2-Dimensional Seismic Interpretation of Reflection Data and Estimation of Rock Physics & Engineering Properties of Lines 96-PW-06, 884-FMK-106

By

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I commence with the Name of Allah - in Whom all excellences are combined and Who is free from all defects. The Compassionate - One Whose blessings are extensive and unlimited. The Merciful - One Whose blessings are inherent and eternal

Certificate

This dissertation submitted by **Usman ALi** S/O **Farman Shah** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of M.Sc. degree in Geophysics.

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EXTERNAL EXAMINER ______________________

DEDICATION

This work is dedicated to

My Father, Mother, Brothers

and

Sir MATLOOB HUSSAIN

ACKNOWLEDGEMENT

In the name of ALLAH, the most beneficent, the most merciful. I bear witness that there is no God but ALLAH and Holy Prophet Hazrat Muhammad (PBUH) is the last messenger. With the grace of ALLAH, I have been able to overcome yet another task which was impossible without ALLAH's Blessings. All praises are for Allah, who always gave me the strength and ability to overcome challenges, this dissertation yet another example of blessings of ALLAH.

Heartfelt appreciation goes to Sir.Matloob Hussain, for his supervision, constant support and timely advice to shape this dissertation into its final form. His invaluable comments, constructive criticism, his helpful nature and academic support have contributed most in making this task easier and more comfortable.

I would like to express cordial gratitude to my whole family, especially my parents. Their support, prayers, encouragement and confidence has always given me strength to be able to achieve my goals. I sincerely wish to express my appreciation to the whole faculty of Department of Earth Sciences. Their support and guidance has been priceless throughout my course and dissertation work.

Finally, I would like to thank all my friends and colleagues for their endless support, care and affection.

Usman Ali, July 2013

ABSTRACT

FimKassar area is part of Potwar sub-basin of Upper Indus basin which is known for its hydrocarbon structural traps. The work is carried out on 2 seismic lines 96-PW-06 and 884-FMK-106, additionally the data of seven other lines was also used for interpretation which was carried out using licensed software.

The integrated study involves; structural interpretation of seismic data, velocity processing and model building, time to depth conversion & generation of true depth section, 2-D seismic modeling, petrophysical analysis, and well correlation are calculated to investigate the nature and type of sub-surface material present in our study area.

The horizons were identified using formation tops from wells and their depths were confirmed. Crustal shortening analysis has also been carried out on the depth section which indicates a compressional regime. Time and depth contour maps of the horizons of interest have been generated to understand the variation across the study area.

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CHAPTER 1

1. INTRODUCTION

1.1 INTRODUCTION TO THE AREA

The Fimkassar area is located in eastren Potwar of Pakistan. Geographically, Fimkassar field is located in Chakwal district of Punjab province. The tectonic settings hold several billion barrels of reserves, and significant amounts of hydrocarbons are being produced. The thrust and backthrust phases in the eastern Potwar are the result of a northwest-southeast Himalayan compression. This is the regional triangle zone in the eastern edge of Potwar which is the result of large, regionally extensive convergent thrust sheets (Siddiqui *et al*., 1998)..

The Latitude and longitude of the study area are as follows:

Latitude 33° 04' 53'' N

Longitude 72° 56' 11'' E

Fig 1.1 Satellite view of study area.

The study area encompasses the eastern and southeastern Potwar region and is an active exploration province.

1.2 GENERAL GEOLOGY OF FIMKASSAR:

The eastern Potwar region represents the most strongly deformed part of the Potwar fold and thrust belt, with large low angle detachment faults accommodating more shortening than elsewhere in the Potwar fold and thrust belt. The area is dominated by overthrust tectonics, where the formations have been compressed into fold and fault dominated structures. In eastern Potwar, most of the folds trend NE-SW, in contrast to the EW trending folds in the central region. Conventional imbricate thrusts, popup structures, and triangle zones are commonly developed in this area. The tectonic framework of the eastern Potwar region is largely controlled by the Salt Range and Domeli fore thrust systems and the Dil-Jabba and Domeli back thrusts. The Salt Range thrust (SRT) is an emergent thrust front with a large low angle detachment along which the Potwar Plateau has been translated southward. The Salt Range thrust defines the southernmost boundary of the Potwar area. The Domeli thrust is the second major thrust fault in the eastern Potwar. The Domeli thrust is a foreland verging thrust that shows a significant amount of shortening. The Salt Range thrust is a regional thrust fault and bounds the east-west trending mountainous arc and ultimately merges into Jhelum strike slip fault.. In the eastern Potwar, some backthrusts are as large as the main thrusts. The Domeli back thrust is a classic example of a regional backthrust in the eastern Potwar. The Domeli back thrust is interpreted to be a major, late stage feature that developed as a result of the Domeli thrust. No other blind backthrust in any part of the Potwar is larger than the Domeli back thrust. All main faults are sealing as their detachment level is in Precambrian salt (Aamir and Siddiqui, 2006).

Potwar plateau is an elevated, nearly flat region and located about 100 km north of the Salt Ranges. The Kalachitta and Margalla Hills bound the Potwar Plateau to the north, Salt Ranges in the south, the Jhelum fault and the Hazara-Kashmir Syntaxis to the east, the Indus River and Kohat Plateau to the west.

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). The Fimkassar field produces, from Eocene limestone of Nammal, Sakesar and Chorgali formations.

1.1 EXPLORATION HISTORY:

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 Nammal, Sakesar and Chorgali formations. These formations are deformed in an anticlinal structure

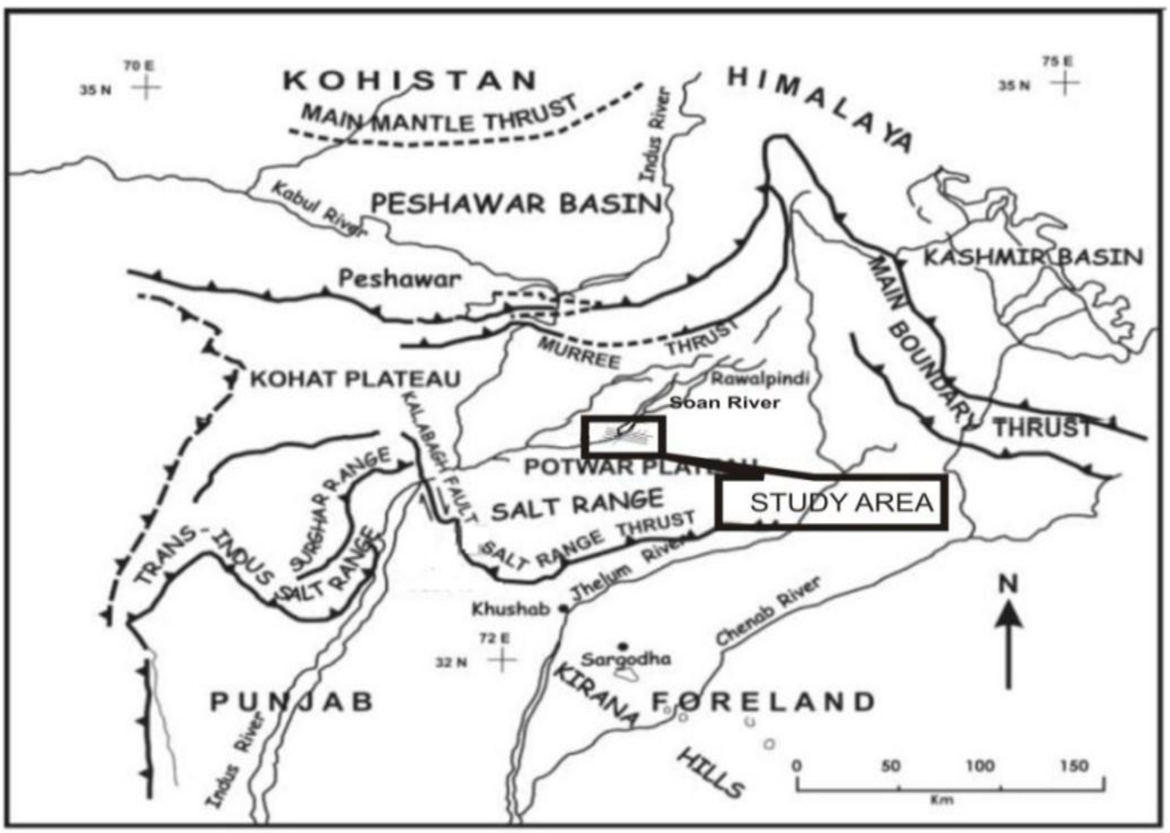


Fig 1.2 Showing geological boundaries of the area (Khawar et al. 2012)

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 local 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 side tracked; 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 provides a seal for hydrocarbon catch for underlying reservoirs of Eocene age. The production history of Fimkassar oil field shows that the production of oil is unpredictable because success in this play highly depends upon the prediction of fractures. (Jadoon *et al*., 2002).

The production history of Fimkassar oil field shows that the production of oil is unpredictable because success in this play highly depends upon the prediction of fractures. (Jadoon *et al*., 2002)

1.2 DATA USED:

a. Base Map

A base map typically includes locations of concession boundaries, wells, seismic survey points with a geographic reference such as latitude and longitude. Geologists use topographic maps as base maps for construction of surface geological maps. Geophysicists typically use shot point maps, which shows the orientation of seismic lines and the specific points at which seismic data were acquired, to display interpretations of seismic data.

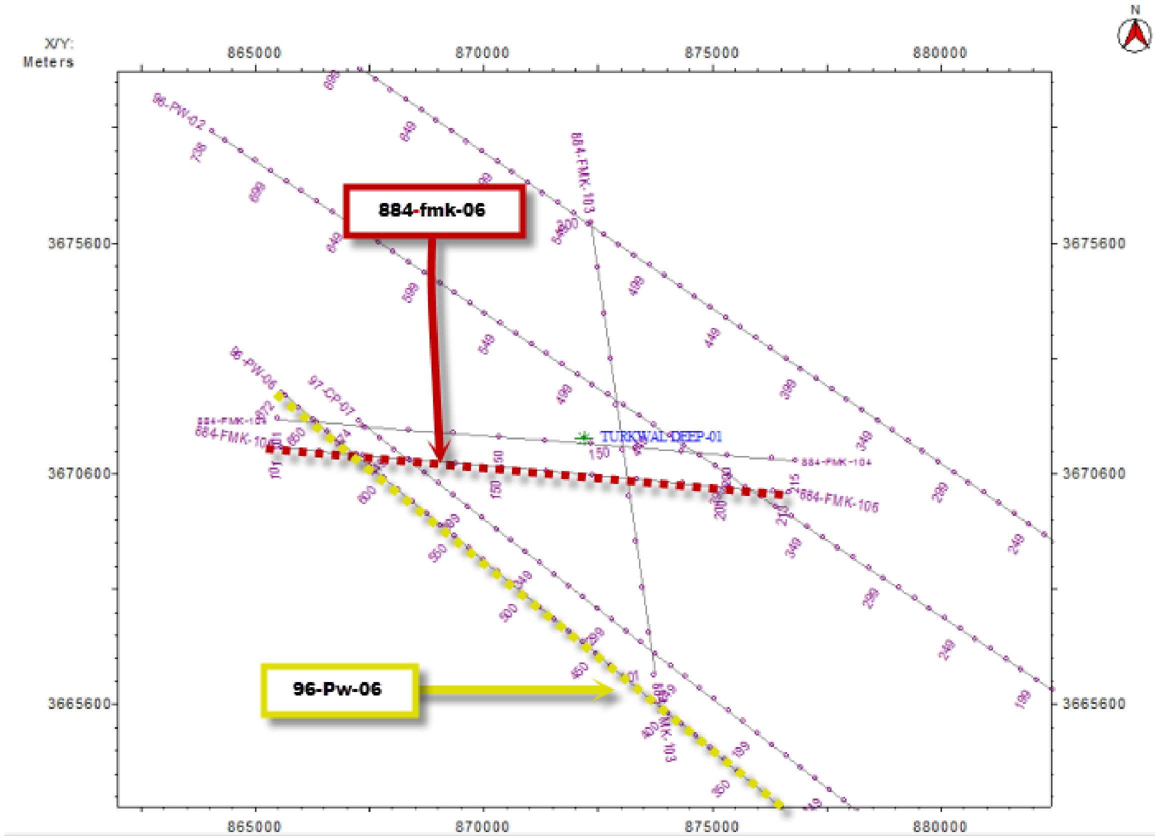


Fig 1.3 Complete base map of the area with (colored) specefic lines of interpretation.

b. Well Data Detail

In the present study a detailed Petrophysical analysis was carried out on 4 wells of Fimkassar field. The depth and well status of the producing horizon of studied wells are given in table .

Well Name	Well Depth	Well Status	Formation Tops (Chorgali)
Fimkassar 02	3067m	Development Well	2902m
Turkwal 01	3245m	Exploratory Well	3021m
Turkwal deep 01	4360m	Exploratory Well	3049m

Turkwal deep X2	4383.7m	Exploratory Well	1740.9m

The Potwar Basin is one of the oldest oil provinces of the world. The first commercial discovery was made in 1914 at Khaur. The eastern Potwar regionis an important oil and gas-producing area. The oil and gas discoveries in the eastern part of the Potwar Plateau, located southeast of the Soan syncline, are mostly from NE-SW elongated anticlines.

1.3 METHODOLOGIES:

- Using different kind of software (e.g kingdom) and helping tools.
- Identification and marking of seismic reflections.
- Structural interpretation of the subsurface strata for play identification.
- Preparation of the depth, time and velocity contour map on the basis of seismic data.
- Identify the reservoir

1.4 OBJECTIVE OF STUDY

- 2D seismic interpretation of line number 97-CP-04 and 97-CP-06.
- To study the effects of the velocity variation along the profile and its distribution in the subsurface.

- To prepare the Time Contour Map and Depth Contour Map of each Formation by using kingdom software to interpret the subsurface structure.

CHAPTER 2

2. GENERAL GEOLOGY AND STRATIGRAPHY

2.1 INTRODUCTION

The information about the geology of an area plays an important role for precise interpretation of seismic data. Main reason behind grasping the knowledge about the geology of the area is that sometimes different lithologies can produce similar seismic signatures and sometimes similar lithologies can produce quite different seismic signatures. So an explorationist must be prepared to deal with such complexities, an interpreter must have knowledge of the geology and its stratification, unconformities and major structures of the study area.

2.1.1 TECTONIC HISTORY

Himalayan Collision System represents an active collision orogen between Eurasian subcontinents. The collision is active since about 55 MA, it also involves continuous uplifting erosion and deposition of the sediments.

Potwar plateaus is situated in the lesser Himalayas of Pakistan, a zone of deformed meta sedimentary and sedimentary rocks originally deposited in the northern Indian continental margins and in the Indo gangetic foreland basin, this zone is south of high crystalline Himalayas which contain meta sedimentary and igneous rocks from north to south of the northern Asian continental margin, meta-volcanic, igneous and meta sedimentary rocks of Kohstan Island Arc terrine, igneous and high grade metamorphic rocks of intensity deformed northern margin of Indian plate, thrust fault have been traditionally assigned for the fault contact between these zones (Sercombe et al.,1998).

2.1.2 STUDY AREA

As Potwar Plateau represents the southern margin of the Himalayan collision zone hence a variety of faults and folds can be seen in the area but here only main structures covering the study area are discussed.

a. Soan Syncline

This is a broad, wide and asymmetrical syncline that divides the Potwar Plateau into Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Plateform Zone (SPPZ). Soan River marks its axis (Shami and Baig, 2002). Dhok-Pathan formation overlying the Nagri formation crops out south of Dhurnal area on the northern limb of Soan syncline. The area north of Soan Syncline is characterized by horizontal shortening and imbricate thrust faulting (Jaswal *et al*., 1997).

b. Chak Naurang Anticline

Chak Nauran Anticline is an example of a fault propagation fold. This southward verging anticline has two limbs, a steeply dipping southern limb and a moderately dipping northern limb. No fault has been mapped at the surface. Reflection data shows a strong northward-dipping basement reflector overlain by a thick evaporates section. Above the evaporites, the strongly reflective platform sequence is offset, and the fault appears to lose displacement up section the Rawalpindi and Siwalik molasses (Pennock *et al*., 1989).

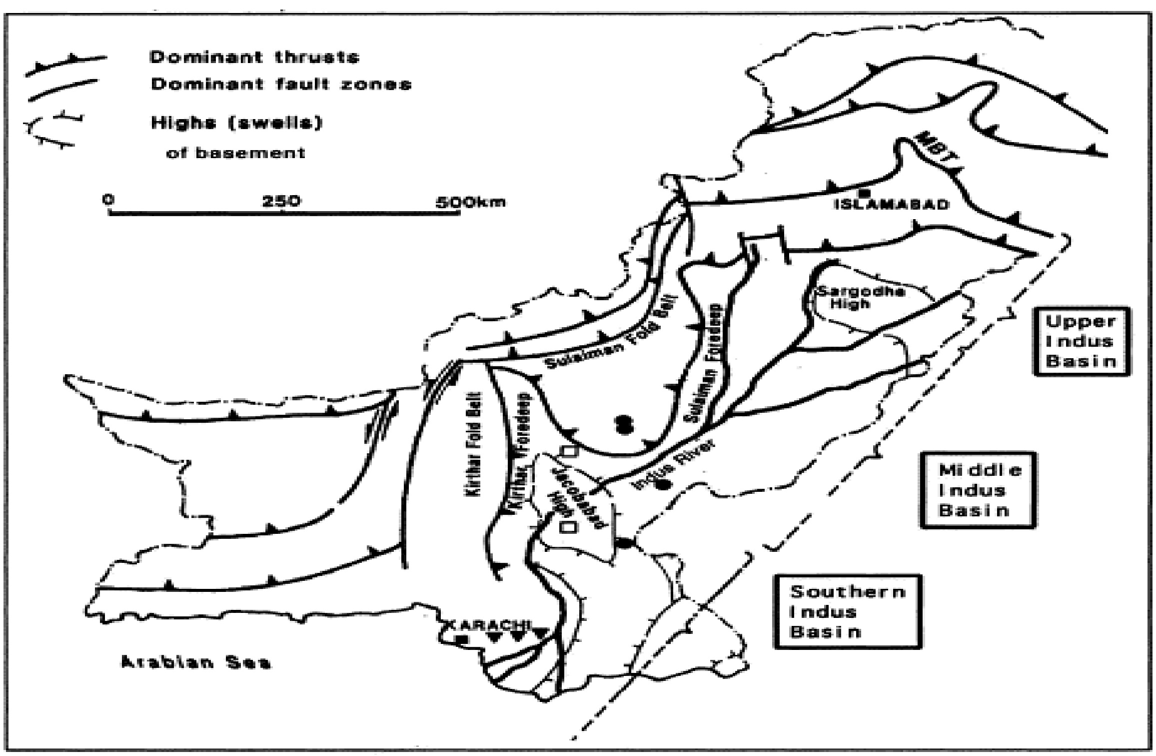


Fig 2.1 Tectonic boundaries of Pakistan

(http://www.sciencedirect.com/science/article/pii/S0012821X00001886)

c. Tanwin Banis Anticline

This anticline has a salt-thicked core. However strong reflectors, similar in seismic character to the platform sequence, appear to be overridden by thrusts on both northwest and southeast. This geometry is interpreted as incipient triangle zone. This triangle zone can be mapped a minimum of 9km to the southwest. However, only 9km to the northeast the Tanwin-Bains fold is interpreted to be covered by a southwest-verging thrust that has developed a small popup back thrust (Pennock *et al*., 1989).

d. Adhi Gungril Anticlines

These are relatively symmetrical structures. Their crestal region dips more gently than their moderately dipping flanks. Seismic reflection data indicates the Adhi Gungril structure is a pop-up bounded by reverse faults to the northwest and southeast (Pennock *et al*., 1989).

e. Joya Mair Anticline

This is a doubly plunging anticline and plunges 100° southwest and 4° northeast. The fold axis of anticline trends northeast-southwest and is cross-folded to form northwest-southeast trending Joya Mair antiformal syncline. The Chinji Formation is exposed in the core and the Nagri Formation lies along the limbs. The geologic, structural, borehole and seismic data shows that the Joya Mair structure is a triangle zone in the subsurface. The triangle zone is the result of southeast and northwest directed Himalayan thrusting. The Joya Mair triangle zone lies in the Southern Potwar Platform Zone and is segmented along left-lateral Vairo and Dhab'Kalan faults (Shami and Baig, 2002).

2.2 TECTONIC FRAMEWORK OF PAKISTAN

Pakistan lies at junction of two convergent Indian and Eurasian plates. Foreland fold and Thrust belts are conspicuous feature of convergent continental plate boundary and NW Himalayan fold and thrust belt is one of it is characterized by number of active faults. Himalayas are youngest mountain system of the world. In northern Pakistan there are three mountain ranges Hindukash, Karakoram and Himalayas, Geographically two rivers Hunza and Indus separate them. The ranges in the west of Hunza are Karakoram Ranges between Hunza and Indus River (NW of Pakistan) are Hindukash Range and Himalayas are located in the west of Indus River.

Tectonically Pakistan has been divided into following.

- NW Himalayan fold and thrust belt
- Indus Plate form and fore deep
- Kohistan-Ladakh magmatic arc
- East Balochistan fold and thrust belt
- Kakar Khorasan Flysch Basin and Makran Accretionary zone
- Chagi Magmatic Arc
- Karakoram block
- Pakistan off-shore

2.3 BASIN OF PAKISTAN

The structure in Pakistan or we can write it as Indus basin is divided into number of regime i.e. compression regime at foreland margins, basement uplift in the Central Indus Basin and extensional regime in the Lower Indus Basin (Kadri, 1995).

The Basin and their subdivision includes the following

2.3.1 INDUS BASIN

On the basis of difference in structure, sedimentary facies development and chronostratigraphic sequences, the Indus basin is subdivided as following four basins (Bender, 1995).

- Upper Indus Basin
- Central Lower Indus Basin
- Northern Lower Indus Basin
- Southern Lower Indus Basin

2.3.2 UPPER INDUS BASIN

It is the Northern part of Pakistan and Sargodha high separates the lower Indus Basin and Upper Indus Basin.

Upper Indus Basin is divided into following

- Potwar Basin
- Kohat Basin

2.3.3 POTWAR BASIN

It is the part of NW Himalayan Fold and Thrust belt. It lies on western flank of Indian and Eurasian plate collision zone. Potwar is divided into Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ). These are separated by soan syncline. Potwar basin is covered by molasses ranging in age Miocene to Pliocene. Precambrian to Tertiary sequence is exposed along the ranges in south.The structure are mostly bounded by hinterland and foreland verging faults, pop up zone is formed due to strike slip fault.

Soan syncline exist which is major tectonic feature of Potwar plateau. Northern limb of Potwar basin is dipping steeply as compared to southern limb and southern limb is older than northern limb. From East to West due to lack of lubrication in basement, structures become complicated and increased internal deformation. Gravity, drill hole ad seismic data showed that, Potwar underlies a gently dipping basement about (1- 4 degree). Tectonic in the Potwar is thin skin tectonic without significant involvement of basement (Kazmi & Jan, 1997).

Oil fields of Kohat-Potwar basin is shown in Fig 2.2. Oil fields of Kohat- Potwar basin are Dakhni, Meyal, Khaur, Dhurnal, Ratana, Toot, Dhullian, Fimkassar, Joya Mair, Chak Narang, Balkassar and Pindori.

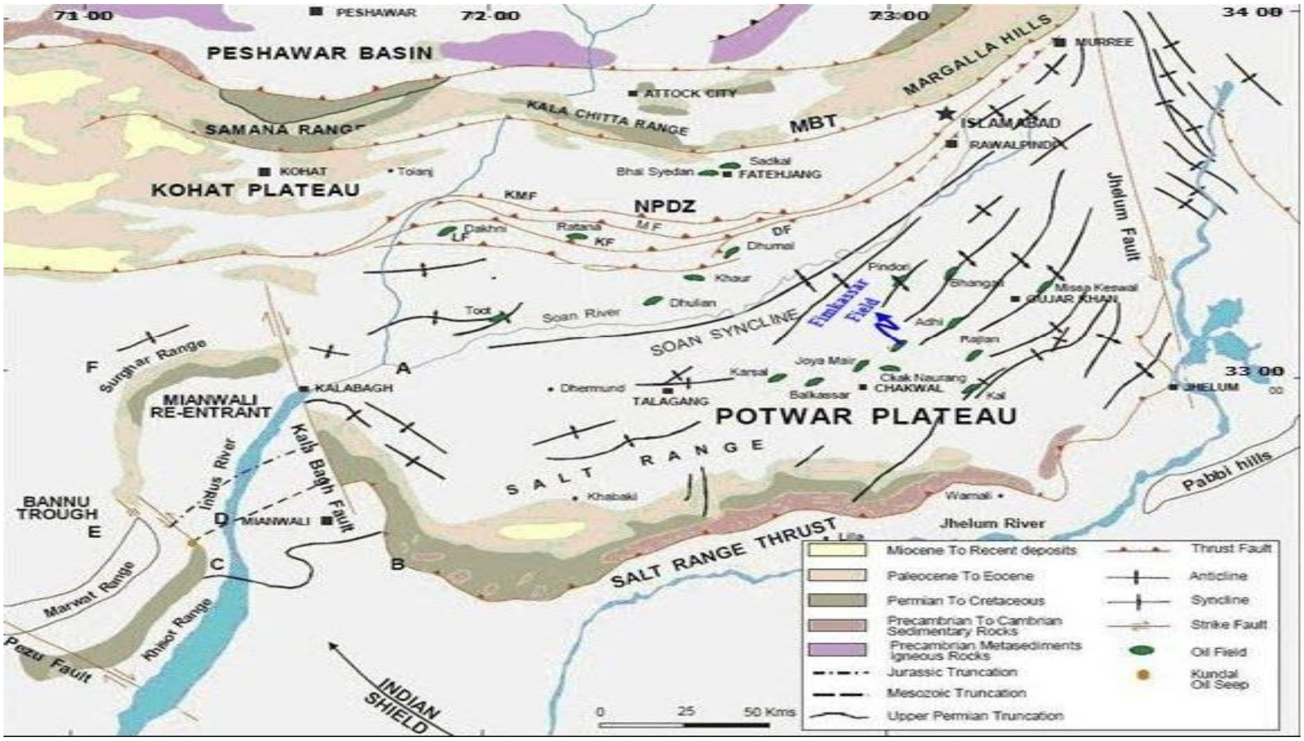


Figure 2.2: Map showing major structural features and oil fields of the Kohat-Potwar plateaus, Fimkassar area is also highlighted (William et al., 1998).

2.4 STRUCTURAL FEATURES OF POTWAR SUB BASIN

Main structural features of the area are given below

- Pop up anticline
- Tawin and Kanet synclines
- Salt Cored anticline
- Triangle zones
- The Soan syncline
- The Salt range
- The Salt range thrust

2.5 GEOLOGICAL BOUNDRIES

Geological boundaries of Fimkassar area are given in Table 2 indicating different phases of geological processes in surrounding adjacent areas in which basin is formed.

Table 1: Showing geological boundaries of North Potwar Deformed Zone.

Direction	**Geological Boundaries**
South	Salt range and Punjab sub basin
West	Kalabagh Fault(Indus river) and Kohat Plateau
East	Jehlum Fault (river) and Hazara Syntax
North	Kala Chitta Ranges and Margalla hills

2.6 PETROLEUM GEOLOGY

Hydrocarbon potential of the area is based upon the capability of rocks to produce hydrocarbon from raw organic matter under condition of high temperature and pressure. The hydrocarbon can be accumulated either by stratigraphic or structural traps.

The source (patala), reservoir (Namaal, Chorgali and Sakesar) and cap rock (Murree and) of the study area are mentioned in stratigraphic column of Fimkassar area in Fig 2.3.

2.6.1 STRATIGRAPHY AND DEPOSITIONAL HISTORY

Rocks from Precambrian to quaternary age are present in Potwar plateau. Total thickness of these rocks is about 26,000 feet were deposited in a variety of environments ranging from marine to fluvial, Periods of uplift and erosion were quite extensive indicating several major unconformities. Permian and Triassic strata are separated by unconformity, indicated a regression of sea and emergent conditions persisted during Permian/Early Triassic followed yet another marine transgression in Triassic. The rocks of Cretaceous, Jurassic and Triassic age were deposited on a west-northwest facing passing margin after the breakup Gondwanaland with maximum development of Mesozoic rocks in the western Potwar and salt range, overlapped by Paleocene strata towards East (Yeats & Hussain, 1987; Hasany & Khan, 1997). Generalized stratigraphic chart of Fimkassar filed is shown in Fig 2.3.

2.6.1 HYDROCARBON POTENTIAL OF POTWAR AREA

Kohat- Potwar basin is an oil-prone onshore basin that developed during the collision of the Indian and Eurasian continental plates. The USGS recognizes that there are several separate total petroleum systems in this area (Wandrey et al., 2001).

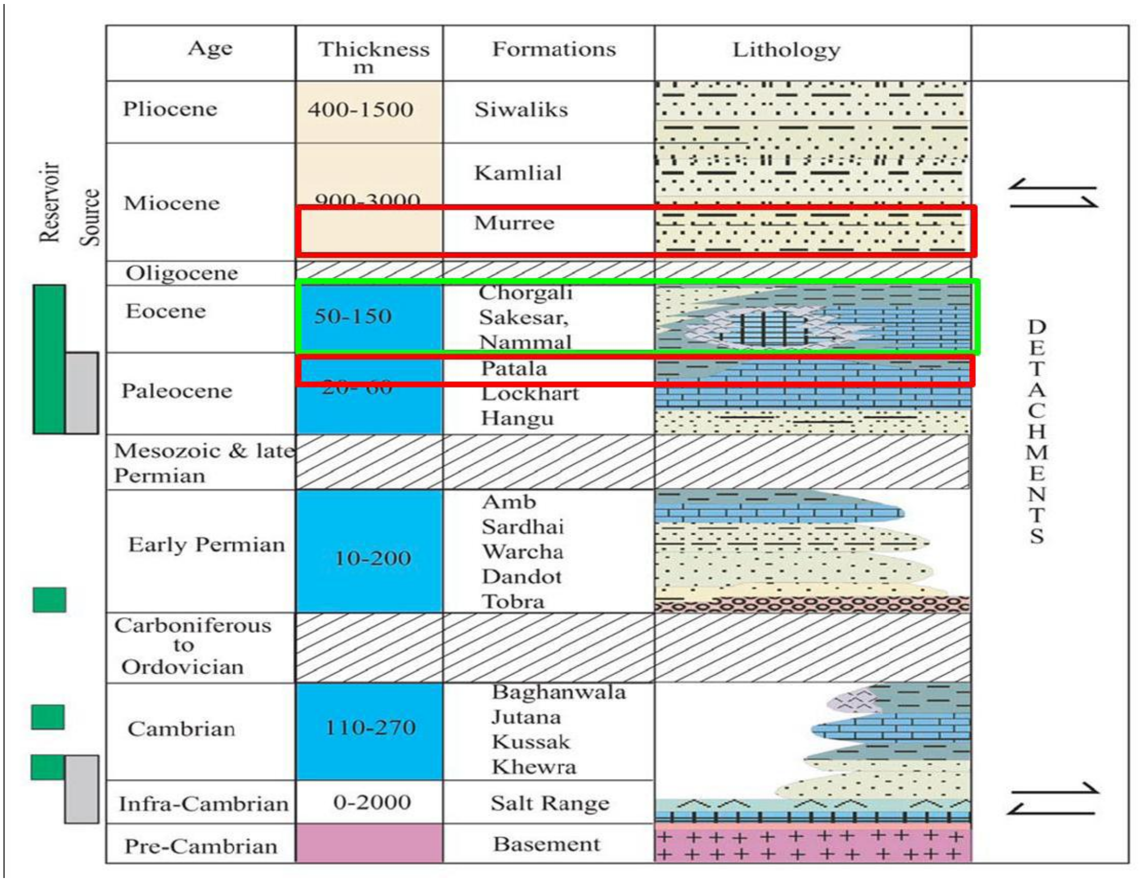


Figure 2.3: Generalized stratigraphic column of Fimkassar (Siddiqui et al., 1998).

Potwar marine facies has great potential of hydrocarbon, which accounts for 48% of the world known petroleum. Previous drilling was restricted up to Eocene carbonate. Recent discoveries in Potwar result in delineation of deep subsurface crest. Potwar region which is traditional oil producing area of Pakistan has the average geo-thermal gradient of the order of 2^0C per 100 meter. Hence the oil window lies between 2750-5200 meters (Kadri, 1995).

2.6.1 SOURCE ROCK

The source rock oil correlation study is not carried out in the present research that could have enabled us to identify and characterize the source rock of the field with confidence. However, Hydrocarbon Development Institute of Pakistan (HDIP), in collaboration with Federal Institute for Geosciences and Natural Resources Hanover, Germany have identified a number of source rock horizons through Infra-Cambrian to Eocene in the Potwar basin and surrounding areas.

These investigations imply that the organic rich shales of the Paleocene(Patala formation) can be considered as the main formation which is acting as source to the Potwar basin (Bender and Raza, 1995). Also, Salt Range formation (Pre-Cambrian) contains oil shale intervals, which shows source rock potential (Porth and Raza, 1990).

The oil to source correlation indicates that most of the oil produced in Potwar Basin has been sourced through Patala formation. Khewra shales of lacustrine to marine origin, containing woody, which are capable of generating, paraffinic to normal crude oil and gas.

2.6.2 RESERVOIR ROCK

During middle Eocene times the landmass of India was very close to the Tibetan mainland. A gulf that ran northeast-southwest connected the Tethys Sea between India and Asia with the global ocean. Paleo latitude of the Potwar basin was approximated at 30 degrees north based on a Kuwait type sabkha deposits and paleo geographic maps based on magnetic declination of volcanic (Powell, 1979). Although the effective reservoir at Fimkassar oil field lies within the Sakesar and Chorgali formations, the Nammal and Kuldana formations are also worth mentioning in this area because these four formations (Nammal, Sakesar, Chorgali and Kuldana) are part of the same depositional sequence (Vail *et al*., 1977). The Nammal, Sakesar, Chorgali and Kuldana Sequence were deposited on a ramp which fits the classic models for Tertiary low latitude carbonate ramps (Buxton and Pedley, 1989). These are characterized by slope gradients of less than degree and extend 10 to 100 of kilometers along strike (Buxton and Pedley, 1989). An arid climate also contributed to saline/hypersaline conditions in the Potwar basin. Hence Paleozoic-Tertiary dominantly marine sedimentary rocks form petroleum systems in Potwar basin and are exposed in Salt Range along the frontal thrust and the fractured carbonates of Sakesar and Chorgali formations are the major producing reservoirs in the study area.

2.6.3 SEAL ROCK

The Rawalpindi Group (Miocene age) acts as cap rock for the reservoirs of Chorgali (Eocene age) and Sakesar limestone (Eocene age) in Fimkassar. The clays and shales of the Murree formation also provide efficient vertical and lateral seal to Eocene reservoirs (Shami & Baig, 2003).

CHAPTER 3

3. SEISMIC METHOD

3.1 INTRODUCTION

Seismic Methods deal with the use of artificially generated elastic waves to locate hydrocarbon deposits, geothermal reservoirs, groundwater, archaeological sites, and to obtain geological information for engineering. It provides data that, when used in conjunction with other geophysical, borehole and geological data, and with concepts of physics and geology, can provide information about the structure and distribution of rock types.

Exploration seismic methods involve measuring seismic waves traveling through the Earth. Explosives and other energy sources are used to generate the seismic waves, and arrays of seismometers or geophones are used to detect the resulting motion of the Earth. The data are usually recorded in digital form on magnetic tape so that computer processing can be used to enhance the signals with respect to the noise, extract the significant information, and display the data in such a form that a geological interpretation can be carried out readily (Kearey et al, 2002).

Importance OF Seismic Methods

The importance of the seismic methods over other geophysical methods as mentioned by Robinson & Coruh (1988) is due to its accuracy, resolution and presentation. In addition to oil and gas prospecting, the seismic methods are also employed for the:

a. Measurement of the bedrock depth

b. Ground water investigation

c. Geotechnical purpose.

Following are the main seismic methods:

3.2 SEISMIC REFLECTION METHOD

The basic technique of seismic exploration consists of generating seismic waves and measuring the time required for the waves to travel from the source to a series of geophones, usually disposed along a straight line directed toward the source. From a knowledge of travel times to the various geophones, and the velocity of the waves, one

attempts to reconstruct the paths of the seismic waves (figure 3.1)

Structural information is derived principally from paths that fall into two main categories: refracted types of path, the travel times depend on the physical properties of the rocks and the attitudes of the b paths in which the principal portion of the path is along the interface between two rock layers and hence is

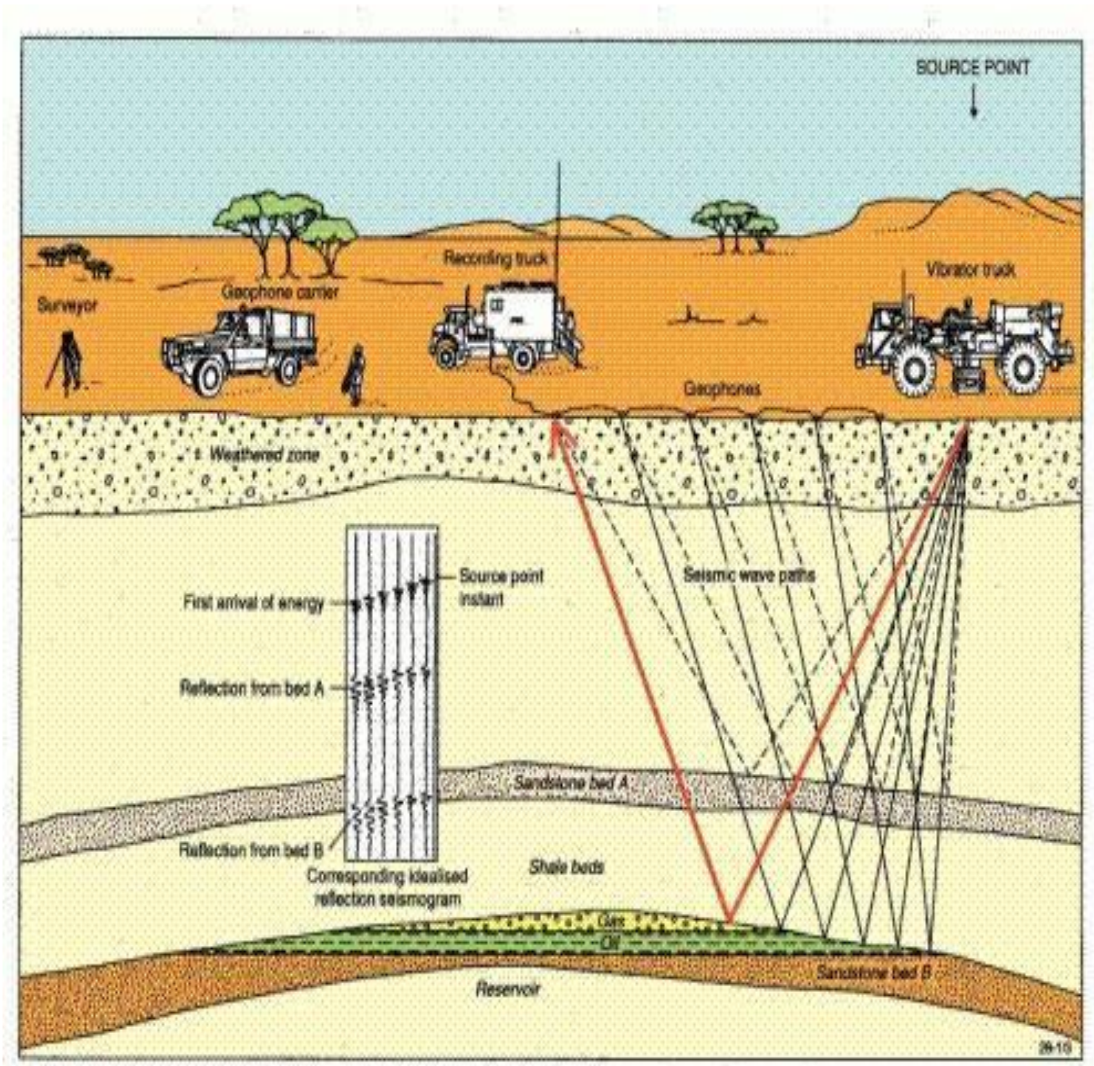


Figure 3.1 Seismic Reflection Geometry (http://mines.industry.qld.gov.au/geoscience/default.htm)

approximately horizontal; and reflected paths in which the wave is reflected back to thesurface, the overall path bein essentially vertical. For both reflection f acoustic from the subsurface arrive at geo phones some measureable time ofter the souece pulse. If we know the speed of sound in the earth and geometry of wave path we can convert this seismic travel time to depth. By measuring the arrival time at successive surface locations we can produce a **profile**, or cross-section, of seismic travel times.

3.3 SEISMIC REFRACTION METHOD

Refraction method is based on the study of elastic waves refracted along geological layer. This method is generally used for determining low velocity zone (weathered layer).

There is one type of refraction, which gives rise to a phase that can travel back to the surface. This corresponds to the case of critical incidence. Seismic refraction method is helpful in the interpretation of seismic data (Al-Sadi, 1980).

The waves which return from the top of interface are refracted waves, and for geophones at a distance from the shot point, always represent the first arrival of seismic energy (figure 3.2).

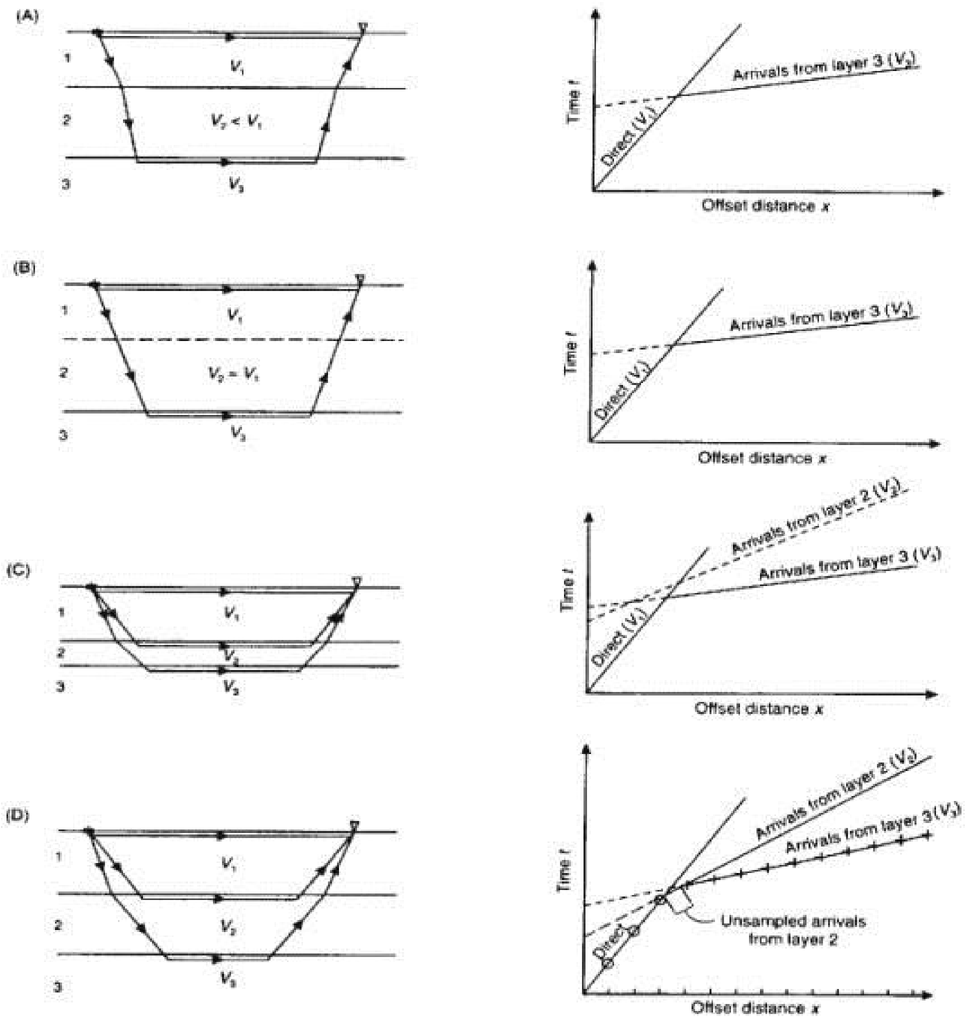


Figure 3.2 Fundamental concept of refraction(http://dc196.4shared.com/doc/vV__vKWb/preview.html)

When an incidence wave crosses an interface between layers of two different velocities, the wave is **refracted**. That is, the angle of the wave leaving the interface will be altered from the incident angle, depending on the relative velocities. Going from a low-velocity layer to a high-velocity layer, a wave at a particular incident angle (the "**critical angle**") will be refracted along the upper surface of the lower layer (figure3.3). As it travels, the refracted wave spawns up going waves in the upper layer, which impinge on the surface geophones. Sound moves faster in the lower layer than the upper, so at some point, the wave refracted along that surface will overtake the direct wave.

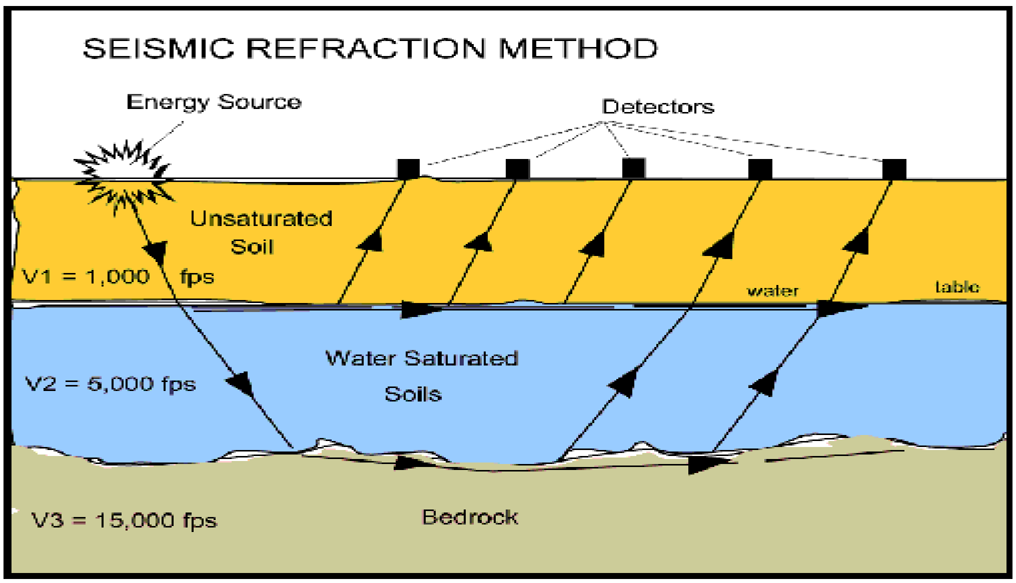


Figure 3.3 Seismic Refraction Geometry (http://www.geologicresources.com/seismic_refraction_method.html)

This refracted wave is then the first arrival at all subsequent geophones, at least until it is in turn overtaken by a deeper, faster refraction. The difference in travel time of this wave arrival between geophones depends on the velocity of the lower layer. If that layer is plane and level, the refraction arrivals form a straight line whose slope corresponds directly to that velocity. The point at which the refraction overtakes the direct arrival is known as the "**crossover distance**", and can be used to estimate the depth to the refracting surface.

Seismic refraction is generally applicable only where the seismic velocities of layers increase with depth. Therefore, where higher velocity (e.g. clay) layers may overlie lower velocity (e.g. sand or gravel) layers, seismic refraction may yield incorrect results. In addition, since seismic refraction requires geophone arrays with lengths of approximately 4 to 5 times the depth to the density contrast of interest, seismic refraction is commonly limited to mapping layers only where they occur at depths less than 100 fee (Dobrin &Savit, 1988).

3.4 SEISMIC WAVES

Seismic waves are messengers that convey information about the earth's interior. Basically these waves test the extent to which earth materials can be stretched or squeezed somewhat as we can squeeze a sponge. They cause the particles of materials to vibrate, which means that passing seismic waves temporarily deforms these particles can be described by its properties of elasticity. These physical properties can be used to distinguish different materials. They influence the speeds of seismic waves through those materials (Robinson & Coruh, 1988).

There are mainly two types of Seismic Waves:

a. Body Waves

These are those waves which can travel though the earth interior and provide vital information about the structure of the earth. The body waves can be further divided into the following;

1. P-Waves (Primary Waves)

The particular kind of waves of most interest to seismologists are the compressional or P-waves also called as compressional waves, longitudinal waves, primary waves, pressure waves, and dilatation waves (see Fig. 3.5). In this case the vibrating particles move back and forth in the same direction as the direction of propagation of waves. P-waves can pass through any kind of material

- solid liquid or gas. The P-waves velocity depends upon density and elastic constants (Dobrin & Savit, 1988).

The seismic velocity of a medium is a function of its elasticity and can be expressed in terms of its elastic constants. For a homogeneous, isotropic medium,

the seismic P-wave velocity Vp is given by;

$$Vp = \sqrt{\frac{(4/3)\mu + k}{\rho}},$$

Where:

μ is the shear modulus.

kis the bulk modulus.

ρ is the density of the medium.

2. S-Waves (Secondary Waves)

In shear waves, the particles vibrate in a direction perpendicular to the direction of propagation of waves (see Figure 3.4).

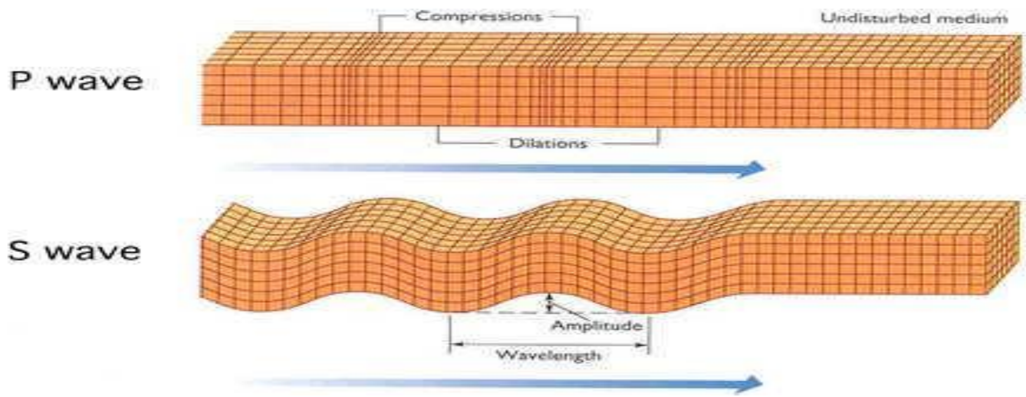


Figure 3.4 the propagation of P & S-waves in an Elastic Medium.
(http://quake.abag.ca.gov/students/seismic-waves/)

They are also called as Shear waves, transverse waves, and converted waves. For ideal gases and liquid μ=0.

S-waves cannot pass through fluids. The velocity of S-waves is given by (using the same notation as of Vp) (Dobrin & Savit, 1988).

$$Vs = \sqrt{\frac{\mu}{\rho}} .$$

3.4.1 Characteristics Of Body Waves

These waves travel with low speed through layers close to the earth's surface, as well in weathered layers (Robinson & Coruh 1988) .

Frequency of body waves in exploration vary from 15Hz to 100 Hz

b. Surface Waves

A part from body waves more complicated patterns of vibration are observed as well. These kinds of vibrations can be measured only at locations close to the surface. Such vibrations must result from waves that follow paths close to the earth's surface, hence known as surface waves. In a bounded elastic solid, surface wave can propagate along the boundary of the solid. Frequency of surface waves is less than 15Hz. Surface waves are also of two types;

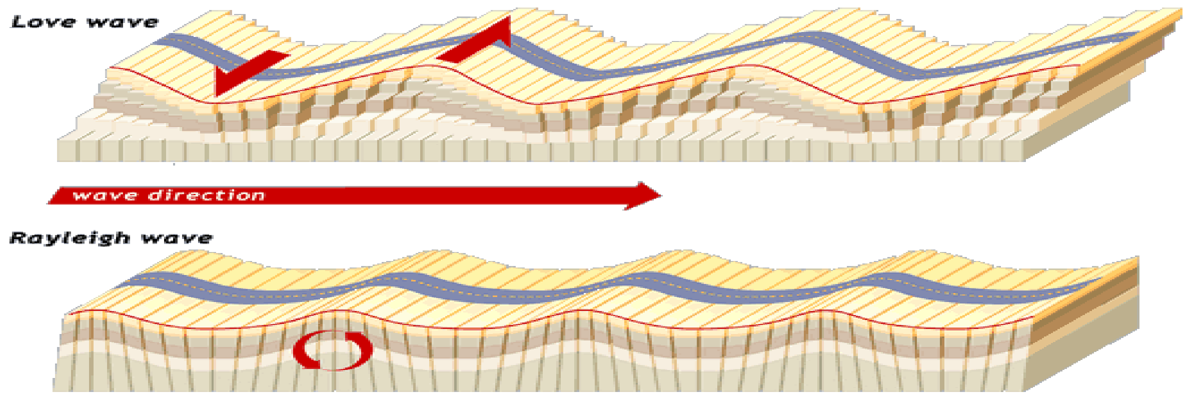


Figure 3.5 Propagation of Love & Rayleigh waves in an Elastic Medium (http://7bcore1.wikispaces.com/Glossary)

1. **Raleigh Waves**

Type of surface waves having a retrograde, elliptical motion at the free surface of a solid and it is always vertical plane. Raleigh waves are principal component of ground roll. The Figure 3.5 shows the propagation of Raleigh waves in an elastic medium (Kearey, 2002).

2. **Love waves**

A type of surface waves having a horizontal motion i.e. transverse to the direction of propagation. The velocity of these waves depends on the density and modulus of rigidity and not depends upon the bulk modulus (k). Figure 3.5 shows

the propagation of Love-waves in an elastic medium (kearey, 2002).

3.5 LAWS GOVERNING THE PROPAGATION OF SEISMIC WAVES

There are the following laws usually governs the propagation of seismic waves.

a. Huygens's Principle

This principle states, "each point on a wave front may be considered as source of new wave front.

b.Fermat's Principle

It is defined as "the elastic waves between two points along path requiring the least time"**.**

c. Snell's Law

The direction of reflected and refracted waves traveling away from a boundary depends upon the direction of the incident waves and speed of the waves (figure 3.6).

Sini/ Sinr = VO / V1

Where,

I = angle of incidence

R = angle of refraction

VO = velocity of 1st medium

V1 = velocity of 2nd medium

The angle of incidence "i" for which angle of refraction is 90o, is called "*Critical Angle*" and for refraction is denoted by ic as follows, (Sin ic = Vo / V1)

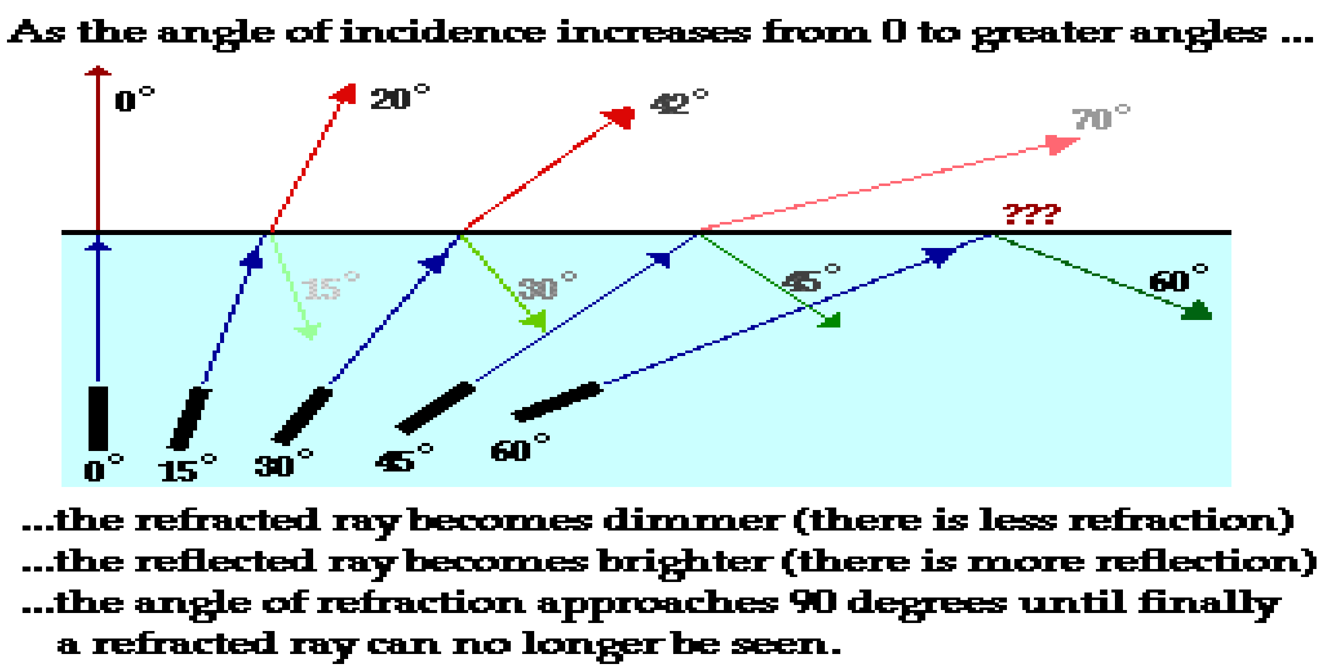


Figure 3.6 Showing Refraction and angle of incidence

*(*http://www.physicsclassroom.com/class/refrn/*).*

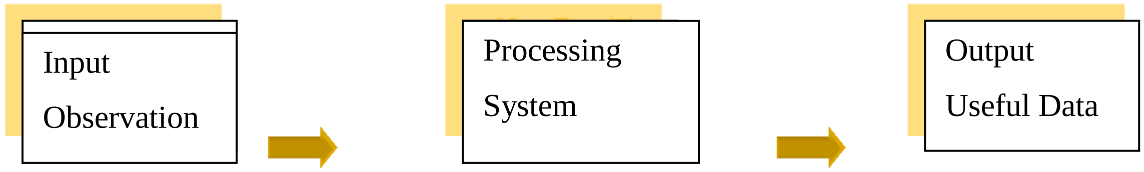
3.6 SEISMIC DATA PROCESSING

Data processing is an approach by which the raw data recorded in the field is enhanced to the extent that it can be used for the geological interpretation (Al- Sadi, 1980).

3.6.1 SEISMIC PROCESSING FLOW CHART

Fig 3.7 shows a generalized flow chart of seismic processing. Both the mechanical and interactive processes are included in the processing flow chart.

Data processing is a sequence of operation, which are carried out according to the pre-defined program to extract useful information from a set of raw data as an output system.



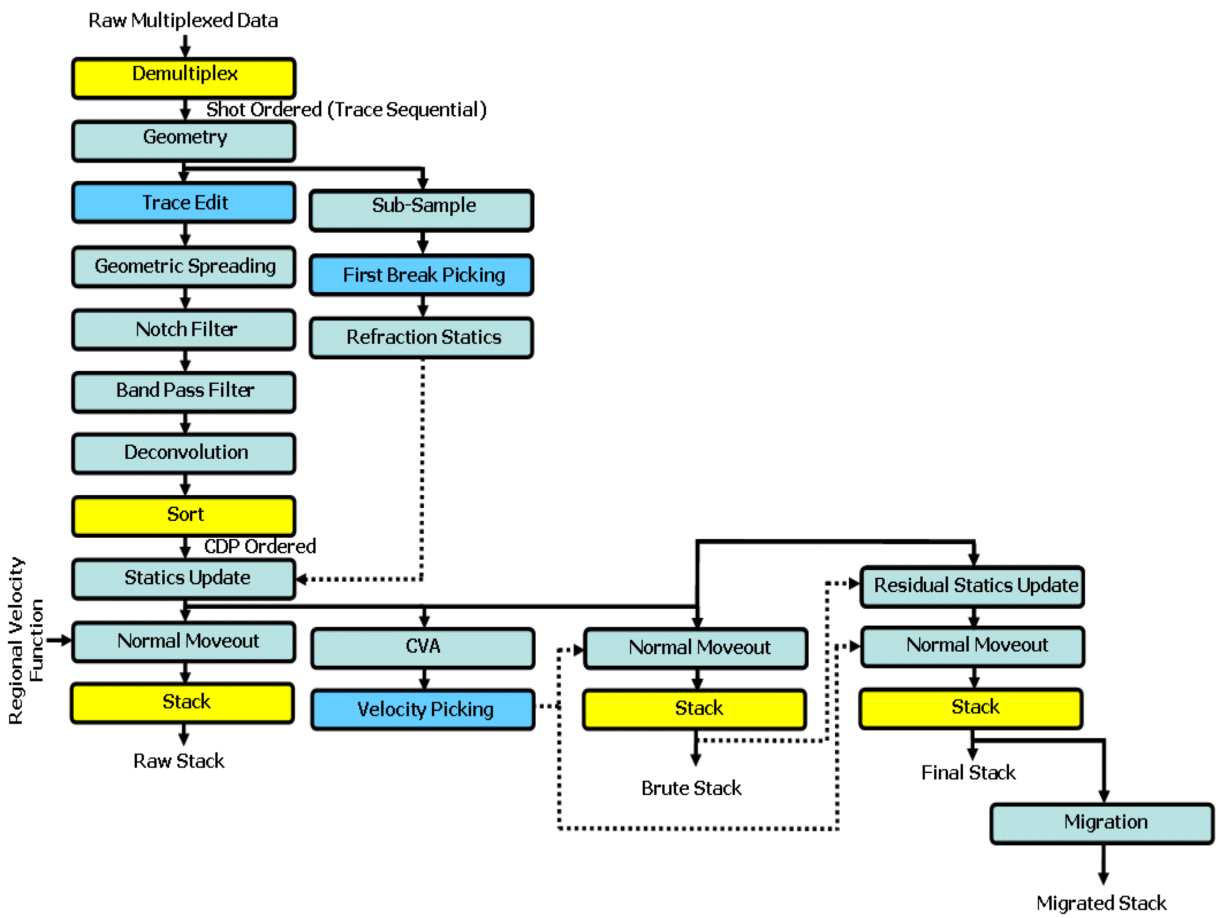


Figure 3.7: Generalized flow chart of Seismic Data Processing

3.6.2 AIM AND PURPOSE

The basic aim and purpose of data processing is to produce a perfect seismic section by applying a sequence of correction. Actually the seismic reflections from the depth are generally week and need to be strengthened by digital processing of field data (Robinson & Coruh, 1988).

3.6.3 PRIMARY STAGES AND PROCESSING SEISMIC DATA

According to Yilmaz, 2001 there are three primary stages in Processing Seismic Data. In usual order of application they are:

3.7 BASIC SEISMIC ACQUISITION

The purpose of seismic data acquisition is to record the effects produced by mechanical disturbance somewhere at the surface or close to the surface of the earth, and observing its effects at a number of locations along the surface in such a manner that their relation with the initial disturbance can be interpreted.

One important thing, for the equipment, is for it to be at least slightly better than necessary so as to avoid setting a limitation on what the processing can accomplish and to what the interpretation can do. It includes all those steps which yield final output to be processed and interpreted. The instruments so adopted to acquire seismic data now-a-days differ from those used in past, but essential principle for all instruments is same.

The seismic data acquisition starts with, field by few organization divided as if it is land organization or marine organization. Then the whole work starts with field equipment and methods to be adopted for the acquisition of seismic data. The essentials for the 2D-seismic data acquisition and processing are discussed briefly in this chapter.

3.7.1 ENERGY SOURCES

The mechanical disturbance which is at the origin of a seismic observation is generated by displacing momentarily a small volume of rock from its rest position. There are different ways of doing so that whether to apply such an artificial disturbance on land or in water.

a. Vibroseis

b. Dynamite

Following major steps are followed in the process of acquisition:

a. Base map

b. Basic spread

c. Channel pattern

d. Sample interval

a. Base Map:

Information about seismic profile, there orientation and length.

b. Basic Spread:

Spread is the arrangement of geophones.

TYPES:

End on spread

Inline spread

L spread

Symmetric/Split spread

Cross spread

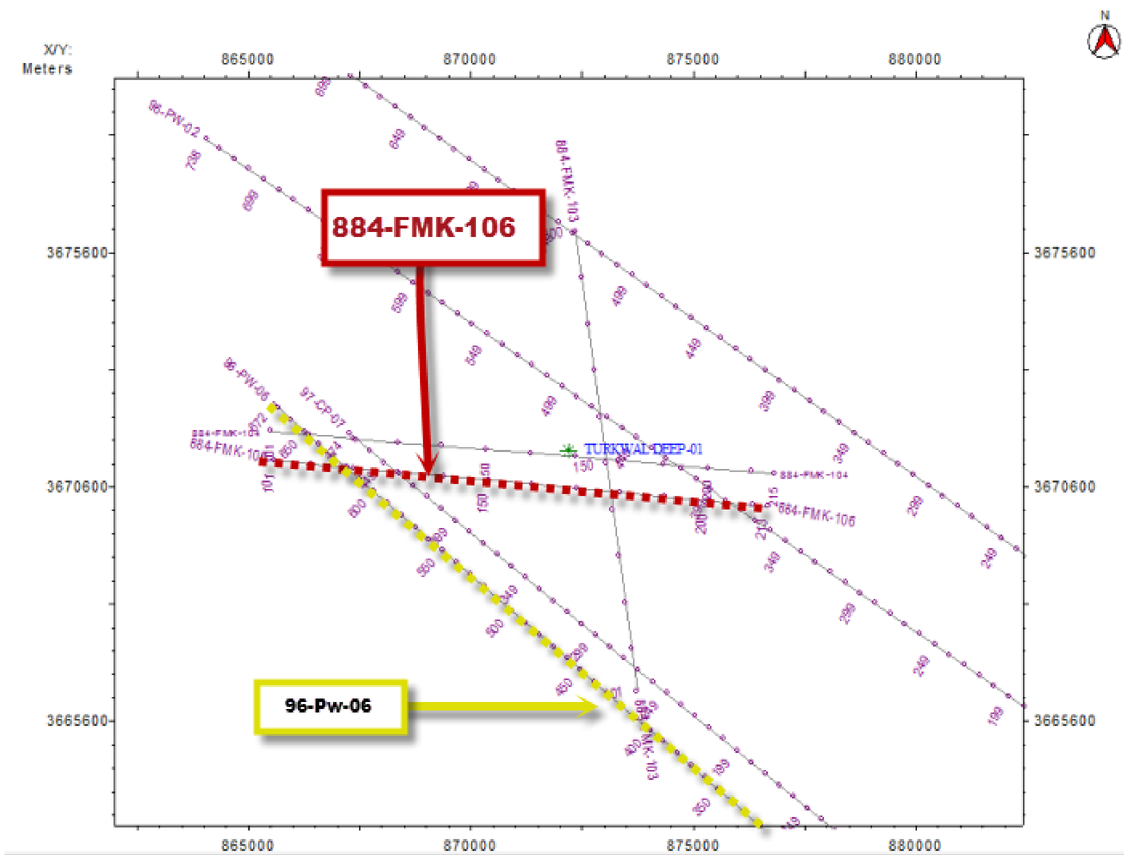


Fig 3.8 Base map of seismic lines which helps in interpretation.

c. Channel pattern:

In it we can know that how many geophones are connected in a series.

d. Sample interval:

The interval between the readings, such as the interval between two successive samples of a digital seismic trace.

As interval of samples are 2ms or 4ms.

CHAPTER 4

4. SEISMIC INTERPERTATION

4.1 INTRODUCTION

Interpretation is a technique or tool by which we try to transform the whole seismic information into structural or stratigraphical model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, we try to locate the zone of final anomaly. It is rare that correctness or incorrectness of an interpretation is ascertained, because the actual geology is rarely known in well manner. The test of good interpretation is consistency rather than correctness. Not only a good interpretation be consistent with all the seismic data, it also important to know all about the area, including well information, surface geology as well as geologic and physical concept.

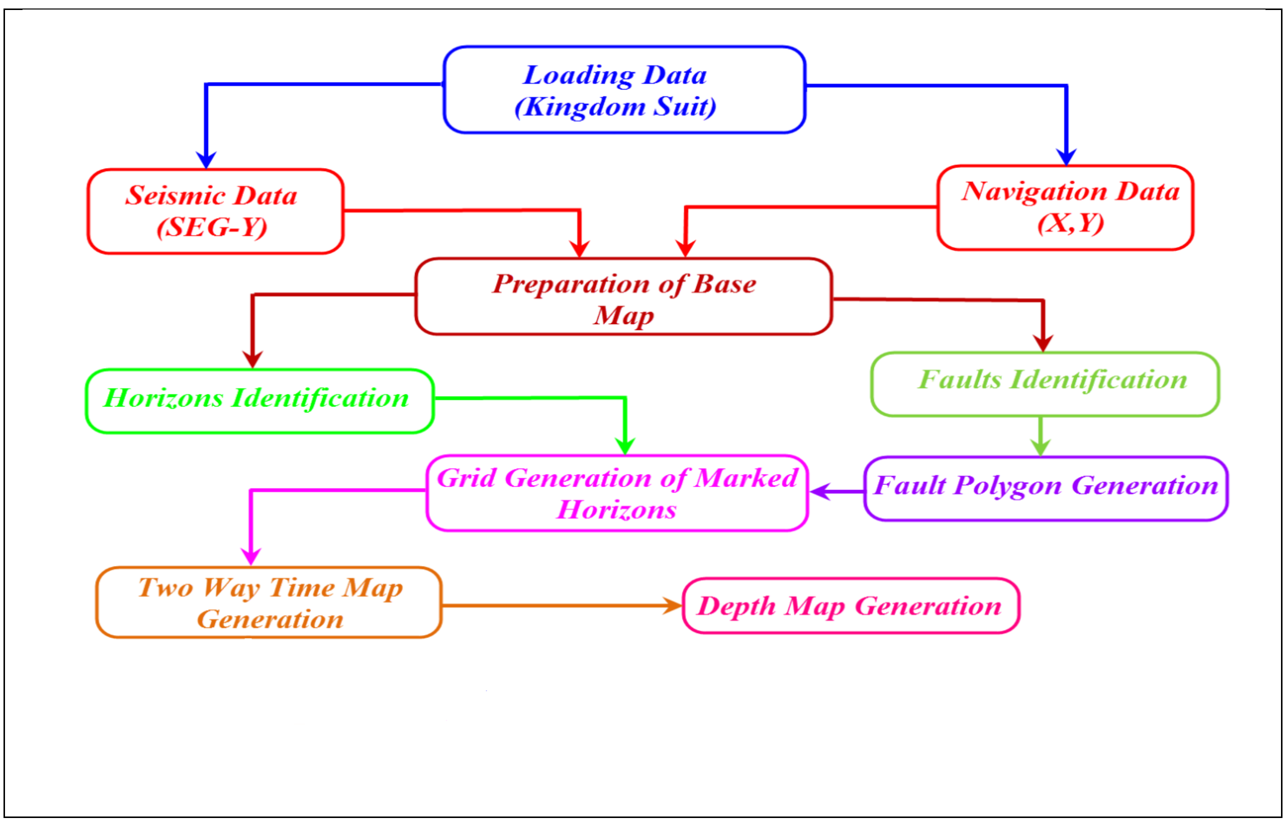


Fig 4.1 Flow chart of basic steps involved in interpretation.

An interpreter of seismic data may have good hold in both geology and geophysics. It is the ingenuity and in-depth understanding of an interpretor to extract geologic significance from aggregate of many minor observations. For example, down dip thinning of the reflection might be result from normal increase velocity with depth or thinning of the sediments or flow of the shale or salt may develop illusory structure in the deeper horizon.

Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. Conventional seismic interpretation is an art that requires skill and thorough experience in geology and geophysics. The seismic method has thus, evolved into a computationally complex science.

The computer based working (Processing & Interpretation) is more accurate, precise and satisfactory which provides more time for further analysis of seismic data. .

4.2 STRUCTURAL INTERPRETATION

Seismic'data interpretation is mainly done on the basis of available information and stratigraphy of the area. Seismic is correlated with the formation tops penetrated in the wells using well tops if available. In this study, seismic interpretation is done by picking horizons in Kingdom suit and reflector is continued in all other seismic line s. Major faults are picked on the dip lines and their parts are correlated across the strike lines to map the structures throughout the area. Misties are major concern during interpretation, which is resolved by using of bulk shift of different time. Two way time (TWT) maps are generated using fault polygons in order to describe the structural inclination at different levels. The study area is in compressional regime, pop up and snaked head structures are present in the area. The horizons which are marked on seismic section show thrust and reverse faulting. Faults are oriented in the northeast-southwest (NE-SW) direction.

Comparing all the maps it is obvious that pop-up and snaked head structures are present in the study area. Navigations and SEG-Y of given two seismic lines of Fimkassar area are loaded in software (Kingdom Suit) and following procedure is adopted as shown in Fig 4.1.

a. Preparation of base map.

b. Marking of seismic horizons.

c. Fault identification and marking the faults.

d. Fault polygons generation.

e. Contour maps generation (Time & Depth).

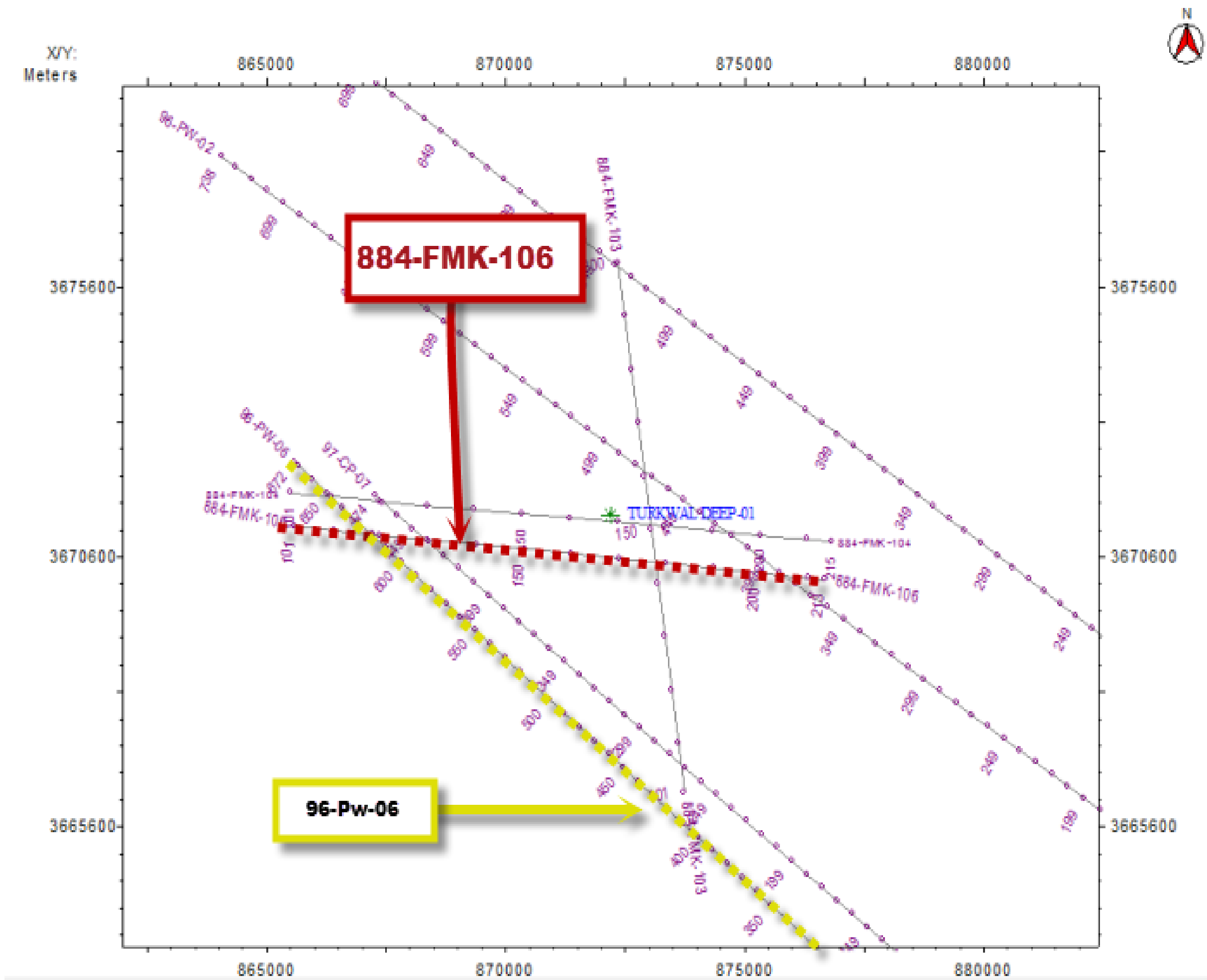


Fig:4.2 showing base map of the area

4.2.1 PREPARATION OF SEISMIC HORIZON

The first most task ofter the preparation of base map is to mark the interface which are present between geological formation. For this purpose, good structural as well as stratigraphic knowledge of the area is required. Thus during interpretation process, I mark both, the horizons and faults on the seismic section.

In this area we are interested in Eocene reservoir rocks (Skassar,Nammal,Chorgali) and to mark the horizon and fault I pick the well tops data from where I find the depth and from velocity function I calculate the average velocity of the area by using DIX equation. Than calculate the time of each reflector and by using this time I mark the Horizons.The horizons are named on basis of well tops of the well Fimkassar-02 and Turkwal-01.

4.2.2 INTERPRETATION OF SEISMIC SECTION

The interpreted seismic section of the line 884-fmk-106 and 96-pw-06 is shown in Fig 4.3 and Fig 4.4 respectovly. Total three seismic horizons namely, Chorgali, Sakesar and Nammal of Eocene age are marked. Along these seismic horizons, three faults are also picked shown in Figures 4.3 and 4.4.

Main structures and faults are clearly show that compressive forces are acting in this area.Pop up structure are formed due to back thrusting and make good traps for hydrocarbons accumulation. A well is producing hydrocarbons which is shown in Fig:4.3

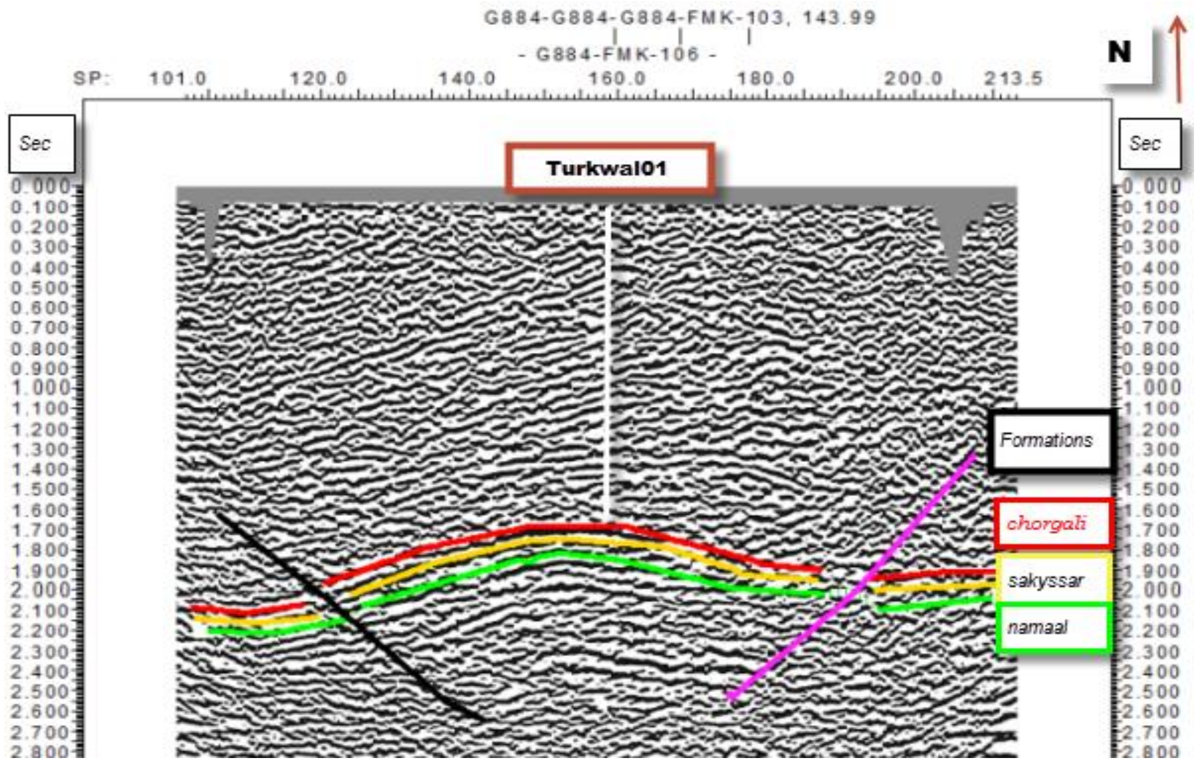


Fig 4.3 Section of line 884-FMK-06 showing marked horizons

Interpretation of this line show that this reign contain both snaked head and pop-up structures and making most favorable traps for hydro carbons accumulation.

4.2.3 POLYGONS

Before generation of grid fault polygons it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points (represented by a "+" or a "x" sign by Kingdom software) can be manually joined to make a polygon. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted in to polygons prior to contouring. The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false

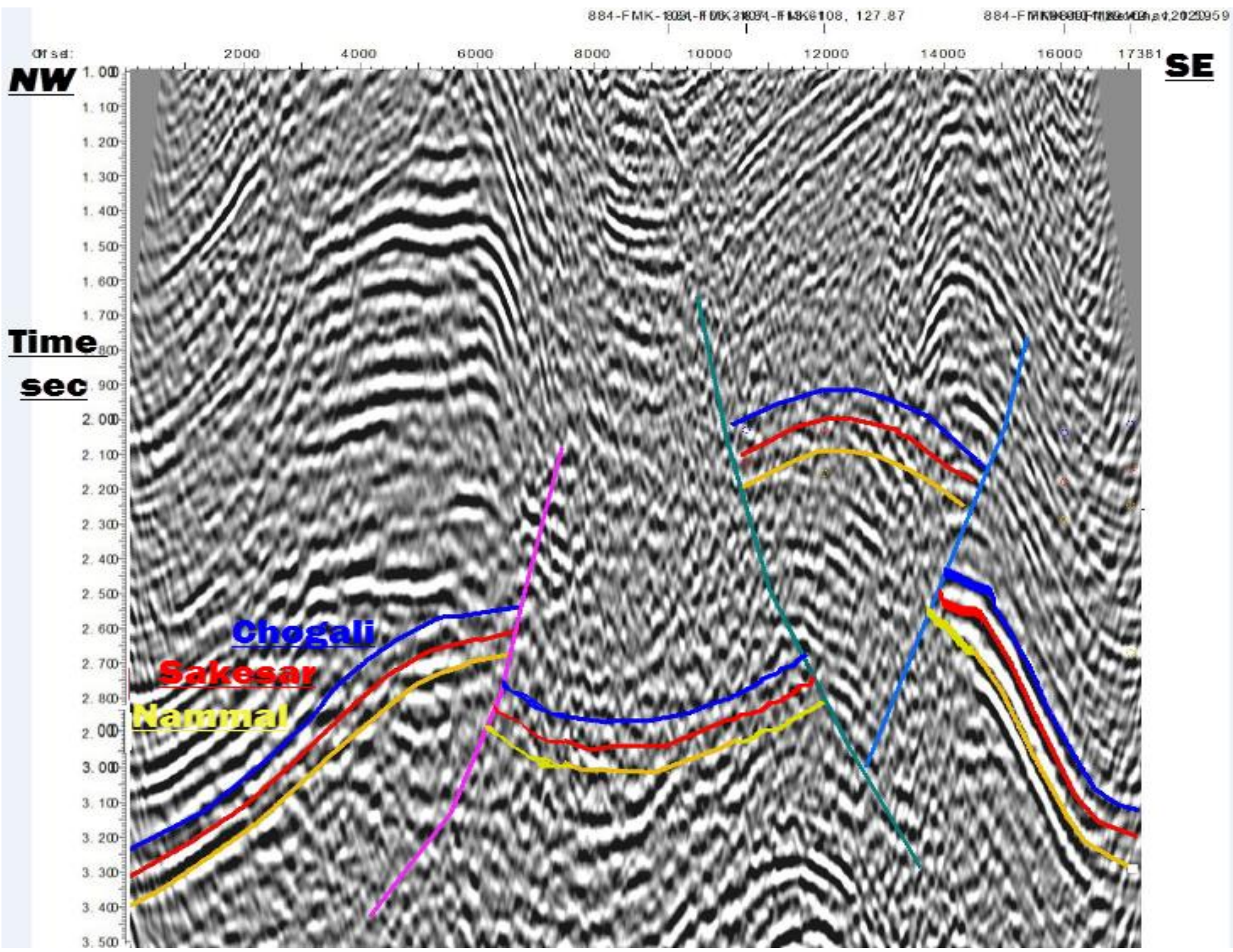


Fig 4.4 Section of line 96-PW-06 showing marked horizon

picture of the subsurface. Fig 4.5 formed at Chorgali level shows that after construction of fault polygons, the high and low areas on a particular horizon become obvious. Moreover, the associated color bar helps in giving information about the dip directions on a fault polygon if dip symbols are not drawn. Fault polygons are constructed for all marked horizons and these are oriented in NE-SW direction.

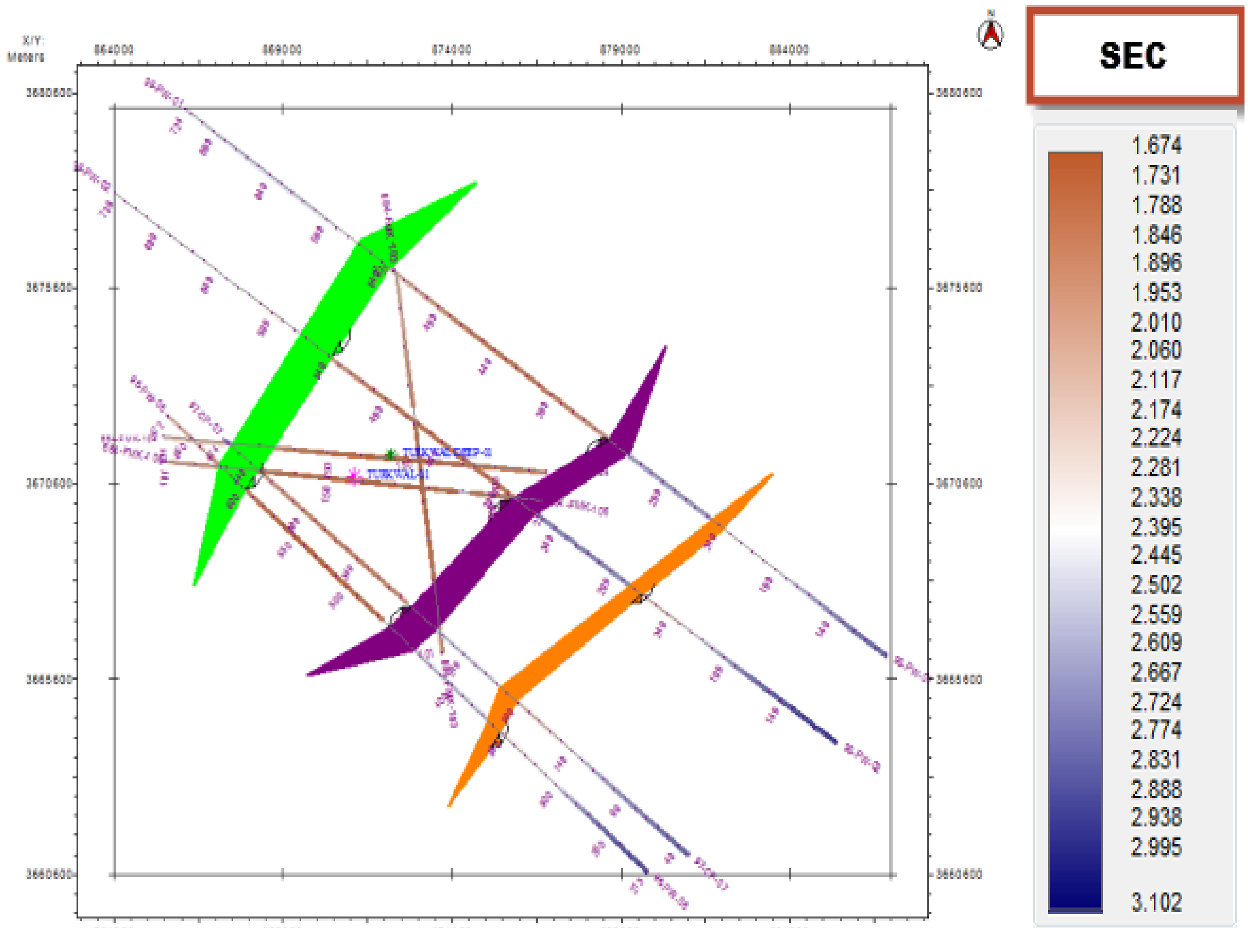


Fig:4.5 fault polygons

4.2.4 GRID

After marking the fault polygons, we start to create grid. To interpolate the area between the lines we use gridding. Grid is also necessary for making time and depth contour map.grid is true 2-D representation of of reflector and show complete variation in its depth by different colours.

4.2.5 CONTOUR MAPS

Contouring is the main tool used in the seismic interpretation. After contouring it becomes obvious that what sort of structure is forming a particular horizon. Chorgali Formation is selected for the purpose of constructing contour maps.

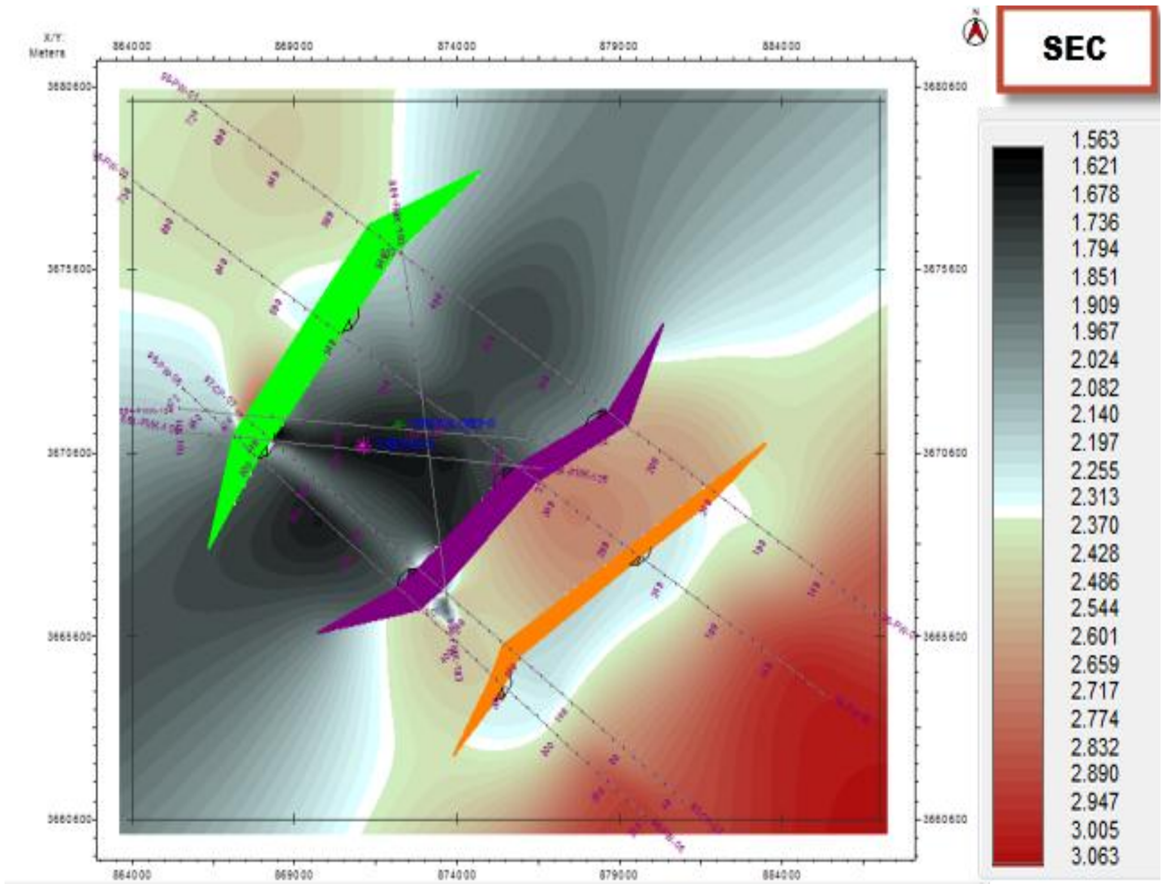


Fig:4.6 Grid of Chorgali formation

4.2.6 TIME AND DEPTH CONTOUR MAPS OF CHORGALI FORMATION

Chorgali formation is the first zone of interest. It is producing both Oil & Gas and is mainly composed of limestone with some shaly content. On the seismic section Chorgali reflector is not very strong and it is very difficult to locate. Chorgali time & depth contours maps shown in Figs 4.7 and4.8 respectivly are plotted on the seismic base map along with well locations and fault polygons. Here fault polygons making the areas of interest more prominent by providing structural traps for hydrocarbon accumulation in the form of pop-up structure. The contour interval in time & depth contour maps is set as 30 m/sec and 50 m respectively. Two Way Time (TWT) contour map of Chorgali formation is shown in Fig 4.7. Time variation is mentioned through the color bar from (1.563 to 3.063 sec). Yellow colored portion (1.563 to1.876 sec) is showing the shallowest part while blue colored portion (2.883 to 3.063 sec) is

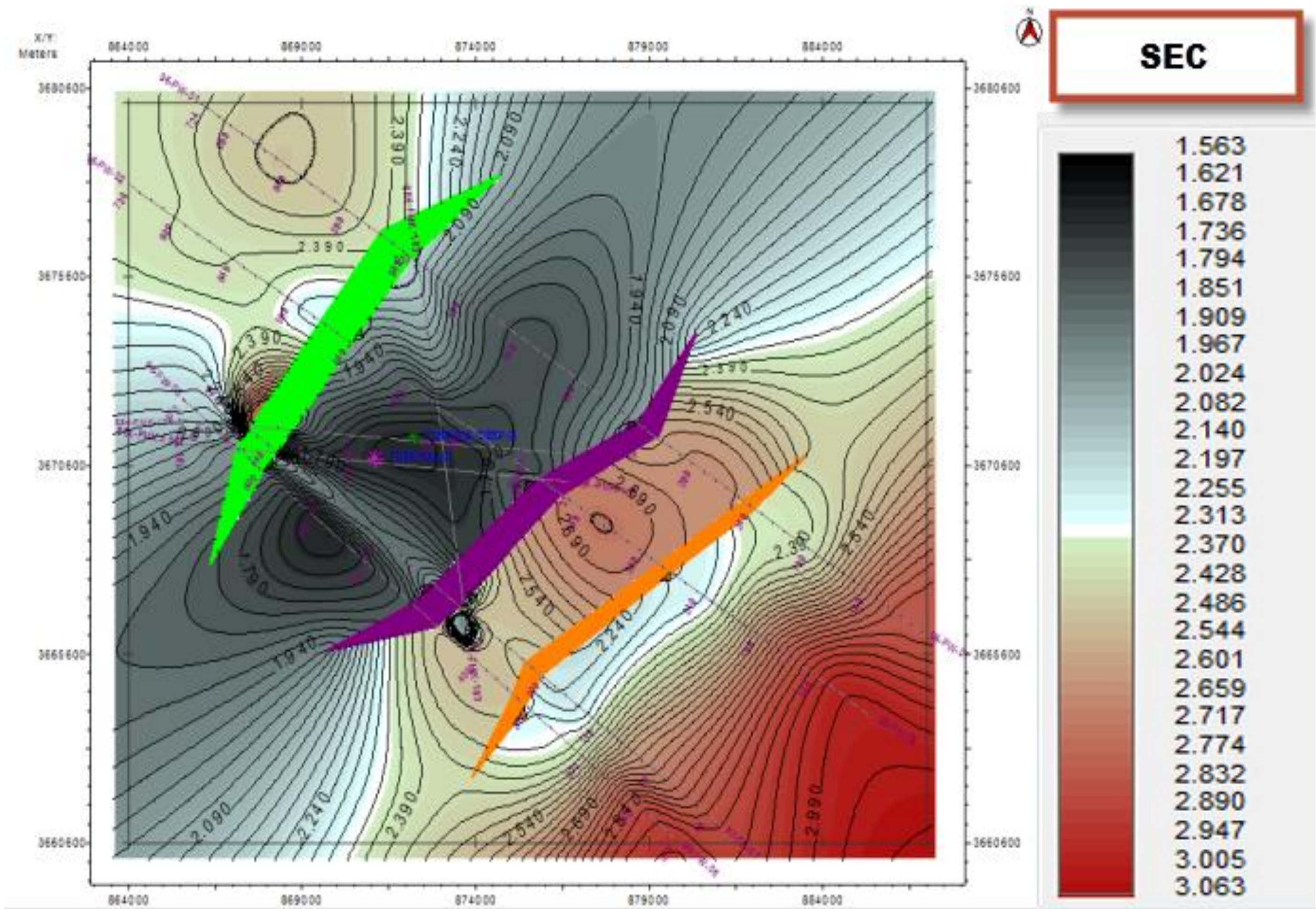


Fig:4.7 time Contour map of Chorgalli formation

showing deeper part of the formation. It is clear from the Fig 4.7 that the Chorgali formation is deepening NW-SE direction as the time is increasing in this direction, while formation is uplifting toward NE-SW direction because time is decreasing in this direction. Hence light yellow color from (1.563 to 1.663 sec) is showing highest (peak) point and it is the most favorable area for hydrocarbon extraction.

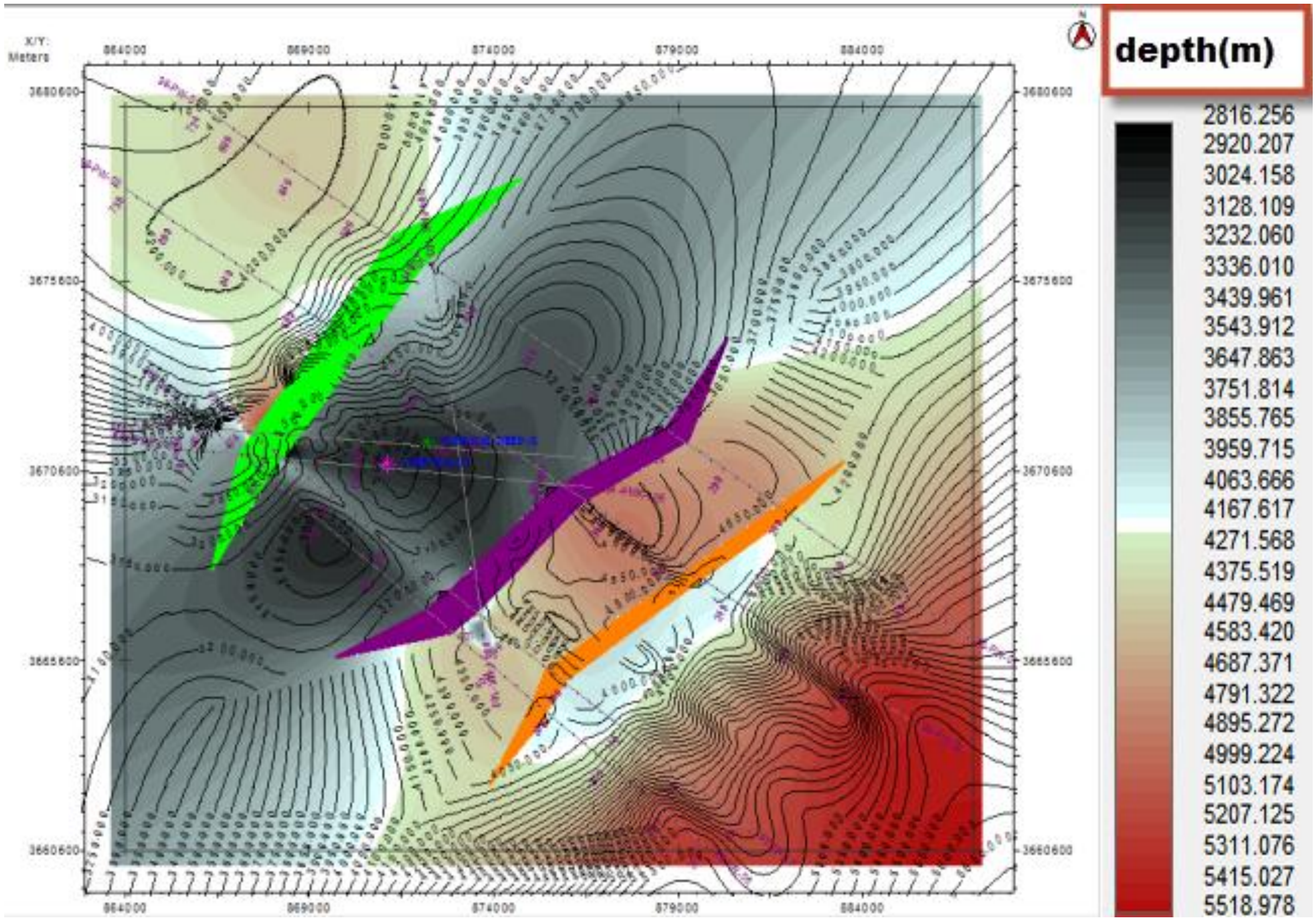


Fig:4.8 Depth Contour map of Chorgalli formation

Depth contour map of Chorgali formation is shown in Fig 4.8. Depth variation is mentioned through the color bar from top 3030.97 m to bottom 5622.916 m. Yellow portion (3030.97 to 3497.707 m) is showing the shallowest part while blue color (5442.410 to 5622.916 m) is showing deepest part of the formation. It is clear from the Fig 4.8 that the Chorgali formation shows deepening towards NW-SE direction as the depth is increasing in this direction, while formation is uplifting towards NE-SW direction because depth is decreasing in this direction. Hence light yellow color from (3030.976 to 3186.55 m) is showing highest (peak) point and it is the most favorable area for hydrocarbon extraction.

4.3 INTERPRETATION USING INTERACTIVE SOFTWARE TOOLS

All work has been carried out using a combination of computer software products. This has several advantages which include accuracy, precision and efficiency providing more time for further analysis of data. Navigation Data was transformed to UTM Zone 41 North and all digital maps along with geo-referenced imagery were produced using KINGDOM provides an interactive interface for marking horizons & faults, similar to a seismic interpretation workstation. It stores this information into a digital file.

CHAPTER 5

5. ROCK PHYSICAL PROPERTIES ESTIMATION AND PETROPHYSICAL ANALYSIS

5.1 INTRODUCTION TO ROCK PHYSICS

Rock Physics describes a reservoir by physical properties such as porosity, rigidity, compressibility; properties that will affect the how seismic waves physically travel through the rocks, and to establish a relation between these materials and the observed seismic response of a rock at certain physical conditions. The techniques can be used for rock physics modeling, i.e. to predict the elastic (seismic) properties from the geology, or for rock physics inversion, i.e. to predict geology from elastic (seismic) observations

In Rock physics we mainly use Sonic, Density and Dipole logs in order to fulfill our goal to establish relationship between P wave velocity Vp, S wave velocity Vs Density with Bulk, Rigidity module Porosity, etc.

5.1.1 FOLLOWING ROCK PARAMETERS AND ENGINEERING PROPERTIES ARE CALCULATED USING WELL DATA

- Density
- Bulk modulus
- Shear modulus
- Young’s modulus
- Poisson’s ratio

5.1.2 DENSITY

Density is a major property of the rock which describes the amount of solid part of the rock body per unit volume. Simply mass per unit volume is called density. Higher denser rocks make the seismic velocity to drop down (sheriff, 1999).

The attenuation is higher for more dense rocks. The case is reverse for the lighter rocks. Seismic velocity is inversely proportional to density.

Direct estimation of density from seismic velocities have been done by using the formula

$\rho = 0.31 * (Vp)^{0.25}$

Where ρ = Density, Vp = P-Wave velocity in m/sec.

Density is used in various reflectivity and moduli calculations.In seismic methods, the density and velocity are most important parameters .The geologist determine the rock types or compaction, age, digenesis and burial history while the engineer determine the porosity, saturation, temperature and pressure gradient.fig5.1 shows the variation of density with depth,as the density of hydrocarbon is much low, so the zones of low density(2936to2942) may indicate hydrocarbon or other less dense material.

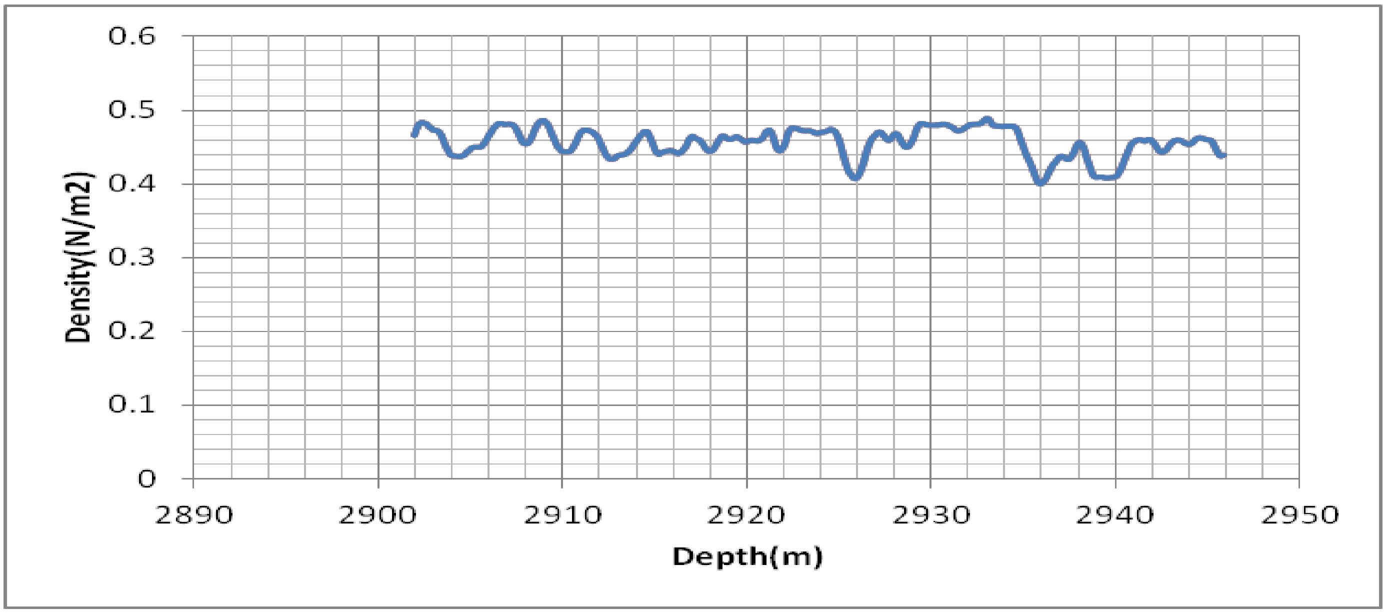


Fig:5.1 showing the density of chorgali Fm

5.1.3 YOUNG MODULUS

Young's modulus or modulus of elasticity (E) is a measure of the stiffness of an isotropic elastic material. It is the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds. It describes the material's response to linear strain. The value of young modulus is calculated by the following relation,

$E = (9 * K * \mu)/(3 * K + \mu)$

Where, E is young modulus, K is bulk modulus and μ is shear modulus.

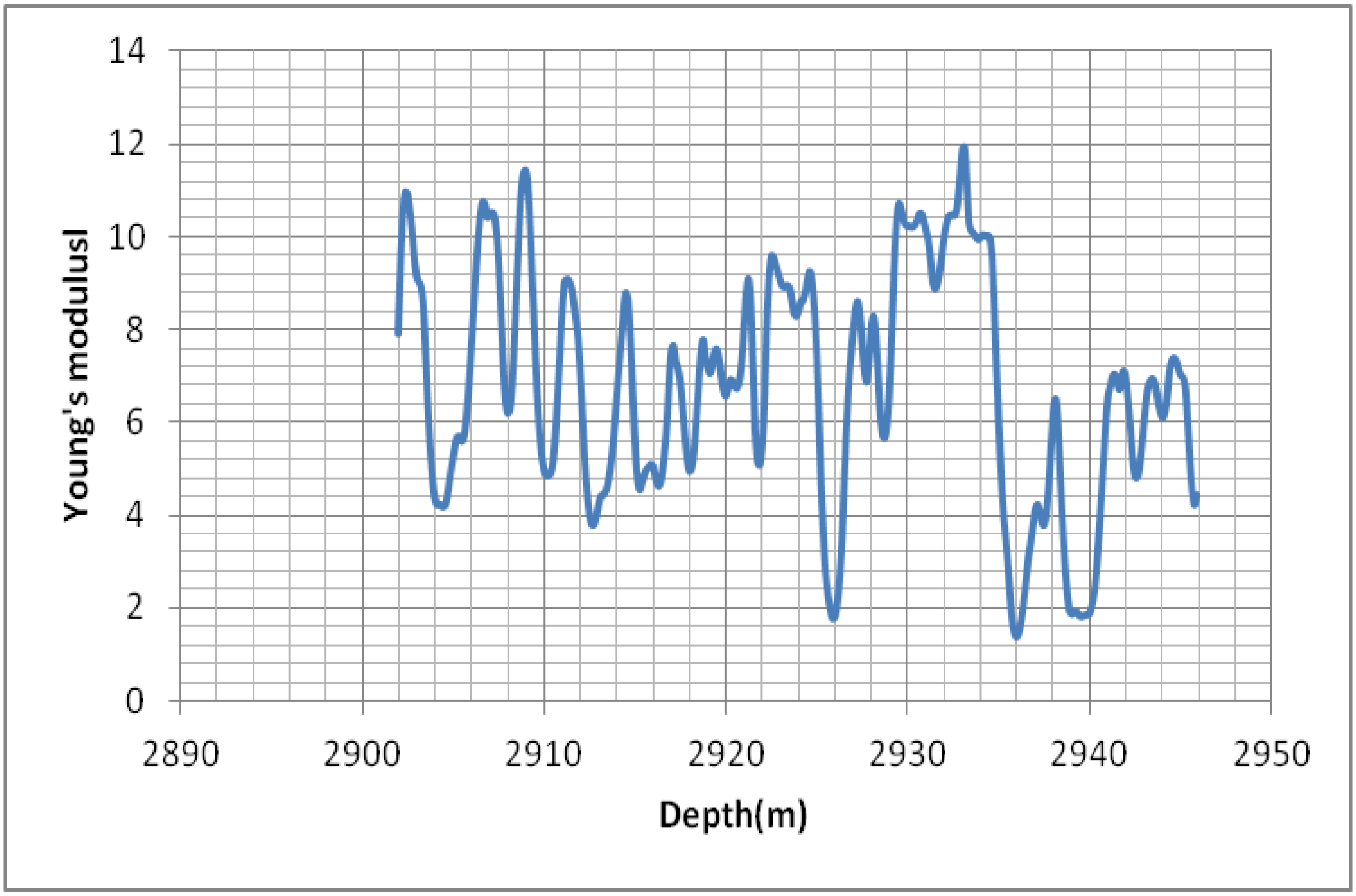


Fig:5.2 showioung Young's modulus of chorgali Fm

5.1.4 POISSON'S RATIO

Poisson's ratio (σ) is defined as the transverse strain divided by longitudinal strain. This means that it is the measure of incompressibility of the rock body. In Post stack data shear wave velocity has been estimated only as a parameter as post stack data do not have shear components. Also Poisson's Ratio is more dependent upon P- wave velocity rather than S-Wave velocity.

Estimation of Poisson's ratio from shear wave velocity and density have been done by using the formula

$\sigma = ((0.4*(Vp^2/Vs^2)-1)/(Vp^2/Vs^2)-1)$

Where σ =Poisson Ratio, Vp = P-Wave velocity in m/sec, Vs =Shear wave velocity.

In other words we can say that the Poisson's Ratio is the measure of the behavior of a seismic wave when it passes through the rock body.

Zone of high poisson's ratio(2936to2942) show the compressible area with high probability of presence of hydrocarbons .

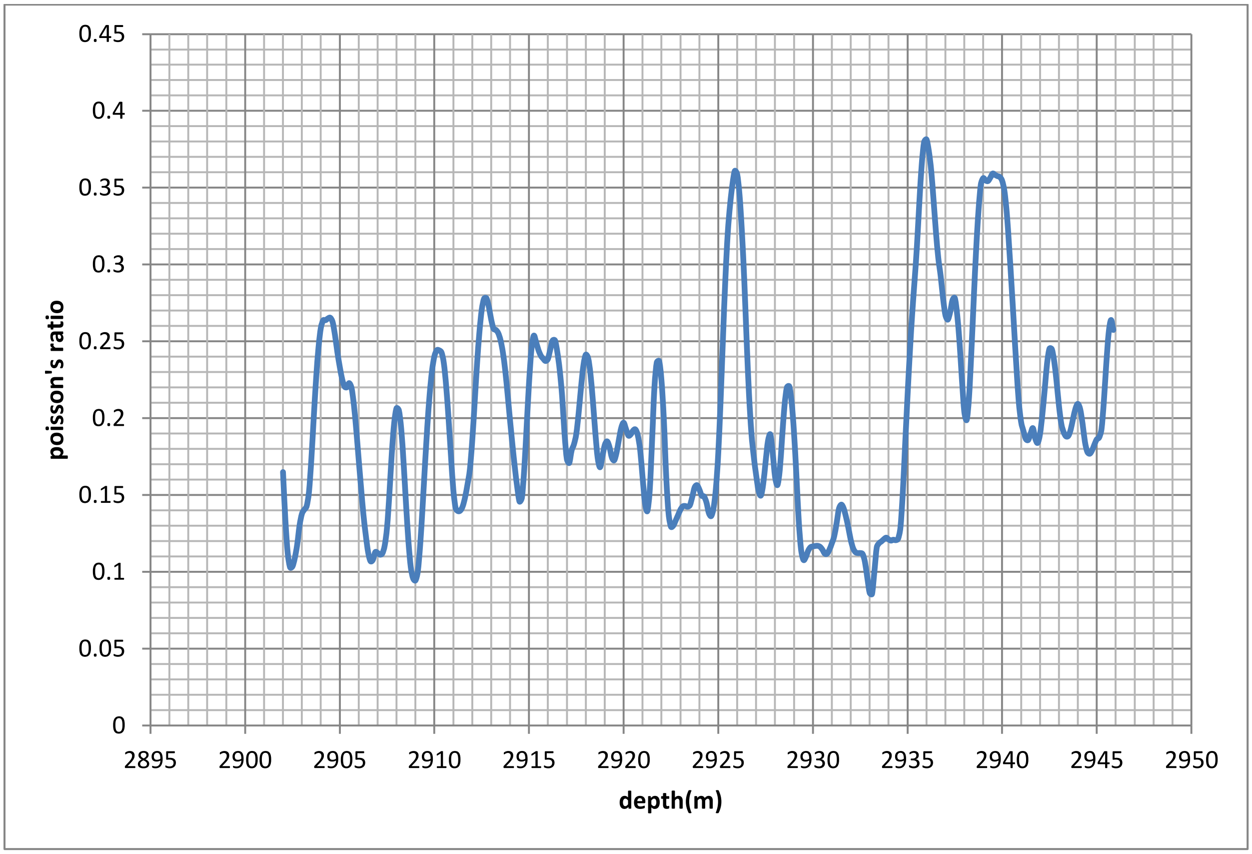


Fig:5.3 showing the graph of poisson's ratio of chorgali Fm

5.1.5 SHEAR MODULUS

Shear modulus or modulus of rigidity (μ), is defined as the ratio of shear stress to the shear strain (angle of deformation). It is concerned with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force (such as friction). It describes the material's response to shearing strains.

The value of young modulus is calculated by the following relation.

$\mu = \rho * V_s^2$

Where ρ is density and V_s is velocity of secondary waves.

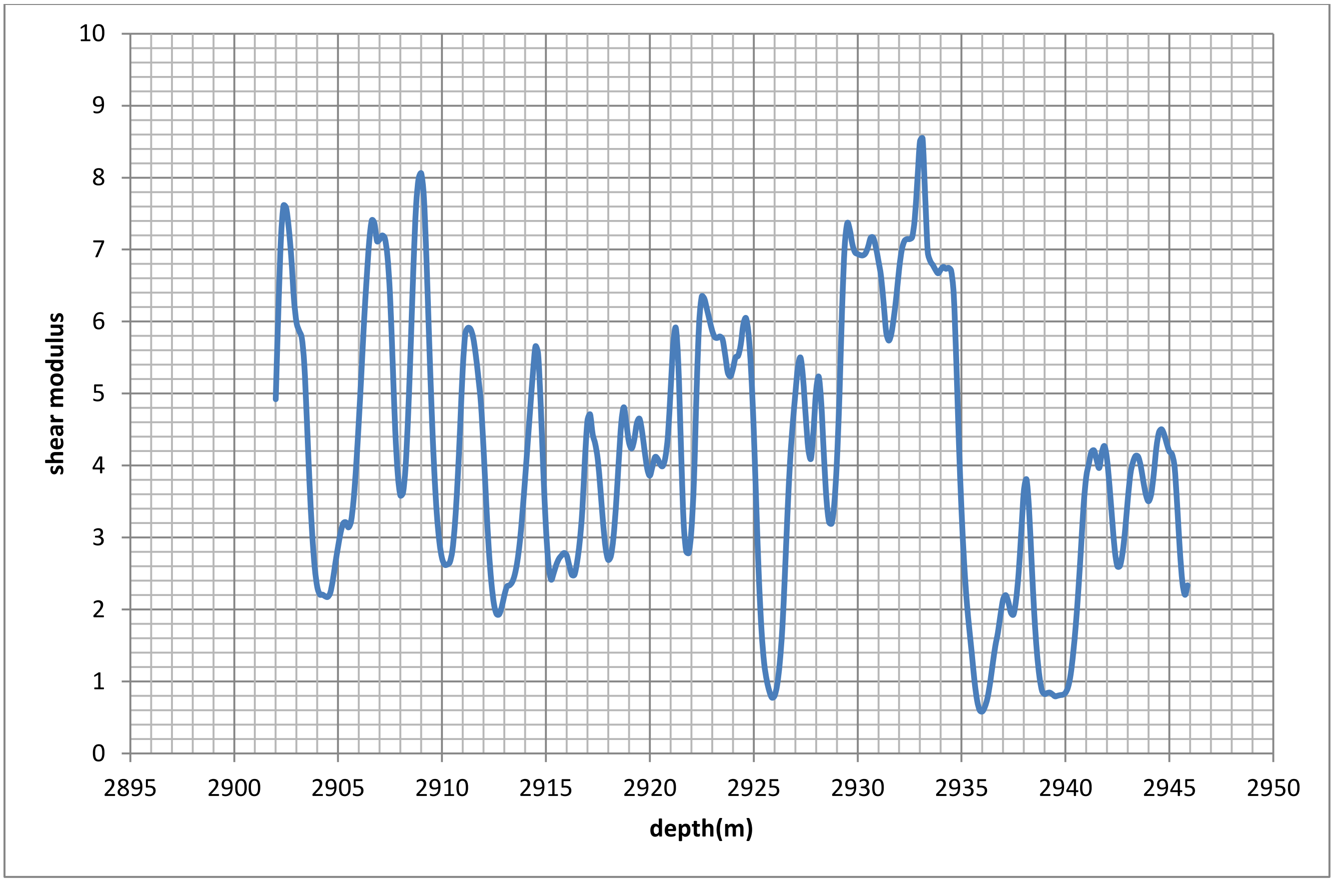


Fig:5.4 showing the graph of Shear Modulus of chorgali Fm

5.1.6 BULK MODULUS

The bulk modulus (K) of a substance measures the substance's resistance to uniform compression. It is the ratio of volume stress to volume strain. It is defined as the pressure increase needed to affect a given relative decrease in volume. It describes the material's response to uniform pressure. For a fluid, only the bulk modulus is meaningful.

The value of K is calculated by the following rel

$$K = \rho*[Vp2-4/3*Vs2]$$

Where;

K = Bulk modulus, Vp = P-wave velocity, Vs = S-wave velocity, ρ =Density

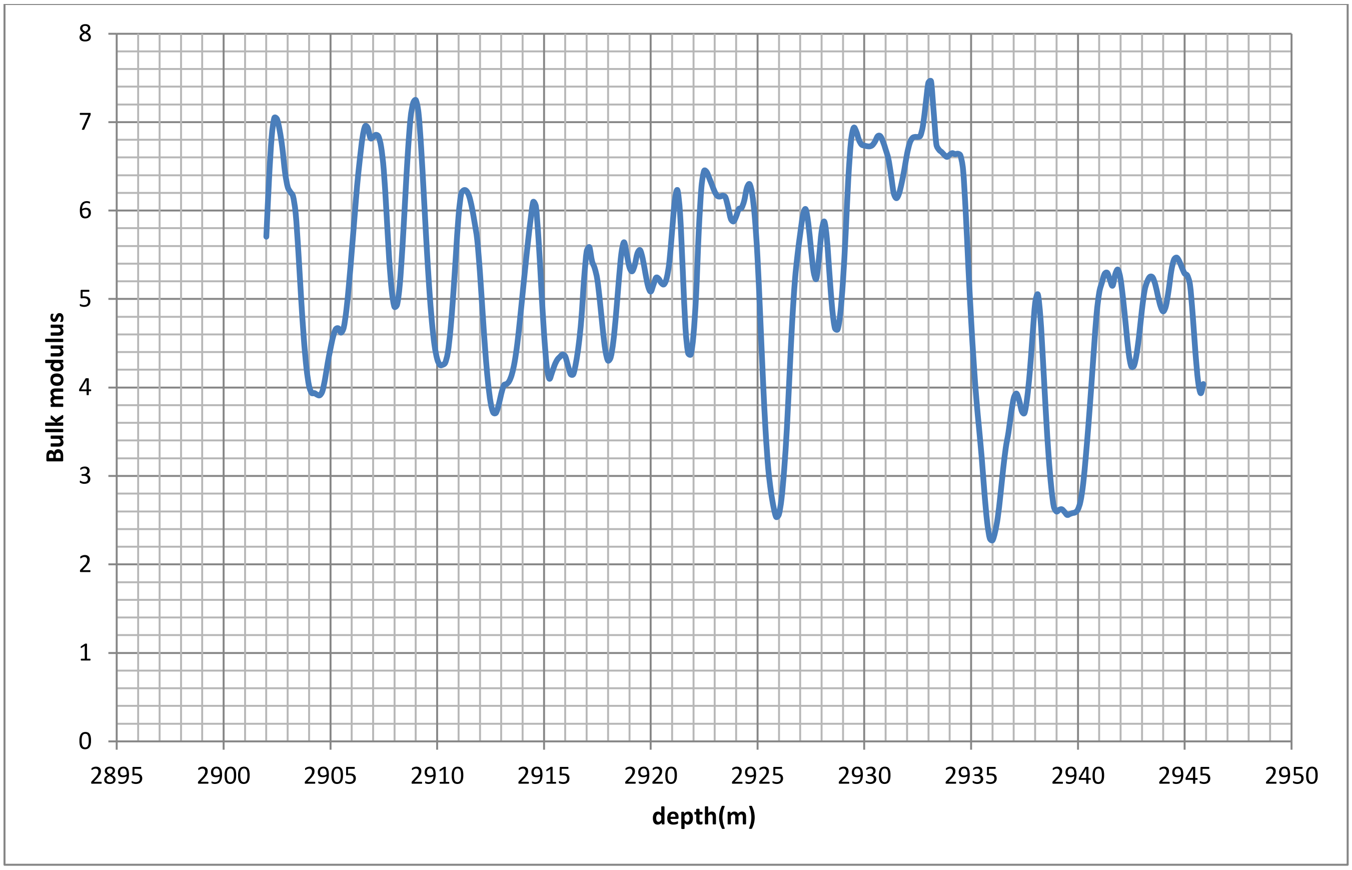


Fig:5.5 showing the graph of Bulk Modulus of chorgali Fm

5.1.7 INTERPERTATION RESULTS

Chorgali formation having depth range from 2902 to 2946 m. Physical properties of rock has been calculated for the whole depth of formation and also for the zone of interest, determined on the basis of their response on passing of seismic waves.

Calculation shows that the zone ranges from 2924m to 2928 and from 2936 to 2942 contain high amount of porosity. It seems to b interested zone but when we compare this with graph of volume of shale (fig:5.6) we found that this zone is porous but impermeable so it does not contain any kind of hydrocarbons.

5.2 PETROPHYSICS AND ROCK PHYSICS

Petrophysics'uses all kinds of logs, core data and production data and integrates all relevant information. Thus purpose of petrophysics is to obtain physical properties such as volume of shale, porosity, water saturation and permeability, which are related to production parameters.Petrophysics is more concerned with using well bore measurements to contribute to reservoir description. On the other hand, rock physics uses well log data to establish P-wave velocity (Vp), S-wave velocity (Vs), density, and their relationships to elastic moduli (bulk modulus and rigidity modulus), porosity, pore fluid, temperature, pressure, etc. for given lithologies and fluid types. Rock physicist may use information provided by the Petro-physicist, such as shale volume, saturation levels, and porosity in establishing relations between rock properties or in performing fluid substitution'analysis.

5.2.1 PETRO PHYSICAL ANALYSIS

Petrophysics is the study of the physical properties that describe the occurrence and behavior of rocks and fluids within the rocks. 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.

5.2.2 DATA SET

The petrophysical analysis has been carried out for reservoir characterization of Fimkassar area. For this purpose the data of the drilled borehole, Fimkassar-02 is used. The log curves of these boreholes are used i.e. Spontaneous potential (SP) log, Gamma ray (GR), Sonic log (DT), Latro log deep (LLD), Latro log medium (LLM), Latro log shallow (LLS), Neutron log, Density log (RHOB), and Photoelectric effect (PEF) etc. For petrophysical analysis, the following parameters are determined on the basis of these log curves.

1. Volume of shale
2. Porosity (Average porosity and effective porosity)
3. Water saturation
4. Hydrocarbon saturation

5.3 VOLUME OF SHALE

Volume of shale can be calculated from different logs like resistivity logs, SP log and gamma ray log. In this study gamma ray log
used to calculate shale volume.

5.3.1 GAMMA RAY LOG

This'log is actually a measurement of the natural radioactivity of the formation. Gamma radiations are emitted in the form of electromagnetic energy called photon. When photon collides with electrons, some energy is transferred to electron called Compton scattering. These scattered radiations reached the detector and are counted after absorption of gamma rays from natural radioactive source present within the layer. These emissions are counted and displayed as count per second which is termed as gamma ray log. This log is very important and used for various purposes however, its basic purpose'is to differentiate between sand and shale.

5.3.2 VOLUME OF SHALE CALCULATION

The volume of shale is estimated from gamma ray response. To calculate the volume of shale in different zones of interest, the following mathematical relation given below in equation (3) is used (Asquith and Gibson, 2004).

$$Volume\ of\ Shale\ (Vsh) = (\ GRlog - GRmin)/(\ GRmax - \ GRmin)$$

where,

Vsh = Volume of shale

GRlog= Gamma Ray Log,

GRmin= Minimum value of Gamma Ray reading,

GRmax= Maximum value of Gamma Ray reading.

There'are different relationships between gamma ray magnitude and shale content; these relationships can be in the form of linear or non-linear response. For linear response, different mathematical relationships are used for calculating volume of shale. All these relationships are empirical. For non-linear'response (used in this interpretation), Gamma Ray Index = Volume of shale.

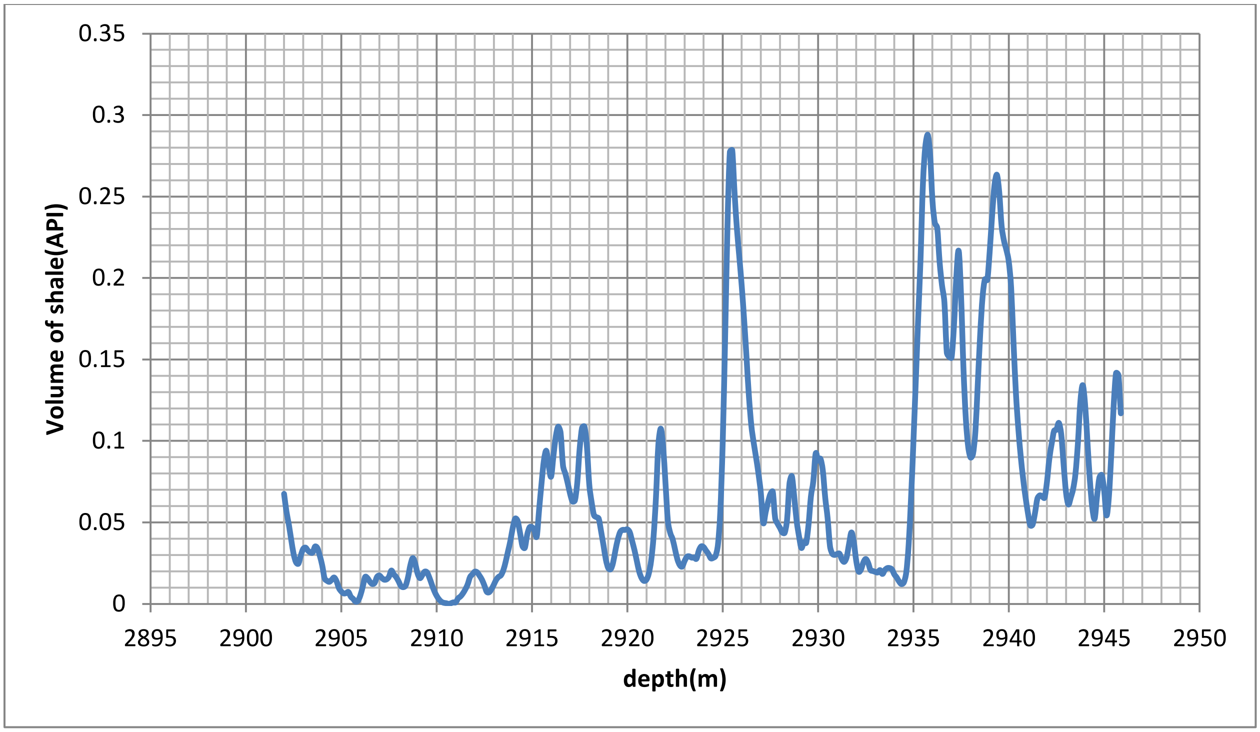


Fig5.6 showing the volume of shale of Chorgali Fm

5.4 CALCULATION OF POROSITY

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.

5.4.1 SONIC LOG

Sonic'log device consists of a transmitter that emit sound waves and a receiver that picks and record the compressional waves as it reach 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 time (Δt) is depended upon lithology and porosity of the formation. Sonic log can also be used for the following purposes in combination of other'logs as,

a. Porosity (using interval transit time).

b. Lithology identification (with Neutron and/or Density).

c..Mechanical properties of formation (with Density).

5.4.2 CALCULATION OF POROSITY FROM SONIC LOG

The mathematical relation used for calculating the porosity from sonic log is given in equation

$$PHIs=(\Delta t\ log-\Delta tm)/(\Delta tf - \Delta tm)$$

where,

PHIs= Sonic derived porosity,

Δtlog= Interval transient time of formation,

Δtm= Interval transient time of matrix

Δtf= Interval transient time of fluid (fresh mud=189 & salt mud=185).

The interval transient time of formation increased due to presence of Hydrocarbon, which is called as hydrocarbon effect. This effect has to be removed, if not, sonic derived porosity may be too high.

5.4.3 DENSITY LOG (RHOB)

Gamma'rays collide with electrons in formation and scattered gamma rays (Compton scattering) received at detector and counted as

indicator of formation density. An increase in counting rate causes a decrease in bulk density of formation and vice versa. Bulk

density from the density log is considered to be sum of density of fluid times its relative volume ( ) plus density of matrix time its

relative volume (1-). However, density log separately and also along with other logs used to achieve various'goals.

5.4.4 CALCULATION OF POROSITY FROM DENSITY LOG

As density reading is a function of both porosity and rock type. If the rock type is known

then porosity can be calculated (Asquith and Gibson, 2004). In this research, rock type in zone of interest is known from gamma ray which is Limestone. The following relation is

used for calculating density porosity.

Density Porosity = (Density Matrix - Density Log) / (Density Matrix- Density Fluid)

5.4.5 NEUTRON LOG POROSITY

This'is the porosity log which measure concentration of hydrogen ions in the formation. Neutron is continuously emitted from a chemical source in neutron logging tool. When these neutron 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 neutron collide with hydrogen atom. Hydrogen is usually indication of presence of fluidsin pores, so energy loss is related to the formation porosity. In shale free formation (clean formation), this log measures the liquid filled porosity where the porosity is filled by water or oil. Neutron porosity will be very low when pores in the formation are filled with gas instead of oil or water. This occurs because there is less concentration

of ions (hydrogen) in the gas as compared to water and oil. This decreasing of neutron porosity due to presences of gas called as'gas

effect.

Neutran porosity is calculated by fallowin reration

$$PHI_n = sqrt(PHI_s + PHI_d)/2$$

5.4.6 AVERAGE POROSITY

Average porosity is the sum of all the porosities calculated by different logs divided by number of logs used for calculating the porosity. The average porosity is calculated for reservoir, which Sakesar and Chorgali of Eocene age. Hence all the logs are interpreted to the depth of reservoir. The relation for calculating the average porosity is given below in

$$(PHIs+PHIn+PHId)/3$$

5.4.7 EFFECTIVE POROSITY (PHIe)

Effective' porosity is defined as the porosity of interconnected pores, derived after removing the effect of shale, because in shale rich zone there is no effective porosity. Effective porosity is used for calculation of water saturation for the reservoir zone. It can be calculated with the help of the following formula given in'equation

$$PHIe=PHIavg(1-Vsh)$$

5.5 CALCULATION OF WATER SATURATION

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 given in equation. All the parameters of Archie equation can be calculated from resistivity and spontaneous potential’logs

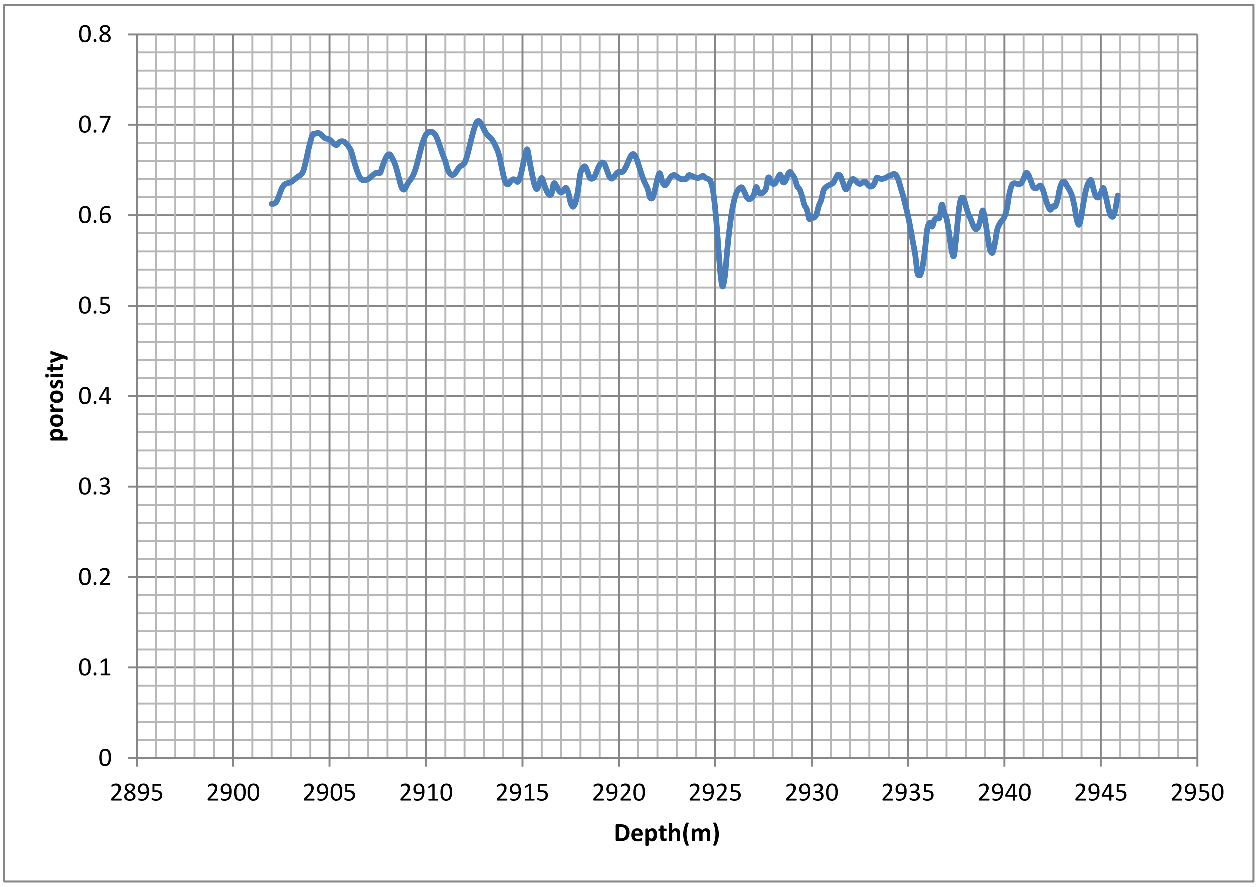


Fig:5.7 showing the graph of effective prosity of chorgali Fm

.

$$Sw = \sqrt[n]{(F \times RW)}/Rt$$

where,

Rw= Resistivity of water,

Rt= True resistivity,

n= saturation exponent and its value varies from 1.8 to 2.5 and it was taken as 2,

F= Formation factor ($F = \frac{a}{\emptyset m}$),

a= Constant and its value is assumed as 1,

∅= Effective porosity,

m= Cementation factor (with a constant value 2).

To calculate Sw first we have to calculate Rw

5.5.1 CALCULATION OF RESISTIVITY OF WATER (RW) OF FIMKASSAR-02

To calculate the resistivity of water fallowing steps are taken;

1. Read the SP value at the depth of maximum deflection, which gives SSP and is calculated by using the equation

SSP=SPclan−SPshale

Where;

SSP = Static Spontaneous Potential,

SPsand= Spontaneous potential for sand,

SPshale= Spontaneous potential for shale.

The value of SSP For well Fimkassar-02 is -60 mv

2. Calculate the formation temperature (FT) from relation given in equation at the depth of the SP value. Use Gen-6, (Schlumberger chart), with total depth and maximum temperature from the log header.

$$FT = [\frac{BHT - FD}{TD} \times FD]$$

where,

FT = Formation temperature,

BHT = Borehole temperature,

FD = Formation depth,

ST = Surface temperature,

TD = Total depth.

The value of formation temperature calculated for Well Fimkassar-02 is51℃ (TD = 3250 m, FD = 2946 m, BHT = 82℃ , ST = 26℃)

3. Resistivity of mud filtrate (Rmf) at surface temperature (ST= 26℃) and water salinity 15000ppm is calculated using fig:5.8(Schlumberger chart) , and it is 0.479 Ωm for well Fimkassar-01.

4. Now after calculating the value of , calculate the resistivity of mud filtrate at zone of interest (FT) and it is calculated by equation

$$R_{mf}2 = R_{mf}1 \times \frac{(T1+6.77)}{T2+6.77}$$

where,

Rmf1= Resistivity of mud filtrates at surface temperature,

T1= Surface temperature,

T2= Formation temperature,

Rmf2= Resistivity of mud filtrates at formation temperature.

For well Fimkassar-02,Rmf2 = 0.27 Ωm

5. Resistivity of mud filtrate equivalent (Rmfe) at formation temperature, this is important step and is performed by considering the

following, two conditions,

a. If is greater than 0.1 Ωm then correct it to formation temperature using the following relationship given in equation

Rmfe=0.85× Rmf

b. If is less than 0.1 (Ωm) then use chart SP-2 (Schlumberger Chart) given in appendix-2 to derive a value of at formation temperature.

As value of is greater than 0.1 Ωm for the wells, so condition **a** used to calculate the resistivity of mud filtrate equivalent.

for well Fimkassar-02 I calculate the value which is 0.23 Ωm.

6.Compute Rmfe/Rwe from SSP using following relation;

$\frac{Rmfe}{Rwe}$=$10^{-SSP/k}$

Where;

K=(Ft+336)/5

And Ft is Formation temrature in ℃

My calculation show that;

$$\frac{Rmfe}{Rwe} = 5.95$$

Now to get value of Rwe (equlient water resistivity) divide Rmfe by this ratio;

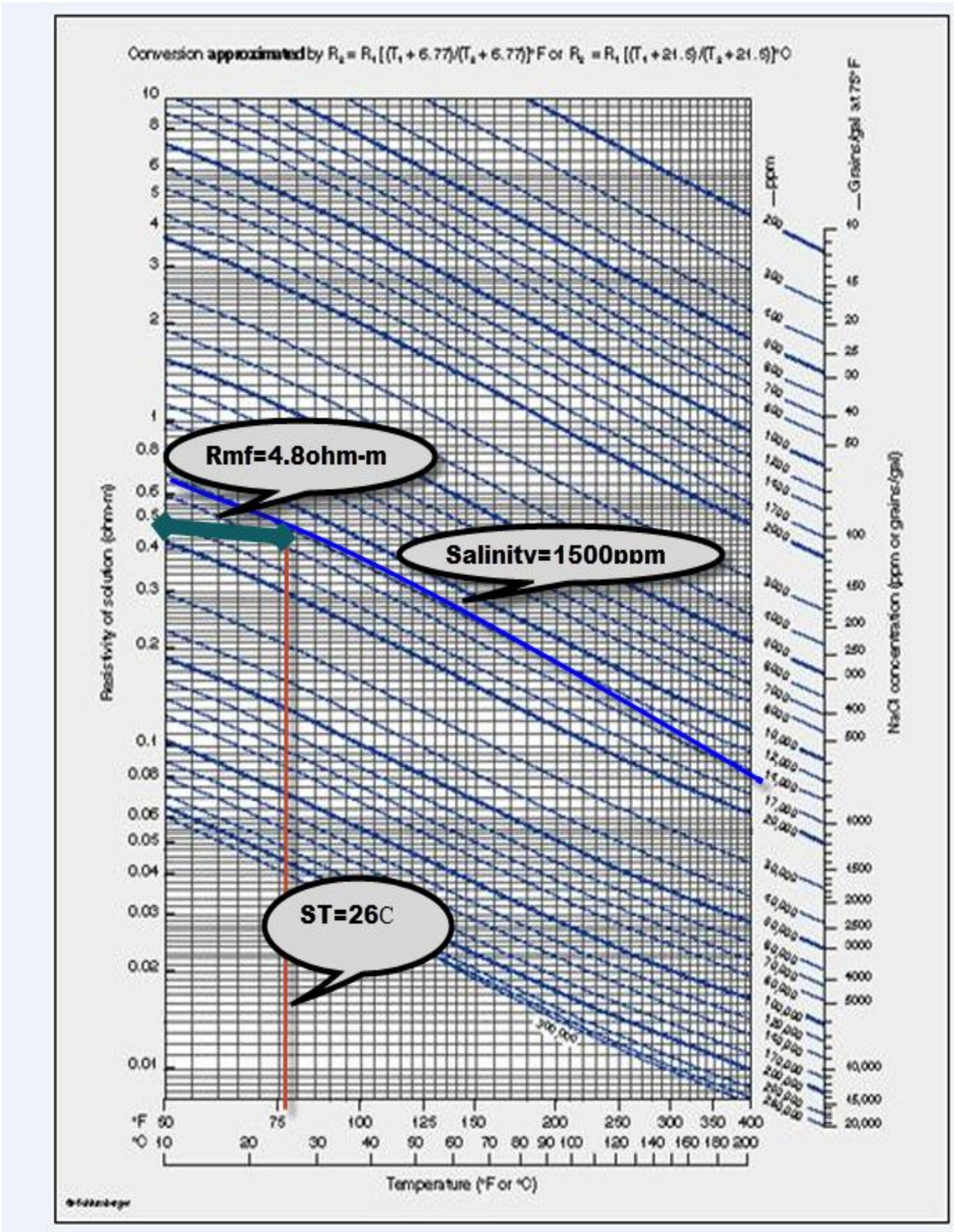


Fig:5.8 Schlumberger chart

$\frac{0.23}{5.95}$=0.04

7.Convert Rwe to Rw by using following fig:5.10

It is v simple take the value of Rwe at formation temperature and chec the crosponding value of Rw which is required value

of formation water resistivity at formation tempture.

And than calculate Sw by this value (Rw=0.045Ωm)

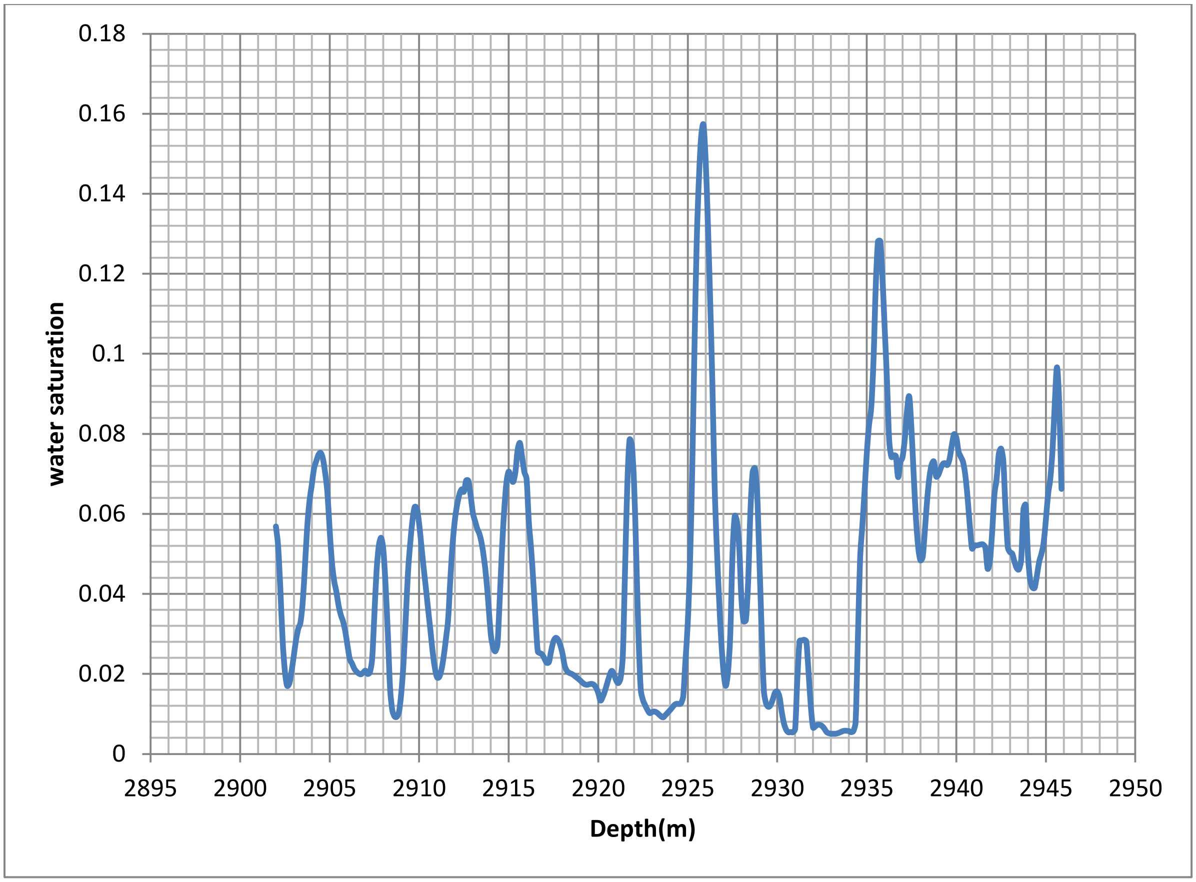


Fig:5.9:showing the water saruration against depth

5.6 CALCULATION OF HYDROCARBON SATURATION

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation and is calculated by relation given in equation

$$Sh = 1 - Sw$$

where,

Sh= Hydrocarbon saturation,

Sw= Water saturation.

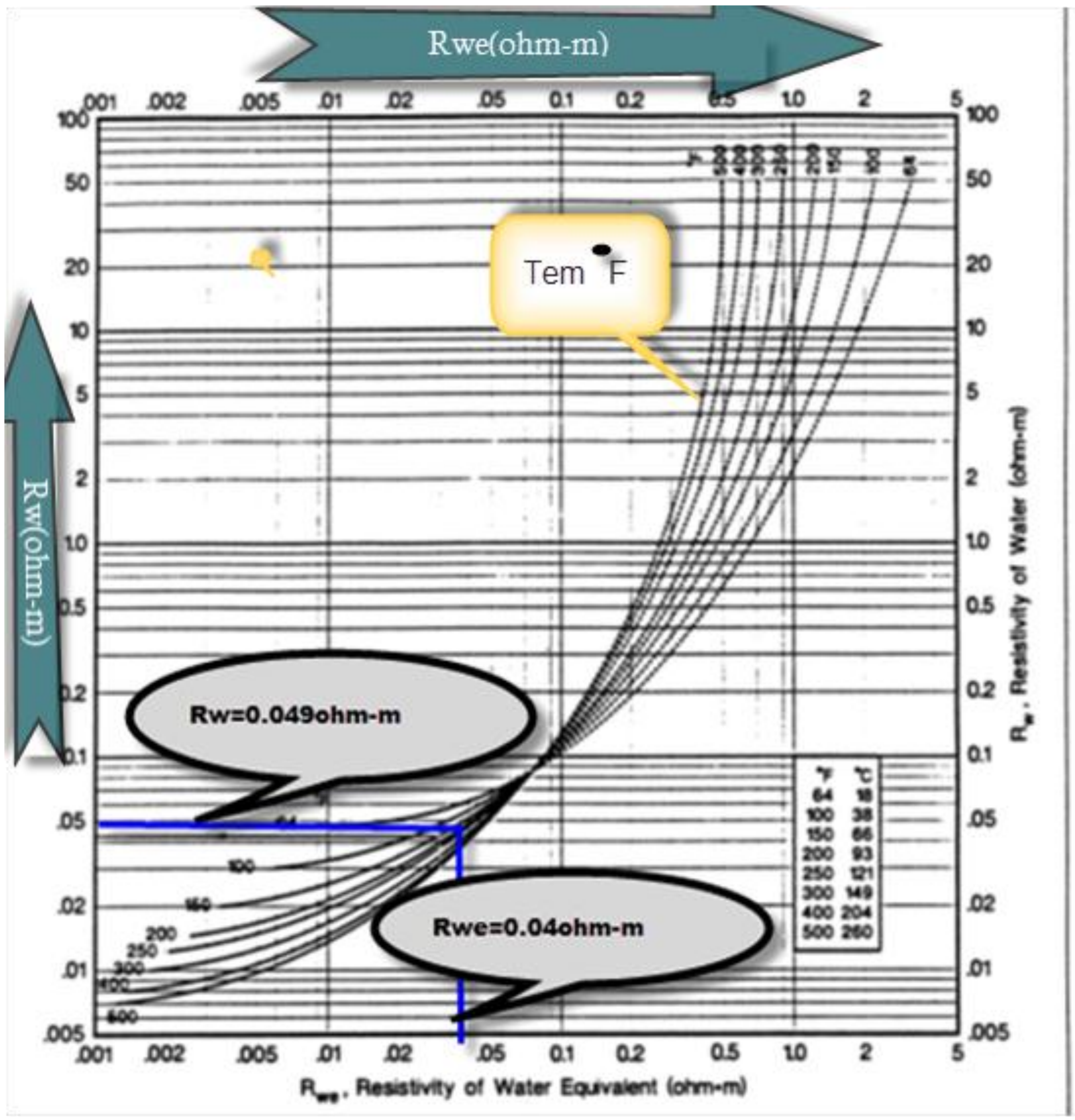


Fig:5.10 Schlumberger chart for calculation of Rw

As the is the remaining percentage pore volume other than the percentage of pore volume occupied by water, hence this method is an
indirect method which quantitatively estimate hydrocarbon saturation.

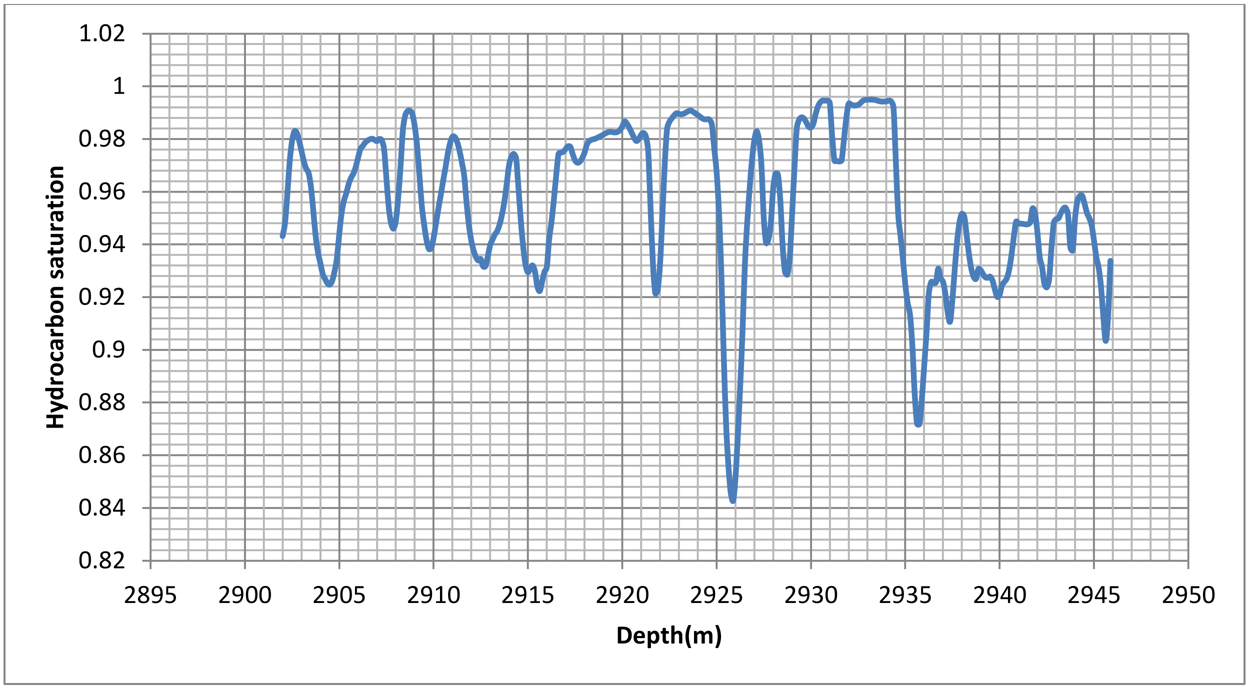


Fig:5.9 showing the saturation of hydrocarbon

5.7 INTERPRETATION RESULTS OF CHORGALI FORMATION (WELL FIMKASSAR-02)

Chorgali formation having depth range from 2902 to 2946 m. In Chorgali formation, petrophysical interpretation has been done for the whole depth of formation and also for the zone of interest, determined on the basis GR response, porosity values and on the basis of hydrocarbon effect and gas effect.

5.7.1 FOR WHOLE DEPTH OF CHORGALI FORMATION (2902 TO 2946 M)

Average volume of Shale in %age = = 33%

Average density porosity in %age = = 9%

Average porosity in %age = = 11%

Average effective porosity in %age = = 6%

Average water saturation in %age = = 53%

Average hydrocarbon saturation in %age = = 47%

5.7.2 FOR ZONE OF INTEREST OF CHORGALI FORMATION (2903.5 TO 2920 M),

Average volume of Shale in %age = = 20%

Average density porosity in %age = = 9%

Average porosity in %age = = 12%

Average effective porosity in %age = = 10%

Average water saturation in %age = = 48%

Average hydrocarbon saturation in %age = = 52%

6. CONCLUSIONS

By performing different methodology on the seismic and well data set of the study area and using different software tools I concluded following;

- On the basis of general stratigraphic columns present in the area, three reflectors are identified. Reflector 1 can be considered as Chorgali. Reflector 2 can be considered as Sakesar. Reflector 3 can be considered as Nammal. Reflector 4 can be considered as Basement.
- The seismic section shows a displacement and a Popup anticlinal structure in the area.
- Time and Depth contour maps help us to confirm the presence of anticlinal structure in the given area. Surface contour map gives the real shape of sub-surface structure, which is anticlinal. This anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation.
- **4.** The petrophysical interpretation of well Fimkassar-02 leads probable zone for hydrocarbon extraction in chorgali formation from (2903.5 to 2920 m)
- **5.** Rock Physics provide us the link between reservoir properties and seismic data analysis and these rock physics analyses suggests the probable zones of water and hydrocarbon accumulation. .
- The overall results indicate the economic viability of Chorgali limestone as a reservoir.

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