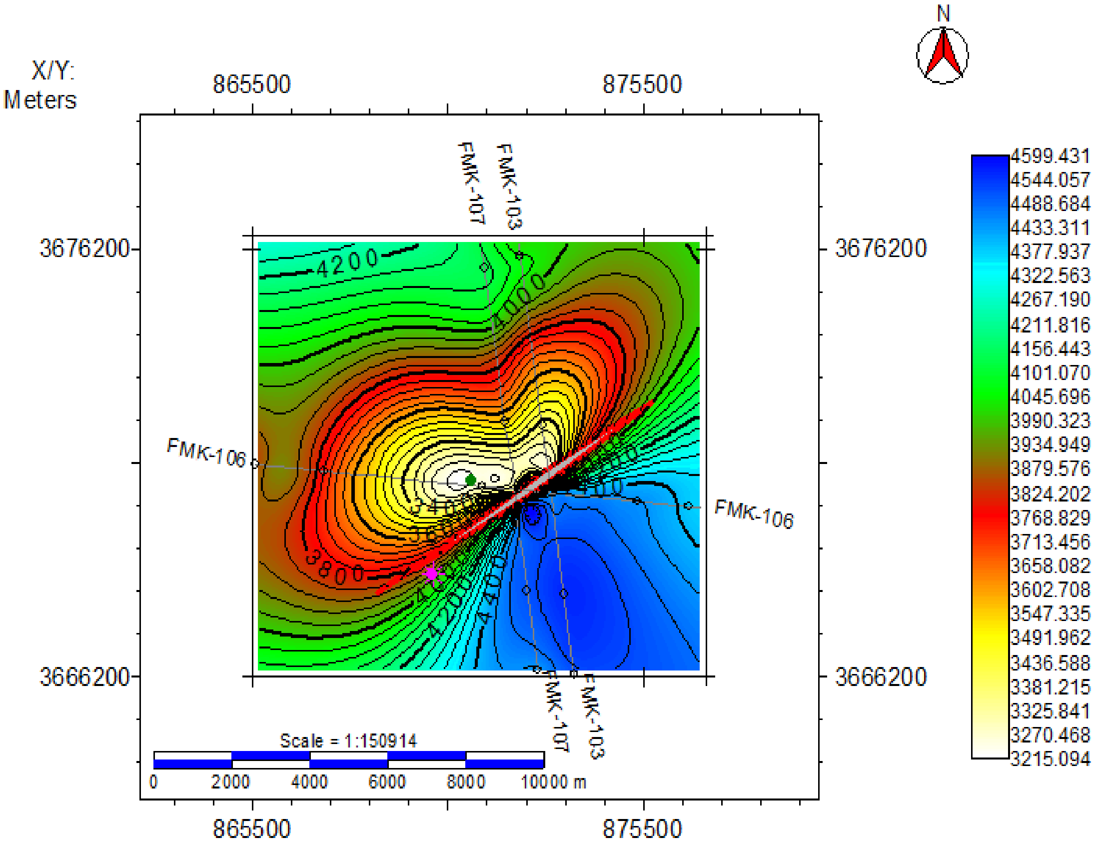


Fig 3.10 Depth contour of Hangu Formation

3.10 CONCLUSION

The following interpretations are made from these time and depth contours shown in figure.

The interpreted structure for Chorgali, Patala and Hangu Formation is a snaked head structure. The snaked head structure is formed due thrust fault F1. This structure with the reverse fault acts as a trap in the area which is best for hydrocarbon accumulation.

CHAPTER 4

PETROPHYSICS

4.1 Introduction:

This study facilitates in identification and quantification of fluid in a reservoir (Ali et al., 2014). Knowledge of reservoir physical properties like volume of shale, porosity, and water and hydrocarbon saturation is needed to define accurately probable zones of hydrocarbons. The physical property like volume of shale, porosity, saturation of water and saturation of hydrocarbon is needed to identify the probable zones of hydrocarbons accurately. The combination of petrophysics with rock physics enables the geophysicists to understand the physical properties of rocks in the study area. Petrophysics is apprehensive with using well measurements to subsidize reservoir depiction (Daniel, 2003). To accurately characterize oil or gas in a reservoir, measurements such as resistivity, porosity and density are made, from which volume of shale, average porosity water saturation and hydrocarbon saturation can be quantified.

4.2 LOG DATA USED

The petrophysics analysis has been carried out to measure the reservoir characterization of the Fimkassar area using the borehole data of Fimkassar-02.

I used the log curves including.

Spontaneous potential log (SP),

Gamma ray (GR), Sonic log (DT),

Latero log deep (LLD),

Latero log shallow (LLS),

Neutron log,

Density log,

Photo electric effect log (PEF).

4.3 Petrophysical analysis:

For petrophysics analysis the following parameters are calculated for reservoir rock.

Volume of shale (by Gamma ray log)

Porosity of reservoir (by SONIC, DENSITY and NEUTRON logs)

Water saturation (by LLD, LLS and SP logs)

Hydrocarbon Saturation (HCS)

Permeability of reservoir rock (Ross Willey equation)

4.3.1 Estimation of volume of shale:

The volume of shale can be estimated from the response of Gamma ray log. The response of Gamma ray must be known through different lithologies. The gamma ray log is the passive logging because we measure the Formation properties without using any source. It is the measures the Formation radioactivity. The gamma ray emits from the Formation in the form of the Formation in the form of the electromagnetic energy which are called the photon. When photon collides with the Formation electron hence, they transfer the energy to the Formation electron, so the phenomenon of the Compton scattering occurs. Now these emitted Gamma rays reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray. The volume of the shale is calculated by using (Asquith and Gibson, 2004) equation given below.

$$\mathrm{IGR} = \frac{\mathrm{GRlog} - \mathrm{GRmin}}{\mathrm{GRmax} - \mathrm{GRmin}}$$

IGR = Gamma Ray Index

GRlog = Gamma Ray reading of the formation

GRmax =Maximum gamma Ray (shale)

GRmin = Minimum gamma Ray (clean sand and carbonate)

Then following formula is used to find volume of shale:

Consolidated:

Vshale = 0.33[2(2*IGR) - 1]

Unconsolidated:

Vshale = 0.0883[2(3.7*IGR) -1]

The Gamma ray log shows maximum value when shale is encountered and shows a minimum value when clean lithology like sand is encountered. These values are calculated from given log response and then volume of shale is estimated.

4.3.2 Porosity from logs

Porosity is the ratio of volume of voids to total volume of rock. Porosity is calculated for different zones of interest by using the following logs,

Sonic log,

Neutron log,

Density log.

4.3.2.1 Sonic Porosity (Φs)

Using sonic log, porosity can be easily calculated which is almost near to actual porosity. The interval transit time (ΔT) is dependent upon both lithology and porosity of the medium. Sonic log device consists of a transmitter that emit sound waves and a receiver that picks and record the compressional waves as it reaches the receiver.

This log is a recording verses depth of time (t) which is required by a compressional wave to go across 1 feet of Formation, called interval transient time Δt, while it is the reciprocal of the velocity of sound wave. This transient time (Δt) is depended upon lithology and porosity of the Formation (Asquith and Gibson, 2004). Sonic log can also be used for the following purposes in combination of other logs as given by (Daniel, 2004). Therefore, a formation's matrix velocity must be known to find out Sonic porosity by the following formula given by Wyllie (Wyllie et al., 1958). Sonic porosity has been calculated by using the following the formula:

$$\Phi s = \frac{\Delta T - \Delta Tma}{\Delta Tf - \Delta Tma}$$

Where,

Φs = Sonic porosity μs/ft

ΔT = Log response

ΔTma = Transit time in matrix

ΔTf = Transit time in fluids

Wyllie formula for calculating sonic porosity can be used to determine porosity of consolidated sandstone and carbonates. According to Wyllie interval transit time (ΔT) increased due to the presence of hydrocarbon (i.e., hydrocarbon effect). To correct this Wyllie suggested the following empirical correction for hydrocarbon effect.

$\Phi = \Phi s \times 0.7$ (for gas)

$\Phi = \Phi s \times 0.9$ (for oil)

4.3.2.2 Density Porosity (Φd)

In the density logging gamma ray collide with the electron in the formation and scattered gamma ray (Compton scattering) received on the detector which indicate the density of the Formation increase in the bulk density of the Formation causing the decrease in the count rate and vice versa. Bulk density which is obtained from the density log is considered the sum of the density of the fluid density and the matrix density of the Formation.

If rock type is known then porosity is calculated by using (Asquith and Gibson, 2004) equation. The rock lithology is known by using gamma ray log in this case it is limestone. Density porosity has been calculated with the help of following formula:

$$\Phi d = \frac{\rho ma - \rho b}{\rho ma - \rho f}$$

Where,

ρm = 2.71 gm/cm3 (for Carbonates)

ρf = 1 gm/cm3

ρb = log Response in zone of interest

4.3.2.3 Neutron Porosity (ΦN)

This is the type of porosity log which measure concentration of Hydrogen ions in the Formation. Neutron is continuously emitted from chemical source in the tool of the neutron logging. When these neutrons collide with nuclei in the Formation and results in loss of some energy. Hydrogen atom has same mass as that of neutron, maximum loss of energy occurs when electron collides with hydrogen atoms.

Hydrogen is an indication of the presence of the fluid in the Formation pores; hence loss of energy is related to the porosity of the Formation. The neutron porosity is very low when the pores in the formation are filled with the gas instead of the water and oil; the reason is that gas having les concentration of the hydrogen as compared to water and oil. This less porosity by the neutron PHI due to the presence of the gas called the gas effect (Asquith and Gibson, 2004).

The neutron tool responds to volume of water filled spaces and gives a measure of porosity (The geological interpretation of well logging, Rider, 1986), which is expressed below:

$\mathrm{Log}10\boldsymbol{\Phi} = aN + B$

a = constant

B = constant

N = neutron-tool-reading

Φ = true Porosity

4.3.2.4 Total porosity (ΦT)

The total porosity is the sum of all the porosities calculated from different logs divided by the number of logs used for calculating porosities. The total porosity is calculated for the reservoir which is Sakessar in this case. Total porosity has been calculated by the help of following formula.

$$\Phi T = \frac{1}{3}(\Phi s + \Phi d + \Phi N)$$

Where,

ΦT = Total Porosity = Average porosity

ΦD = Density Porosity

ΦS = Sonic Porosity

ΦN = Neutron porosity

4.3.3 Water Saturation (Sw)

Water saturation is the percentage of pore volume in rock that is occupied by water of Formation. If it is not confirmed that pores in the Formation are filled by hydrocarbons, it is assumed that these are filled with water. To determine the water and hydrocarbon saturation is one of the basic goals of well logging. To calculate saturation of water in the Formation, a mathematical equation was developed by Archie shown below. All the parameters of Archie equation can be calculated from resistivity and spontaneous potential logs. Water saturation has been calculated with help of the Archie's Equation:

$$Sw = n\sqrt{}[\left(\frac{a}{\Phi m}\right) x \left(\frac{Rw}{Rt}\right)]$$

Where

Sw = water saturation

Rw =w ater resistivity (formation)

Φ = effective porosity

n = tortuosity factor

m (cementation factor) = 2

a (constant) = 1

Rt = log response (LLD)

Rw has been calculated with help of the SP charts.

4.3.4 Estimation of true resistivity:

Basically, there are different types of electrical Resistivity Logs. But in my work, I have only two logs available in my data which are simply explained as follow. These logs are used to measure the resistivity of the subsurface, but they measure the resistivity of the Formation fluids. They are very helpful to differentiate between water filled Formation and the hydrocarbon filled Formations. Resistivity logs include the following.

Laterolog Deep (LLD).

Laterolog shallow (LLS).

4.3.4.1 Laterolog Deep (LLD):

Latero log deep is used for the deep investigation of the quietly undisturbed (Uninvaded zone) and it is called Laterolog deep (LLD). This log is also used for saline muds also in case of fresh mud.

This log is generally used for measuring the Formation resistivity. It has deep penetration as compared to the (LLS).

4.3.4.2 Laterolog Shallow (LLS)

Laterolog shallow (LLS), used for shallow investigation of the transition zone/ invaded zone. The depth of the investigation is smaller than the LLD.

These logs are used to calculate the true resistivity.

4.3.5 Saturation of Hydrocarbon

It is denoted as Shc, Saturation of hydrocarbon is calculated by given formula below.

Shc = 1-Sw

Sw = Saturation of water

Shc = Saturation of hydrocarbon

4.4 Well log interpretation of FIMKASSAR-02.

SMT Kingdom is used for interpretation of well Fimkassar-02. For borehole condition determination Caliper log, having diameter (8.5 inches), is used which almost remains constant throughout the well but also shows irregularity at several depth ranges throughout well. This irregular effect is known as Ruguosity, which is due to collapse of well and it showed an increase in diameter of wellbore. Therefore, in the depth ranges where there is Ruguosity, the value of any other log is not reliable.

Track 1 is known as lithology track. Caliper, GR, SP logs run in track 1. These logs tell about lithology. Caliper log show average value 8-9 inches. At different places caving and washout is present. GR log tell us about shale, high value of GR tell about shale. Average value of GR log is 25 API. Sp log tell about permeable zone. SP log show positive values.

Track 2 is known as resistivity log. We have LLD, LLS in track 2. LLD is lateral log deep whose depth of investigation is high, but it doesn't give us true readings. LLD tell us about resistivity of virgin zone which is high at some zones. LLS is lateral log shallow, which tell us about resistivity of shallow zone and tell us about flushed zone. Both resistivity logs follow same trend but LLD show high values then LLS in some zones which indicate hydrocarbon.

Track 3 is porosity log. We have Density, Neutron, Sonic in track 3. Density log tell about density of lithologies. Average value of density is 2.7g/ cc. Sonic log tell us about travel time. Average value is 80 ms/ft but in reservoir zone 60 ms/ft. Neutron log tell us about hydrogen index means about water. Neutron log show good values.

Volume of shale calculated and run-in track 4.

Then I calculate density porosity and run-in track 5. Density porosity calculated only in reservoir. Average value of Density Porosity is 0.1-0.25.

Then I calculate average porosity and run-in track 6. For calculating this we use Density porosity and Neutron porosity.

Then I calculate Effective porosity. We use PHID, NPHI and VSH and then PHI-EFF run in track 7.

Then I calculate SW. I use Archie's generalized equation and run-in track 8.

Then SH calculate and run-in track 9.

In Sakesar formation, petrophysical interpretation has been done for the whole depth of formation and for zone of interest, determined on the basis GR response, porosity values and based on hydrocarbon effect and gas effect.

For whole depth of Sakesar formation (2946 to 3067 m)

Average volume of Shale in %age = 38%

Average density porosity in %age = 3%

Average porosity in %age = 3%

Average effective porosity in %age = 2%

Average water saturation in %age = 56%

Average hydrocarbon saturation in %age = 44

For Zone of Interest of Sakesar formation (2946 to 2991m),

Average volume of Shale in %age = 21%

Average density porosity in %age = 5%

Average porosity in %age = 3.5%

Average effective porosity in %age = 3%

Average water saturation in %age = 43%

Average hydrocarbon saturation in %age = 53

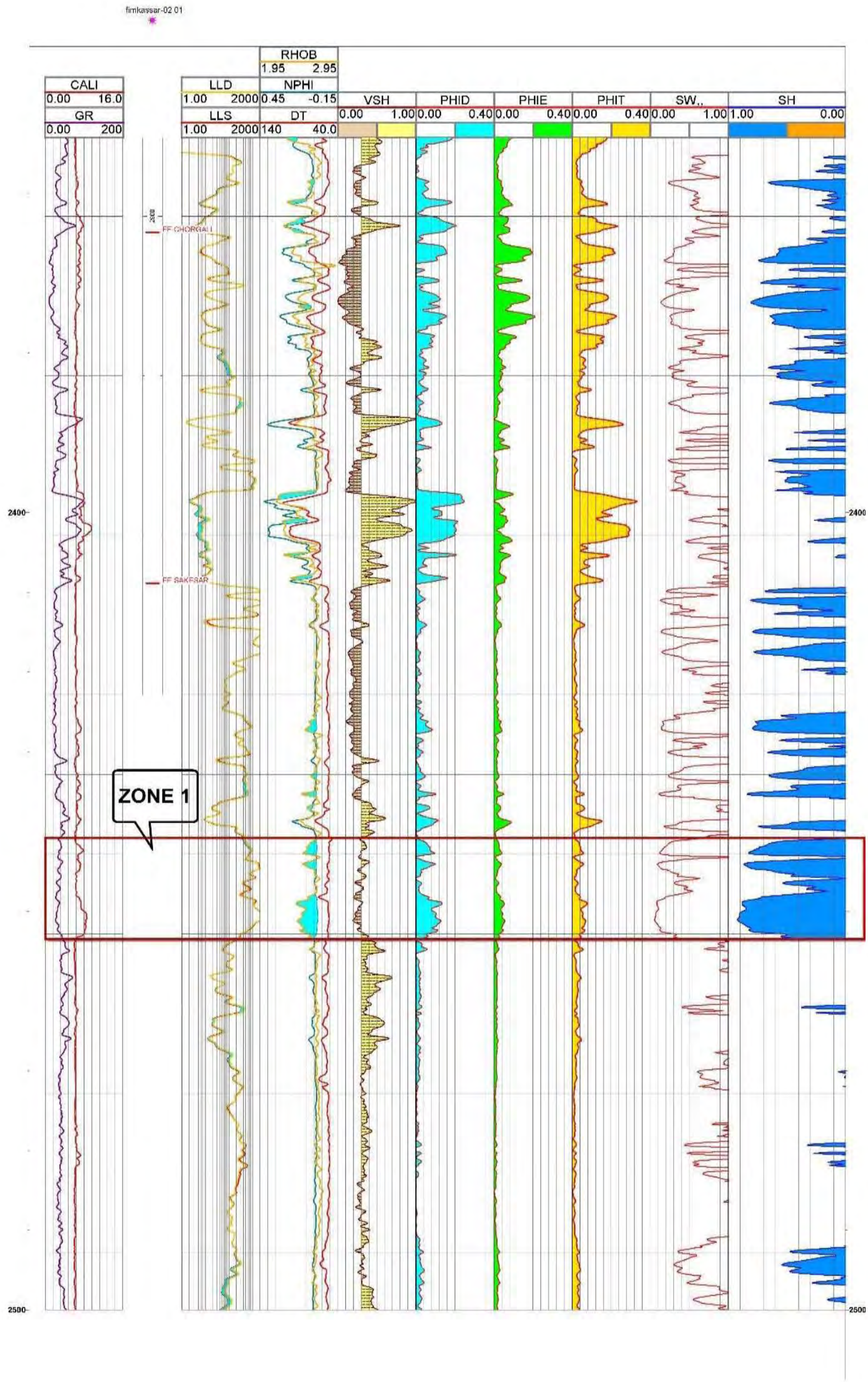


Figure 4.1 Petrophysical Interpretation of well Fimkassar-02

CHAPTER 5

Rock Physics and Facies Modelling

5.1 Introduction

Rock Physics is an integration science linking seismic data, its derived attributes, Petrophysical data, computed as well as lab measured elastic parameters and core data. It consists of a wide range of empirical relations that have been established through best-fit least square regression. Correlations can be established between any two or more rock properties that ca be used to compute one rock parameter with another.

Rock physics templates have been developed to visualize lithological and mineralogical variations in terms of Petrophysical logs; derived rock physics derived seismic attributes and can be applied for the quantitative interpretation of well log and seismic data. (Perez et al, 2011) constructed rock physics templates using a combination of Hertz–Mindlin contact theory and the lower modified Hashin–Shtrikman bounds to guide interpretations of estimated ultimate recovery in shales.

5.2 Computation of Elastic Logs

The P-wave velocity (sonic) log, S-wave velocity (computed shear sonic) log and density log are used to compute the elastic logs of various moduli along with acoustic impedance and shear acoustic impedance logs as shown in Figure 5.2.

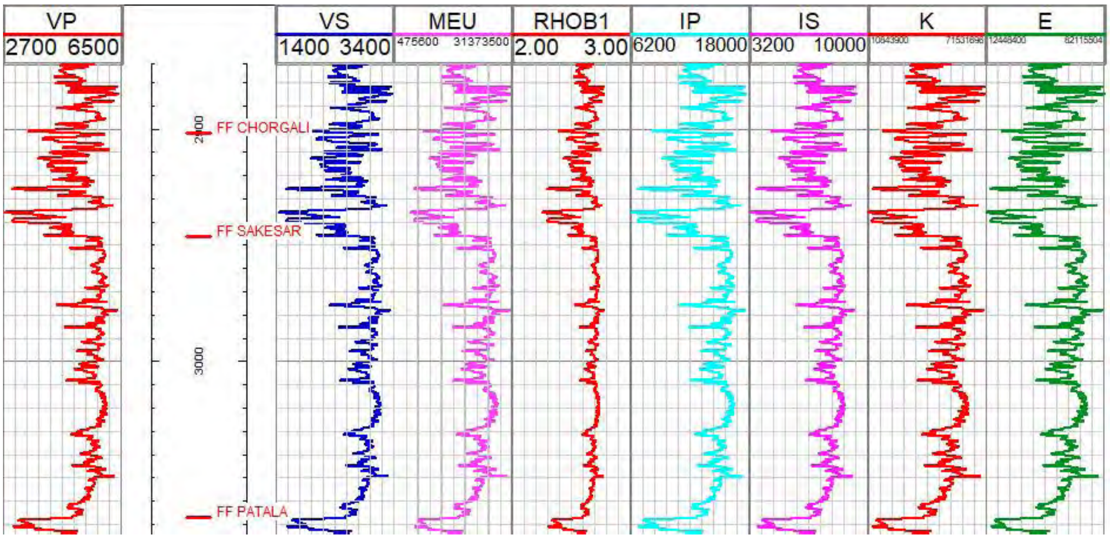


Figure 5.1: Acoustic Impedance and Elastic Logs computed from Petrophysical logs of Fimkassar-02.

The Petrophysical logs along with the computed Acoustic Impedance and Elastic Logs are used in various types of cross plot for classification or facies modeling. Before we go into the details of each facies modeling cross plot a brief description of each elastic parameter is given below.

5.2.1 Acoustic Impedance

Acoustic impedance is a layer property of a rock and is equal to the product of compressional velocity and density (Onajite et al., 2014). The density log and the compressional wave velocity log generated from the DT log are used to compute the acoustic impedance log by using equation:

$$AI = V_P \times \rho_{\boldsymbol{b}}$$

Where, ρb is the density of the formation and Vp is he compressional wave velocity.

5.2.2 Shear Impedance

Shear impedance is a layer property of a rock and is equal to the product of shear velocity and density also known as elastic impedance (Connolly, 1998, 1999). Similarly, as acoustic impedance the density log and the shear wave velocity derived from the Castagna et al., (1993) empirical relation was used to generate the shear impedance log using equation:

$$SI = V_S \times \rho_b$$

Where, ρb is the density of the formation and Vs is the shear wave velocity.

5.2.3 Young's Modulus

This modulus is obtained to measure the stiffness of the material. The relation between the density, compressional wave velocity, young's modulus, and shear wave velocity is given in equation (Mavko et al., 2009).

$$E = \frac{\rho V_S^2 (3V_P^2 - 4V_S^2)}{V_p^2 - V_p^2}$$

Where, ρ is the density that is obtained from the density (RHOB) log, Vs and Vp are the shear wave and compressional wave velocity that is obtained from the sonic log (DT).

5.2.4 Poisson's Ratio

The Poisson's ratio is used to indicate the maturity of the shale oil/gas zone. The low value of poisson's ratio will indicate the mature oil/gas shale zone. The relation between the poisson's ratio, compressional wave velocity, and shear wave velocity is given in equation (Mavko et al., 2009).

$$\sigma = \frac{\left(\frac{V_P}{V_S}\right)^2 - 2}{2\left(\frac{V_P}{V_S}\right)^2 - 2}$$

5.3 Facies Modeling

Cross plot-based facies analysis is an important methodology accepted worldwide to properly characterize a hydrocarbon reservoir and exploit the remaining volumes in development phase. In this study, shale, shaly sand and clean sands are characterized using various cross plots. Common methods for cross plot-based facies modeling are polygon bounds and cluster analysis. With the help of Log data of Fimkassar-02 different cross plots which are compared with the standard cross plots to identify the lithologies, and the prospect zone to be marked.

5.3.1 Porosity versus Density

Porosity versus density is a standard cross plot template for classification of facies as shown in Figure 5.3. The GR log is used for lithology classification.

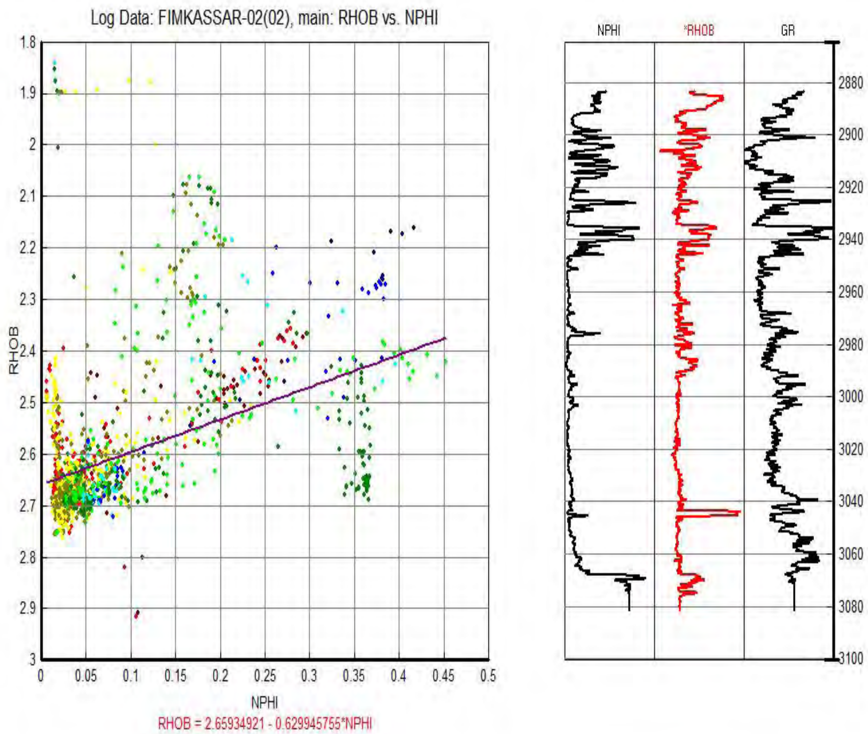


Figure 5.2 Porosity-Density Cross-plot with GR log-based characterization.

5.4 Rock Physics Empirical Relations

Another important work in Rock Physics is to establish correlations between various petrophysical, elastic and seismic parameters. A regression trend has been fitted between P-Wave Velocity and Porosity using 1st order least squares regression using data of well Fimkassar-02.

NPHI = 0.7097 – 0.0001 Vp

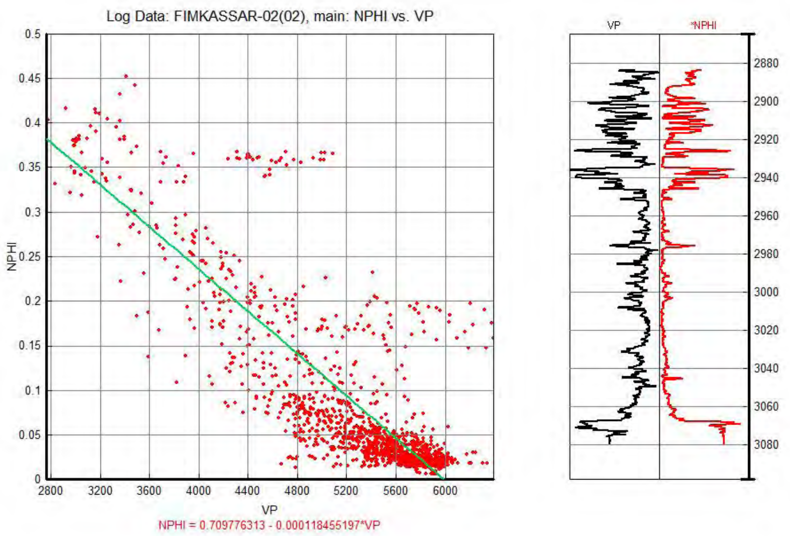


Figure 5.3 Best Fit Regression trend between P-wave velocity and porosity.

Conclusions

Conclusions drawn after this Thesis work are as follows:

The area contains thin pay zones in terms of nodular bedded limestone that is sealed by shale that act as a source as well. Reverse faulting is pronounced in the area. The uplifting and down going blocks collectively make pop-up and snake head structures also petrophysical analysis confirms the zone with limestone having porosity, permeability and low volume of shale as well as high hydrocarbon saturation zone.

The area contains hydrocarbons in the limestone of Sakesar Formation that is bounded by shale. One zone is marked as a potential zone that lies between 2984m-2991m having average porosity 3.5% with hydrocarbon saturation of 80% respectively. The converted time to depth section helps in viewing the true picture of the subsurface along with the opportunity to confirm that the area lies in the compressional regime.

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