2D SEISMIC INTERPRETATION USING ROCK PHYSICS AND PETROPHYSICS STUDY OF TAJJAL AREA, LOWER INDUS BASIN PAKISTAN.

BY

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BS-GEOPHYSICS

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ISLAMABAD, PAKISTAN

“IN The Name of ALLAH, the Most Merciful & Mighty”

“PAY THANKS TO ALLAH EVERY MOMENT AND GO TO EXPLORE THE HIDDEN TREASURES, IT’S ALL FOR YOUR BENEFIT”

(AL-QURAN)

CERTIFICATE

This dissertation submitted by **MUNEEB UR REHMAN** S/O **MUHAMMAD ARIF** 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 BS degree in Geophysics.

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DEDICATION

TO MY BELOVED PARENTS (ABU AND AMMI), AS WITHOUT THERE LOVE AND SUPPORT I AM NOTHING.

TO MY BROTHERS AND SISTER FOR SUPPORTING ME AND SETTING HIGHEST EXAMPLES OF INSPIRATION.

TO MY MENTOR AND BEST GUIDER
MISS ARUJ MUJEEB

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious and the Most Merciful. I bear witness that Holy Prophet Muhammad (PBUH) is the last messenger, whose life is perfect model for the whole mankind till the Day of Judgment. I am thankful to Allah for the strengths and His blessing in completing this thesis.

Special appreciation goes to my supervisor Dr. SHAZIA ASIM for her supervision and constant support. Her invaluable help of constructive comments and suggestions throughout the experimental and thesis works have contributed in the success of this research. I express my sincerest appreciation to HASSAN AHMED QAZI for his guidance in the preparation of this thesis and his assistance in any way that I may have asked.

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I sincerely pay my gratitude especially to my brother MUHAMMAD KASHIF and sister UZMA ARIF for their endless care and moral support during my studies. Thank you for the precious gift of your companionship and memories.

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ABSTRACT

The study locale is Tajjal and is located in Sindh province of Pakistan. It lies at the boundary of lower and central Indus Basin. In order to interpret the subsurface picture, 2D seismic time profile data of four migrated seismic lines (SEG-Y Format) and three wells i.e. KADANWARI-01, KADANWARI-10 and KADANWARI-11 (LAS file) is used. The locale has been identified as extensional regime and the main reservoir is Lower Goru Formation especially its B-Sand interval.

Seismic Interpretation of Tajjal area involves 04 Seismic Lines. The seismic data acquisition and processing was carried out by LASMO OIL PAKISTAN. These lines have been interpreted on the basis of Seismic Interpretation criteria. Generation of synthetic seismogram is achieved by using two way time for each well top. Two way time for each well top or reflector is calculated by using depth, sonic log data of well and replacement velocity of the area tie this synthetic seismogram with the Seismic line (TJ89-516) on which well is located (KADANWARI-01). With the help of synthetic seismogram three horizons i.e. Sui Main Limestone, Ranikot and Lower Goru Formation were marked on lines TJ89-503, TJ89-510, TJ89-516 and TJ89-526 and Normal faults are observed.

Models of elastic properties derived from the sonic velocity of well confirm that the Lower Goru formation is initially comprised of intervals of Sandstone and Shale along with fluid substitution as indicated by high and low values of Rock Physical parameters.

CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION TO AREA

TAJJAL area is located between Longitude 69° 48' 11"E to 69° 10'54"E and Latitude 27°48′18″N to 27° 54′32″N and lies near the boundary of Lower and Middle Indus Basins. Figure 1.1 shows the satellite image of Tajjal area.

Fig.1.1: Satellite image of location of Tajjal area

The Middle Indus Basin is a prolific basin located in the central part of Pakistan. The Kadanwari Gas Field is located in this gas prone basin (Figure 1.2). The field was discovered in 1989 and brought on stream in May 1995. The region is important for its gas fields mainly SAWAN, MIANO, KADANWARI, PIRKOH, SUI etc. The locale of allotted lines lies in the Kadanwari field.

Tajjal area located 75km SE of Sukkur in the kherpur district Sindh. The topography consist of sandy dunes and Barren dry land. The area has a tropical climate having hot summers with an average temrature of 48 C and cold winters having an average temperature of 20C. Stratigraphically Tajjal Area occupies the Lower Indus basin. Structurally Tajjal represents an extensional regime and has a negative flower pattern of Faults. Prospect wise the area is Gas prone and many gas producing Wells are located.

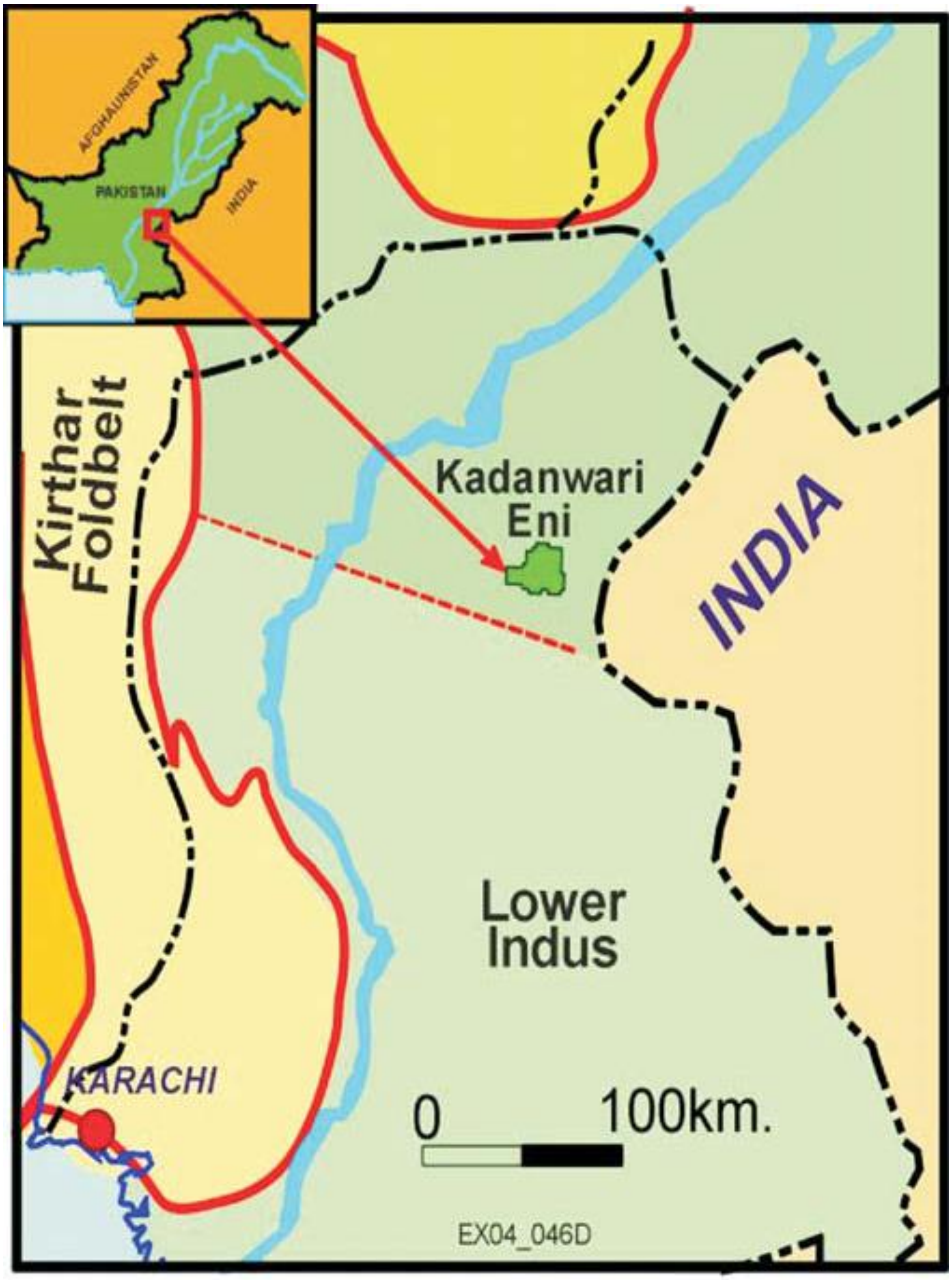


Fig.1.2: Location map of Tajjal area (Nasir etal 2007)

1.2 SEISMIC DATA DESCRIPTION

The study of the area consists of lines TJ89-503, TJ90-510,

The seismic data acquisition and processing of my lines TJ89-503, TJ89-510, TJ89-516 and TJ89-526 and Well data of KADANWARI-01, 10 & 11 was carried out by LASMO OIL PAKISTAN by October 1990. The data is provided by Department of Earth Sciences; Quaid-i-Azam University, DGPC and LMKR.

1.3 BASE MAP

It is a map that shows all the lines under consideration of the area and it also shows the boundary of the block concession. The base map is important for interpretation point of view because it depicts the spatial location of seismic section and also shows how seismic sections are interconnected. A base map typically includes location of lease and concession boundaries, wells, and seismic survey points. Base map provides the structure for contouring. The base map of the area is generated by loading data in Universal Transverse Mercator (UTM, zone 42N) geodetic reference system in SMT Kingdom 8.6. The base map, given in Figure 1.2 which shows the orientation of the lines present in the Tajjal area.

Four lines ar used to construct the base map are give in Table 1.1:

Sr.no.	Line name	Dip/Strike	Orientation
1	TJ89-503	Strike	NE-SW
2	TJ89-510	Dip	NW-SE
3	TJ89-516	Dip	NE-SW
4	TJ89-526	Dip	NE-SW

Table1.1: Seismic lines description.

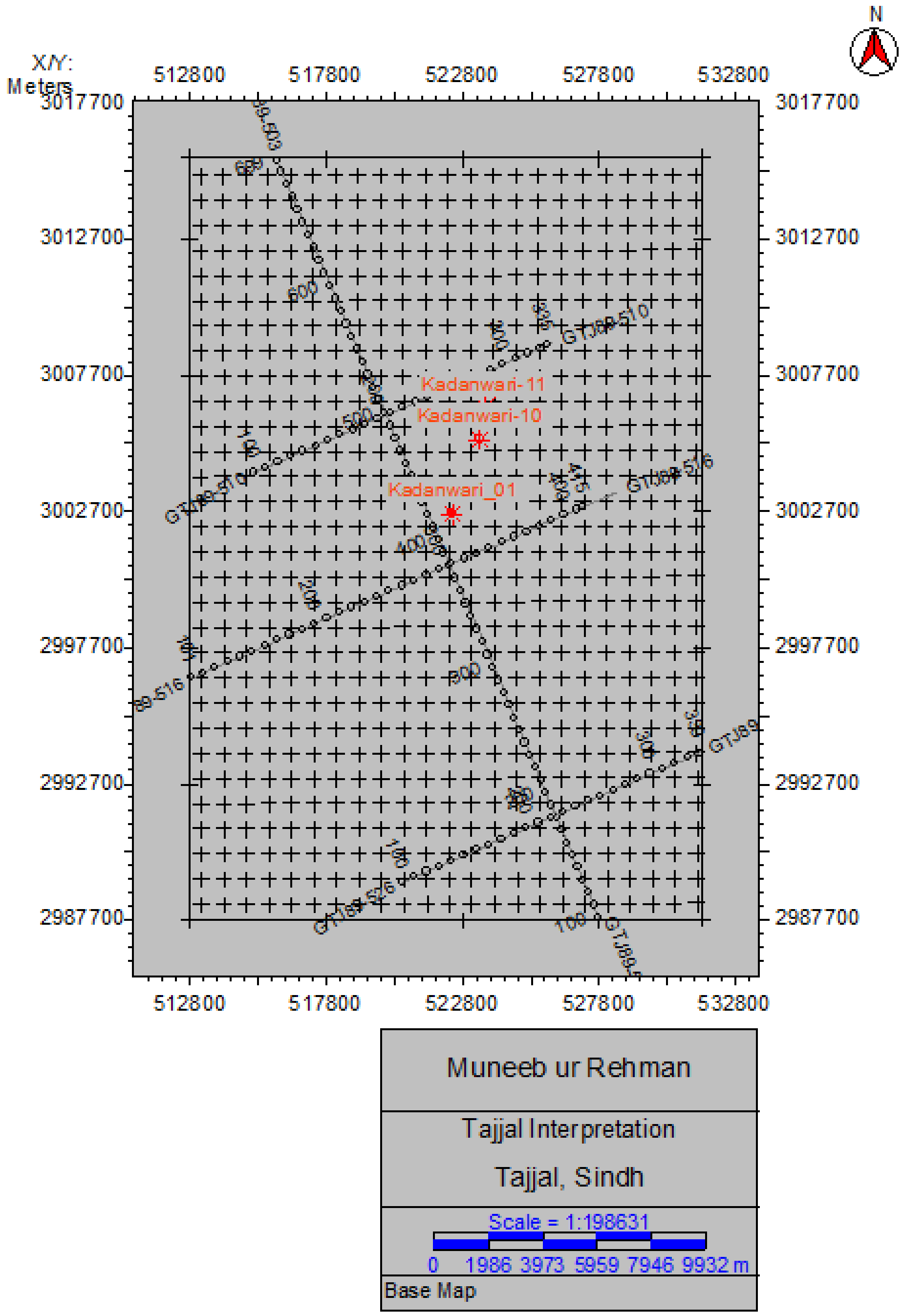


Fig.1.3: Base map of study area. (UTM zone: 42N).

1.4 AIMS OF THE STUDY

Following are the aims and objectives of this study:

- To understand subsurface geology of study area.
- To interpret the subsurface structure by marking horizons and faults.
- Seismic attribute analysis to confirm the interpretation.
- To study the physical behavior of reservoir zone by using Rock physics & Petro physics parameters.

CHAPTER 2 GEOLOGY OF THE AREA

2.1 MAJOR DIVISION OF INDIAN SUB-CONTINENT

The most prominent fact with regard to physical geography and geology of the Indian region is that it comprises of three distinct units which are different from each other in their physical as well as geological characteristics. The two among these three units has fundamental basis in India and distinctive characters of these were impressed upon it from early period of its geological history and since then each area has pursued its own individuality. These three divisions are;

1. The triangular Plateau of the Peninsula (i.e. the Deccan, south of the Vindhyas), with the island of Ceylon.
2. The mountainous region of Himalayas which boarders India with west, north and east, including the countries of Afghanistan, Baluchistan and hill traces of Burma, known as the extra-peninsula.
3. The great Indo-Gigantic plain of Punjab and Bengal separating the two former areas and extending from the valley of the Indus in Sindh to that of the Brahmaputra in Assam. **(Wadia,1952)**.

2.2 TECTONIC FRAMEWORK OF PAKISTAN

Pakistan is unique in as much it belongs to the two domains of landmasses, i.e. Tethyan Domain and Gondawanian Domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions of Pakistan fall in Tethyan Domain that present a complicated geology and complex crustal structure. (Kazmi & Jan, 1997). Pakistan includes almost the three divisions of Landmasses. On the basis of plate tectonic features, geologic structure, Orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into following broad tectonic zones; (Kazmi & Jan, 1997).

1) Indus platform and foredeep.
2) East Baluchistan fold-and-thrust belt.
3) Northwest Himalayan fold-and-thrust belt.
4) Kohistan-Ladakh magmatic arc.
5) Kakar Khorasan flysch basin and Makran accretionary zone.
6) Chaghi magmatic arc.
7) Pakistan offshore.

2.2.1 Indus Platform and Foredeep:

This zone extends over an area exceeding 2,50,000 Km^2 in southeastern Pakistan and includes the Indus plain and Thar-Cholistan deserts. It hosts more than 80% of Pakistan's population, extensive coal deposits, variable oil and gas field potential for geothermal energy and vast groundwater reservoirs. (Kazmi &Jan, 1997).

Gravity and seismic surveys, supported by limited borehole data indicate that the eastern part Precambrian rocks from gentle westward dipping monocline covered by veneers of Mesozoic to Cenozoic marine to deltaic sediments. However, there are broad zones of up wrap and down wrap which are well defined by gravity surveys. The sedimentary pile, particularly the fore deep at the western edge of platform slope where the sedimentary cover is up to 10,000 m thick. (Kazmi & Jan, 1997).

2.2.1.1 Structural Zones:

The Indus platform and foredeep comprise the following main structural zones.

- **Buried Rides:**
  Sargodha-Shahpur ridge.
  Nangaparkar ridge.
- **Zones of up-wrap:**
  Mari-Khan dot high.
  Jacobabad-Khairpur High
  Tharparker High.
- **Zones of downwrap and slope:**
  Northern Punjab monocline.
  Southern Punjab monocline.
  Cholistan Shelf.
  Panno Aqil Graben.
  Nawabshah slope.
  Lower Indus Trough.
  Nabisar slope.
- **Fore deeps:**
  Suleiman fore deep.
  Kirther fore deep.

2.3 THE INDUS PLAIN'S CHARACTERISTICS:

As stated in section 2.1 that the peninsula as an earth feature holds distinct feature from the extra-peninsula. of all the differences:

The first difference is stratigraphy, or that connected with the geological history of area. From the Cambrian period the Peninsula has been a land area, a continental fragment of earth's surface which since that epoch in the earth's history has never been submerged in beneath the sea, except temporarily and locally. No considerable Marine sediment of later age than Cambrian was even deposited in the interior of land mass. the extra-Peninsula on the other hand, has been a region which has lain under the sea for the greater part o its history.

The second difference is geo-tectonic. The Peninsula of India reveals quite a different type of architecture of earth's crust from that shown by the extra-Peninsula.

Peninsular India is part f earth's outer shell that comprises of the oldest rock beds that stand upon the firm and The immovable foundation. Lateral thrusts and mountain building forces have had little effect in folding or displacing its original basement. The strata everywhere shows high dip angles, closely packed folds and other violent departures from original structure.

The third difference is the diversity in physiography of the two areas. The difference lies in external or surface relief. In the Peninsula, the mountains are mostly of RELICT nature i.e. they are not mountains in the true sense of the term, but are mere outstanding portions of old plateau of the peninsula that have escaped, for one reason or another, the weathering of ages that has cut out all the surrounding parts of the land ; they are so to say are huge valleys, with low imperceptible gradients, because of their channels having approached to the base level of the erosion. Contrasted with the other mountains of extra-peninsula are true mountains or TECTONIC mountains i.e. those who owe their origin to a distinct uplift in the earth's crust and as a result have their spike or line of extension, more or less confirmable to the axis of that uplift. The rivers of this area are rapid torrentional streams, their eroding power are always active and they have cut deep gorges through the mountains in the mountainous part of their track.

2.4 LOWER INDUS BASIN:

This basin in characterized by passive roof duplex type structure and a passive back thrust along the Kirther Fold belt, a Passive roof thrust forming a front culmination wall along the margin of fold belt well along the margins of fold belt and the Kirther depression and out of syncline intra molasses detachments in the Kirther depression sequence. The Kirther and Karachi depressions contain several large anticlines and domes and some of these contain small gas fields. The eastern part of the basin comprising the Sindh monocline is largely comprises faulted and tilted blocks of Mesozoic rocks from which structural traps overlain by Deccan trap Basalt and Tertiary sedimentary rocks. The Northern margin of lower Indus Basin comprises the Suker Rift Zone which bears large anticline structures and contains the Khandot and Mari Gas fields. The latter is a giant field 6.3 TCF of reserves. Figure 2.1 shows the Tectonic map of lower Indus Basin.

The main reservoir rocks in the Sindh Monocline are Cretaceous Lower Goru sandstone. In Karachi depression production is from Paleocene Ranikot Limestone and sandstone, in Kirther depression and Sukker Rift zone it is of Eocene Sui Main/Habibrani Limestone. The lower Indus basin is also characterized by high geothermal gradients which range from 2 to over 4^{0}C/100m Figure 2.2 shows the oil and gas discoveries in Lower Indus Basin.

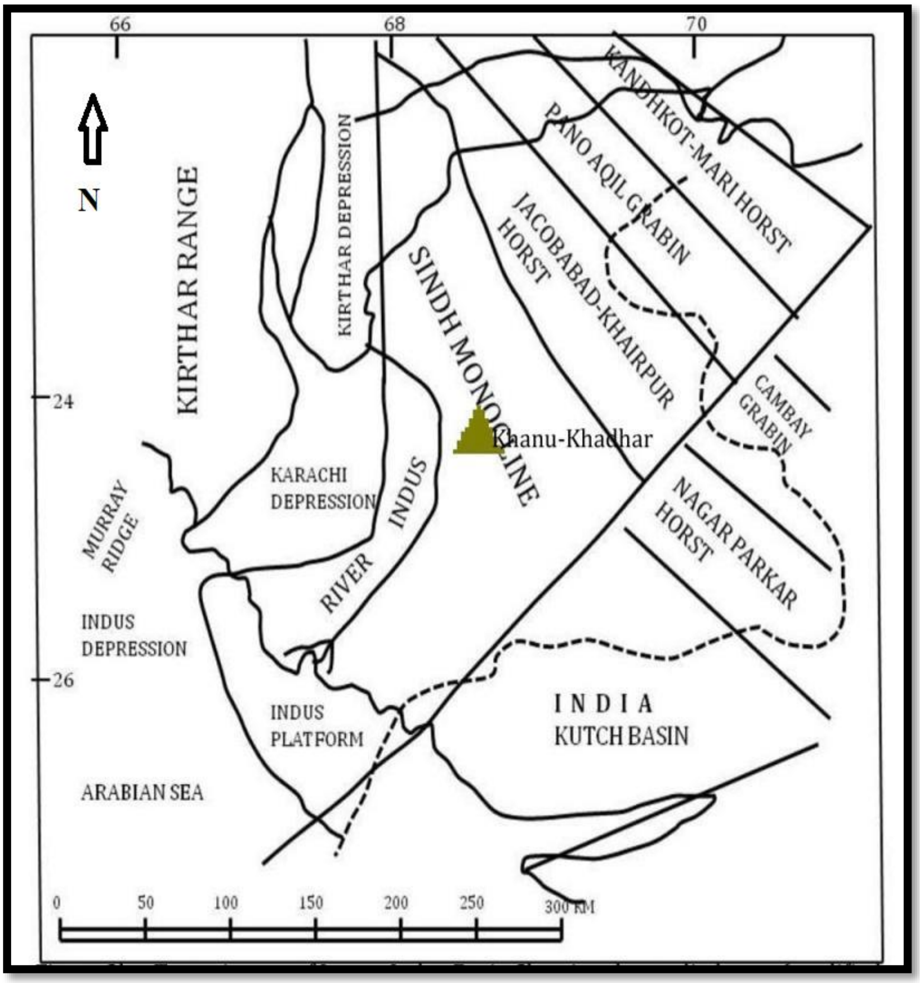


Fig.2.1: Tectonic map of lower Indus Basin (Raza et al. 1970)

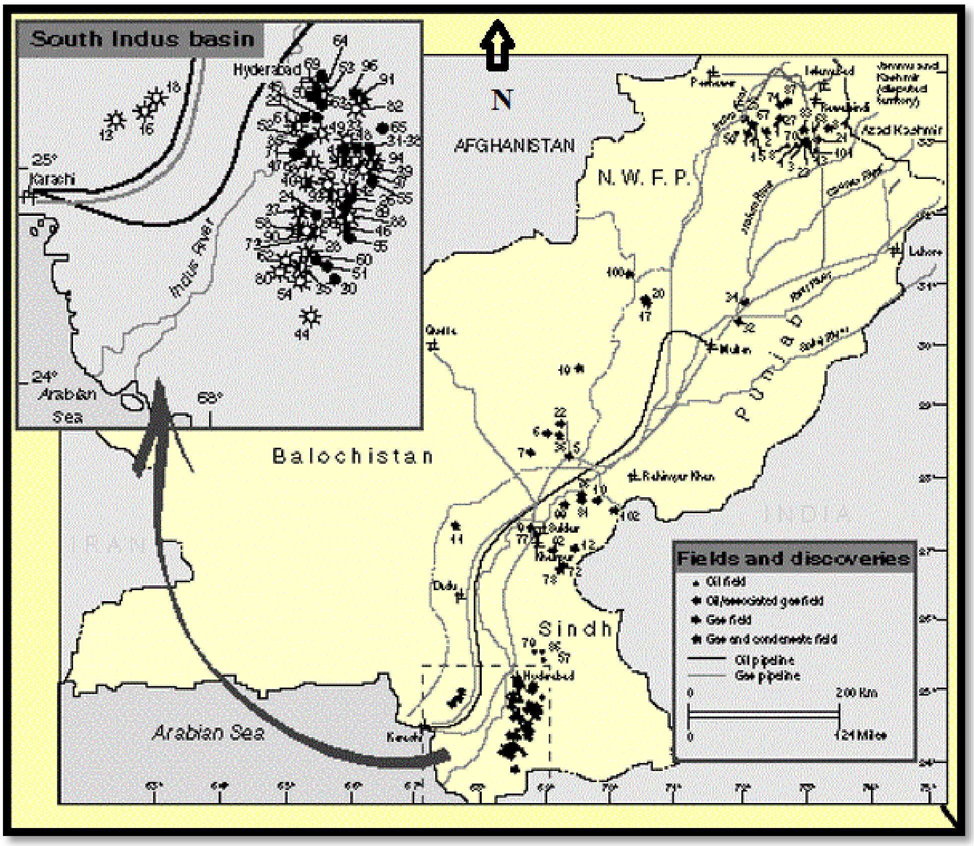


Fig 2.2 Oil and gas discoveries in Lower Indus Basin.

2.5 STRUCTURE OF THE STUDIED AREA:

Almost all of the lower Goru discoveries are located near one or another structural high (Mari high, Jacobabad-Khairpur high, Badin uplift high) which has implications for the migration pathways, timing of the reservoir charge and hydrocarbon entrapment in structural and stratigraphic features. Most of these structural high are inversion features identified on the regional seismic lines. The first uplift episode occurs near the K-T boundary and is manifested as the base Tertiary unconformity. The Paleocene Ranikot thin out towards and propagate out and thicken away from these highs. Moreover , the majority of deep basement related and shallower tectonic related faults terminate against this unconformity. Generally the entire Cretaceous section is changing character from strongly linear and single fault at top to en-echelon left lateral segment at lower and upper Goru levels. This tectonic event was the result of trans tensional tectonics related to first docking of Eurasian plate and encounter clock wise rotation of the Indian plate. The second uplift event in the middle and lower Indus Basin took place during the late Eocene-Oligocene times. The structural high probably underwent recurrent phases of upheaval in response to successive phases of thrust loading in the west and northwest. The final modification of the shape of traps and potentially the secondary hydrocarbons migration and reservoir charge took place during this period.

2.6 STRATIGRAPHY OF THE AREA:

In Lower Indus basin deposition of sediments ranges from Precambrian to Pleistocene. The deposition was however interrupted several times. From top to bottom the stratigraphic section can be divided into four groups. Fig.2.3 is showing the division of stratigraphic section their ages and rock types.

The stratigraphic succession changes from east to west. The Precambrian basement is westward. The important unconformities occur at the base of the Permian and the Tertiary. In the eastern part of the basin, the Tertiary has direct contact with the Jurassic sequence. The Indus Lower Indus Platform basin reflects sedimentation associated with rifting.

Stratigraphic column (Table 2.1) encountered in wells. Which directly gives the information about the stratigraphic section lies in the study area.

Sr.no	Epoch	Formation.	Depth(Meters)
1.	Pliocene-Pleistocene	Siwalik	7.75
2.	Late Eocene	Darazinda	301
3.	Late Eocene	Pirkoh	414
4.	Eocene	Sirki	474
5.	Eocene	Habib Rahi	538
6.	Early Eocene	Ghazij	674
7.	Early Eocene	Sui Main Limestone	1259
8.	Late Paleocene	Lakra	1345
9.	Late Paleocene	Bara	1454
10.	Early Paleocene	Khadro	1522
11.	Early Cretaceous	Upper Goru	2001.5
12.	Early Cretaceous	Lower Goru	2545

Table 2.1 Stratigraphic column encountered in wells

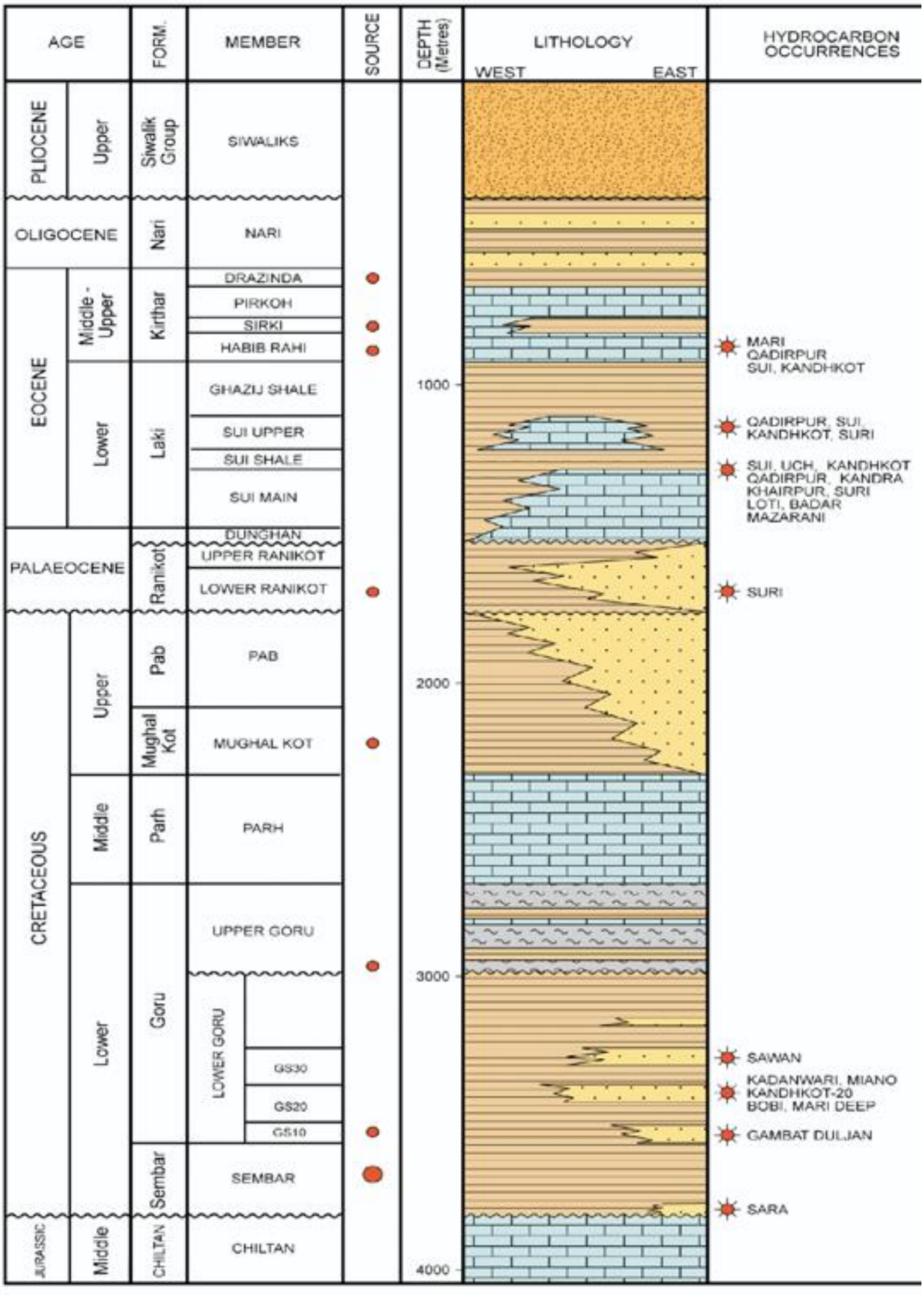


Fig.2.3: stratigraphy and well occurrence of Lower Indus Basin (Nasir etal, Pakistan Journal of Hydrocarbon Research Vol. 17, (June 2007)

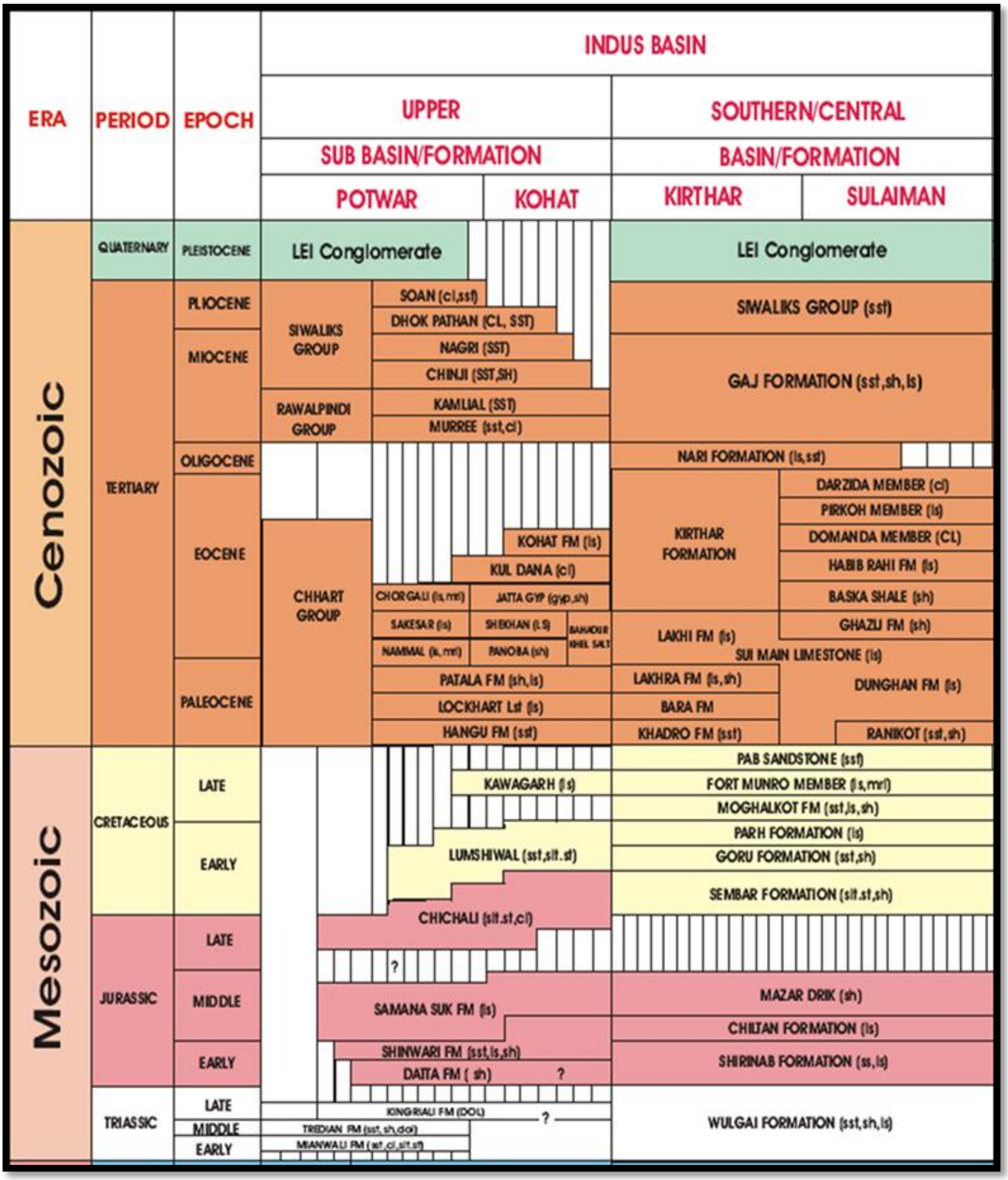


Fig.2.4: The division of stratigraphic section (I.B Qadri)

2.7 Exploration History of the Study Area:

On July 21, 1987 the Petroleum Concession Agreement for Tajjal Block was awarded for a consortium comprising of ***LASMO*** (which was afterwards acquired by Eni *AEP*- Agip Exploration & Production).

The Kadanwari gas field is located in the Thar Desert, 75 km southeast of Sukkur in the Khairpur district of the Sindh province. It lies to the south of Pakistan's main gas producing area where Sui, Mari and Kandhkot gas fields are located.

Kadanwari gas field was discovered in 1989 and bought on stream in May 1995. The field was discovered by K-1 well, which was drilled in September 1989. The well tested dry gas at a rate of 28.6MMscfd from a sandstorm reservoir developed in the Lower Cretaceous Lower Goru Formation at a depth of approximately 3325m. This was an unusually deep gas reservoir at that time by both Pakistan and world standards.

The Lower Goru has layers of sand and shale. These sands act as reservoir rock with rapidly varying reservoir characteristics within a few km. The Lower Goru sands has been divided into further sub units of Sand. Each company working in the area has its own subdivision, here we are following the LASMO subdivision which has divided reservoir units into seven sand bearing members, B to H. The main producing sands in the area are E and G but D, and F have also produced in few wells. The source of the Lower Goru sands is considered to be the Indian Shield to the south and east, locally prograding or aggrading sands are deposited during an overall rise in sea level. In the study area the main producer is G-sand which is about 60m thick and within the limit of seismic resolution.

2.8 Regional Geological Study of the Area:

The Lower Indus Basin runs in the dominant trend of North-South is bounded by the Indian Carton (Nagar Parker granite area) to the East, the Kohat Pothowar Plateau to the North, fold and thrust belts of the Suleiman and Kirthar ranges to the West (Kadri, 1995).
Structurally, the area is divided into Foldbelt and foreland regimes. The Foldbelt part includes the folded Kirthar Range along the Western boundary of the Indo-Pakistan Plate. The gently westward sloping continental shelf makes the foreland i.e. Kirthar Foreland. The foreland extends from the Foldbelt eastward to the Indian Shield and southward to the Indus offshore fan (Kadri, 1995).

Kirthar Foredeep trends North-South and has a faulted Eastern Boundary with Thar Platform. It is inferred that the sedimentation had been continuous in this depression. This depression is the area of great potential for the maturation of source rock (Kadri, 1995).

Kirthar Foldbelt is also North-South trending tectonic feature. Structures located in the Kirthar Foldbelt are related to compression and strike-slip movements of the western margin of the Indo-Pakistan Plate. This is the feature where significant crustal shortening occurred against Eurasian plate. Intense structural deformation in the Kirthar Range has resulted in deep seated thrusts. Stratigraphy form Triassic to recent has been observed from the exposed outcrops while Precambrian to Permian may be present in subsurface (Kadri, 1995).

It can be concluded from the above discussion that the region has shown both the compressional and extensional tectonics in association with wrenching. At the Western marginal, there is a structural high i.e. Kirthar Foldbelt. Transpresional regime has been established in the Kirthar Foldbelt, where positive flower structures and thrusted anticlinal structures are observed. While towards eastern side, there lies Thar Platform. It depicts transtensional tectonics related to the drifting of Indo-Pakistan Plate. Due to extensional tectonics, Horst and Garben structures has been formed on a gentle broad monocline. Furthermore extension resulted in the development of negative flower structures (Kadri, 1995).

2.9 Tectonics of the Study Area:

The study area is bounded with Sangarh depression from East, Kirthar Foldbelt from West, Sukkur Rift from North and Thar Platform from South.

The Tajjal area is located on Khairpur high area. It is actually a basement high and mostly the Eastern part that extends to the Indian border obscured by desert sands except in the areas near Khairpur and Sukkur where Eocene carbonates crop out (Nasir, et al, 2007).

The Kadanwari Block is situated on the eastern and southeastern shoulder of the basement induced regional North-South trending Khairpur high. This high played a key role in the formation of hydrocarbon bearing traps in all of its surroundings including in the Kadanwari Block.

The three tectonic events mainly responsible for the structural configuration of the study area are: First is the late Cretaceous uplift and erosion, Second event is a late Paleocene right-lateral wrenching, and third one is the late Tertiary to Holocene uplift/inversion of the Khairpur high.

CHAPTER 3 SEISMIC PARAMETERS

3.1 INTRODUCTION

The seismic survey is one form of geophysical surveys that aims at measuring the earth's geophysical properties by means of physical principles such as magnetic, electric, gravitational, thermal, and elastic theories. It is based on the theory of elasticity and therefore tries to deduce elastic properties of materials by measuring their response to elastic disturbances called seismic (or elastic) waves. Seismic surveys are used to locate and estimate the size of underground oil and gas reserves. Seismic images are produced by generating, recording and analyzing sound waves that travel through the Earth. These sound waves are also called seismic waves. The oil and gas exploration industry has deployed this evolving technology for decades to determine the best places to explore for oil and gas.

3.2 SEISMIC METHOD

The Basic technique of seismic exploration consist of generating seismic waves and measuring the time required for the wave to travel from the source to a series of geophone. Knowing the value of travel time and velocity of the wave one attempts to reconstruct the path of the seismic waves.

3.2.1 General introduction to wave phenomena:

A wave can be defined as a periodic disturbance that transmits energy through a medium, without the permanent displacement of the medium.

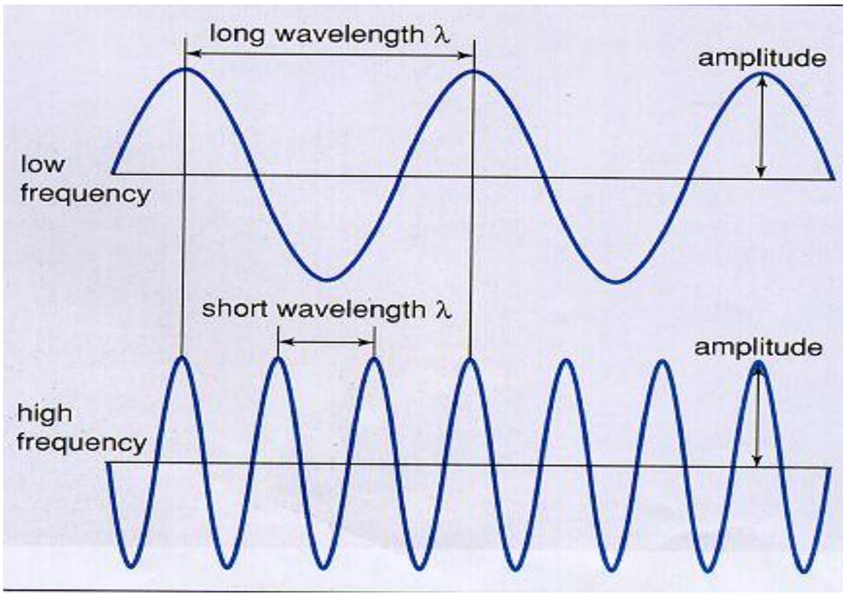


Fig 3.1 showing wave Parameters

The energy transported by a wave is directly proportional to the square of the amplitude of the wave. This energy-amplitude relationship is sometimes expressed in the following manner.

$$E \propto A^2$$

Frequency (f): The number of cycles a given point moves through in 1 second. Frequency is measured in Hertz (Hz). If the frequency is very low, then it is common to refer to the period (T) of the signal in seconds. $T = 1/f$

Angular frequency (ω): Frequency is the number of rotations per second. The angular frequency is the number of radians per second and given by $\omega=2\pi f$

Wavelength (λ): Distance in metres between two points of the wave having the same phase (e.g. two crests or two troughs). If the waves moves at a velocity, v, then $v = f\,\lambda$

Amplitude: The **amplitude** of a **wave** is the distance from the centre line to the top of a crest or to the bottom of a trough.

Rays: denote the direction in which the wave travels.

Wavefronts: Wavefronts are points on the wave with the same phase (e.g. a line along the crest of a wave is a wavefront). wavefronts and rays are at right angles to each other.

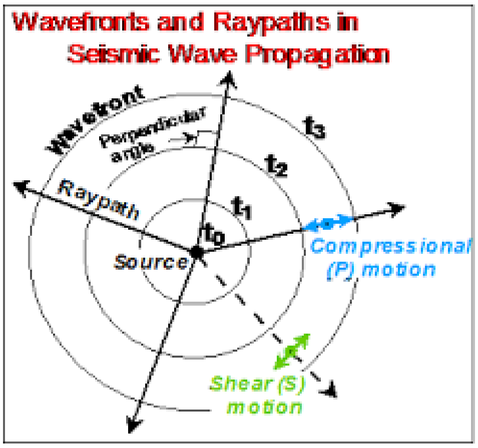


Fig 3.2 showing wave fronts and Ray paths

Huygens Principle: This states that all points on a wavefront can be considered secondary sources of wavelets. These secondary wavelets propagate outwards and at a time later, the overall wavefront is the envelope of secondary wavelets. Examples for a point source is shown below.

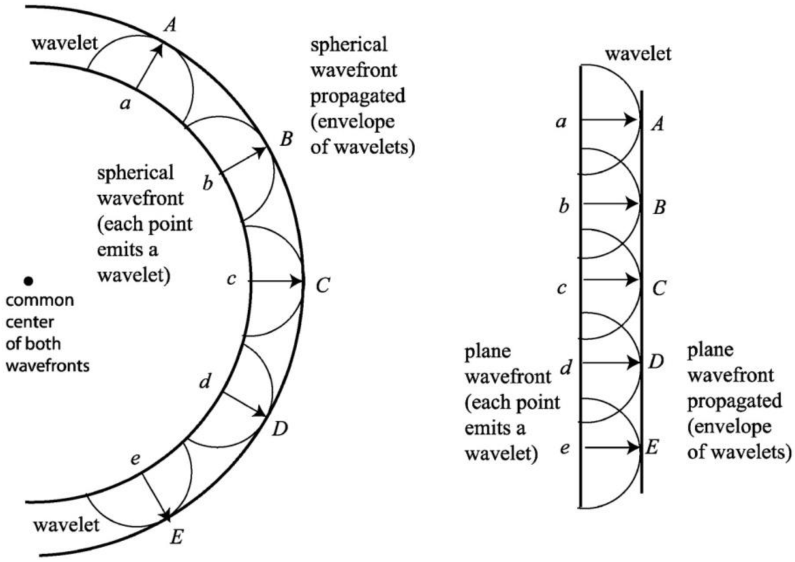


Fig 3.3 showing Huygens Principle

3.2.2 Wave propagation in the Earth:

Waves in the Earth can be divided into two main categories:

(a**) <u>Body waves</u>** travel through the <u>bulk </u>medium.

(b) **<u>Surface waves</u>** are confined to <u>interfaces</u>, primarily the Earth-Air interface.

Body waves in the Earth can be divided into two types:

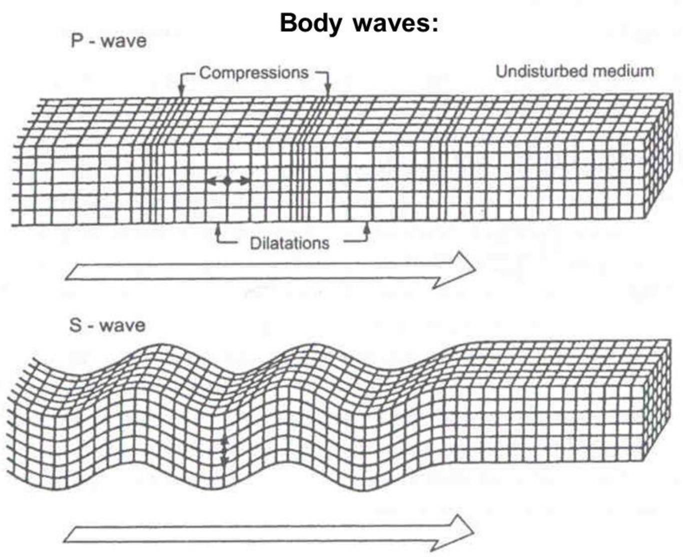


Fig 3.4 showing body waves

P-waves : Particle motion is in the same direction as the wave propagation. They are also called compressional or longitudinal waves and

S-waves: Particle motion is at right angles to the wave propagation. Also called shear waves or transverse waves)

$$V_p = \sqrt{\frac{\kappa + \frac{4}{3}\mu}{\rho}} \qquad V_s = \sqrt{\frac{\mu}{\rho}}$$

Vp = P-wave velocity
Vs = S-wave velocity
κ = bulk modulus (a measure of incompressibility or resistance to change in volume without change in shape)
μ = shear modulus (a measure of rigidity or resistance to change in shape without a change in volume)
ρ = density

Surface waves can also be divided in to two further types.

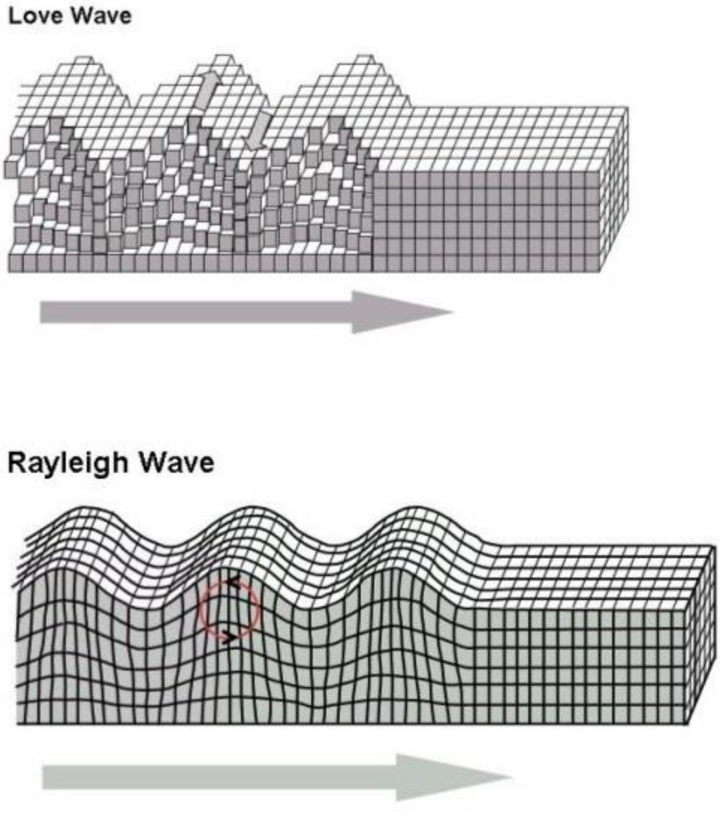


Fig 3.5 showing Surface waves

Rayleigh Waves are like ripples on a lake. Particle motion is in a retrograde ellipse.

Love waves have a horizontal particle motion analogous to S-waves.

●The velocity of a Rayleigh wave does not vary with frequency when travelling in a uniform medium and it is slower than an S-wave. In a layered Earth the velocity of a Rayleigh wave varies with frequency (it is dispersive) and can be used to infer velocity variation with depth.

●Love waves only exist if the Earth is layered and are always dispersive.

●Large earthquakes can generate surface waves that travel around the globe. They can be large in amplitude and cause a lot of damage during earthquakes.

●In exploration seismology, ground roll is a Rayleigh wave that travels across the geophone array.

3.2.3 Seismic energy sources

Basic requirements for an efficient seismic source include:

●Generate sufficient energy in an appropriate frequency band

●Economical

●Non-destructive

●Repeatability

3.2.3.1 Near surface exploration

● A high frequency seismic source is needed to generate short wavelength signals (the wavelength should be less than thickness of layers to be studied). However, if the frequency is too high, then attenuation will become a significant problem.

● A **hammer** striking a metal plate makes an portable, repeatable source. A sledge hammer gives good energy, but relatively low frequency. A smaller hammer will give high frequency signal for shallow imaging. By stacking a number of hammer blows, the signal-to-noise ratio can be increased.

● **Firearms** give higher frequencies, but are not always permitted in civilized countries (e.g. shotgun, semi-automatic etc.)

● **Buffalo guns** and Betsy guns allow a blank cartridge to be fired without using ammunition.

● **Weight drops** are also used and are commonly mounted on the back of a small truck. Larger weight drops have included the use of helicopters.

● **Explosives** were once widely used, but this has declined with the development of the Vibroseis method. Typically rotary drilling is used to place the shot in an 8-10 cm diameter hole at a depth of 6-30 m. Drills can be mounted on a truck, or slung beneath a large helicopter. While spectacular, blasting rocks and soil into the air represents a loss of energy and a safety hazard.

Advantage is Sharp impulsive signal. Strong signals can be generated if needed for imaging the lower crust and upper mantle while **Disadvantage** is Not repeatable, and quite slow. Most energy is in P-waves. Many environmental concerns and cannot be used in urban areas.

3.2.3.2 Marine seismic sources:

Air guns: An airgun works by releasing a bubble of high pressure air into the water. The rapid expansion of the bubble generates seismic energy with a frequency content around 10-100 Hz. Operation of Bolt airgun. The chamber is filled with air at 10-15 MPa which is then released into the water. Airgun array on Veritas ship Airgun array and streamers being towed behind a survey vessel.

Advantages

●Very repeatable, reliable source.

Disadvantages

●The bubble pulse oscillates, generating a relatively long wave train. However, by using an array of air guns at differing depths, the combined waveform can be made shorter in duration (figure from Kearey).

● In water only P-waves are generated, but S-waves can be generated by mode conversion at the seafloor.

● In recent years there has been a lot of concern about how marines seismic exploration affects marine mammals.

3.2.4 Seismic detectors:

3.2.4.1Geophones:

On land, the surface moves as a P-wave or S-wave arrives. Generally reflected signals arrive at steep angles of incidence. Thus P-waves produce surface motion that is dominantly vertical. Geophones measure ground motion by converting motion into electrical signals. Most geophones measure a single component (vertical), but multiple component ones are sometimes used.

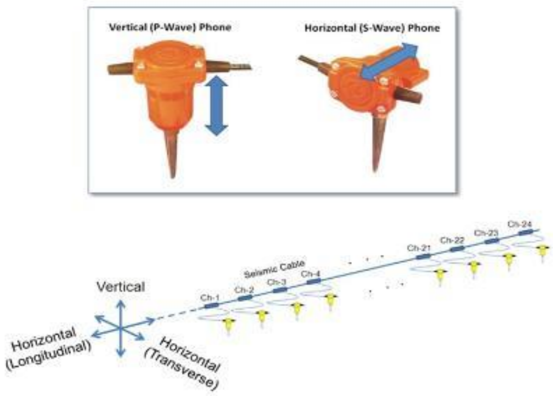


Fig. 3.6 Geophone

3.2.4.2 Hydrophones and streamers:

S-waves cannot travel in water, so only P-waves can be detected in the water. In marine exploration seismic waves are detected by the change in pressure as a P-wave passes the detector. This type of sensor is called a hydrophone and it converts a change in water pressure into an electric signal through the piezoelectric effect.

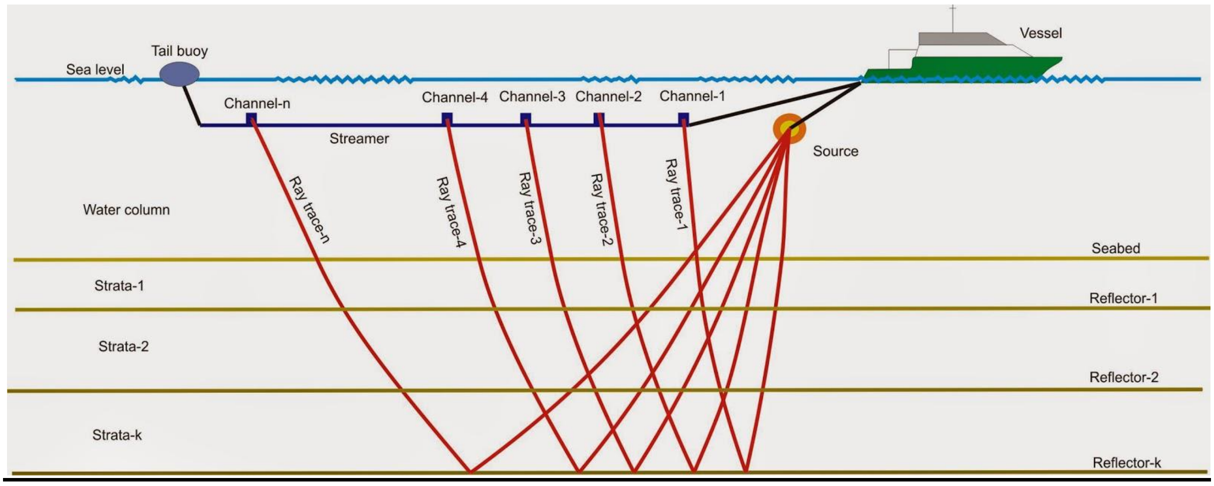


Fig 3.7 Hydrophone

Seismic method is one of the most important geophysical method in all geophysical methods. This predominance is because of various factors i.e. its high accuracy, high resolution and great penetration. This wide seismic method is mostly used in exploration of petroleum. This basic technique of seismic exploration is that seismic waves are generated and the time required for waves to travel from source to the geophones which are arranged in specific pattern is measured. There are two types of seismic methods i.e. seismic reflection and seismic refraction method.

3.2.5 SEISMIC REFLECTION METHOD

The seismic reflection method is based on the study to map subsurface geological structures. Measurements are made of the arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes. The objective usually is to map variations in the depth and attitude of the interfaces which usually are parallel to the bedding.

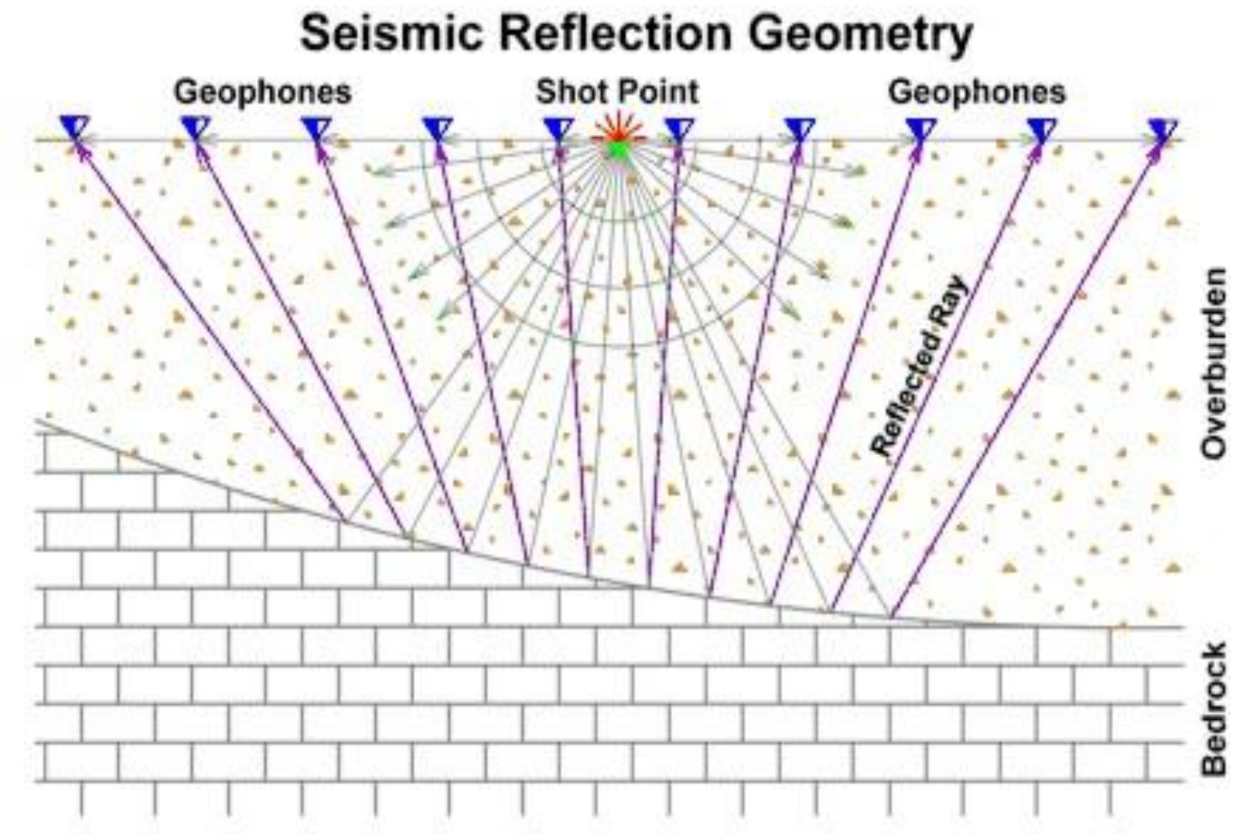


Fig. 3.8 Seismic Reflection Geometry

3.2.6 SEISMIC REFRACTION METHOD

Seismic refraction method is based on the study of elastic waves refracted along geological layers. This method is generally used to map low velocity zone. This method is used as supplement with reflection method.

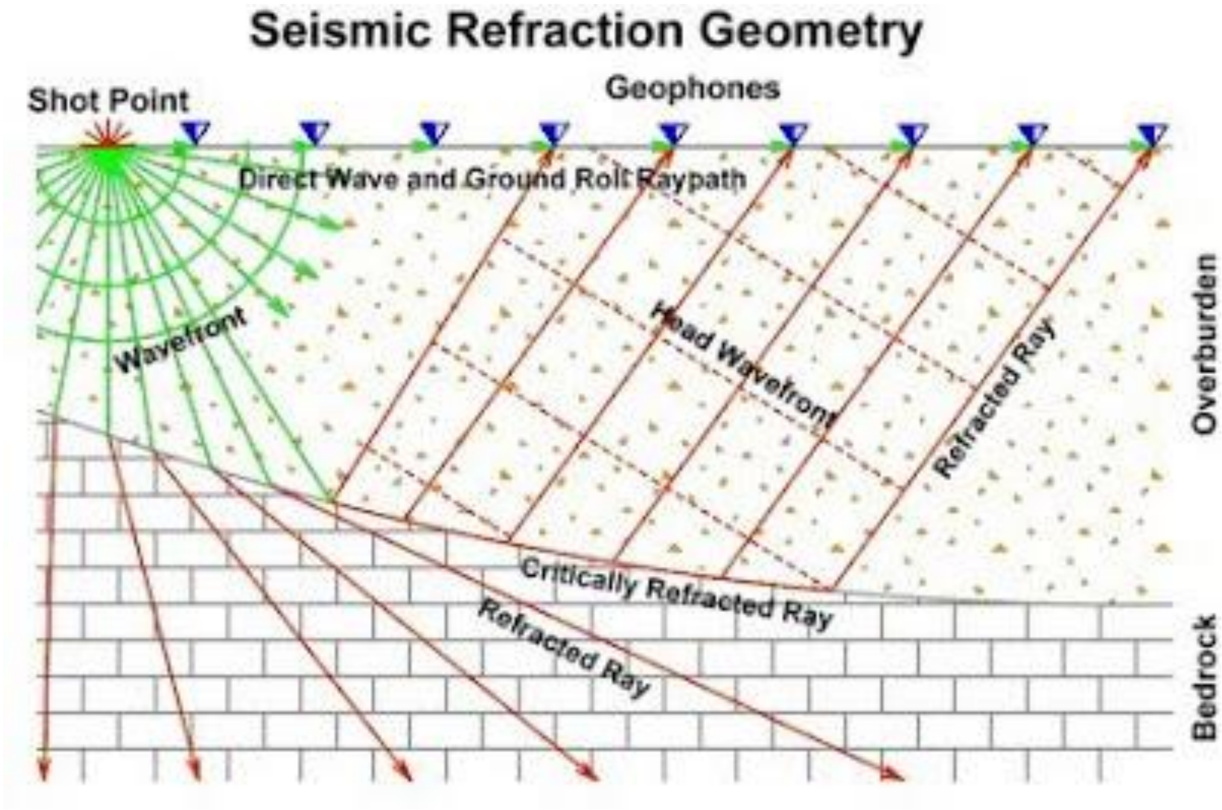


Fig. 3.9 Seismic Refraction Geometry

3.3 SEISMIC DATA ACQUISITION:

Seismic investigation starts in the field with the acquisition of data. The purpose of seismic data acquisition is to record the effects produced by mechanical disturbance at the surface of earth, and its effects are observed at number of locations along the surface in a way that its relation with initial disturbance can be interpreted. It includes all those steps which yield final output to be processed and interpreted. The instruments so adopted to acquire seismic data now-a day's 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.

Seismic acquisition system consists of three basic subsystems:

i) Energy sources (Explosives)
ii) Energy receiving units (Geophones)
iii) Recording system

Explosives or vibrating plates generate the waves and a line or grid of geophones records them. Density changes between rock or soil layers reflect the waves back to the surface and the speed and strength that the waves are reflected back indicates what geological features lie below.

3.4 SEISMIC DATA PROCESSING:

The process of data processing includes the sequence of operations. According to predefined program these operations are carried out to convert set of raw data into useful information. Advancement of technology/electronic computers in last two decades brought the digital revolution in seismic prospecting for oil and gas. After the introduction of computers seismic data processing attained new shape. Figure 3.1 shows the generalized processing flow chart for seismic data processing. The rationale behind the seismic data processing is to convert the recorded information of field into a form that allows geological interpretation, the reflections presentation with maximum possible resolution on the seismic section and the reduction or elimination of different noises. The main objectives of the seismic data processing are summarized as below.

i. Improving Signal to Noise ratio.
ii. Representation of geology in seismic cross-section.
iii. To acquire the target provided by client.

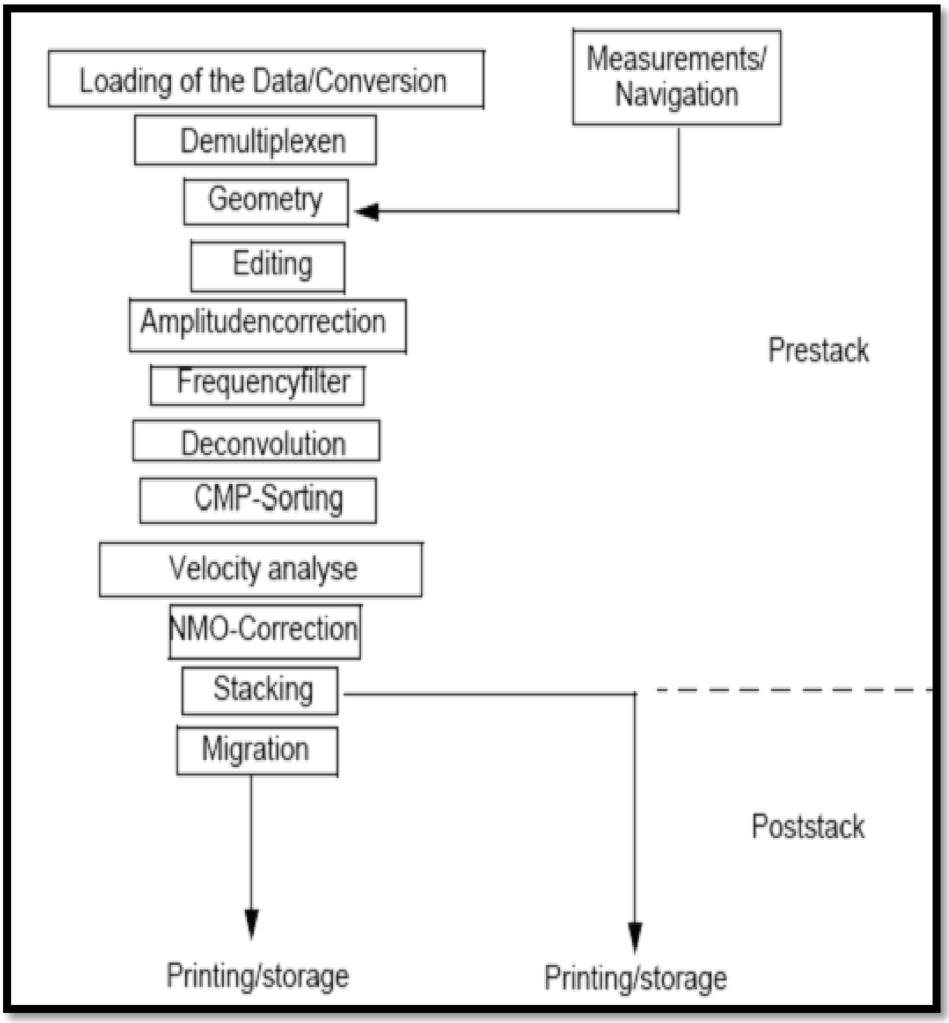


Figure 3.10 Generalized processing flow chart for seismic data processing.

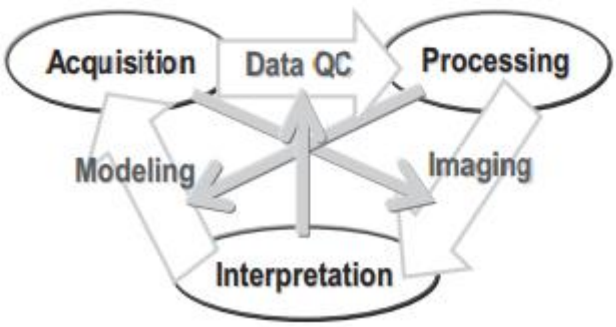


Fig 3.11 relationship between seismic processing steps

Process	Purpose	When Applied	Pitfalls

Data Reduction

DE multiplex	Put data in trace sequential (SEG-Y ,D) format, from multiplexed (SEG-A, B) field tapes. Label headers with geometry information	First. Do in field if possible, as most engineering seismographs do	Incorrect geometry, observer'sreports, time breaks, sample raterecord length, etc.
Gain Recovery	Multiply data by binary gain codesFrom gain ranging.	Second, if needed.	Locating correct gain trace
Editing	Remove bad records, misfiredShots, open channels, noisy traces.	Third, and at other times duringProcessing if needed. Best doneIn field during acquisition.	Must scrutinize plots of all of raw data.
Summing (Vertical stack)	Reduce source and random noise by adding multiple impacts, shots or sweeps at same location	After editing. Often done during acquisition, irreversible	Noisy or unbalanced shots. False triggers. Strong 60 Hz noise willSum to harmonics. Large move uparrays attenuate steep dips and blurStatics.
Correlation	Compress vibrator sweeps into Small wavelets.	After summing to save computer Time. Best after despiking andEditing. Often done duringAcquisition, irreversible.	Incorrect sweeps, harmonics, spikes Produce ghosts. Acts as a bandpass Filter. Very expensive
Gain Function	Remove effect of geometric spreading, amplifying deep events Relative to shallow.	Last step in data reduction above.	Can destroy true amplitude information. Use a reversible function or save unequalized dataset.

Geometric Corrections

CMP Sort	Arrange traces by common midpoint.	After data reduction but before Velocity analysis or NMO Correction.	Incorrect stacking diagram, crooked Seismic lines. Uses little CPU timebut very expensive in terms ofStorage media. Gathers no longercorrespond to physical experiments
Elevation (Datum) Static	Time correction for elevation Differences.	Correct to at least a CMPvariable datum before NMO or Velocity analysis. May correct to final datum after stack.	Assumed velocities above datum, Long offsets.
Uphole Static	Time correction for lateral velocity	Before NMO or velocity Analysis.	Assumed depth of weathered layer;

	Variation in weathering layer.		Long offsets.
Velocity Analysis	Estimate VNMO, Vinterval	After determined time corrections and sorting, before finalMO and stacking or anyMigration.	Assumes zero dip, slow lateral velocity changes, strong reflectors at Velocity changes, and no multiples. Requires time-consuming humanInteraction.
NMO Correction	Correct time on offset traces to Zero-offset time.	After sorting and statics, before Stacking, part of velocity Analysis.	Assumes zero dip, slow lateral velocity changes, no multiples, shortOffsets.
Residual Static	Correct any remaining time shifts to straighten out NMO-corrected Events.	After NMO, before stacking	Eliminates delay information useful For transmission tomography. Assumes only slow lateral velocity Changes. Needs human interaction

Process Purpose When Applied Pitfalls

Data Enhancement

Mute	Zero out arrivals that are not primary P-wave reflections.	Before stacking and/or migration	Arrival variations with midpointmust be catalogued through humanInteraction. Overly sharp clips cause artifacts in further processing
Bandpass Filter	Attenuate noise outside of reflection frequency band	Best before stack, NMO, or Velocity analysis; can be afterStack.	Often much noise in signal free frequency band, or weak signals areFiltered out. Alters true and relative amplitudes
Notch Filter	Attenuate noise in narrow frequency band, such as 60 Hz AC power	Best before stack, NMO, or Velocity analysis; can be afterStack.	Too narrow a notch will causeArtifacts. Destroys true amplitudeAnd phase.
Deconvolution	Compress source wavelet shape and duration, improve resolution, Attenuate reverberations.	Best before stack, NMO, or velocity analysis, can be afterstack	Can unwittingly remove evidence of Real reflectors; will change true Amplitude and phase.
2-D (F-K) Filter	Spatial bandpass filter, attenuates enhances arrivals based on dip, Move out, or apparent velocity.	Any time after data reduction, Depending on type of events.	Alters amplitudes. A good way tomake data look like anything you might want, biasing interpretations
Stack	Mimic zero-offset section, attenuate Random and much coherent Noise.	After sorting, velocity analysis, Muting.	Attenuates dipping structures, accentuates lateral coherence. Depends on inferred velocities.

			Misallocates dipping Structures.
Trace Equalize (AGC)	Amplify weak events or traces Relative to strong. Often best use Just for display purposes.	Anytime, usually just before or After stack.	Lose amplitude information. CanEnd up enhancing noise.

Imaging

Post-Stack Migrate	Correctly position dipping events Horizontally.	After stacking and usually Equalization	Depends on average and/or interval Velocities. Cannot improve on steep or crossed dipping events that do not Stack well.
Depth Conversion	Correctly position events vertically.	After stack and usually migration.	Depth error proportional to average Velocity error.
Pre-Stack Migrate	Correctly position steeply-dipping Andcrossing reflectors. Invert for Earth properties. NMO correction and stacking are a simplified Migration that assumes zero dip.	Partial migration (dip move out or DMO) can be done before NMO and stack. Full prestack Migration done after data reduction and often after filtering, equalization, and deconvolution No stacking. Usually applied only to good data from well Characterized areas.	Heavily dependent on velocity estimates and susceptible to gross error whenlateral velocity variations are Not correctly accounted for Extremely expensive.
Database Formation	Organize 3-d seismic depth section To be interactively viewed by interpreter and related to geology, well measurements, other geophysical data, etc. in on-line environment.	Final result of processing. Interpreter should be able to change velocities based on supplemental data and see result on entire sequence of seismic processing Interactively.	Interpreter could force data to meet His prejudices. Mis-ties and inconsistenciesbetween seismic and other Data must be accounted for.

Table 3.1 Seismic Data Processing Description

CHAPTER 4 INTERPRETATION

4.1 INTRODUCTION:

Subsurface structural analysis means to analyze the structure deep down the earth surface. Geophysicist practices this analysis to find out the most probable structure for hydrocarbon accumulation. For subsurface structural analysis, these are two methods:

i) Correlation and ii) Seismic interpretation.

In this dissertation Seismic interpretation has been done with the help of Seismic Micro Technology (SMT) i.e. Kingdom 8.6 & Land Mark Geographix.

4.2 SEISMIC INTERPRETATION:

Interpretation is the transformation of seismic reflected data into a structural picture by the application of corrections, migration and time depth conversion (Dobrin and Savit, 1988).

Interpretation of seismic data is very complicated process involving many problems and difficulties because every area is different from other ones, so the approach used before probably would not work on the new area. For this purpose, an interpreter has to get really familiar with an area to work it well and trying one thing and then another is an excellent way to really know the area. The importance of seismic work in the exploration for petroleum is evidenced by its extensive application. Almost all the major oil companies rely on seismic interpretation for selecting the sites for exploratory oil wells (Telford et al. 1976).

4.2.1 METHODS OF INTERPRETATION:

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

i) Qualitative Interpretation

ii) Quantitative Interpretation

4.2.1.1 QUALITATIVE INTERPRETATION:

The primary aim of the qualitative interpretation of the seismic data is to map the subsurface geology. Qualitative interpretation is conventional or traditional seismic technique that include the marking of laterally consistent reflectors and discontinues characteristics and their mapping on different scales (space and travel time). The geometry on the seismic section is precisely interpreted in view of the geological concept to detect the hydrocarbon accumulation. The structure and stratigraphic architecture of the petroleum is determined and on behalf of the geometric features the location of the well is established. Stratigraphy analysis involves the delineating the seismic sequences, which present the different depositional units, recognizing the seismic facies characteristic which suggest depositional environment and analysis of the reflection characteristic variation to locate the both stratigraphy change and hydrocarbon depositional environment (Sheriff, 1999).

In structural analysis main emphasis is on the structural traps in which tectonic plays an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other, so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, pop up, duplex, horsts and grabbons structures, etc. (Sheriff, 1999).

4.2.1.2 QUANTITATIVE INTERPRETATION:

Seismic quantitative interpretation technique as compared to the traditional seismic interpretation technique is more useful. One of the 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 prospects 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 and elastic impedance inversion, and forward seismic modeling. Seismic Interpretation Workflow for seismic data interpretation is given in figure 4.1. Base map is prepared by loading navigation and SEG-Y data in software. Horizons of interest are marked 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.

4.3 STRUCTURAL INTERPRETATION OF TAJJAL AREA:

Seismic survey is conducted to acquire data for subsurface analysis. Seismic Interpretation of Tajjal area involves 10 Seismic Lines. These lines have been interpreted by marking three horizons (SML, RaniKot and Lower Goru). Interpretation of these seismic lines shows linear discontinuity. The trapping mechanics in Lower Indus Platform basin reservoir rocks have tremendous reserves of hydrocarbons and the tectonics modification of the basin has formed variety of trap structures. The reservoir rocks which are deposited are porous and permeable rocks. They are present in carbonates and sandstones, whereas the sources rocks are all Shaly in nature.

4.3.1 METHODOLOGY OF INTERPRETATION:

Interpretation of Seismic data must follow following steps:

i. Preparation of base map.
ii. Generation of synthetic seismogram.
iii. Fault identification and marking.
iv. Horizon marking.
v. Interpretation.

Work flow chart for seismic interpretation is given in figure 4.1.

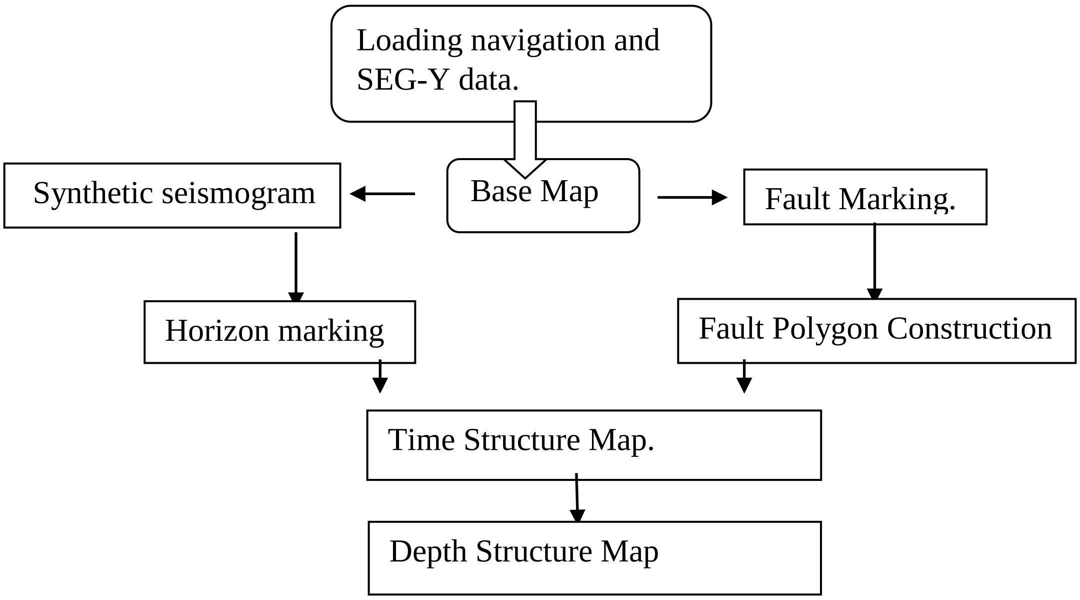


Fig.4.1: Work flow chart for Seismic Interpretation.

4.3.2 MARKING OF HORIZONS AND FAULTS:

The time section gives the position and configuration of reflectors in time domain. But the most important phenomena is fault marking along these seismic sections after which reflectors are marked on given data. After looking into the structural geological maps and tectonic activity maps, we are able to understand the tectonic regime i.e. extensional. So depending on which we have marked few major normal faults on the seismic section.

For marking the horizon we need to identify the major reflectors and in our case our focus was on the petroleum play of the area thus a few reflectors has been marked. For the identification of reflectors we first use the simple method of seismic to well tie. For this purpose the well Kadanwari-01 has been used. We loaded the velocity data along with the well to tie the well with the seismic. After identification of major reflectors we further confirmed those reflectors by generation synthetic seismogram of the Kadanwari-01 well.

For the generation of synthetic seismogram we need two major curves i.e. DT and RHOB. Acoustic Impedence was calculated using the above described curves and finally the synthetic seismogram is generated by convolving reflectivity series with the Klauder wavelet.In the figure 4.2. Tie this synthetic seismogram is showing the conformity of the formation tops.

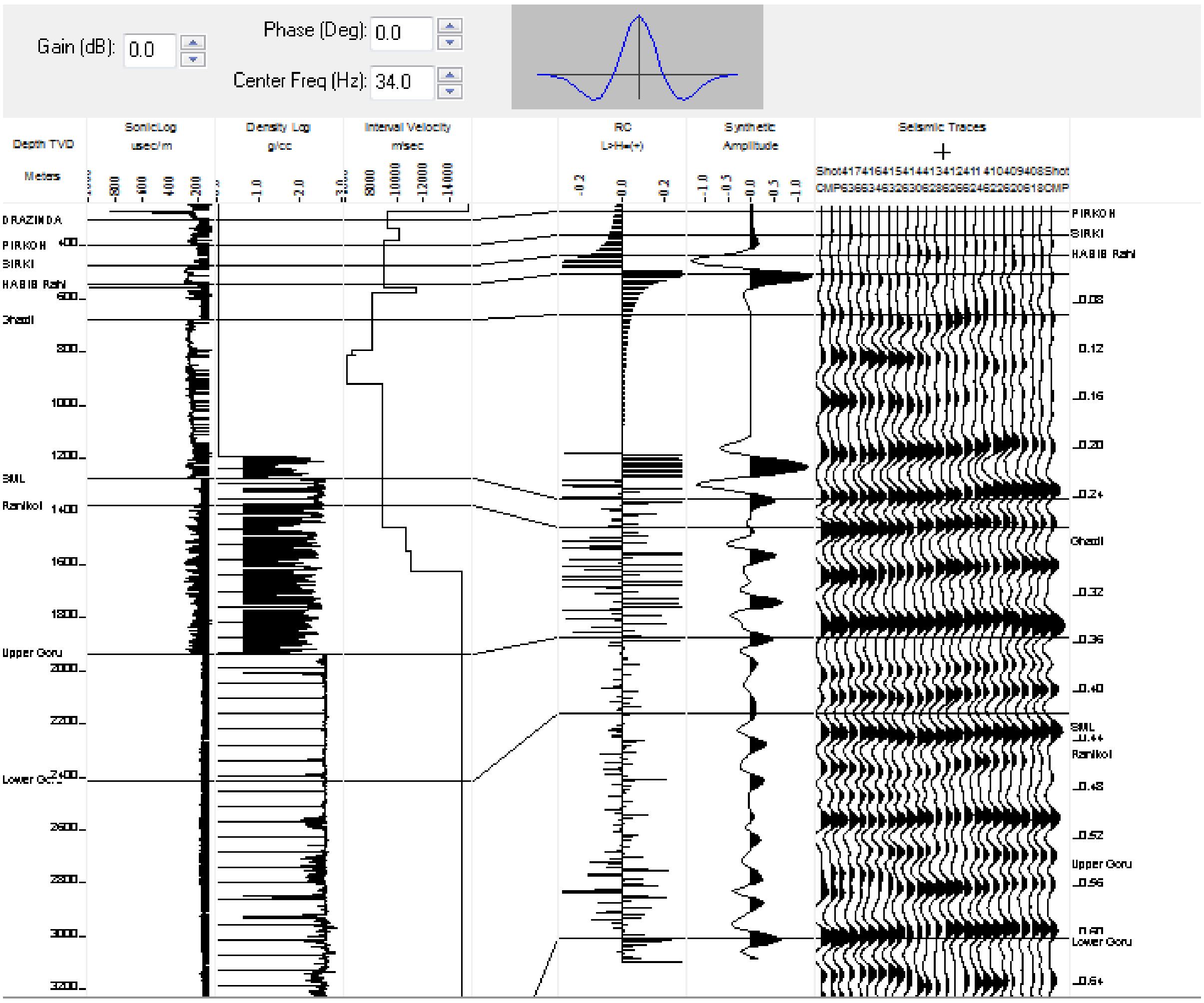


Fig. 4.2: Synthetic seismogram of Kadanwari-01

After generating the synthetic seismogram it is shown along the well as shown in the figure 4.3.

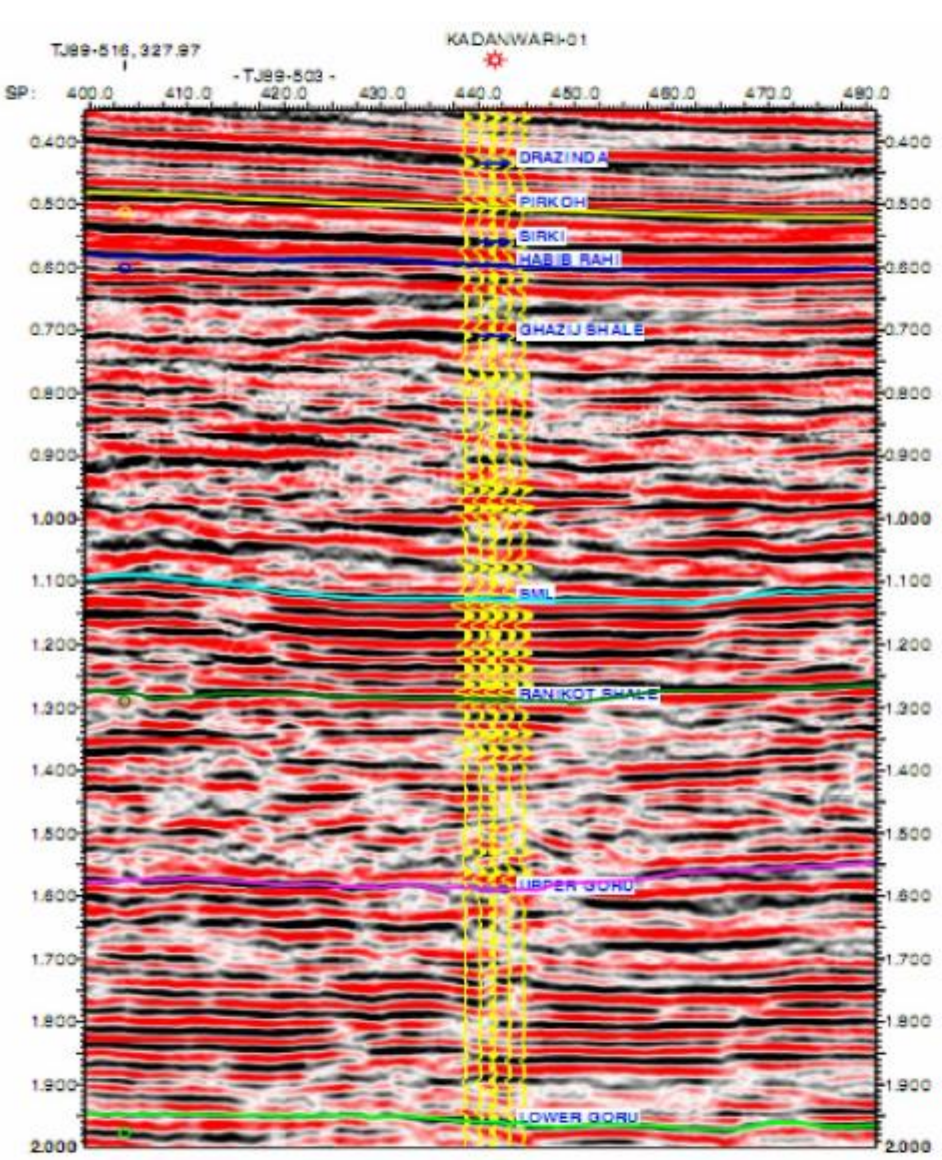


Fig. 4.3 synthetic along Well conforming Well Tops

I have been provided by four seismic lines among which 3 are the dip lines and one is strike line. Well Kadanwari-01 is near to the strike line GTJ89-503 so this line is considered as the key line.

Seismic Line GTJ89-503:

This line is extending from North to south and the shooting direction of line is South to North. In project we have three wells but the Kadanwari-01 is closest to this line so after the well tie, few reflectors i.e SML, RaniKot and Lower Goru has been picket. The reflectors are dipping towards North. This line is acting as our key line in the project and we from through seismic tie option we have shifted the reflectors to other three lines which are cutting GTJ89-503 at different shot points.

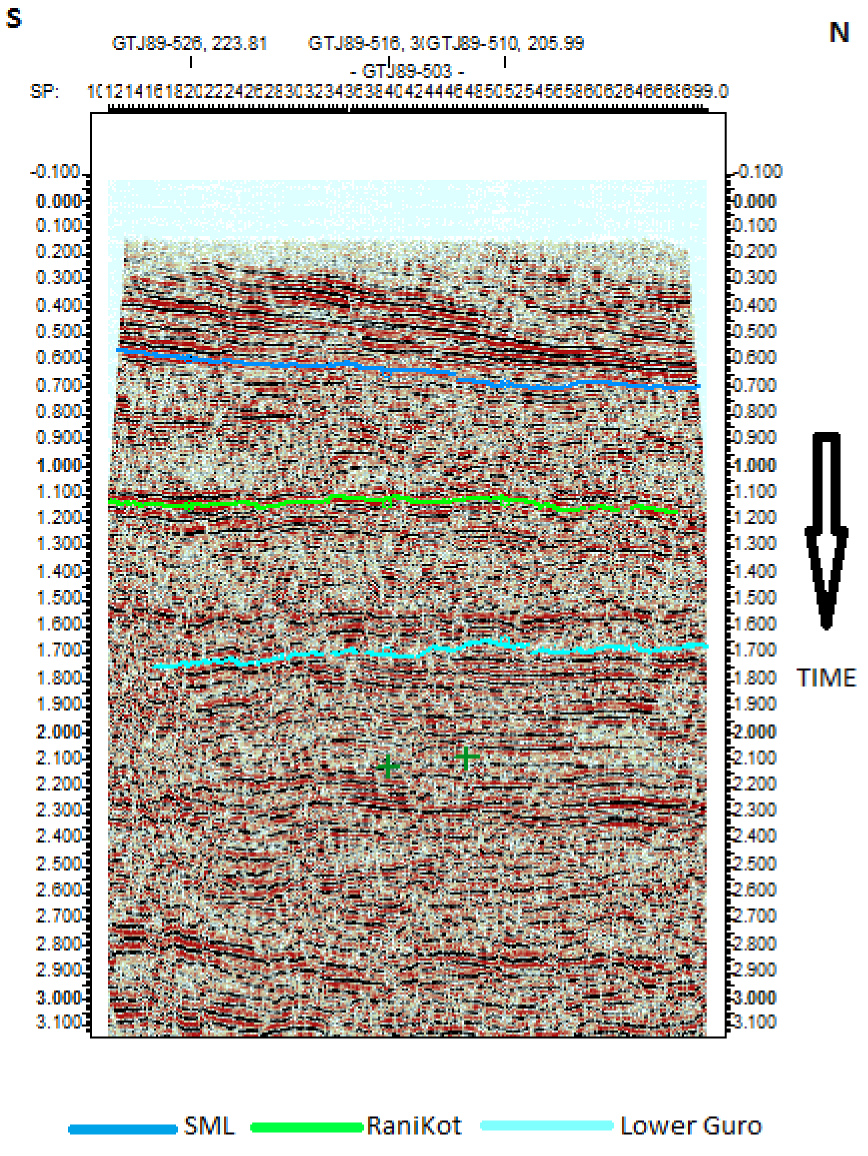


Fig 4.4 Seismic Line GTJ89-503 (Time in Sec)

Seismic Line GTJ89-510:

This line is a dip line and extending from West to East and to precisely the direction is South-West to North-East. The shooting direction of this line is from the West to East. Though we have encountered faulting in other seismic sections but on this line no major faults has been marked. A slightly two way dipping reflector is seen at Lower Goru and for the rest of two reflectors we can see the slight dip towards East.

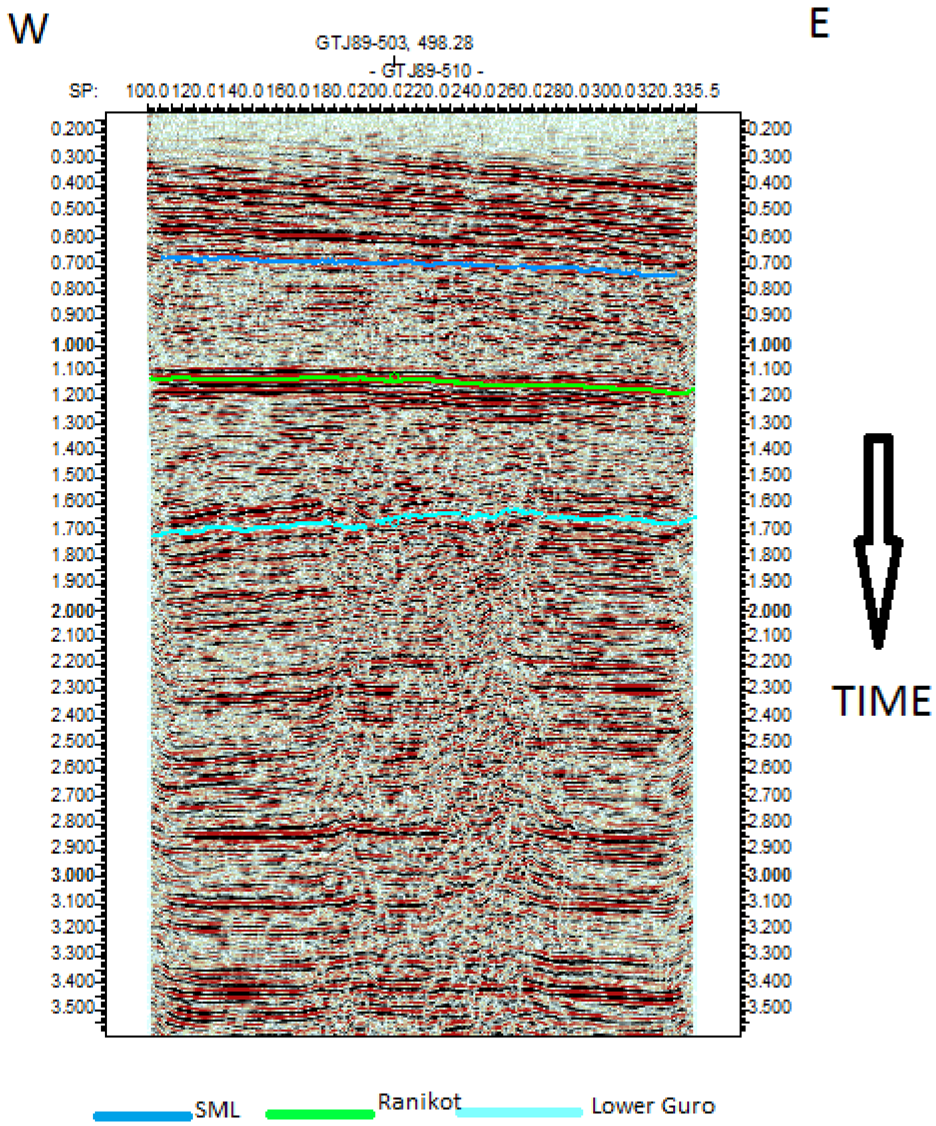


Fig 4.5 Seismic Line GTJ89-510 (Time in Sec)

Seismic Line GTJ89-516:

After the seismic tie with the line GTJ89-503, the reflectors are marked on GTJ89-516. So as we move in the south of the block we can see that the faulting is getting more prominent. So faults are encountered at along three horizons. So before extending the reflectors to both direction, faults are marked on the seismic section. As the block lies in the extensional regime so Normal faulting is observed on the seismic section as well. We have marked four faults on the seismic section. After which we first extended the reflectors to east and then by correlation marked the horizon on west side.

Though some major faults are present but the heave is not much and we see very little displacement on the all three horizons.

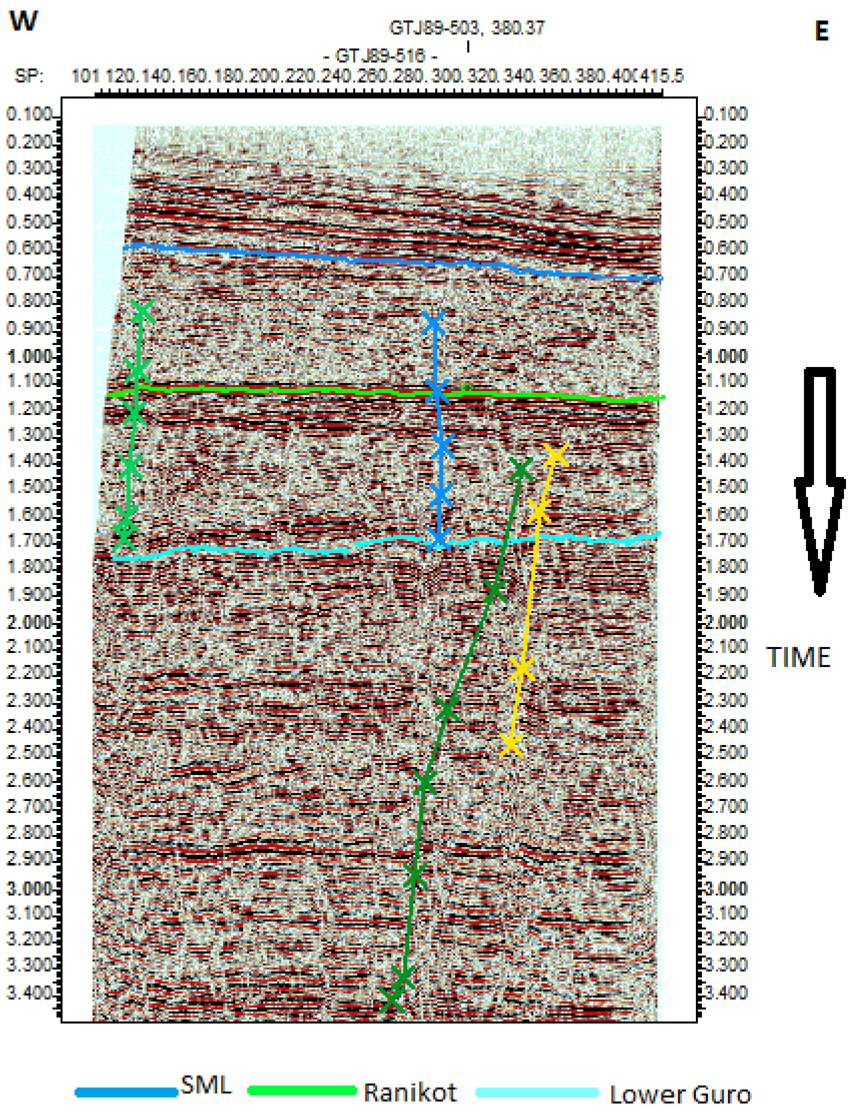


Fig 4.6 Seismic Line GTJ89-516 (Time in Sec)

Seismic Line GTJ89-526:

The seismic line GTJ89-526 is the last line used in the project. It is another dip line and has same orientation i.e. West to East. This line is located in south of the block. One major fault is marked in the line but as the length of the line is not much so might be we missed the faults we already marked on the seismic section GTJ89-516. There are few more dip lines that lies between the 516 and 526 that might have the fault occurrence on them. So it is observed that either the faults are missed due to short length and might be present if we extend the line to North-East. More data can elaborate the structure better.

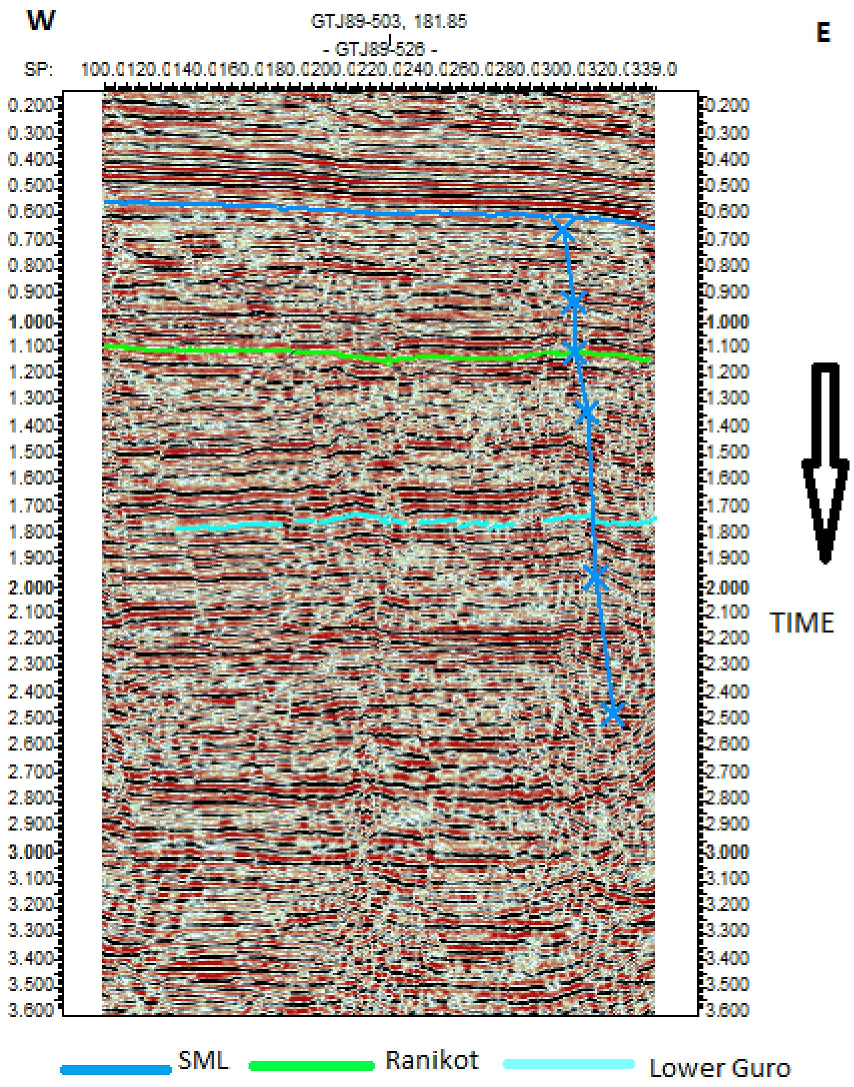


Fig 4.7 Seismic Line GTJ89-526 (Time in Sec)

4.3.3 Time & Depth Contouring:

After the marking of horizons the next step was to generate the faults polygons and create grids. After the creation of grids, contours are constructed using the grids. The time variations are displayed in some maps below after that the time grid has been created and time structures maps are created. By using the Average velocity in the area the time grids are converted to depth grids using the simple formula i.e.

$S = V*T/2$

Where

S = Depth Grids

V = Average Velocity Used.

T = Time grid of each reflector.

As the time noted down is two way time so we divided it by 2 to get one way time which enables us to get the correct Depth.

Time Variation of Sui Main Limestone (SML):

The map below shows the distribution of SML time along the seismic lines. We can see that in North color values ranges from yellow to green color range that means that the time gradient in the map shows shallow times in the North and deeper in the south. So SML is shallower in the North.

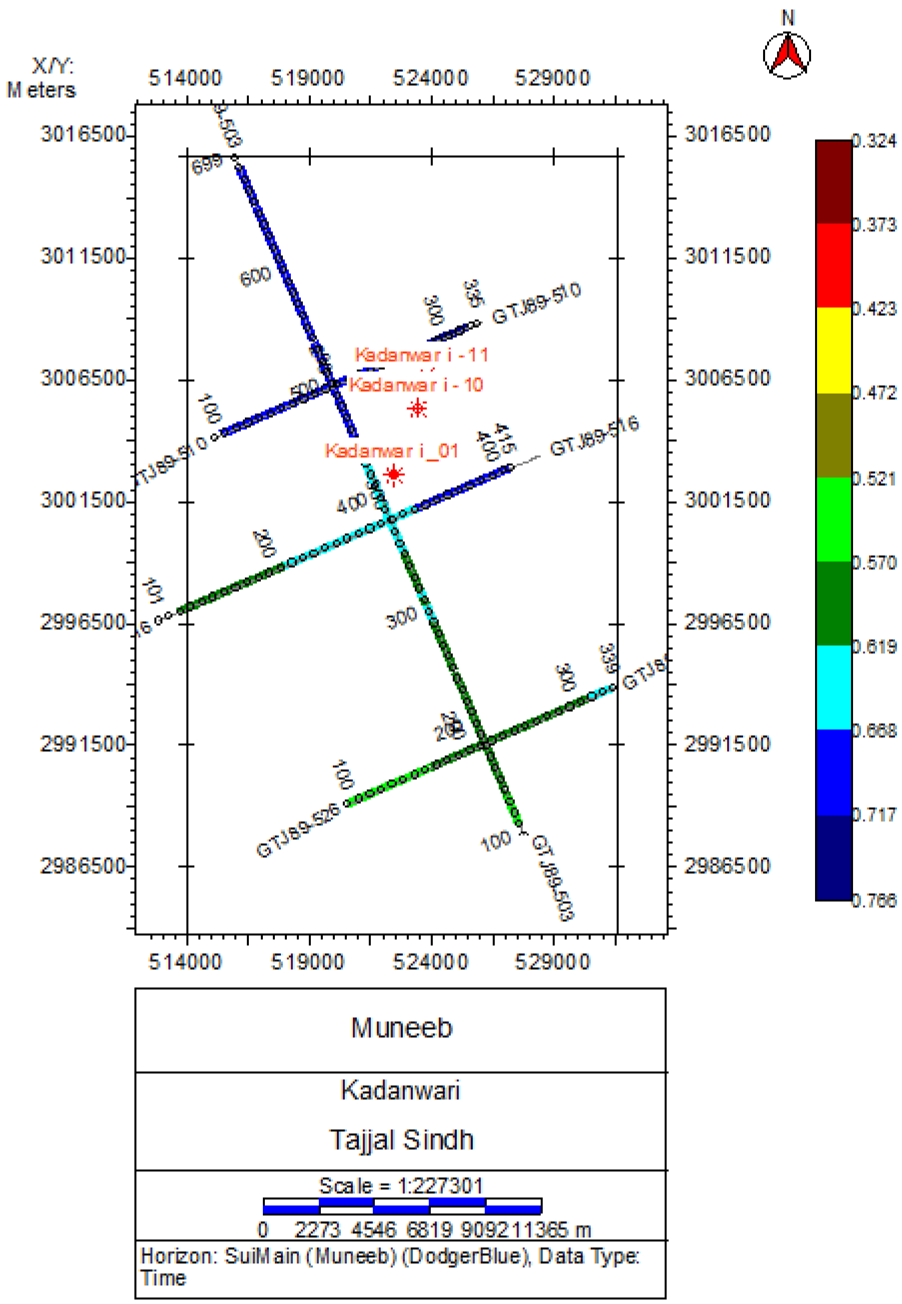


Fig 4.8 Time Variation of SML (Time in Sec)

Time Variation of Ranikot:

The map below shows the time variations of the ranikot formation. The time scale here shows the shallower values with Red color and greater values in the Blue. Whole map shows that time values ranges in between 1.13 sec to 1.78 sec.

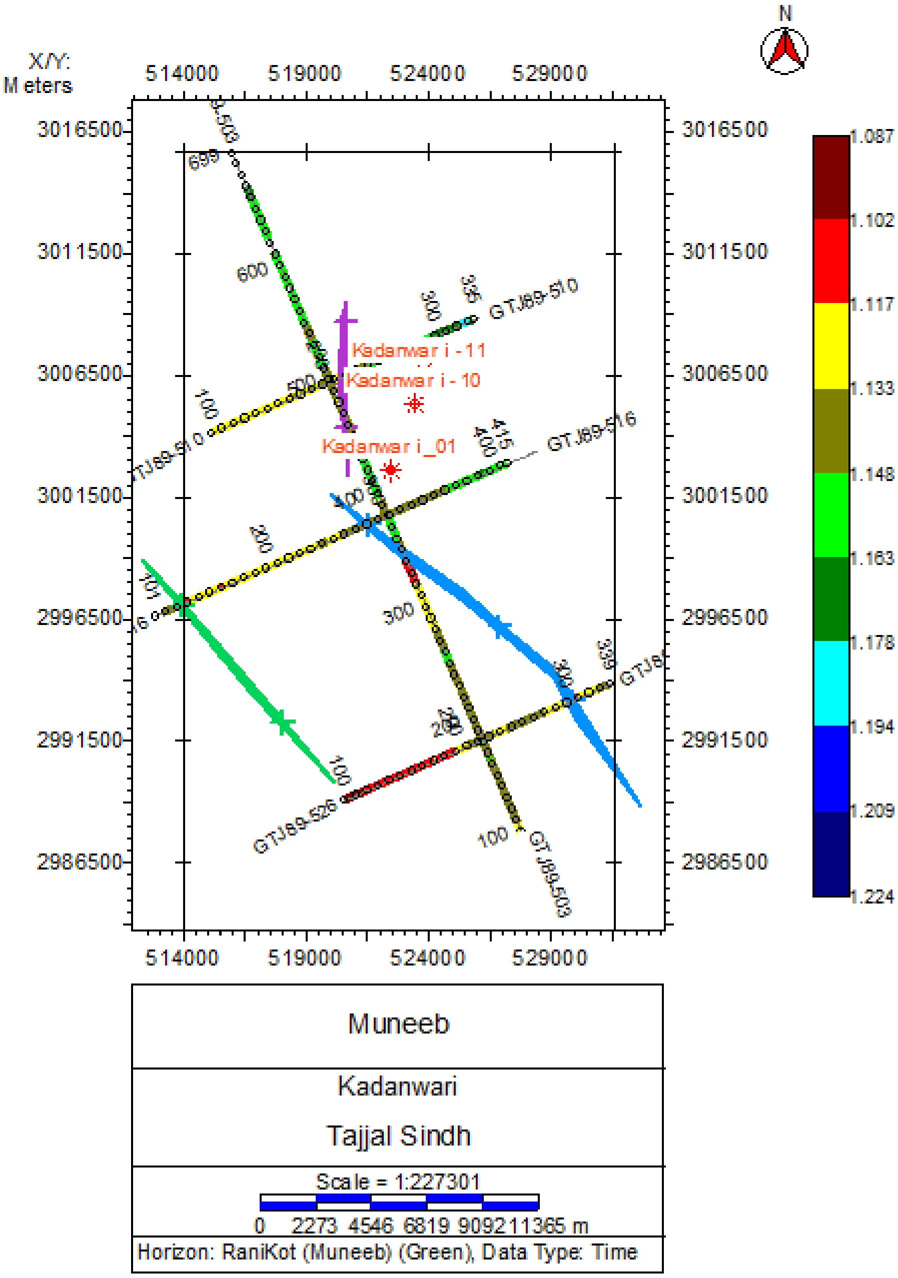


Fig 4.9 Time Variation of RaniKot (Time in Sec)

Time Variation of Lower Goru:

In this map Lower Goru time variations along the given lines are shown. The color range varies from 1.6 sec to 1.7 sec, Lower goru time lies in between this range. Along with the color variations shown on along lines, fault polygons are present on all maps in Blue, Green, Yellow and purple colors.

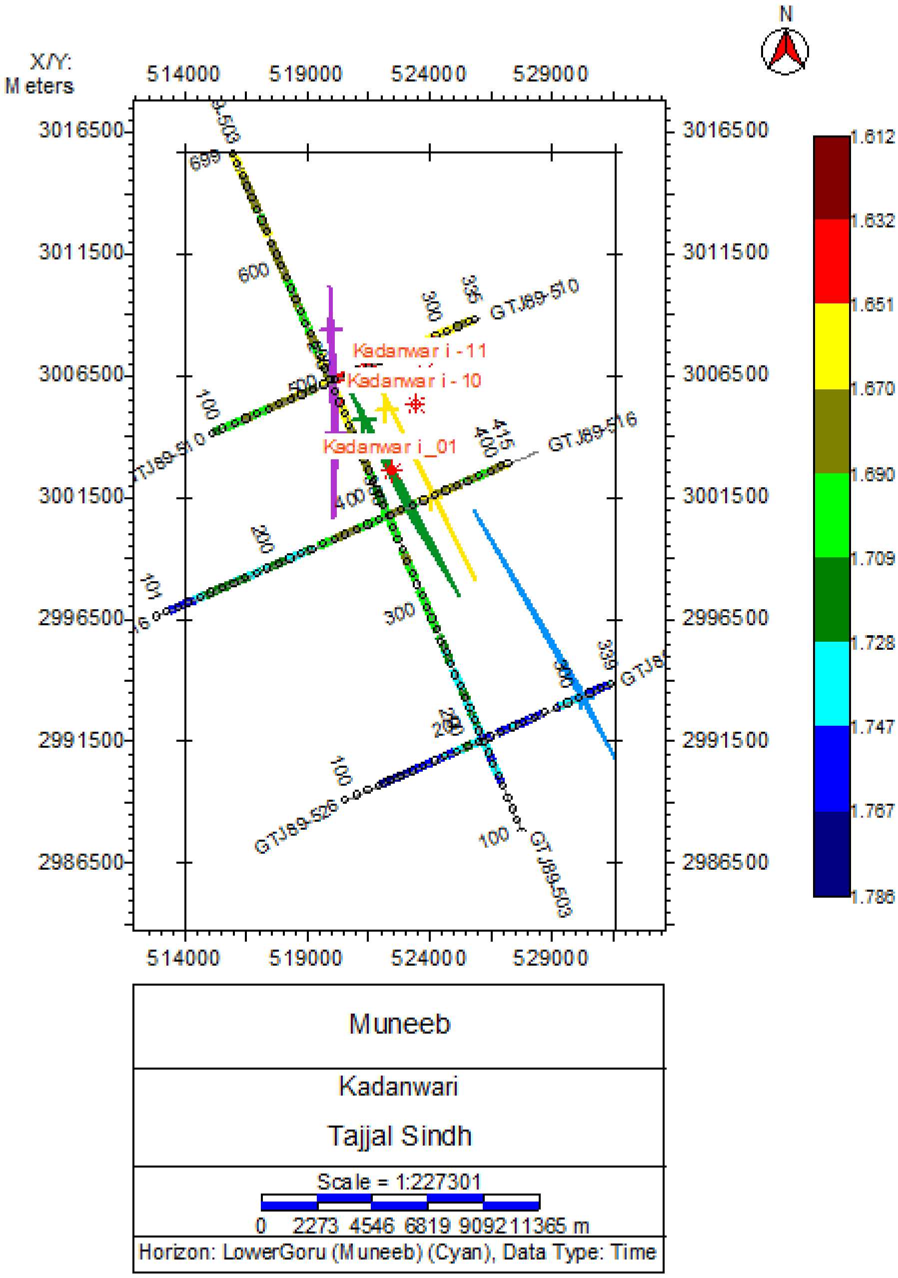


Fig 4.10 Time Variation of Lowe Goru (Time in Sec)

Time Structure Map Sui Main Limestone (SML):

After marking SML on all lines, the time variations along all line are shown above. The next step was to create the Time grid so that we can get the time contours and evaluate the Leads. There is no major lead at the level of Sui Main Limestone. All contours are open contours there are few anomalies where contouring is not correct i.e. due to the absence of some data there. We can refine this grid by adding few more seismic lines.

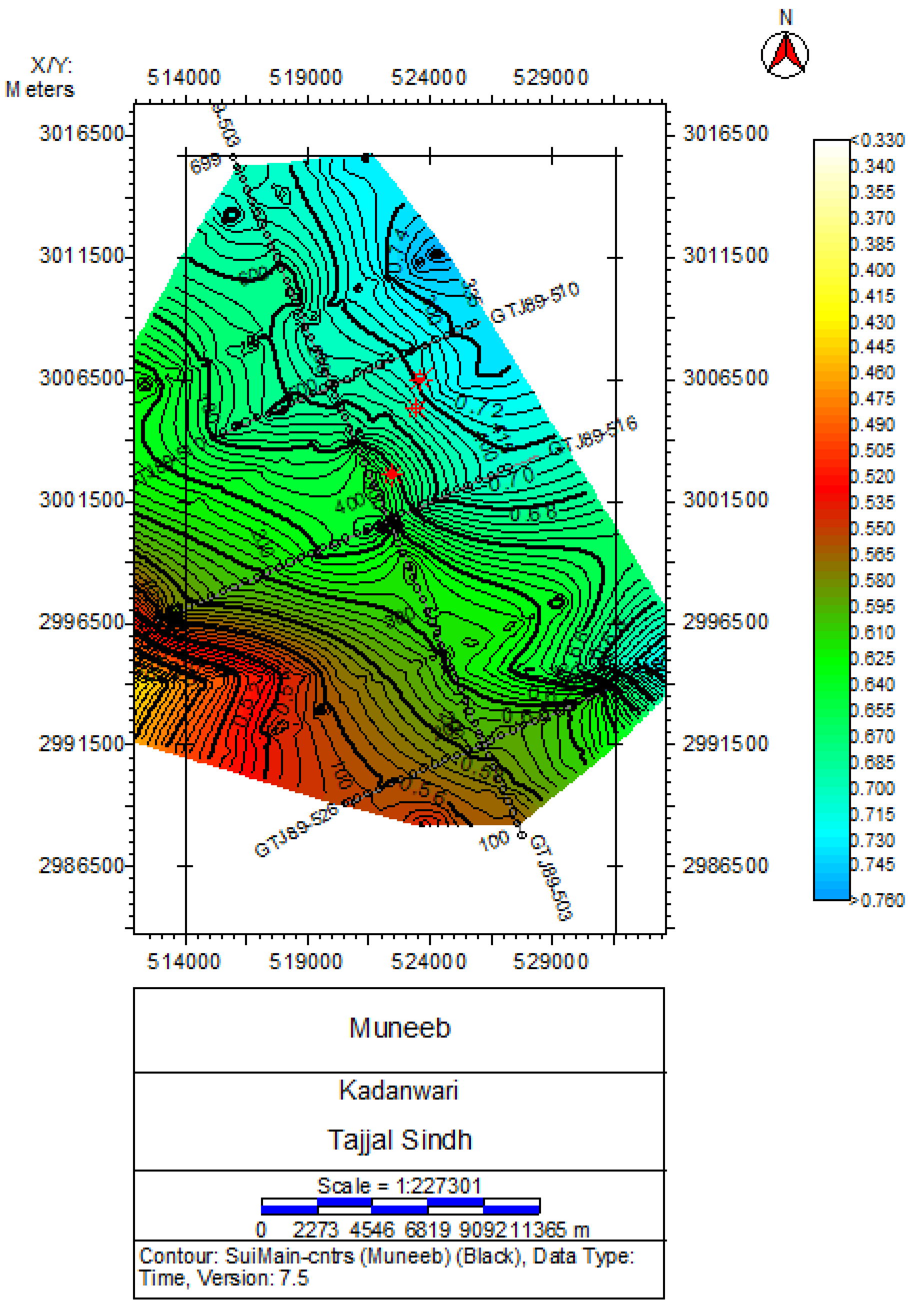


Fig 4.11 Time Structure Map of SML (Time in Sec)

Time Structure Map of RaniKot:

The map represents the time structure along the Ranikot formation. There is one major anticline but that lies on the NW side of map and we don't have much control there. We can refine this interpolation by adding more data. One more strike line can serve the purpose.

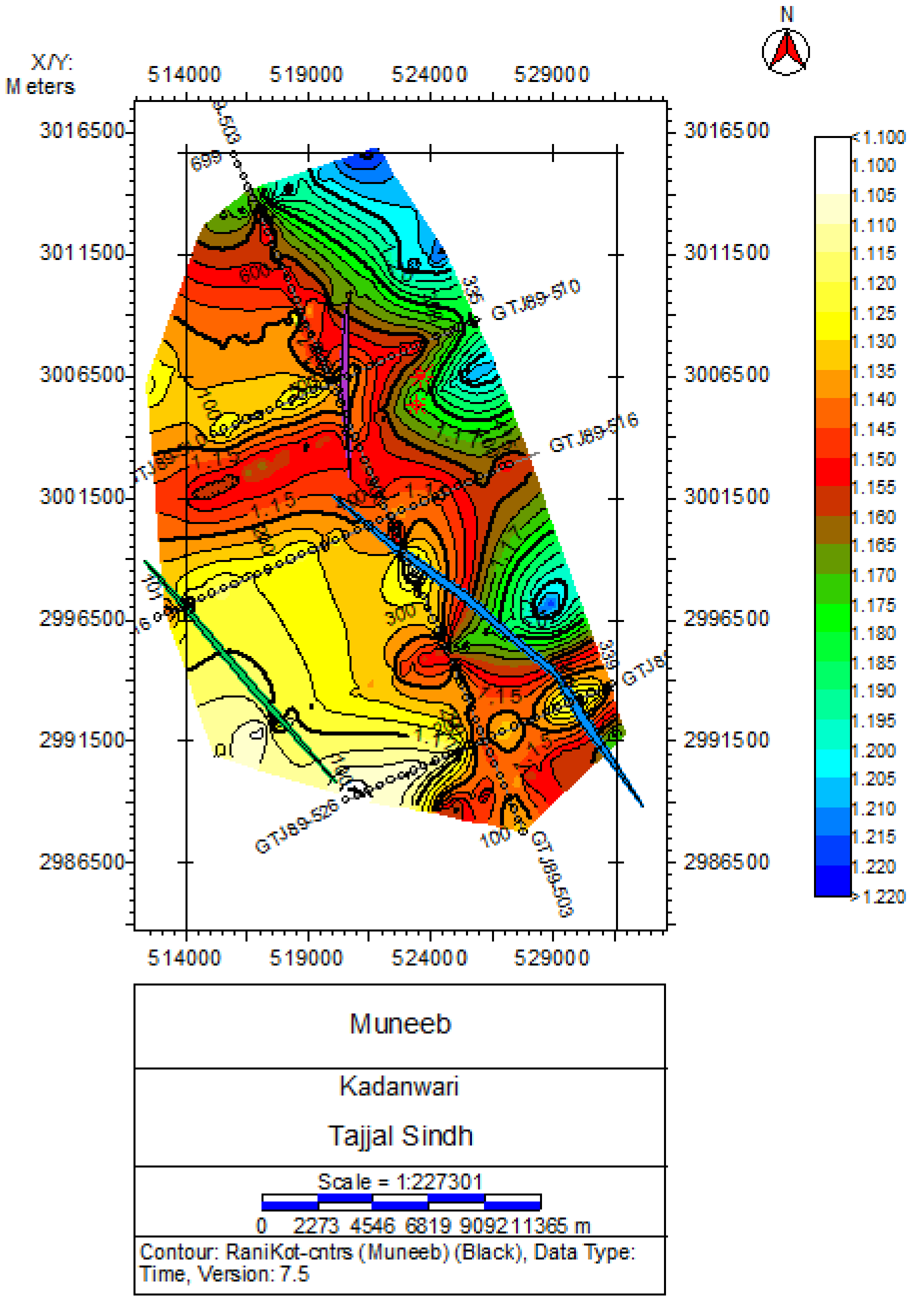


Fig 4.12 Time Structure Map of RaniKot (Time in Sec)

Time Structure Map Lower Goru:

Lower goru is our reservoir rock in the region. Time structure map of lower goru is shown below that shows low values zone around the three wells i.e. Kadanwari-01, 10 and 11. That means that the possible lead exist in that region. There are few faults at Lower goru which tell us that our structure is fault bounded, combination structure.

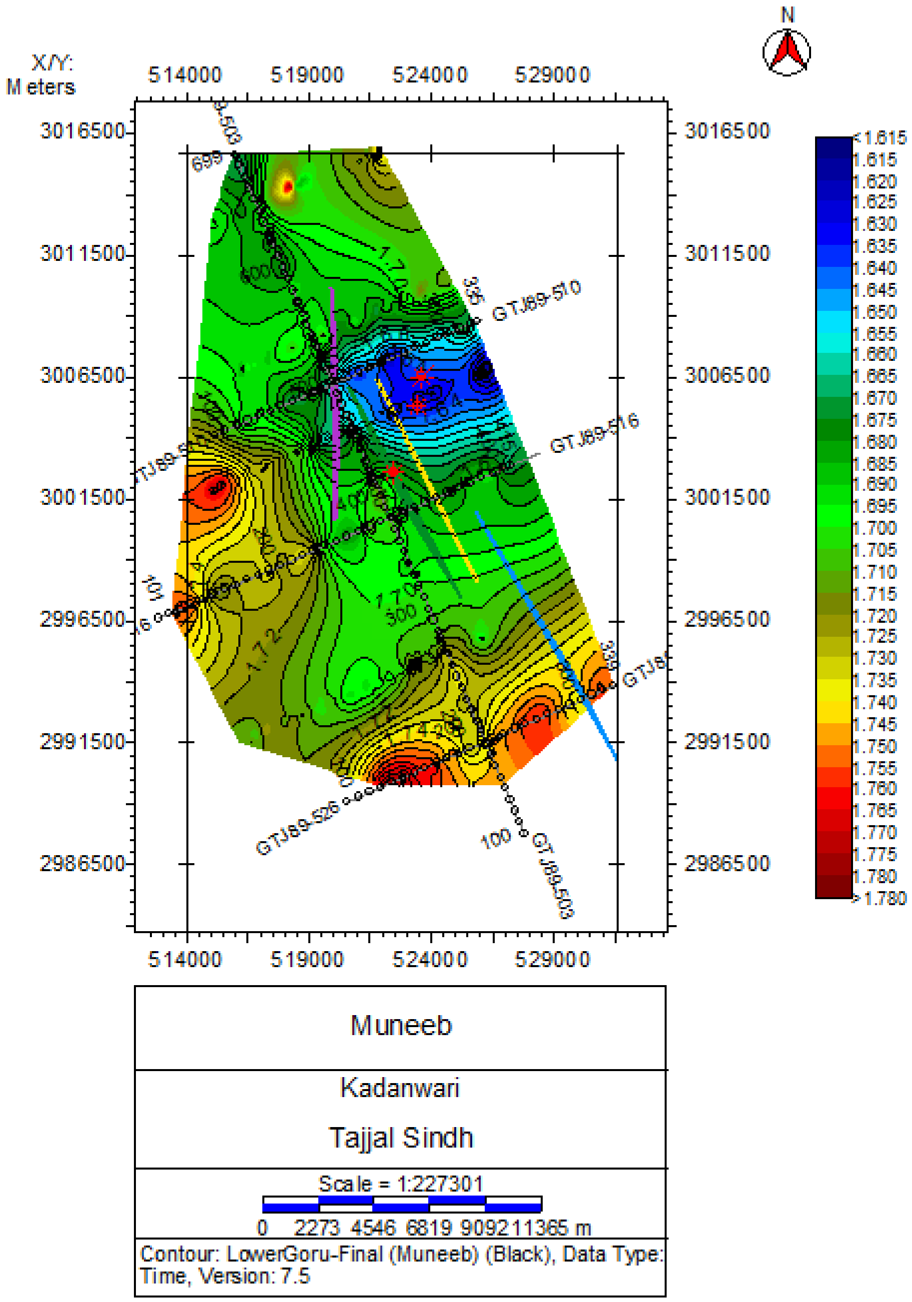


Fig 4.13 Time Structure Map of Lower Goru (Time in Sec)

Depth Variation of Sui Main Limestone (SML):

Map shows the distribution of SML depth values along the seismic lines. This map shows that the depth of SML Varies from 2300 to 2501 meters. The color ramp showing the depth variation that is represented along the line.

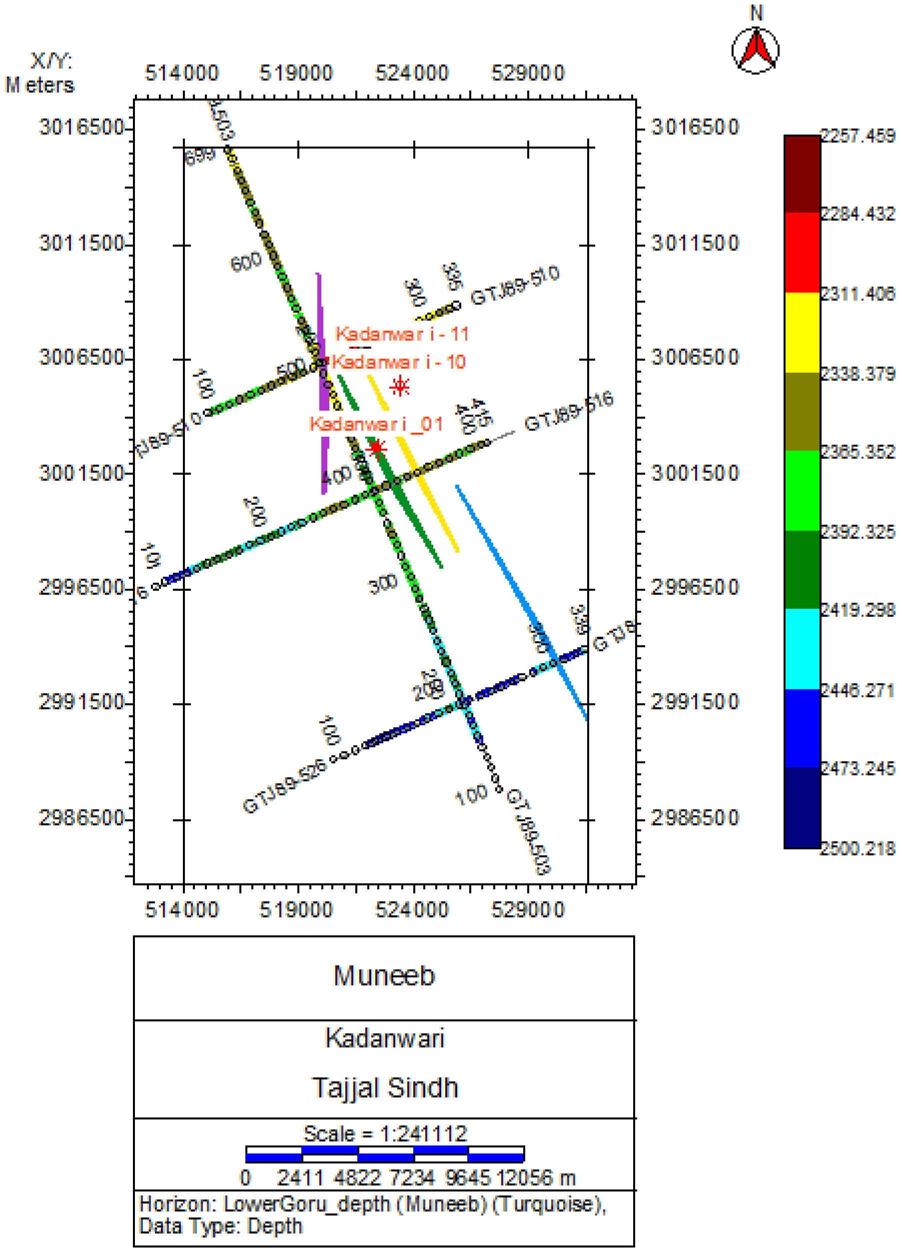


Fig 4.14 Depth Variation of SML (Depth in meter)

Depth Variation of Ranikot:

This map shows the depth variation of Ranikot formation in Kadanwari block. This map shows that the depth of Ranikot Varies from 1350 to 1530 meters.

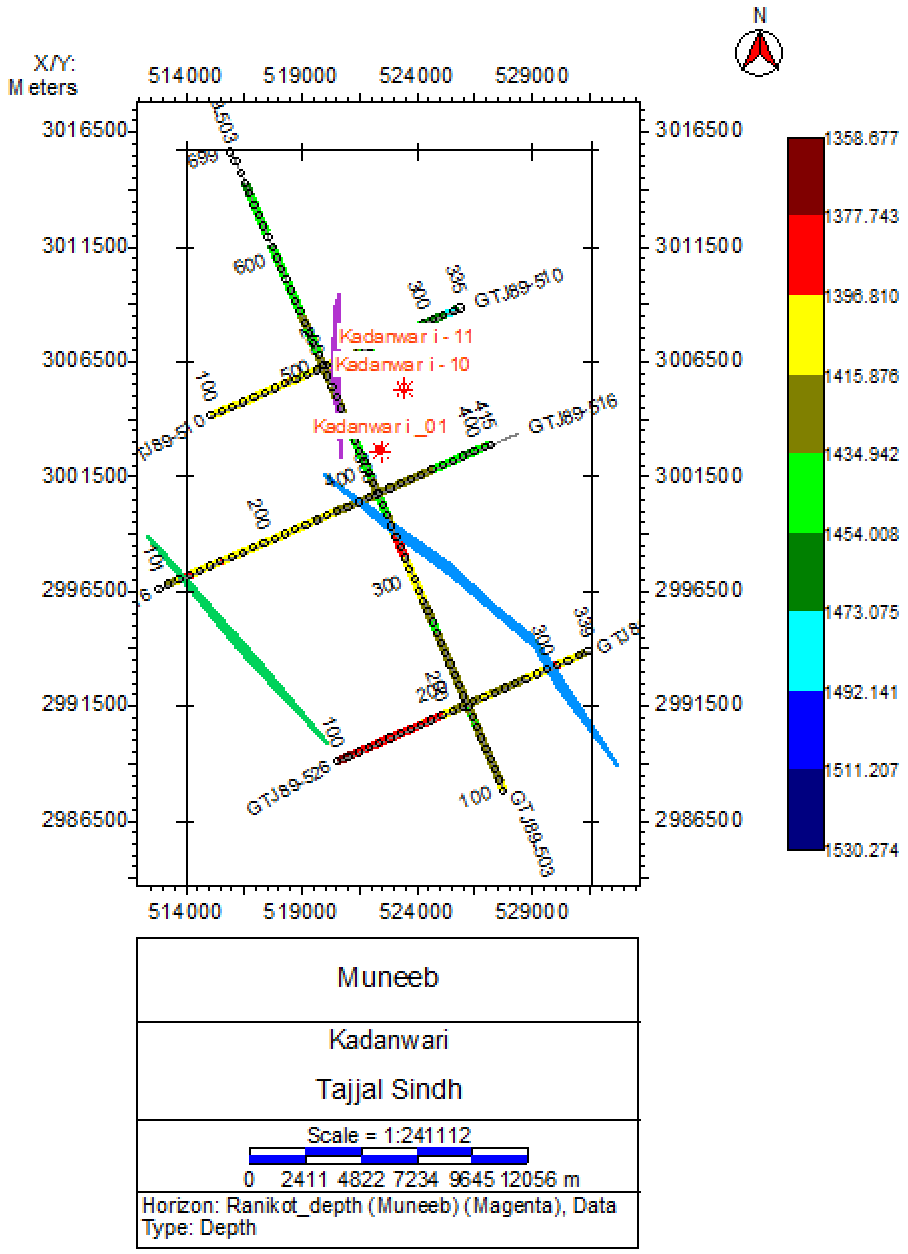


Fig 4.15 Depth Variation of RaniKot (Depth in meter)

Depth Variation of Lower Goru:

The map shows the depth variation of Lower Goru formation. The depth varies from green to blue colors along the line that means that lower goru has a depth ranges from 2300 to 2500. This also shows that the formation is shallower in North and is deeper in the south.

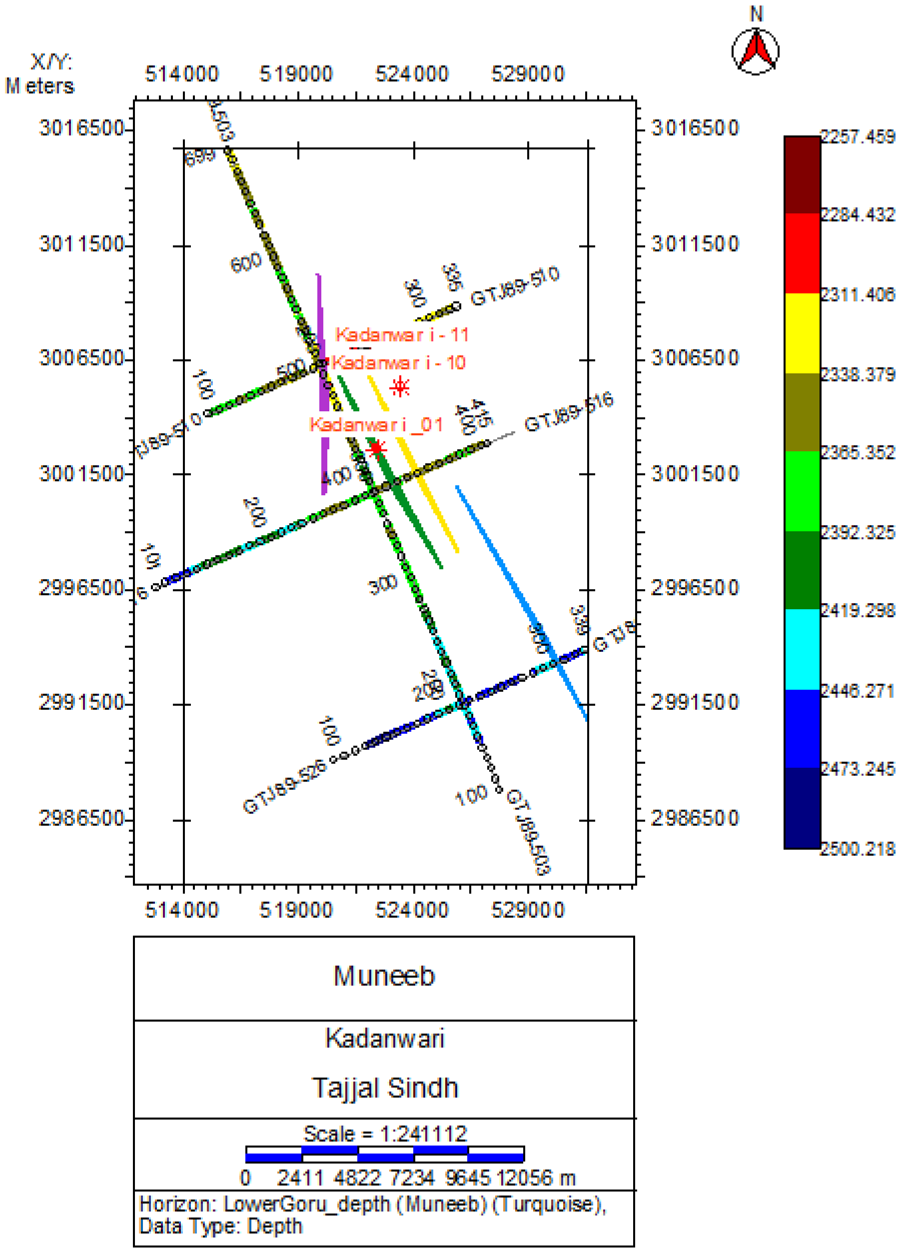


Fig 4.16 Depth Variation of Lower Goru (Depth in meter)

Depth Structure map of Sui Main Limestone (SML):

The map shown below is the depth structure map of SML. Like the time structure map SML depth structure map has no closed contours thus showing that there is no structure at the SML level.

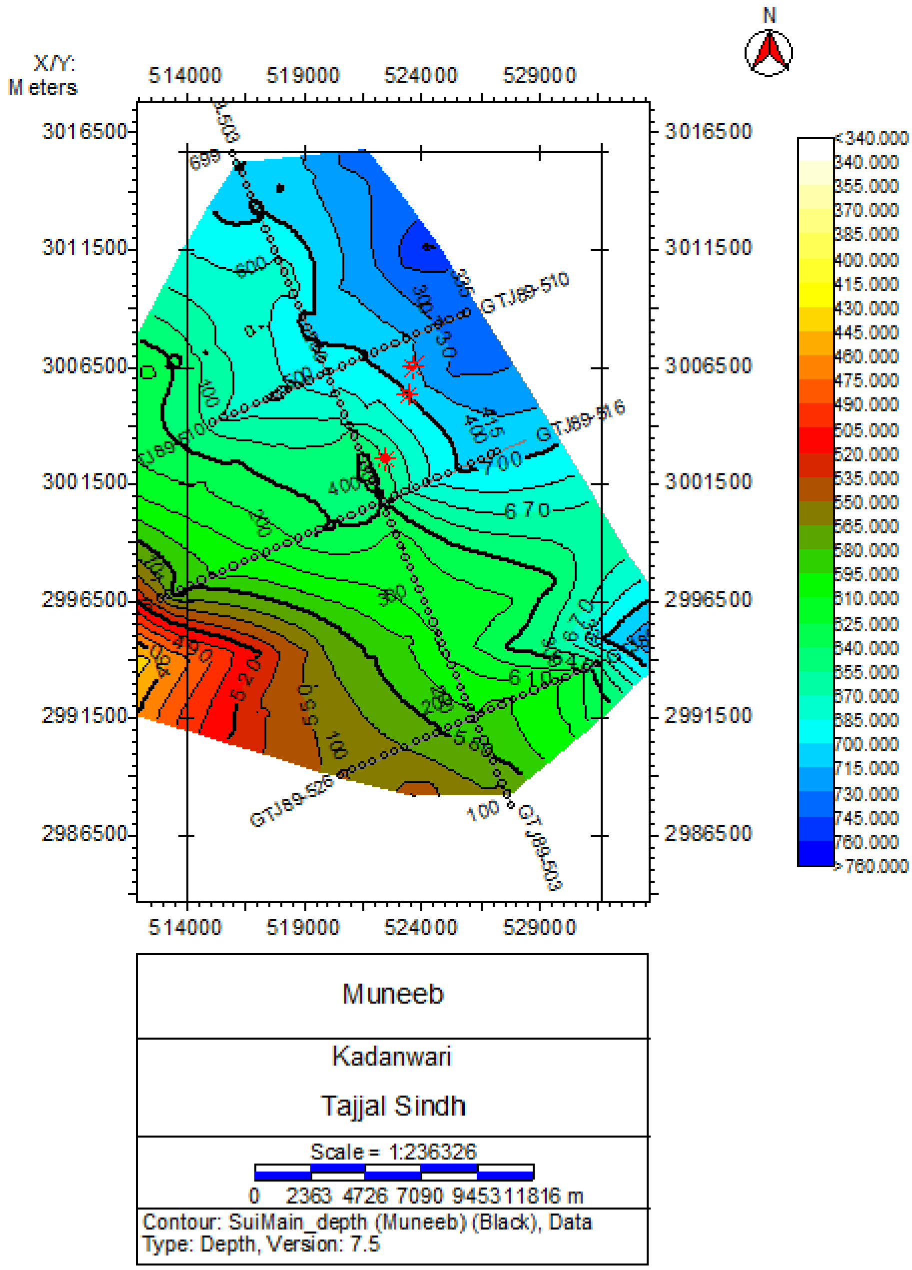


Fig 4.17 Depth Structure map of SML (Depth in meter)

Depth Structure map of Ranikot:

Depth structure map of Ranikot formation shows that the there is a probable lead near line GTJ89-510. This lead can be further confirmed by adding few seismic lines.

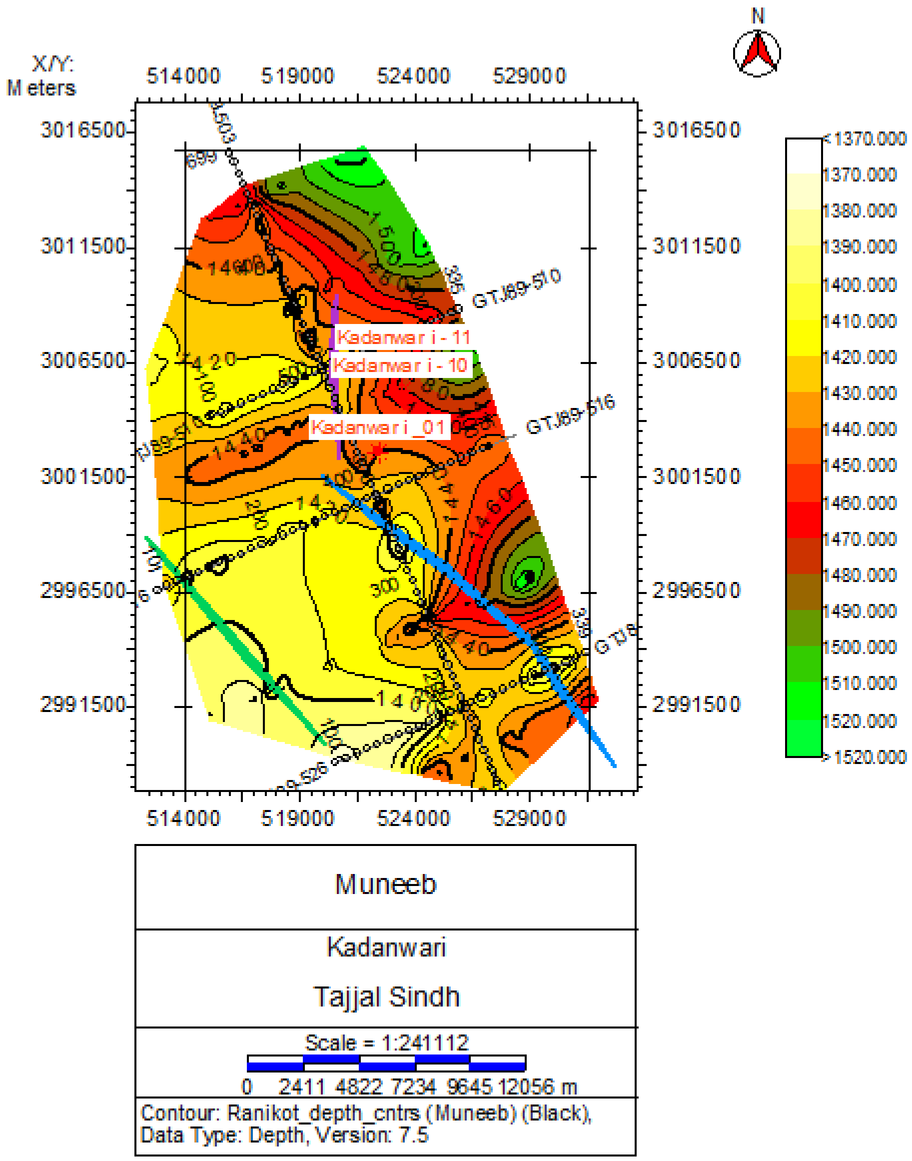


Fig 4.18 Depth Structure map of RaniKot (Depth in meter)

Depth Structure map of Lower Goru:

The map shown below represent the depth structure mapping of the reservoir formation i.e. Lower Goru. This map also shows the structure near the three wells. Color range along the lead is also yellow showing the peak of the anticline. Petrophysical analysis can be used for the conformation of production in this region.

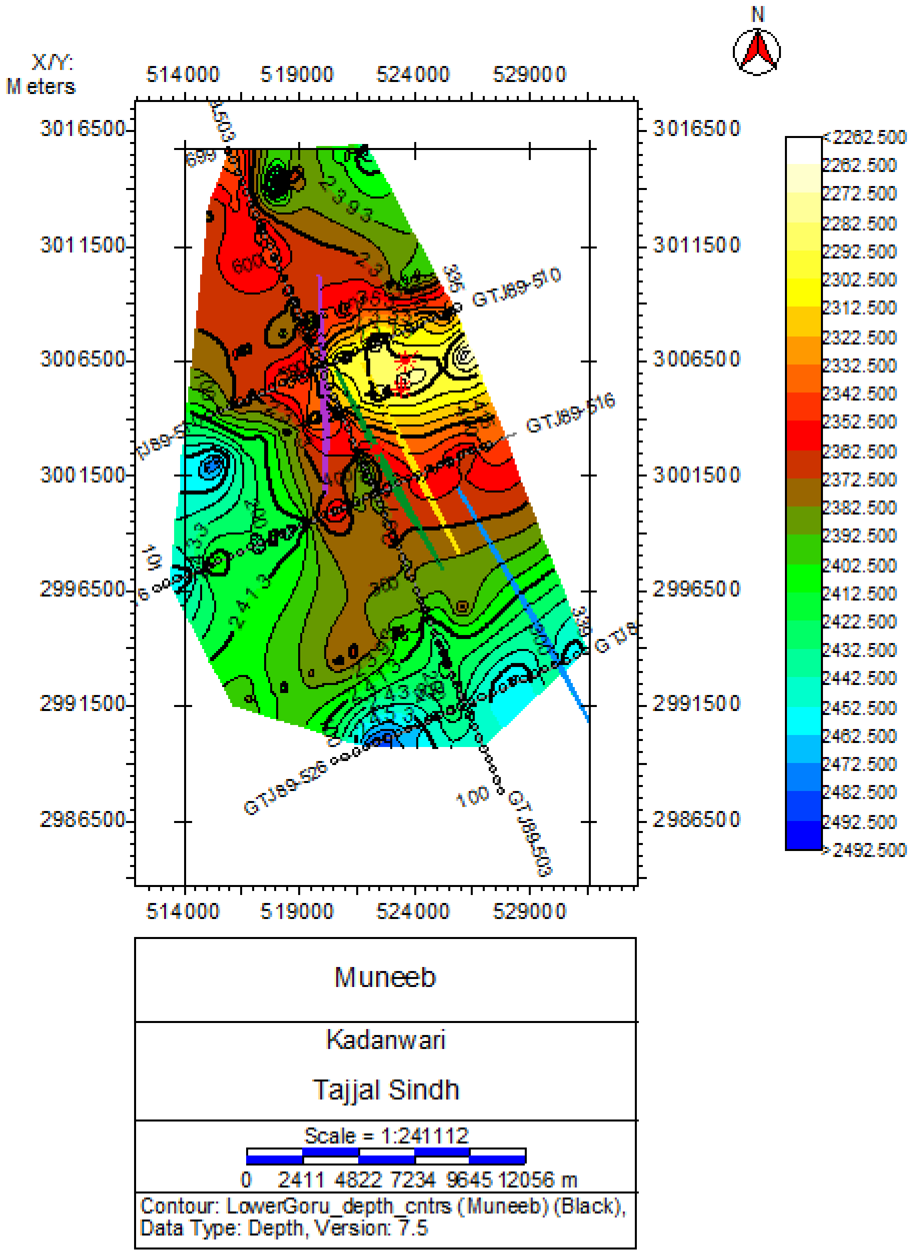


Fig. 4.19 Depth Structure map of Lower Goru (Depth in meter)

CHAPTER 5 SEISMIC ATTRIBUTES

5.1 SEISMIC ATTRIBUTES

A seismic attribute is any quantity derived from seismic data using measured time, amplitude, frequency, attenuation or any combination of these. It intends to output a subset of the data that quantifies rock and fluid properties and/or allows the recognition of geologic patterns and features. Almost all seismic attributes are post-stack but there are few pre-stack ones. They can be measured along a single seismic trace or throughout various seismic trace. The first attributes developed were related to the 1D complex seismic trace and included envelope amplitude, instantaneous phase, instantaneous frequency, and apparent polarity. Acoustic impedance obtained from seismic inversion can also be considered an attribute and was among the first developed. In this research attribute analysis for major reservoir in the area i.e. Lower Goru Formation has been calculated.

5.2 CLASSIFICATION OF SEISMIC ATTRIBUTES

The Seismic Attributes are classified basically into two categories.

i. Physical Attributes.
ii. Geometric attributes.

5.2.1 PHYSICAL ATTRIBUTES

Physical attributes are defined as those attributes which are directly related to the wave propagation, lithology and other parameters. These physical attributes can be further classified as pre-stack and post-stack attributes. Each of these has sub-classes as instantaneous and wavelet attributes. Instantaneous attributes are computed sample by sample and indicate continuous change of attributes along the time and space axis. The Wavelet attributes, on the other hand represent characteristics of wavelet and their amplitude spectrum. Post stack attributes are derived from the stacked data.

5.2.2 GEOMETRICAL ATTRIBUTES

The Geometrical attributes are dip, azimuth and discontinuity. The Dip attribute or amplitude of the data corresponds to the dip of the seismic events. Dip is useful in that it makes faults more discernible. The amplitude of the data on the Azimuth attribute corresponds to the azimuth of the maximum dip direction of the seismic feature.

5.3 ATTRIBUTES ANALYSIS

Following attributes were applied to line TJ89-520 and the results are interpreted.

5.3.1 Dip Variance

Dip variance attribute is designed to mark discontinuity in seismic data. So it is placed in the category of discontinuity attributes. Basically it uses statistical variance (squared differences) of “adjacent” seismic amplitudes. The following are the advantages of discontinuity attributes (Brouwer and Huck, 2011).

i. Automated fault delineation .
ii. Assistance in manual fault picking.
iii. Auto tracking of seismic horizons in time slices without fault picks

In line TJ89-516 dip variance attribute is applied and shown in Figure 5.1, white portion clearly delineate the faults and their direction and shows that faults and horizons are picked correctly.

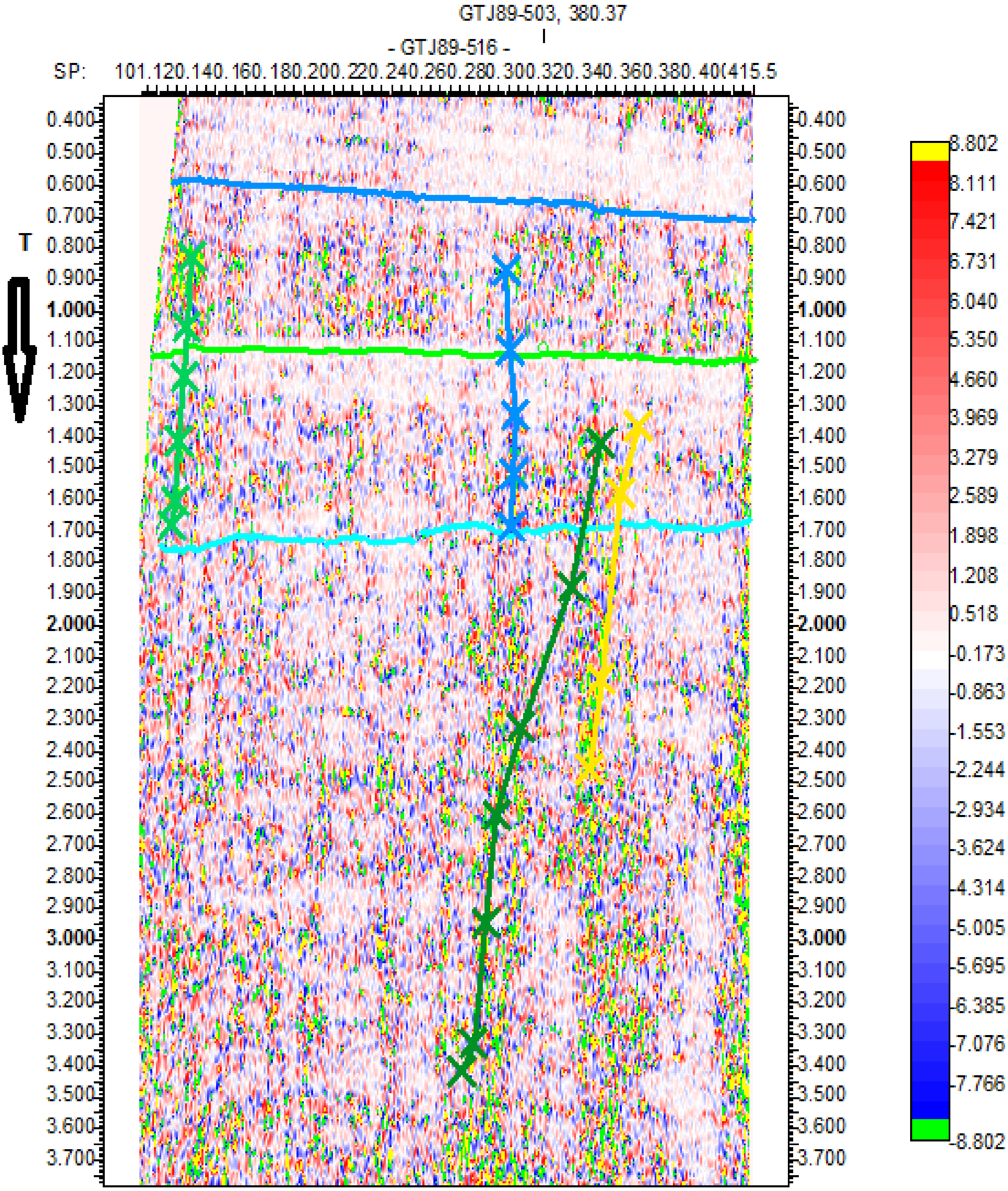


Fig. 5.1 Dip variance attributes applied to TJ89-516 (Time in Sec)

5.3.2 Instantaneous Frequency

Instantaneous Frequency (Hz) is the rate of change of phase over time (Sheriff, 1999).

$$\mathbf{Freq(x,t)}=\partial \arctan[g(x,t)*f(x,t)]\partial(t)=[f(x,t).dgdt-g(x,t).df\ dt][f2(x,t)+g2(x,t)]$$

Since the phase function is multi-valued with jumps, the instantaneous frequency is actually computed as the derivative of the arctangent function, which avoids the discontinuities. Instantaneous frequencies relate the wave propagation and depositional environment, hence they are physical attributes and they can be used as effective discriminators, (Subhramanyam, D. and Rao, P.H. 2008)

i. Instantaneous frequency can indicate bed thickness and also lithology parameters.
ii. Indicates the edges of low impedance thin beds.
iii. Hydrocarbon indicator by low frequency anomaly. This effect is sometimes accentuated by the unconsolidated sands due to the oil content of the pores.
iv. Fracture zone indicator, appear as lower frequency zones.
v. Bed thickness indicator.
vi. Higher frequencies indicate sharp interfaces or thin shale bedding, lower frequencies indicate sand rich bedding.
vii. The limit of lateral pinch-out of reservoir can be precisely mapped from changes in pattern of instantaneous frequency. Instantaneous frequency values show increase as the bed thickness reduces and continues to remain high even as the bed thickness falls below the quarter wavelength limit. This is termed ‘ *frequency tuning’.*
viii. Association of low frequency shadows observed sometimes with hydrocarbon reservoirs is believed to be due to high frequency loss linked to absorption. *‘Sweet spot’* analysis softwares developed on this principle are often used by interpreters to predict presence of hydrocarbon promoting the prospect for drilling. Evidence of frequency lowering laterally in a section, on the other hand, can be linked to change in facies and rapid variations suggesting deposition in fluvio-deltaic environment.

In Figure 5.2 high Instantaneous frequency shows a complete continuity in entire reservoir with breakage at some point, showing low frequency, confirms the faults which clearly prove that reflectors and faults has been marked are correctly.

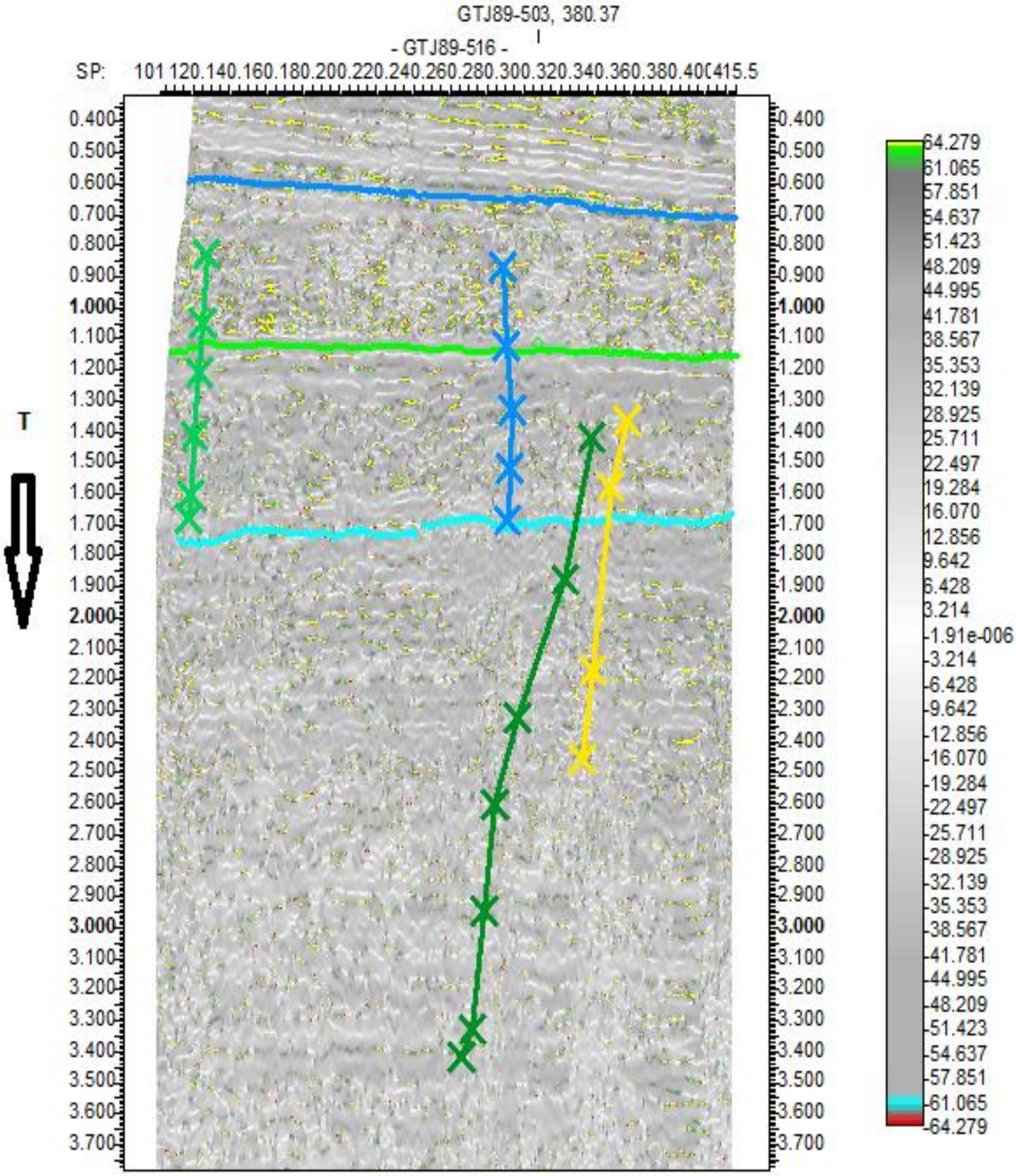


Fig. 5.2 Instantaneous frequency attribute applied on TJ89-516 (Time in Sec)

5.3.3 Envelope of Trace

The Hilbert Transform of the seismic trace generates an imaginary trace and using both these traces the envelope trace is computed. The envelope of seismic trace has a low frequency appearance and have only positive amplitudes. It can highlight main seismic features on the section. Actually this envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient (Subrahmanyam & Rao, 2008).

This attribute represent mainly the acoustic impedance contrast, hence reflectivity. It always remains positive whether the reflection coefficient is positive or negative. Figure 5.3 clearly shows reflection strengths of marked seal and reservoir horizon on TJ89-516. This attribute is mainly useful in identifying;

i. Bright spots
ii. Gas accumulation
iii. Sequence boundaries, major changes or depositional environments
iv. Major changes of lithology.
v. Local horizontal changes indicating faulting.

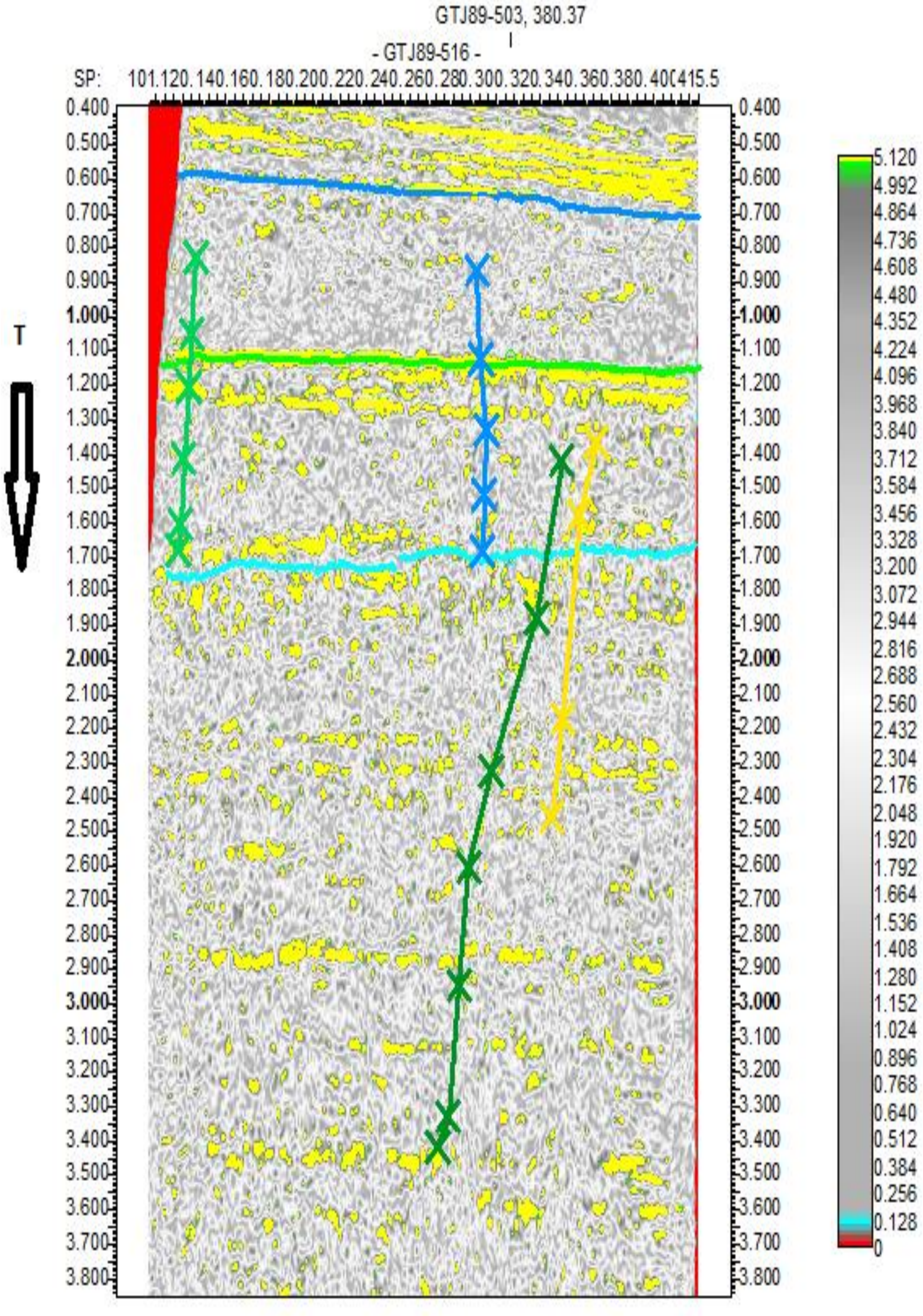


Fig. 5.3 Trace Envelop attributes applied on TJ89-516 (Time in Sec)

CHAPTER 6

ROCK-PHYSICS & PETROPHYSICS

6.1 Rock Physics

Rock Physics describes a reservoir by physical properties such as porosity, rigidity, compressibility properties that will affect 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, and to predict geology from elastic (seismic) observations.

Quantitative Seismic Interpretation shows how rock physics can be functional to predict different parameters of reservoir, such as pore fluids and lithologies, from seismically resulting attributes. It demonstrates how the multidisciplinary combination of rock physics models with seismic data, sediment-logical information and stochastic techniques can lead to more powerful results than can be obtained from a single technique. This provides an integrated methodology and practical tools for quantitative interpretation, characterization of reservoirs in the subsurface and assessment of uncertainty, using seismic and well-log data. The aim, in preparing Quantitative Seismic Interpretation, is to aid illustrate the potent role that rock physics can play in integrating both the data and expertise of geology and geophysics for characterization of reservoir. The Quantitative Seismic Interpretation includes the use of any seismic attribute for which there are specific models and relates them to different rock properties. This technique introduces primary rock physics relations, which help to quantify the fluid properties and geophysical signatures of rock. Since rock properties are outcome of geologic processes, I begin to quantify the seismic signatures of various geologic trends.

Instead of using a regional averaged velocity function which only shows a vertical mean trend of the velocity with depth velocity of DT log was used. The RMS and average velocities are not the true representative of a particular subsurface layer as they provide a vertically summed effect of all overlying layers rock properties.

6.1.1 ROCK PHYSICS ANALYSIS OF LOWER GORU FORMATION

By using wire line log data of Kadanwari-01, rock physics properties of Lower Goru formation were calculated. These properties were calculated from 1600m to 3600m depth. The rock Physics properties of Lower Goru are given below:

6.1.2 P-Wave Velocity and S-wave Velocity:

Sonic travel time of compressional wave is generally used as porosity tool for given lithology. VP-VS relations are keys to the determination of lithology from Seismic and Sonic log data as well as for direct seismic identification of pore fluids using e.g. AVO analysis with passage of time as the waves go deeper, its values are decreasing. Introducing shear wave travel time is very helpful in determining mechanical rock properties. It is found that compressional wave is sensitive to the saturating fluid type.

Fig. 6.1 shows the plot between P wave and S wave velocity vs. depth for the reservoir of the locale i.e. Lower Goru.

Lower values of P-wave and S-wave velocities show the shaly material or fluid substitution and higher values consolidated material. Seismic velocity increases with depth due to compaction of rocks, because of overburden pressure of rocks. S-wave velocity is best indicator of fluids, as these waves can't pass through fluids.
Mathematical formula for the calculation of S-wave is given below:-

$$\mathrm{Vs} = (\mathrm{Vp} - 1.36)/1.16$$ (Castagna et al., 1995)

6.1.3 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. When pressure is applied to a specimen its volume decreases but shape and mass remain unchanged, however the density of the specimen increases (Robinson, E.S, and Coruch, C.,1988).

Fig. 6.1 shows the graph plot for reservoir rock between depth and Bulk Modulus. Lower values show the shaly material or fluid substitution and higher values implies consolidated material.

$$K = -\Delta P / (\Delta V/V)$$

6.1.4 Young's Modulus:

Young's modulus (E) is a measure of the stiffness of an isotropic elastic material. It is defined as 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.

$$E=(FL_0)/(A_O*del.\ L)$$

where

E is the Young's modulus (modulus of elasticity)

F is the force exerted on an object under tension;

A_0 is the actual cross-sectional area through which the force is applied;

ΔL is the amount by which the length of the object changes;

L_0 is the original length of the object.

Fig. 6.1 shows the graph plot between Young's Modulus and depth for Lower Goru. From the graph pot it can be concluded that the lower values show the shaly material or fluid substitution and higher values consolidated material.

6.1.5 Shear Modulus

Shear modulus or modulus of rigidity (μ,S), is defined as the ratio of shear stress to the shear strain (angle of deformation).

$$\mu = \rho * Vs$$

Where μ = Shear modulus
ρ= Density
Vs= S-wave velocity

Fig. 6.1 shows the graph plot between Shear Modulus and depth for Lower Goru. Lower values show the shaly material and higher values stiffer material. Shear Modulus is good indicator of fluid presence, because fluids have zero value of Shear Modulus.

6.1.6 Poisson's Ratio:

Poisson's ratio (σ) is the ratio of transverse strain (normal to the applied load) to longitudinal strain (in the direction of the applied load). When a sample of material is stretched in one direction, it tends to contract (or rarely, expand) in the other two directions. Conversely, when a sample of material is compressed in one direction, it tends to expand (or rarely, contract) in the other two directions.

$$\sigma = \frac{0.5(Vp^2 - 2Vs^2)}{Vp^2 - Vs^2}$$

The graph between depth and Poisson's ratio is shown in Fig. 6.1. Higher values of Poisson's ratio indicate the presence of fluid or non-consolidated material, where as the lower values of the parameter shows the presence of the consolidated material or stiffer lithology.

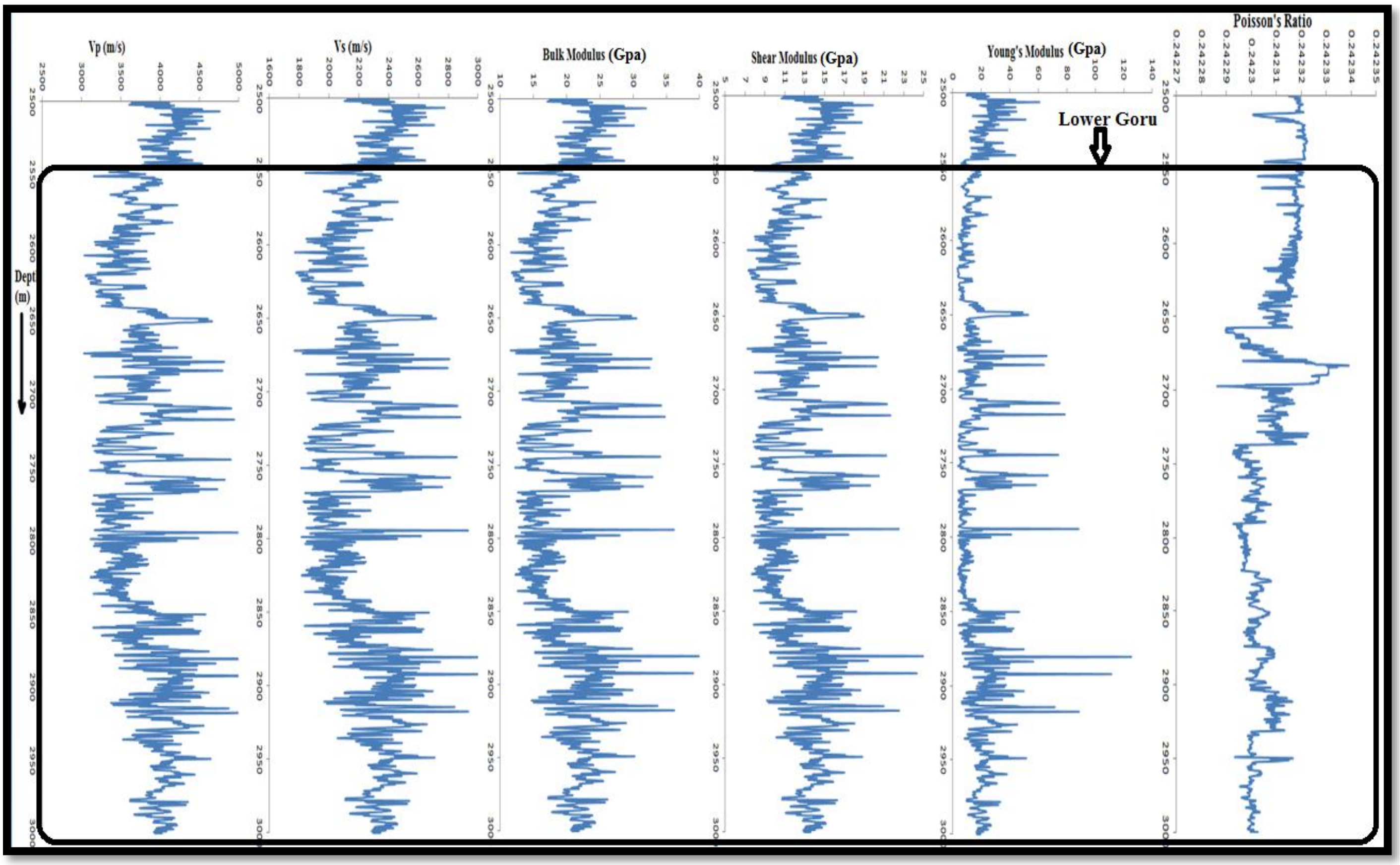


Fig.6.1 Graph plot of Depth vs. Rock Physics Properties.

6.2 Petro Physics:

Petrophysics is the study of physical and chemical properties which defines the occurrence and behavior of rocks and the containing hydrocarbons (oil and gas). Petrophysical interpretation is the process which leads to combining the knowledge of tool response with geology, to provide a complete picture of the changes of important petrophysical properties with depth. (ellis and singer, 2007).

During petrophysical interpretation different logs were used.

Caliper log , gamma ray (gr), neutron log (nphi), density (RHOB), resistivity logs (lls, lld, and msfl), core data and production data leads to petrophysical properties estimateion.each log has its own importance and contributes in quantifying the important reservoir parameter. Gamma ray is particularly use for for defining shale beds. When the sp is distorted or when the sp is featureless. The gamma ray log reflects the proportion of shale and in many regions and it can be used quantitatively as a shale indicator. It is also used for the detection and evaluation of radioactive minerals such as potash or uranium ore. During the log analysis of wells , the gamma ray log is used for the interpretation of shale volume.(rider, 2002)

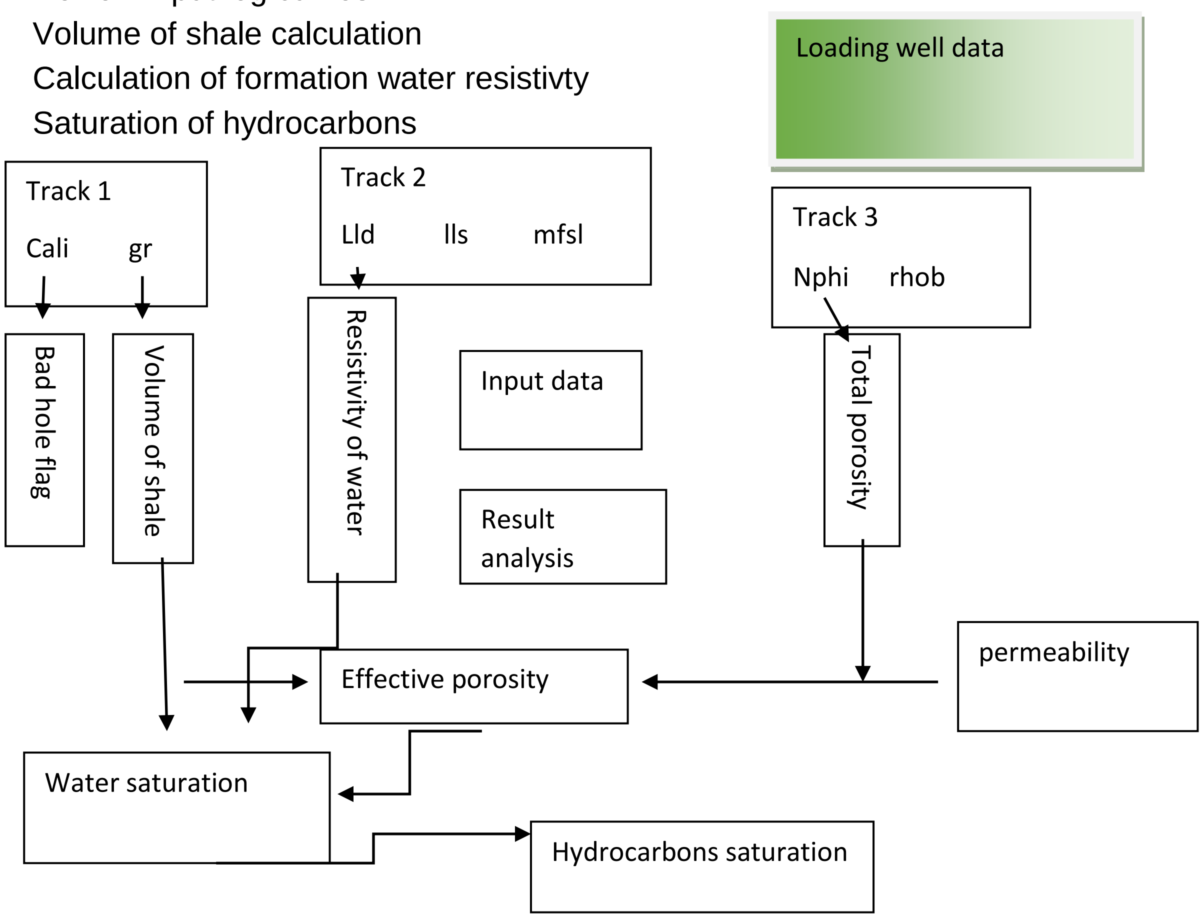
All the measurements and bore hole signatures have their own significance, but the traditional role of well logs has been limited to participation in evaluation of formation which is summerised as:

- Identification of reservoir and their nature (oil and gas)
- Delineation of pay zone in reservoir strata
- Quantification of hydrocarbon contained in the formation
- Estimation of recoverable hydrocarbons

6.2.1 Work flow for petrophysical analysis:

For petrophysics analysis a step by step work flow is followed to achieve the target for calculating petrophysical properties is described In fig. the log signature I,e caliper log, gamma ray (gr), neutron (nphi), density (rhob), letro log deep (lld), letrolog shallow (lls) and micro- spherically focused log (mfsl).the steps are

- Marking the zone of interest
- Review input log curves
- Volume of shale calculation
- Calculation of formation water resistivty
- Saturation of hydrocarbons



6.2.3 Petrophysical Analysis of Kadanwari-01 Well:

In the project we have been provide with three wells but we selected the Kadanwari-01 due to its complete data. Secondly that was the key well that was used for well to seismic tie.

In the Petrophysical analysis we have used Archie's Interpretation to calculate the following.

- Effective Porosity.
- Volume of Shale.
- True Resistivity.
- Water Saturation.
- Bulk Volume of Rock
- Hydro-Carbon Saturation.

The values are then put into template and we have got hydrocarbon shows in the Lower Formation.

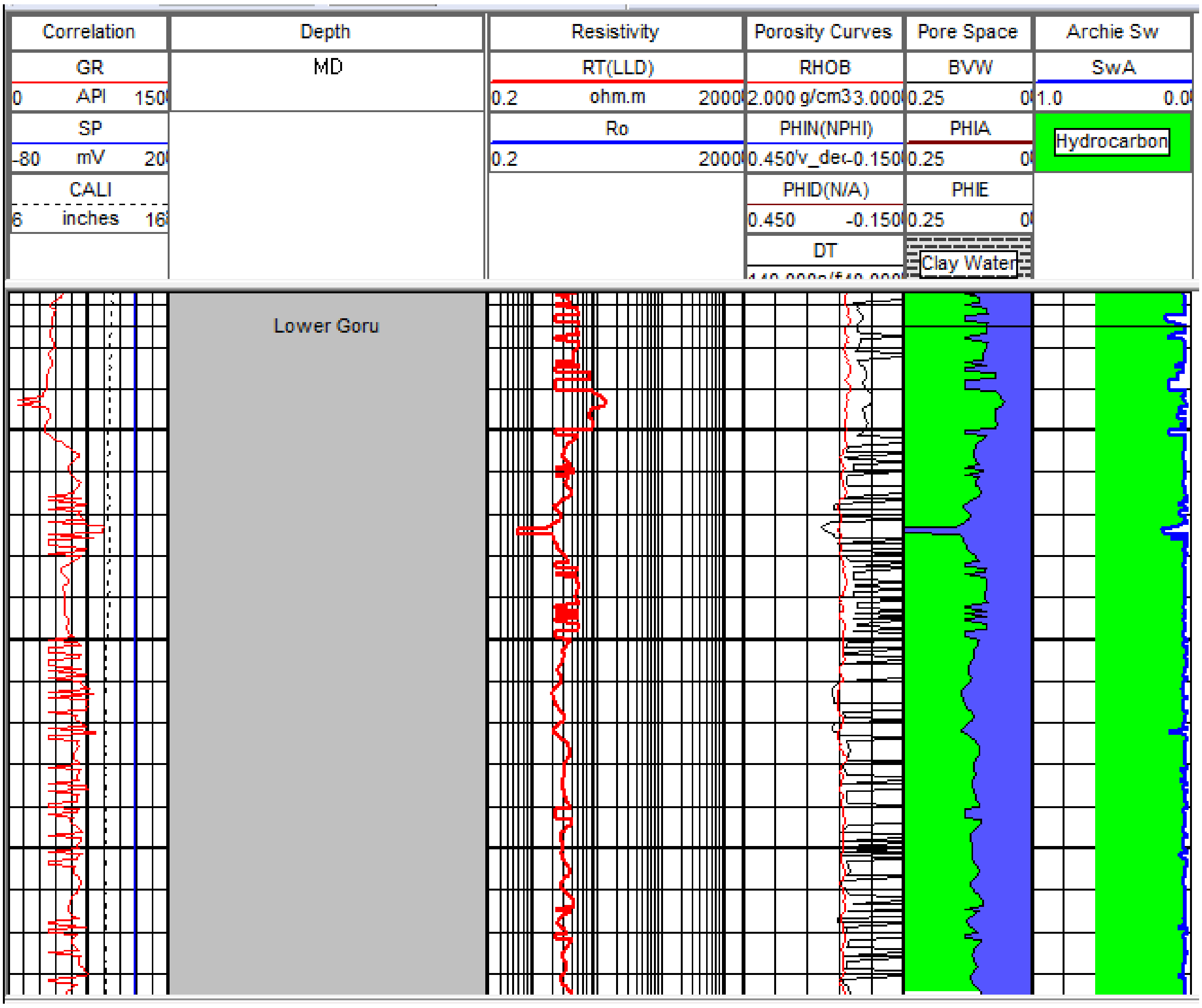


Fig 6.2 Petrophysical analysis of Lower Goru

6.2.4 Regional Cross-section of Wells:

We have been provided with the three wells i.e. Kadanwari-01, 10 and Kadanwari-11. Formations data has been gathered for these wells and using those formation the cross-section of all the three wells has been constructed. This cross-section is drawn from Kadanwari-01 to 11. It shows the thickness of formation tops in between wells and also shows the trend and dip of each formation.

CONCLUSION

From our interpretation it is concluded that there is a complex structural deformation in the older strata and many different fault systems. From 2D Seismic Interpretation of GTJ89-503, GTJ89-510, GTJ89-516 and GTJ89-526 it is concluded that the subsurface structures are related to normal faults in the east and west with small throw The presence of the Normal faults indicate the presence of extensional forces. The younger strata seems to have been affected by slight reactivation of an older fault. The fault bounding the basin is regarded as normal in form represent extension and accompanied with rotation of the basement block. The cap rocks are present for all potential reservoirs such as intra-formational shale for Lower Cretaceous reservoirs i.e. Lower Goru.

Calculation of Seismic attributes i.e. Dip variance, Instantaneous Frequency and Trace Envelop confirm interpretation. These attributes were applied to the line TJ89-516. In case of Trace envelop reflection strengths of marked seal and reservoir horizon can be easily seen in Fig. 5.3, where as In Figure 5.2 high Instantaneous frequency shows a complete continuity in entire reservoir with breakage at some point, showing low frequency, confirms the faults which clearly prove that reflectors and faults has been marked are correctly and in Figure 5.1, white portion clearly delineate the faults and their direction and shows that faults and horizons are picked correctly.

Models of elastic properties derived from the sonic velocity of well confirm that the Lower Goru formation is initially comprised of intervals of Sandstone and Shale along with fluid substitution as indicated by high and low values of Rock Physical parameters. Petrophysical analysis shows lower goru formation in some intervals is good reservoir.

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