Integrated Seismic Interpretation, Petrophysics Study, Seismic Attribute Analysis, Complex Velocity Model Building and AVA Synthetic Modeling to predict Hydrocarbon Potential of Sinjhoro, Pakistan.

By

Ahmed Rafeh

BS Geophysics

(2016-2020)

DEPARTMENT OF EARTH SCIENCES

QUAID-I-AZAM UNIVERSITY

ISLAMABAD

CERTIFICATE

This dissertation submitted by Ahmed Rafeh S/O Muhammad Riaz 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.

RECOMMENDED BY

Professor Dr. M. Gulraiz Akhter______________________

(Supervisor)

Associate Professor Dr. Aamir Ali____________________

(Chairman Department of Earth Sciences)

External Examiner____________________

بسم الله الرحمن الرحيم

To start with the greatest name of Almighty Allah. Most gracious and merciful, with Him is the knowledge of the Hour, He sends down the rain, and knows that which is in the wombs. No person knows what he will earn tomorrow, and no person knows in what land he will die. The knower of the unseen is Allah these are the keys of the unseen, whose knowledge Allah alone has kept for himself and no one else knows them unless Allah tells him about them.

DEDICATION

I would like to dedicate this thesis work to my sweet parents, whose love, encouragement, guidance and prays make me able to achieve such success and honor.

Acknowledgement

In the name of Allah Almighty, the most Gracious, the most Compassionate. Almighty, on whom ultimately we depend for sustenance and guidance. I bear witness that Hazrat Muhammad (SAWW) is the last messenger, whose life is role model for the whole mankind till the Day of Judgment. I thank Allah Almighty for giving me strength and skill to finalize this study.

I would like to manifest my appreciation to my Supervisor. I express my sincerest appreciation to Dr. Khalid Amin Khan for his guidance in the preparation of this thesis. He helped me in all aspects of work, also providing the softwares, which was very valuable for my work.

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

I acknowledge my friends who helped me in my work.

Ahmed Rafeh

November, 2020

ABSTRACT

The current study involves integrated seismic interpretation, rock physics and seismic attributes analysis of Sinjhoro area, with special emphasis on velocity processing and model building. The study area lies in the Southern Indus basin which is known for its huge hydrocarbon reserves.

The integrated study involves; structural interpretation of seismic data seismic along with attributes analysis, time to depth conversion and generation of depth sections, synthetic seismograms, 1D Rock physics analysis including AVA modelling

Horst and graben structures have been identified on the time sections which are more prominent on the depth sections created by using the velocity model. Seismic Velocity Model has been generated using spatio-temporal and horizon based interpolation algorithms. The results indicate that horizon based interpolation generates the best velocity model and therefore it is used in time to depth conversion and other analysis. Moreover, for the confirmation of the marked horizons and their behavior, seismic attribute analysis have been carried out which helps in understanding the lateral continuity, bedding sequences and thickness of desired beds. AVA Synthetic Modeling confirms the presence of Gas in the area.

Table of Contents

Chapter 1

Introduction

1.1 Introduction

Hydrocarbons are most crucial energy source in the world and are essential in the modern world. They are utilized as fuels, lubricants, electrical power generation, heating, and as raw materials to make plastics, fibers, rubbers, solvents, explosives, and industrial chemicals. For the exploration of hydrocarbons, different geophysical techniques are used. Seismic method is one of the most widely used geophysical methods for exploration of hydrocarbons.

1.1.1 Seismic Method

A geophysical prospecting method based on the fact that the velocity of transmission of shock waves through the Earth vary with the elastic constants and the densities of the rocks through which the waves pass. (Kearey, 2002)

Seismic method includes:

- Seismic reflection method
- Seismic refraction method

Theory originally developed to help determine the Earth's deep layer structure (by reflection) is now employed widely in the near surface (by refraction) for a variety of purposes. These methods have been successfully used for several engineering applications, a few among them include locating petroleum reserves, determining water table depths for well water drilling, and developing soil stiffness profiles to aid in characterizing site response during seismic events.

1.1.2 Seismic Data Acquisition

Seismic data can be acquired in two ways i.e. 2D and 3D. Three-dimensional seismic survey has become a major tool in the exploration of hydrocarbons. The first few 3-D seismic surveys were acquired in the late 1970s, but it took until the early 1990s before they gained general acceptance throughout the industry. Until then the subsurface was being mapped using two-dimensional (2-D) seismic surveys. (Vermeer and Gijs, 2002)

1.1.3 Study Area

2D reflection survey was done in Sinjhoro Sindh Pakistan. The area is located at 25°30'-26°29' N, 68°25'-70°13' E. Sinjhoro area is present in Sanghar district of Sindh, Pakistan, about 12 km from Sanghar city, along Sanghar-Shahdad Pur Road. Sinjhoro is Headquarter of Taluka Municipal Administration Sinjhoro. The town is connected with Nawabshah through NWG railways network, but the system is now out of order. This railway line is called Raja Ji Gadi. Geographically the area falls in Lower Indus Basin. The Lower Indus Platform Basin is bounded to the north by the Central Indus Basin, to the Northwest by the Sulaiman Fold belt Basin and the Kirthar Fold Belt Basin in the southwest.

Figure 1.1: Study Area shown on Satellite Imagery of Pakistan.

1.2 SURVEY INFORMATION

It includes all the information about the lines, wells and base map of the study area.

1.2.1 SEISMIC REFLECTION DATA

The seismic reflection data of the study area was obtained by Directorate General of Petroleum Concession (DGPC) Pakistan in digital format. This data was acquired and processed by OGDCL. The seismic lines on which interpretation is carried out are listed in Table 1.1

Table 1.1: Seismic Lines used in the study.

S.NO.	LINE NO.	NATURE	LINE ORIENTATION
1	GO-017-SNJ-03	DIP	SW-NE
2	GO-017-SNJ-08	STRIKE	NW-SE
3	GO-017-SNJ-10	DIP	SW-NE
4	GO-017-SNJ-04	DIP	SW-NE

In addition to seismic data LAS file and formation tops of well is CHAK66-01 is used.

1.2.2 DATA FORMATS

Seismic reflection data which consist of

- SEG-Y
- LAS
- Navigation
- Velocity input from hard copies

1.3 BASE MAP OF THE STUDY AREA

The base map is important component of interpretation, as it shows the spatial position of each picket of seismic section. For a Geophysicist a Base map is that which shows the orientations of seismic lines and specify points at which seismic data were acquired or simply a map which consist of number of dip and strike lines on which seismic survey is being carried out . A base map typically includes location of lease and concession boundaries, wells, seismic survey points and other cultural data such as buildings and roads with geographic reference such as latitude and longitude.

1.3.1 SPATIAL LOCATION

The seismic lines with their orientation and well data used for the generation of Base map are tabulated below in table (1.2).

Table 1.2: Lines used for Contour and making Base Map.

LINE NAME	NATURE	LINE ORIENTATION	WELLS
GO-017-SNJ-01	STRIKE	NW-SE	Chak66-01
GO-017-SNJ-03	DIP	SW-NE	Chak7A-01
GO-017-SNJ-04	DIP	SW-NE	Chak-5DIM South-01
GO-017-SNJ-05	DIP	SW-NE	Chak63-01
GO-017-SNJ-08	STRIKE	NW-SE	
GO-017-SNJ-09	DIP	SW-NE	
GO-017-SNJ-10	DIP	SW-NE	
GO-017-SNJ-13	STRIKE	NW-SE	
GO-017-SNJ-19	DIP	SW-NE	
GO-017-SNJ-20	DIP	SW-NE	
GO-017-SNJ-21	DIP	SW-NE	
GO-017-SNJ-22	DIP	SW-NE	
GO-017-SNJ-23	DIP	SW-NE	

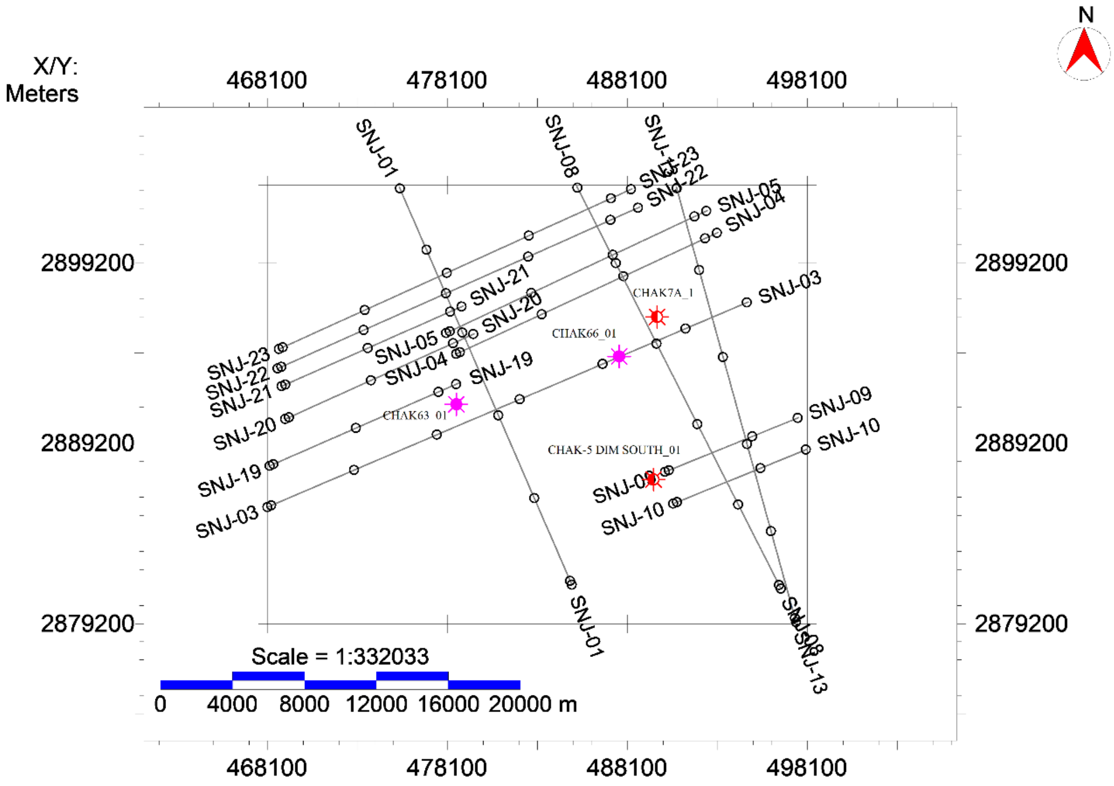


Figure 1.2: Base map.

1.4 PROCESSING SEQUENCE

After the data has been acquired, it passes through the whole processing sequence that includes different data processing techniques that are used to enhance the quality of the data. The raw seismic data is processed to enhance the signal to noise ratio and get the final seismic sections. The processing sequence flow chart is given below in (figure 1.3)

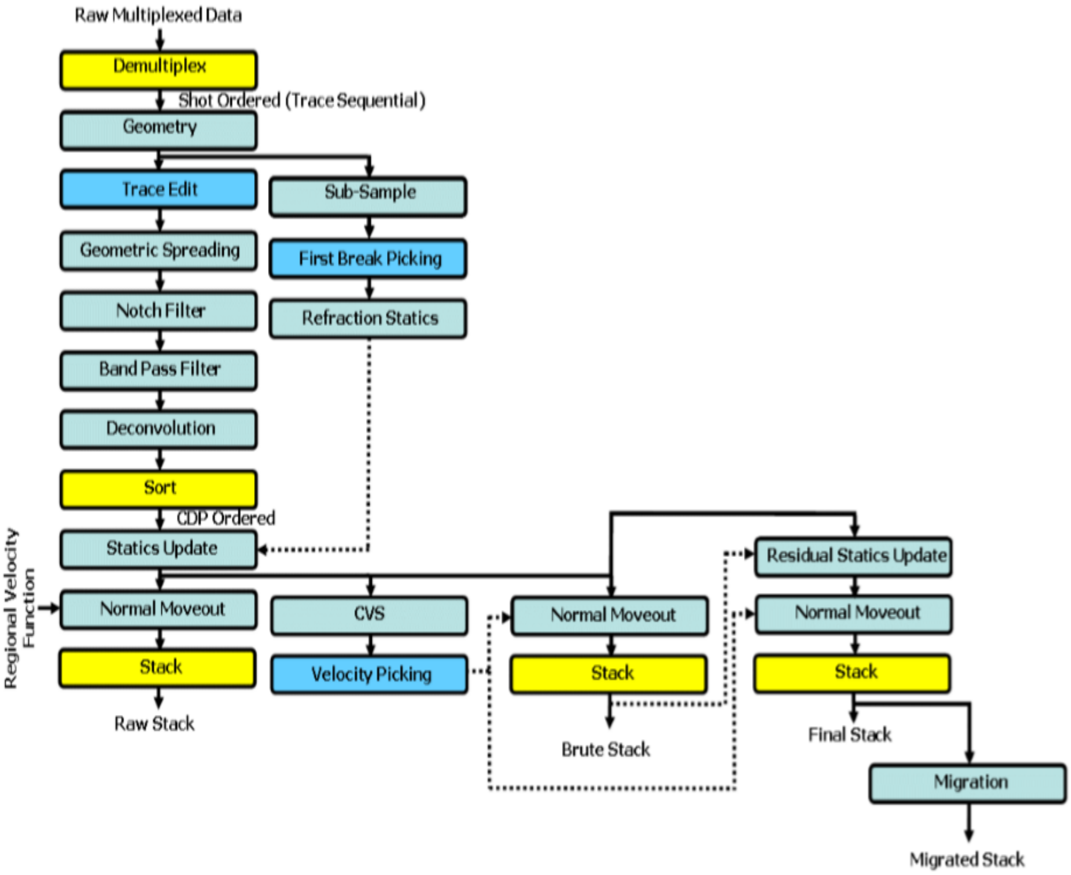


Figure 1.3: Seismic Data Processing flow chart (Khan, 2009)

Chapter 2

General Geology and Stratigraphy

2.1 Introduction

Geology is the study of solid Earth, the rocks it is composed of, and the processes going on inside the Earth. Geology provides the history of the Earth, like plate tectonics, the evolutionary history of life, and past climates. Now a day's geology is used for mineral and hydrocarbon exploration and for the prediction and understanding of natural hazards.

Our previous knowledge of the filed area, its geology and the velocity changes help us in precise interpretation of the lithology and other parameters. Velocity variation in the area can help us identify different reflectors. Geologic information also beneficial in fault picking and their extent.

2.2 Geology and tectonics

Pakistan is unique as much as it is located at the junction of these two diverse domains. The southern part of Pakistan belongs to Gondwanian Domain and is sustained by the Indo-Pakistan Crustal Plate. The northern most and western region of Pakistan fall in Tethyan Domain and present a complicated geology. Pakistan comprises of three main geological subdivisions referred to as Laurasian, Tethyan and Gondwanaland domains (Kazmi, et al., 1997). Late Paleozoic is their origin. All the continents had drifted apart to form a super continent known as Pangea. By late Triassic, Laurasia drifted to the north and Gondwanaland to the south separated by Tethys seaway resulting in the split up of Pangea. Pakistan is located at the junction of Gondwanian and Tethyan domain. As already mentioned, the study area is situated in the Southern Indus Bain of Pakistan. The area is mostly dominated by normal faults and horst and graben structures are common in contrast to the major thrust common in the northern part of Pakistan. The origin of theses crustal features has been recommended by numerous suggestions, but these basements up warps keep on confusing. The late Jurassic-Early Cretaceous rifting of Indian Plate controlled the structures and sedimentology of the Southern Indus Basin. Northeast-Southwest rift systems are possibly produced by Jurassic Early Cretaceous rifting. Parting of the Madagascar and Indian plates in the middle to Late Cretaceous may have caused strike-slip faulting, hotspot activity and thermal doming in the area. This separation in turn caused uplift, erosion, extrusion of the Deccan flood basalts and probably the NNW-striking normal faults. Eocene passive margin conditions caused carbonate deposition. Sinistral transpression with fold-thrust structures overprinted by sinistral flower structures in the west are produced during the Oligocene to present-day Himalayan collision.

Figure 2.1: Tectonic plates in the region.

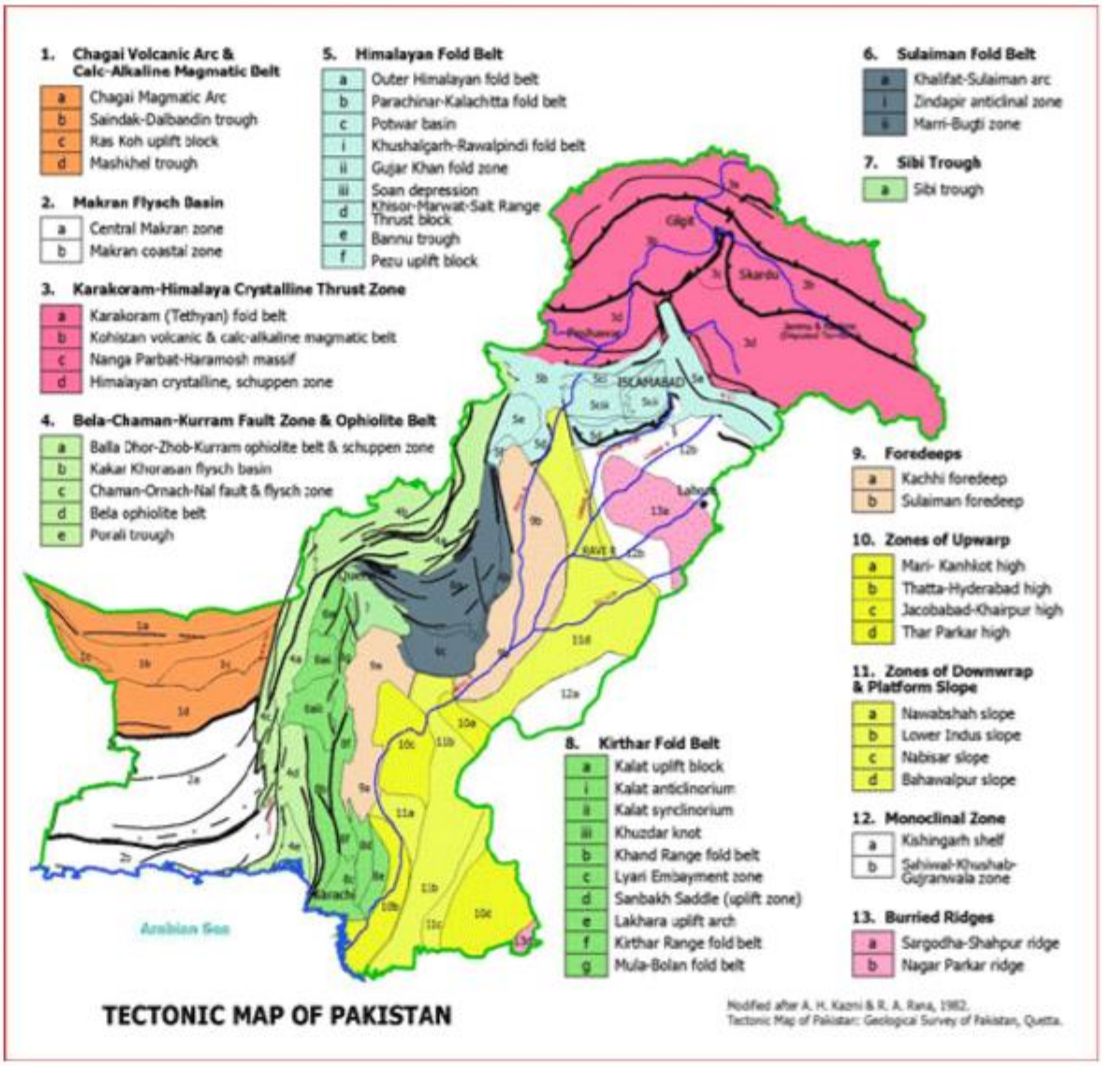
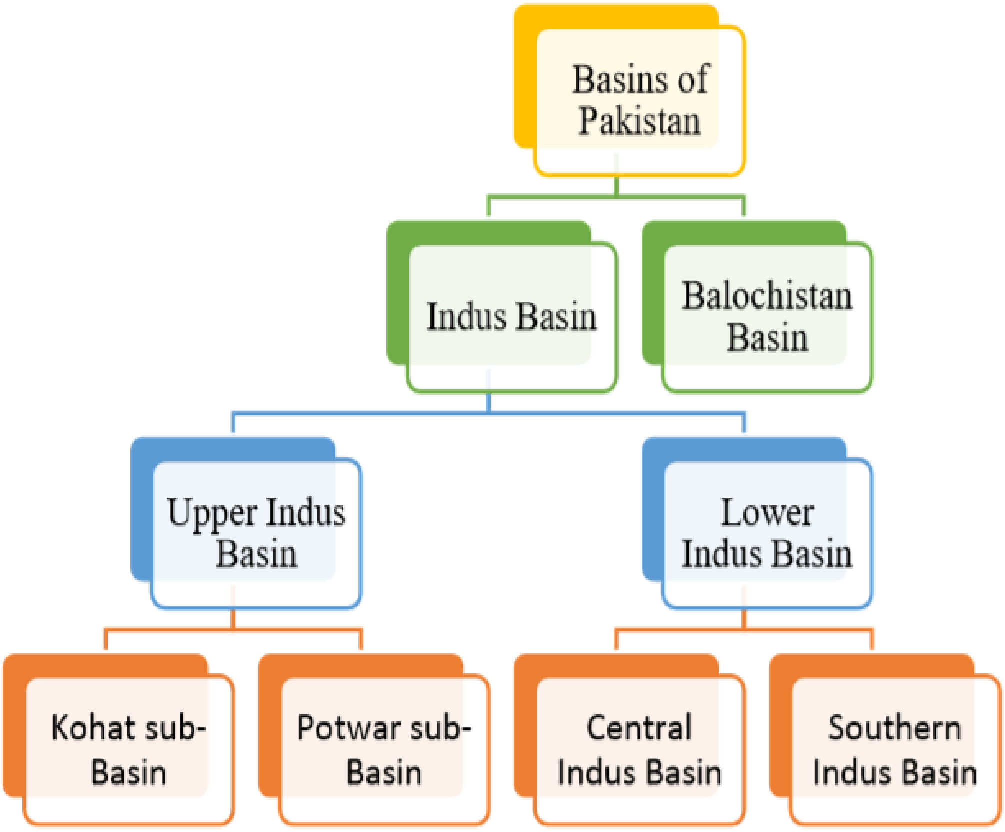


Figure 2.2 Tectonic map of Pakistan Tectonic map of Pakistan showing 13 tectonic subdivision of Pakistan including study area (Kazmi 1982).

2.3 Introduction to Basins of Pakistan

In terms of genesis and different geological histories, Pakistan comprises two main sedimentary basins. The Basinal distribution of Pakistan is shown in the following Flow-diagram.



These Basins were welded together during Cretaceous/Paleocene along Ornach Nal/Chaman Strike slip faults. There is yet another newly identified smaller basin, termed as Kakar-Khorasan Basin, which carries its own geological history for most of its development. This basin came into existence due to the interaction of Indian and Eurasian Plates and is classified as Median Basin. (Kadri, 1995)

2.3.1 Balochistan Basin

The Balochistan Basin comprises the Makran accretionary wedge and the Makran offshore trench. This is the least explored region of Pakistan. Very limited seismic survey has been done and only six wells have been drilled in this vast Basin. Despite several gas reserves shows along the Makran Coast but no commercial hydrocarbons have been found in the basin so far. (Kazmi and Jan, 1997). This basin contains Dalbandin and Kharan trough.

2.3.2 Indus Basin

This is the largest and more thoroughly studied basin of Pakistan. The Indus Basin covers an area of about 533,500 km2 and contains more than 15,000 m thick sediments ranging in age from the Precambrian to Recent. Subdivision of Indus Basin Indus Basin is classified into following basins:

- Upper Indus Basin: Kohat sub-Basin and Potwar sub-basin
- Lower Indus Basin: Central Indus Basin and Southern Indus Basin

2.3.2.1 Upper Indus Basin

This basin is in the northern Pakistan and is separated from the Lower Indus basin by Sargodha High. The northern and eastern boundaries coincide with the Main Boundary Thrust (MBT) the eastern most of the major Himalayan thrusts. The MBT runs through the Margala Hills, Kala Chitta and Kohat Ranges western boundary of the basin is marked by an uplift of Pre-Eocene sediments and eastward directed thrusting to the west of Bannu. The basin is further subdivided into Potwar, to the east and Kohat to the west, by river Indus. (Kadri, 1995)

2.3.2.2 Lower Indus Basin

The southernmost part of the Indus basin is known as Lower Indus basin, Badin Block or adjacent areas are also part of this basin. The approximate limits are south of Khairpur High and extends into the Arabian Sea, Petroleum exploration started in back in 1950’s in the Lower Indus basin. The first gas discovery was Sari-Hundi in Kirthar Range; district Dadu whereas first major oil struck in early 1980's at Khaskheli, near Badin where several large and small oil and gas fields have been discovered since then. The Lower Indus basin can be divided into areas where Neogene to Cretaceous rocks are exposed; western part along Kirthar Range and into the areas where no surface geology exposed or minor at lesser extent geological units of Neogene to Pleistocene are cropping out; Badin Block are areas nearby all are without surface geological expression.

2.4 Stratigraphy of Lower Indus Basin

Stratigraphy of the South Indus Basin ranges from Cambrian to Recent with nondeposition and erosion at various stratigraphic levels. Stratigraphic succession of the Punjab and Lower Indus Platform area, changes from east to west with regional unconformities at base Permian and base Tertiary levels. Middle Jurassic to Eocene strata truncates below base Miocene-Pliocene unconformity eastward in the Punjab Platform while Tertiary sequence has direct contact with the Jurassic sequence in eastern part of the Lower Indus Platform. The thickness of the sediments increases westward. Stratigraphy known in Sulaiman and Kirthar fold belt ranges from Permian to Recent age. Intra-formational sedimentation breaks are pronounced in Permian and Jurassic, while Cretaceous Tertiary unconformity is regional. Erosion in some parts of the Fold belt is so deep that it has exposed the Jurassic rocks at or near the surface (Ahmed et al, 2011).

The stratigraphic succession changes from east to west. Precambrian basement is exposed in the south-eastern corner the basin. The thickness of the sediments increases westward. In the eastern part of the basin Tertiary sequence has direct contact with Jurassic sequence. The stratigraphic chart of the study area is given in Figure 2.3.

2.4.1 Chiltan Limestone

The Jurassic System is represented by limestone, shale and sandstone with subordinate dolomitic and ferruginous beds. It consists of massive thick bedded limestone. The limestone, where developed, overlies the Shirinab formation conformably. Its upper contact with Mazar Drik formation is transitional. The Chiltan limestone correlates with the Samana Suk Formation of the Upper Indus Basin (Shah et.al, 1977).

2.4.2 Sembar Formation

This is the lowermost unit of the Cretaceous sequence in the Kirthar-Sulaiman region, consisting of black shale interbedded with siltstone and nodular, argillaceous limestone. The shale and siltstone are commonly glauconitic. The Formation is 133 m thick in type area (Sembar Pass) and 262 m in the Mughal Kot section. It has a gradational contact with the overlying Goru Formation though at places an unconformity. The fossils most found in the Sembar Formation are belemnites, Hibonites, pistilliformis, H. subfusiformis, and Duvalia sp.

2.4.3 Goru Formation

The Goru formation consists of interbedded sandstone, shale and siltstone. The limestone is grained, thin bedded, light to medium grey in color (Shah ,2009). Based on lithology Goru Formation is divided in two parts:

a) Lower Goru

The lower Goru is main reservoir rock within the area. The lower Goru horizon as a general 5 divisions based on predominant lithologies. The Basal sand unit, lower shale, middle sand unit (good reservoir potential), upper shale and upper sand.

b) Upper Goru

The upper Goru sequence of middle to late cretaceous overlies the lower Goru formation which consists of mainly marl and calcareous claystone occasionally with interbeds of silt and limestone. The Goru Formation is widely distributed in the Kirthar and Sulaiman Province. It grades into overlying Pab formation which has not been reported in Fateh_01 and Icchri_01 wells of the study area. The lower contact with the Sembar formation is conformable and is very locally reported unconformable. The upper contact is transitional with the Goru formation may be correlated with the Lumshiwal Formation of the Kohat-Potwar Province. The formation contains foraminifers and bivalves and age given is Early Cretaceous (Shah, 2009).

2.4.4 Ranikot

Ranikot group is subdivided into Lower Ranikot (sandstone) and Upper Ranikot (shale). One division of Ranikot group suggests that it comprise of three formations which are Khadro formation, consists of olive, yellowish brown sandstone and shale with interbeds of limestone. Keeping ascending stratigraphy order, Above Khadro formation is Bara formation (Lower Ranikot sandstone) consists of variegated sandstone and shale and the upper one is the Lakhra formation (Upper Ranikot limestone) consists of grey limestone, grey to brown sandstone and shale. Various authors have given it different divisions. Below are explained the three formations as part of the Ranikot group with details (Shah ,2009).

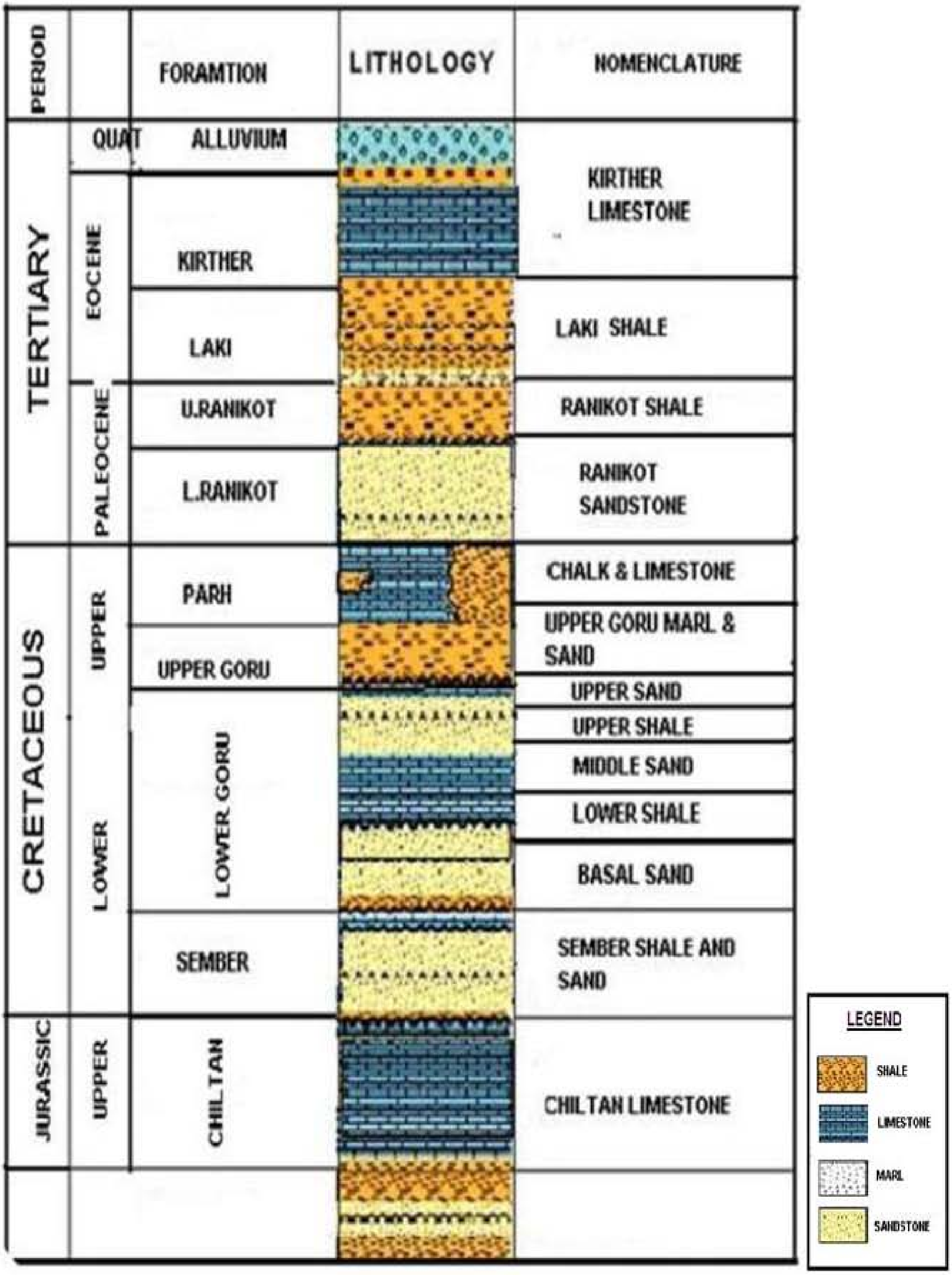


Figure 2.3 Stratigraphic successions in Lower Indus basin.

2.5 Petroleum Plays

A play is “a group of geologically related prospects having similar conditions of source, reservoir and trap. (Kadri, 1995)

2.5.1 Petroleum play elements

Within a basin the presence of play elements plays important role in hydrocarbon accumulation. The seven play elements are:

- Source
- Maturation
- Migration
- Seal or Cap
- Reservoir
- Trap
- Timing

2.5.2 Petroleum Prospects of the Area

i. Source Rocks

Shale sequences in the Sembar formation and Lower Goru formation are known to be well developed source rocks of the area. Of all the possible source rocks in the Indus Basin, however, the Sembar is the most likely source for the largest portion of the produced oil and gas in the Indus foreland. The Sembar was deposited over most of the Greater Indus Basin in marine environments and ranges in thickness from 0 to more than 260 m (Shah et al., 1977).

ii. Reservoir Rocks

The basal sands of lower guru formations are the main objective in the area these sands are hydrocarbon producer. Massive sands are another interesting producing reservoir from its various sand sheet of multiple thickness possibility of reservoir in lower guru sand overlain on basal sands could not be ruled out; however, they have not yet proved to be such up till now. These principle reservoirs are deltaic and shallow-marine sandstones in lower part of the Goru in this area. Reservoir qualities generally diminishes west ward while reservoir thickness increases.

iii. Seal or Cap Rocks

Fine-grained rocks such as shale or evaporites have the tendency as effective cap rocks. Additional seals that may be effective include faults, and up-dip facies changes. The known seals in the study area are composed of inter bedded shale which is overlayed the reservoirs. The thick sequence of shale and marl member of Upper Goru formation acts as a seal for underlying Lower Goru formation.

iv. Traps

All production in the study area is from structural traps. The tilted fault traps in the Lower Indus Basin are a product of extension related to rifting and the formation of horst and graben structures. The temporal relationships among trap formation and hydrocarbon generation, expulsion, migration, and entrapment are variable- throughout the Indus Basin. These provide the significant trapping system along tilted fault blocks and negative flower structures.

Chapter 3

Seismic Data Interpretation

3.1 Interpretation

Interpretation is a tool 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 gravity and magnetic data, well information, surface geology as well as geologic and physical concept. (Telford et al, 1999) Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. The goal is to detect hydrocarbon accumulations delineate their extent and calculate their volumes. Conventional seismic interpretation is an art that requires skill and thorough experience in geology and geophysics. To meet the challenges of exploring ever increasingly complex targets, there have been tremendous advancements in data acquisition equipment, computer hardware and seismic processing algorithms in the last three decades. The seismic method has thus, evolved into a computationally complex science. The computer-based working (Processing & Interpretation) is more accurate, precise, efficient and satisfactory which provides more time for further analysis of data. This whole work is carried out using a combination of computer software products, which include all K-tron Software and Kingdom suite. Our main purpose is to make the reflection as clear as possible to predict the structure and stratigraphy of the subsurface. Geologic meaning of the reflection is the indication of the boundaries where there is change in the acoustic impedance; to distinguish the different horizons with the seismic data we correlate the well information with the seismic data. Seismic data has been interpreted with well control and the well information is used to tie with the seismic data. Structure and estimate of the depositional environment, seismic velocity, seismic stratigraphy and the lithology is identified by using the best available seismic data (Dobrin & Savit, 1988). There are two main approaches for the interpretation of seismic sections:

- Structural Analysis

  Identification of structural features

- Stratigraphic Analysis

  Identification of stratigraphic boundaries

3.1.1 Structural Analysis

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbons are being extracted from the structural traps. It is study of reflector geometry based on reflection time. The main application of the structural analysis of seismic section is in the search for structural traps containing hydrocarbons. Most structural interpretation use two-way reflection times rather depth and time structural maps are constructed to display the geometry of selected reflections events. Some seismic sections contain images that can be interpreted without difficulty. Discontinue reflections clearly indicate faults and undulating reflections reveal folded beds. (Sheriff, 1990).

3.1.2 Stratigraphic Analysis

Seismic stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it. It also helps to identify formations, stratigraphic traps and unconformity. This method also facilitates for the identification of the major pro-gradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation Stratigraphic analysis therefore greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment.

3.2 Work Procedure

The provided data (Navigation file, SEG-Y data, well information and LAS file) was loaded in Kingdom software for interpretation. Interpretation of the data was done in Kingdom and seismic attributes. Wavelet software is also used for Rock physics analysis. K-tron X-Works software is used for velocity analysis.

3.3 Seismic Horizons Identification

The main task of interpretation is to identify various reflectors or horizons as interface between geological formations. This requires good structural and stratigraphic knowledge of the area (Mcquillin et al., 1984). Thus, during interpretation, the horizons and faults are marked on the seismic section. As seismic data in SEG-Y digital format for the four seismic lines is loaded into Kingdom as the software provides interactive interpretation. Another advantage of the application is gridding and contouring for time and depth contour maps

The basic way to interpret multiple seismic lines is, first interpret that seismic line on which there is well, so according to well tops that seismic line is interpreted and further considered it as a reference line for the interpretation of other lines. If it is a dip line then a strike line will tie it at a certain source point, note that source point from the base map and multiplying with 2 to convert source point into CDP numbers and the time along y-axis at which the reflectors are marked on that reference line, so marked all the reflectors at the tie points and extend them on the bases of character and continuity. Now this interpreted strike line will tie all the dip lines so interpret them at the tie points and same were the procedure for the interpretation of other lines.

3.4 Well data

I was provided with the well “CHAK66-01” data. It includes LAS file (well header and logs data) and formation tops.

3.4.1 Well Information

The well is the basic component on which seismic interpretation is based. It is used to confirm the depth of the subsurface formation. Details of well used for the interpretation are given in the Table 3.1.

Well Name	CHAK66-01
Longitude	068.876250˚
Latitude	026.165194˚
K.B. Elevation	0.00
Total Depth	3057.3999 m
Type	Exploration
Operator	O.G.D.C. L
Country	Pakistan

Table 3.1 Detailed information of the well used for interpretation

3.4.2 Formation Tops

Formation tops data was issued by DGPC in the text format. Formation tops detail is given below in the Table 3.2. Among these formations the interest zone lies in the reservoir rocks which is discussed with detail in Chapter 2.

Formations	Depth (m)
ALLUVIUM	0000.000
LAKI	0612.000
RANIKOT	1161.000
PARH	1631.000
UPPER GORU	1773.000
LOWER GORU	2023.000
BASAL SAND	2842.000
TALHAR |SHALE	2866.000

Table 3.2 Formation tops.

3.5 Interpreted Seismic Sections

The time section provides the position and configuration of reflectors in the time domain. Four reflectors along with faults have been marked by different colors.

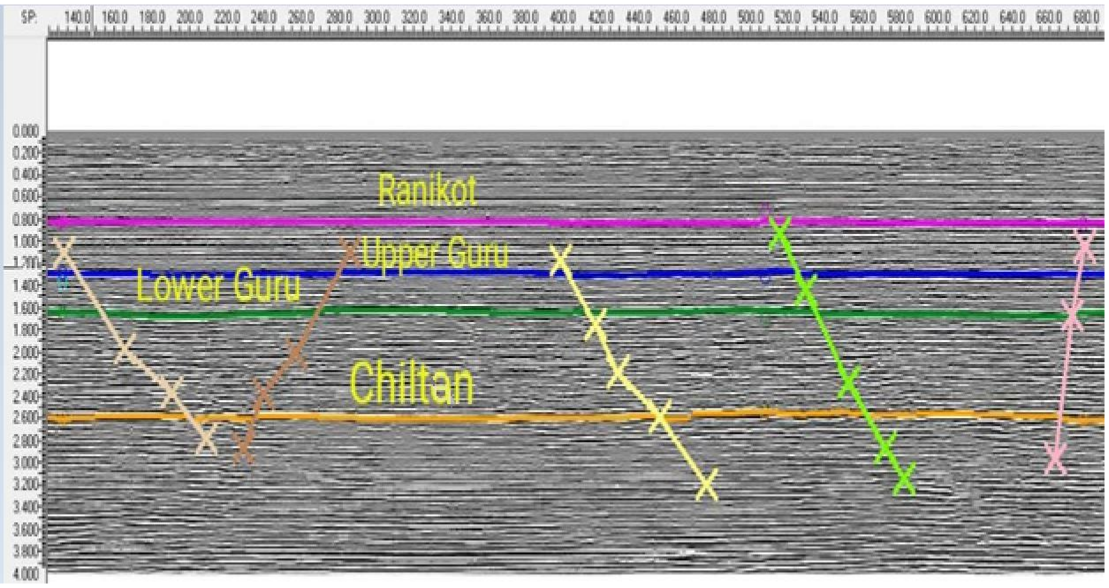


Fig 3.1: Interpreted section (SNJ-04)

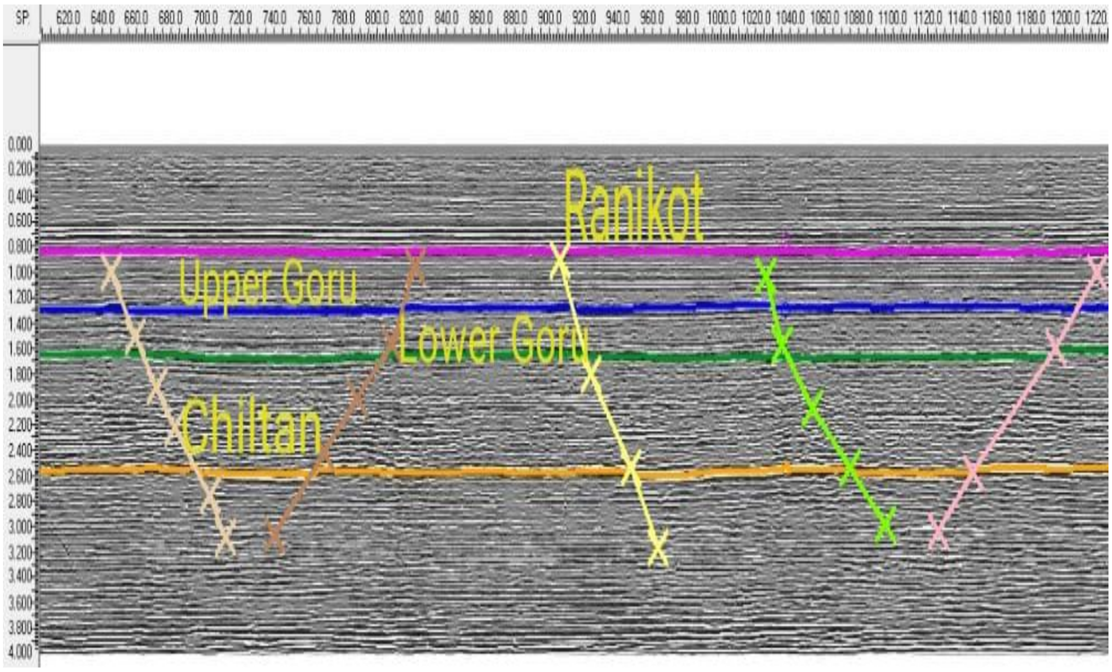


Fig 3.2: Interpreted section (SNJ-03)

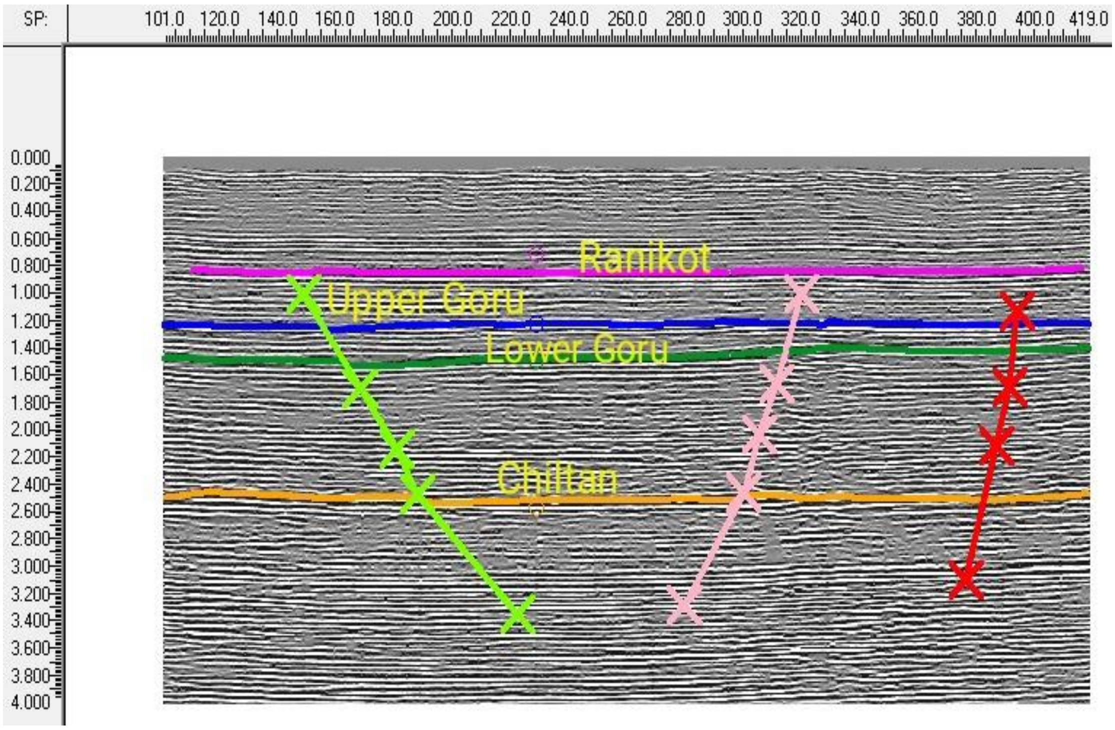


Fig 3.3: Interpreted section (SNJ-10)

3.6 Seismic Velocities Analysis

The seismic velocities determined from velocity analysis are RMS velocity (Vrms). These must be converted into interval (Vint) and finally average (Vavg) velocities for time to depth conversion by using Dix (1955) equation. X-Works uses a velocity processing engine which automatically converts the input Vrms into Vint and finally Vavg for time to depth conversion. When the velocity data is loaded the velocity functions for all three types are displayed at their corresponding CDP locations i.e. Vrms (Sky Blue) with red nods, Vint (Dark Green) and Vavg (Blue).

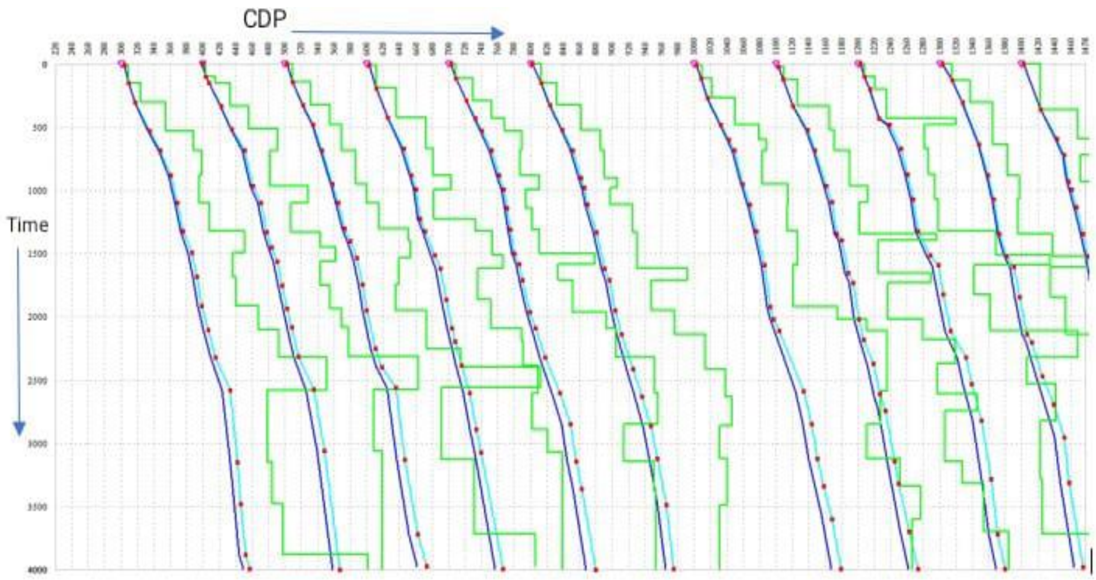


Figure 3.4 Seismic velocities displayed at different CDPs of seismic line SNJ-04

In above figure average velocity (blue), interval velocity (green), Vrms (light blue) and Vrms nodes(red) are mentioned which give another view of the variation in the velocities across the cross section of the seismic line.

3.6.1 Calibration and Smoothing of Seismic Interpolated Velocities

The seismic velocities of seismic lines were highly fluctuated which were not suitable for time to depth conversion and other applications therefore for their velocities are processed using spatio-temporal interpolation at 200 msec and CDP interval of 10 along with 3 X 3 spatio-temporal smoothing. This provides more precise velocities for time to depth conversion.

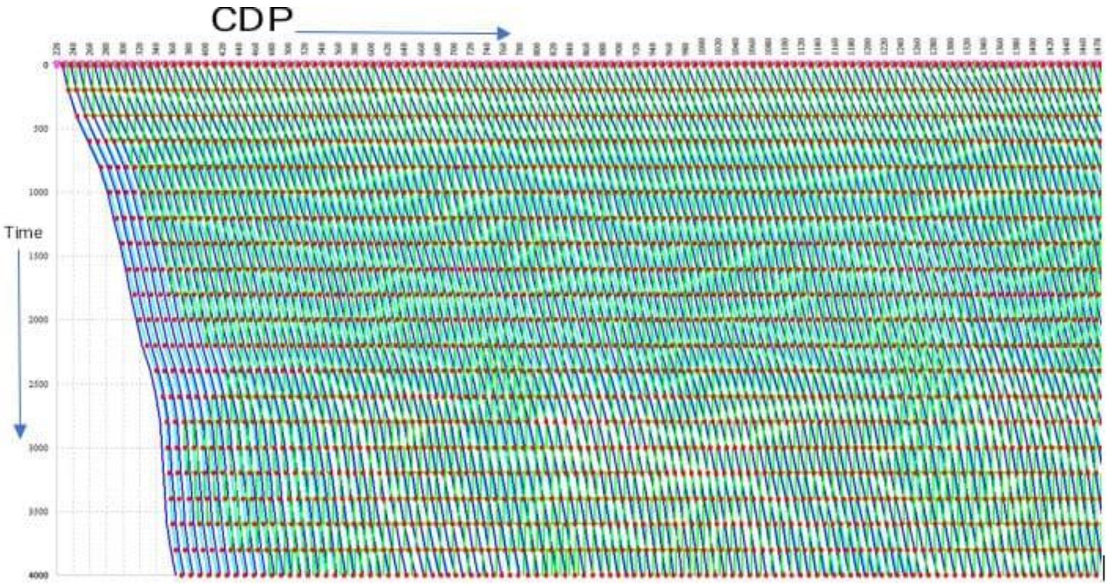


fIg 3.5: Calibrated and smoothened Velocities of seismic line SNJ-04

In above figure average velocity (blue), interval velocity (green), Vrms (light blue) and Vrms nodes(red) are mentioned which give another view of the variation in the velocities across the cross section of the seismic line.

3.7 Seismic Depth Sections

Depth sections provide true geologic image of subsurface structures but require a more precise and robust velocity model (Khan and Akhter, 2011). A good seismic image in time domain is not enough for an exploration or field development interpretation. Good well ties and reliable depth conversion are also required.

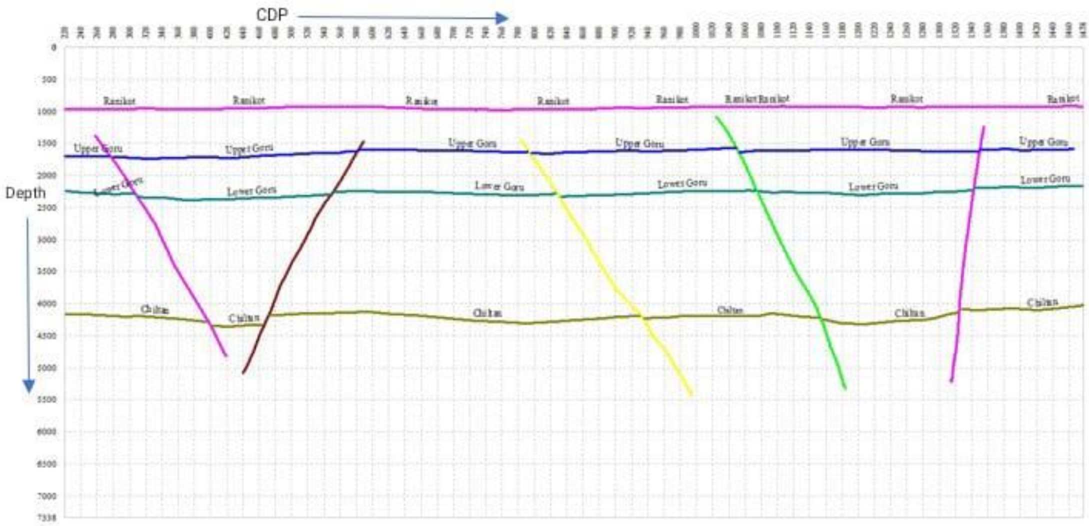


Figure 3.6: SNJ-04 depth section.

3.8 Contour Maps

Contouring map is an important part of the interpretation of the seismic data. Seismic interpretation leads to the display of the essential information that is extracted during interpretation in the form of time and depth contour maps. The contours are the lines of equal time or depth wandering around the map as dictated by the data (Coffeen, 1986).

To construct a subsurface map from seismic data, first a reference is selected. The datum may be sea level or any other above or below the sea level according to the topography (elevation) and thickness of weathering layer (Gadallah and Fisher, 2009). Contouring is the representation of three-dimensional earth on a two-dimensional surface. The spacing between the contour line represents the steepness of the slope; the closer the spacing the steeper the slope and vice versa.

3.8.1 Time and Depth Contour Maps of Upper Goru Formation

Upper Goru formation is the seal rock of our area showing fluctuations in contours confirming the disturbance of the horizon in the form of horst and graben structure.

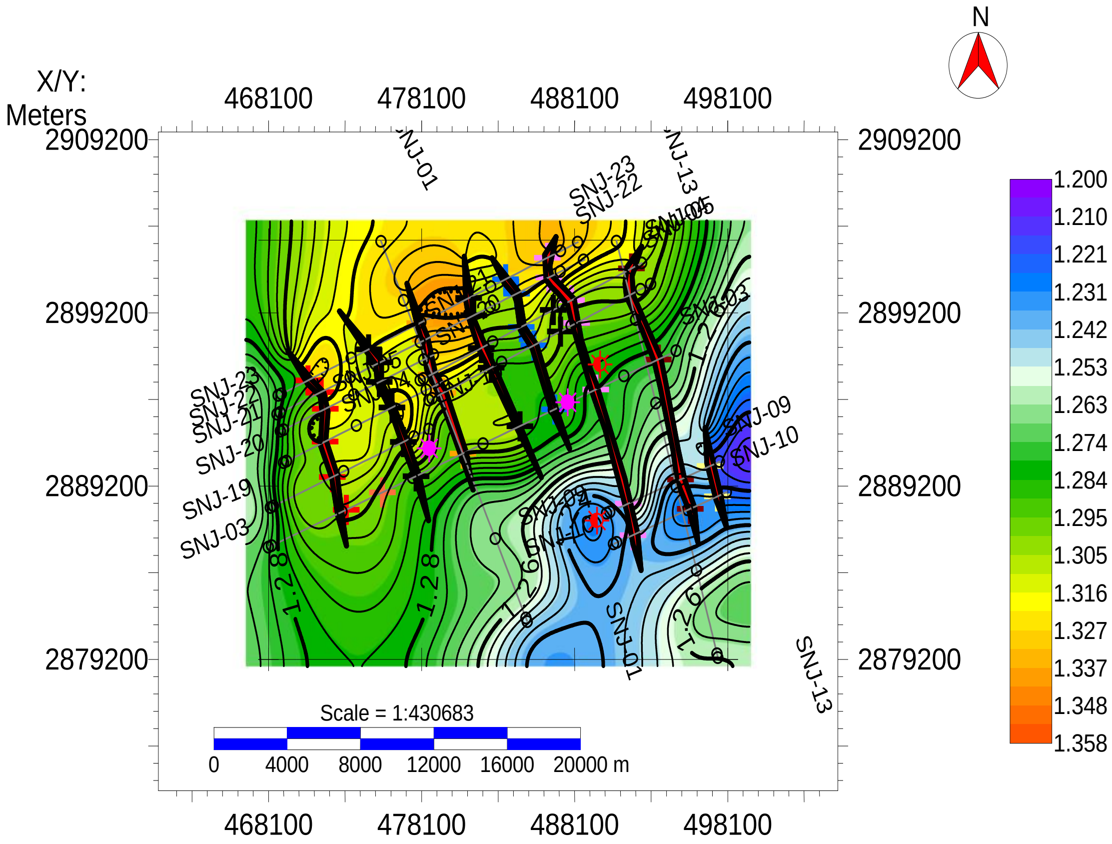


Figure 3.7 Time contour map of Upper Goru formation.

Upper Goru the seal rock of the study area is shown along with fault polygon over the formation. This formation ranges for the time of 1200 msec to 1358 msec. Contours showing the increasing trend from blue (lowest) to orange (highest) value of the time. Eastern portion with blue contours explaining the Graben present in the subsurface.

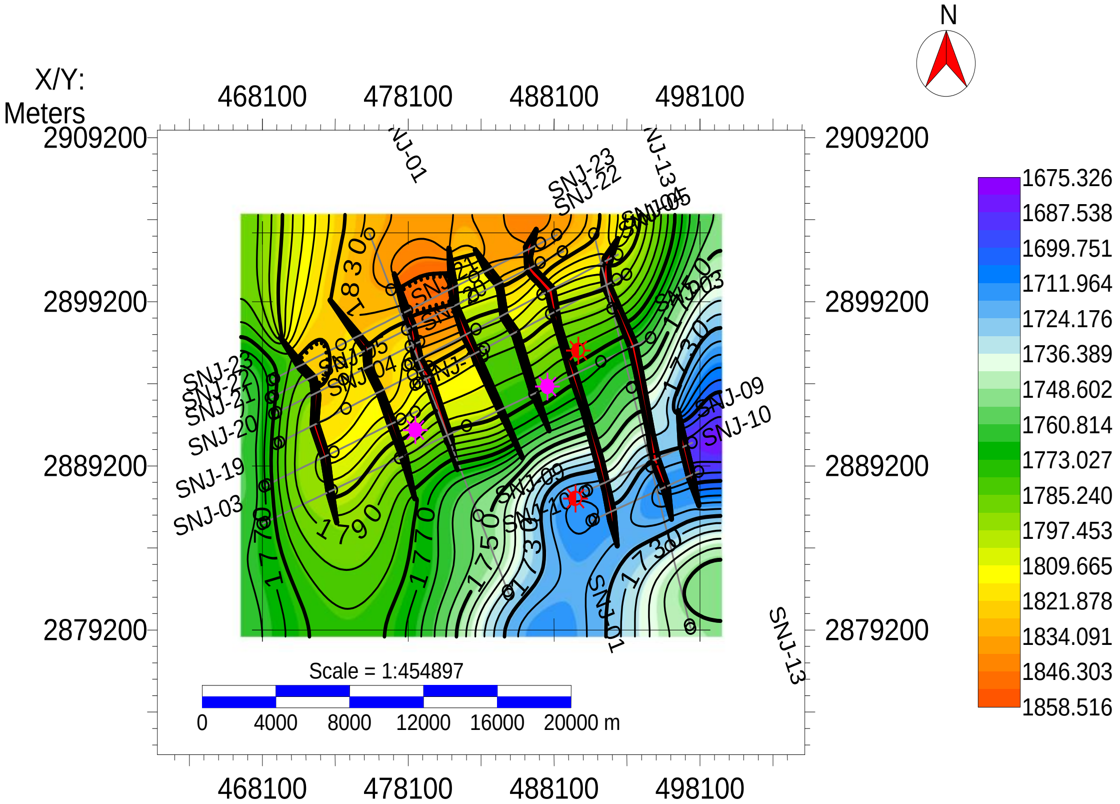


Figure 3.8 Depth Contour map of Upper Goru Formation.

Figure 3.8 confirmed the subsurface structure and the presence of the faults. Orange coloured contours showing the relative low-lying area which is basically Graben while blue coloured contours showing the relative high lying zone of Upper Goru in the subsurface.

3.8.2 Time and Depth Contour Maps of Lower Goru Formation

Lower Goru is the main zone of interest of the study area from the hydrocarbon exploration point of view. Time and depth contour maps of Lower Goru formation are used to understand the structural trap present in the reservoir.

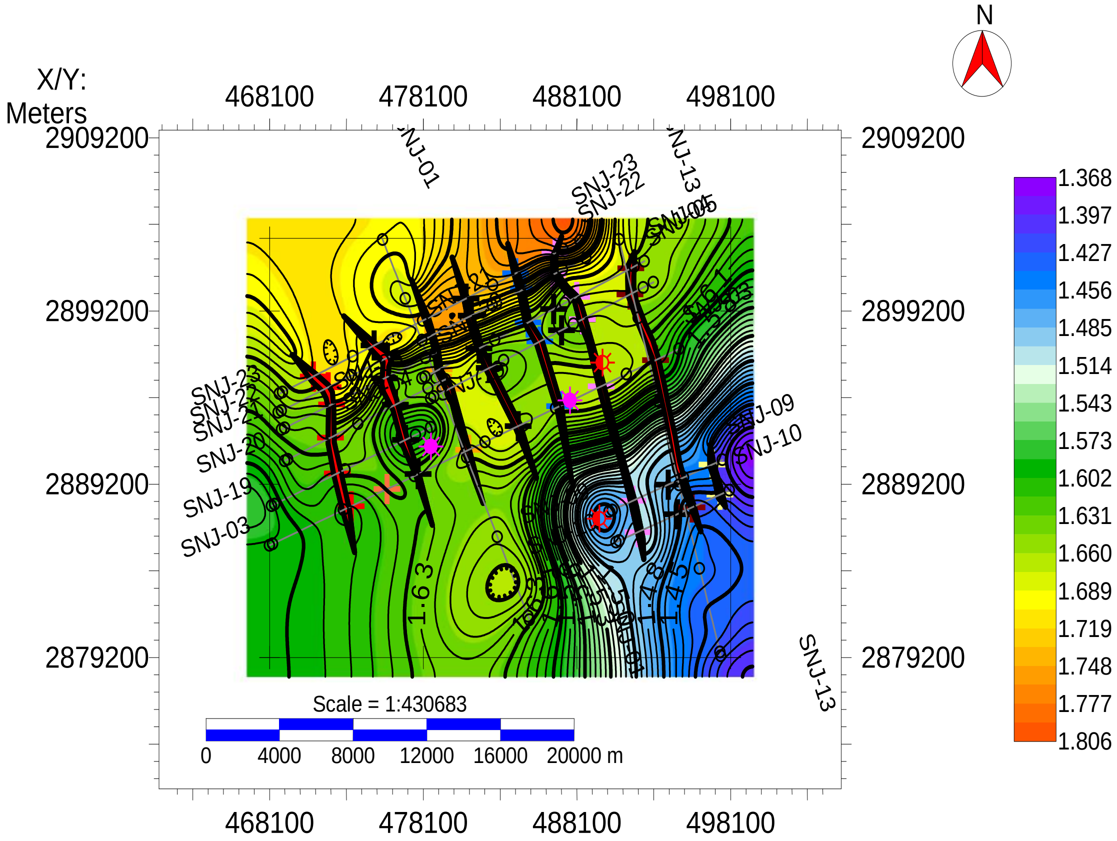


Figure 3.9 Time contour map of Lower Goru formation.

Figure explaining the structure quite well as Lower Goru is the main scope of Explorationists in the study area.

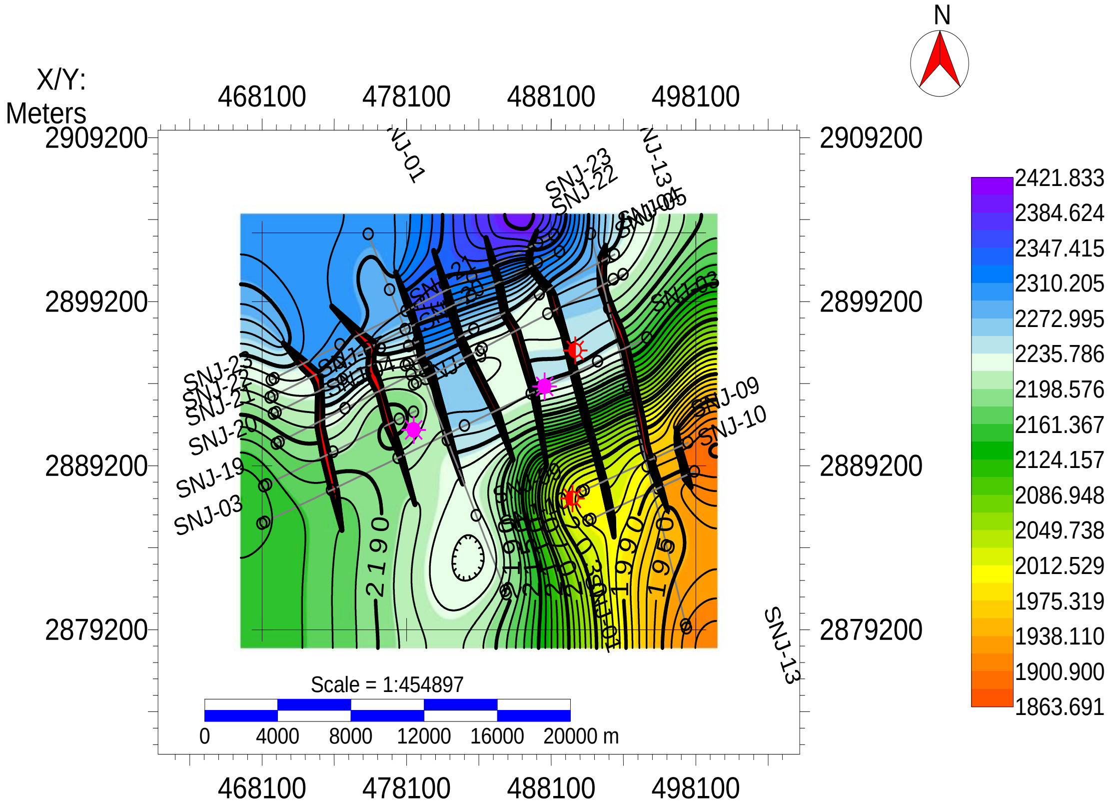


Figure 3.10 Depth contour map of Lower Goru formation.

3.9 Generation of Synthetic Seismogram

Synthetic seismograms provide a crucial link between lithological variations within a borehole and reflectors on seismic profiles crossing the site. In essence, they provide a ground truth for the interpretation of seismic data. Synthetic seismograms are useful tools for linking drill hole geology to seismic sections because they can provide a direct link between observed lithology's and seismic reflection patterns

Chak66-01 is the well is used for synthetic seismogram. DT and RHOB logs are used to generate the synthetic seismogram.

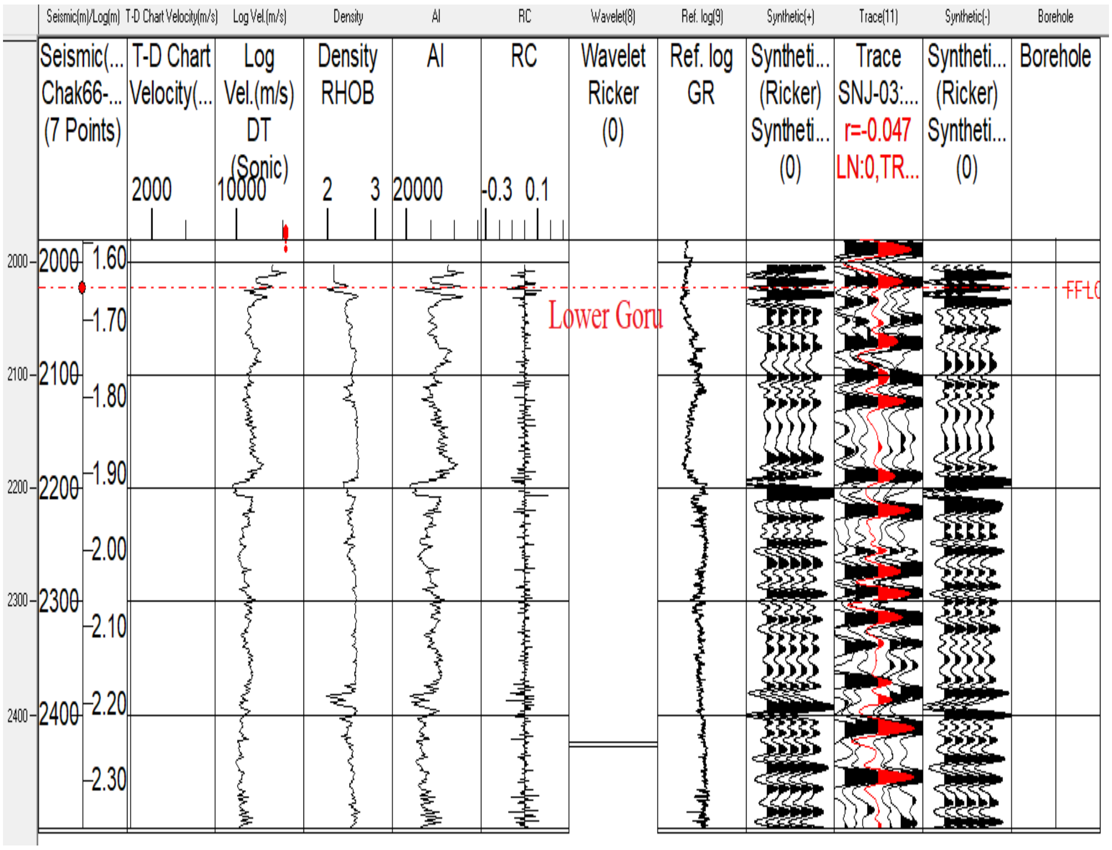


Figure 3.11: Synthetic Seismogram of well Chak66-01

Chapter 4

Petrophysics, 1D Rock Physics Analysis and Seismic Attributes Analysis

4.1 Petrophysics

The petrophysical analysis was carried out by using the wireline logs of Chak-66-01 well.

4.1.1 Log Curves

The log data of Chak-66-01 was available in Logging ASCII Standard (LAS) format. The log curves along with some parameters given in the LAS file header are used to calculate all basic and advance parameters.

4.1.2 Interest Zones

Basal Sands and Massive Sands are our interest zone for reservoir identification.

4.1.3 Calculating Shale Volume

The source formations are commonly shaly with higher radioactive content and are therefore indicated by a higher Gamma Ray value. On the other hand, it is also assumed that the radioactive material is not present in other formations which are termed as clean formations. This creates a contrast between shale and other formations. The mathematical formulation used to calculate the Volume of Shale is given below:

Volume of Shale Vshl[] = (GR[log]-GRclean) / (GRshale-GRclean)

The Gamma Ray log along with sand and shale lines as well as linearly computed volume of shale curves for a depth range of 2000 meters to 3000 meters. Volume of shale plot gives the clear picture of reservoir which is not as better because of more shaly content in the reservoir.

4.1.4 Porosity Calculation

The pore spaces which are not occupied by the rock fragments are named as porosity. Porosity is created due to inter granular spaces, voids formed by dissolution of grains as well as fracturing of rocks. The symbol used for porosity is "ϕ" and expressed either by percentage or in decimals. The primary porosity is developed between the grains at the time of deposition, but due to fracturing and dissolution the pore spaces become void creating secondary porosity. Secondary porosity is mainly observed in limestone. In this work density is calculated using the following methods:

• Density Porosity is derived from density log using the following equation

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

• Neutron Porosity is directly obtained from Neutron log values.

• The Average Porosity is obtained by taking the mean of the above two.

Average Porosity = (Density Porosity + Neutron Porosity)/2

• Effective Porosity is given by.

Effective Porosity = Average Porosity * Vmatrix

Where Vmatrix is Volume of Matrix given by 1- Vshale

These porosities are calculated to confirm the interpretation of porosity logs.

4.1.5 Calculation of Water Saturation

The fraction of pore spaces containing water is termed as Water Saturation (Sw)which is calculated by from the Archie's formula given by.

$$Sw=\{Rw/(Rt*\phi m)\}1/n$$

Where is Resistivity of Water, Rt is True Resistivity (obtained from LLD log), Φ is Porosity, m is Cementation factor (with a constant value 01) and n is Wettability factor (with a constant value 2)

4.1.6 Calculation of Saturation of Hydrocarbon

The fraction of pore spaces containing Hydrocarbons is known as Hydrocarbon Saturation and mathematically given by the following equation.

$$Shc = 1 - Sw$$

As the Shc is the remaining percentage of the Pore volume occupied by Water, hence this method is indirect quantitative estimation of the hydrocarbons.

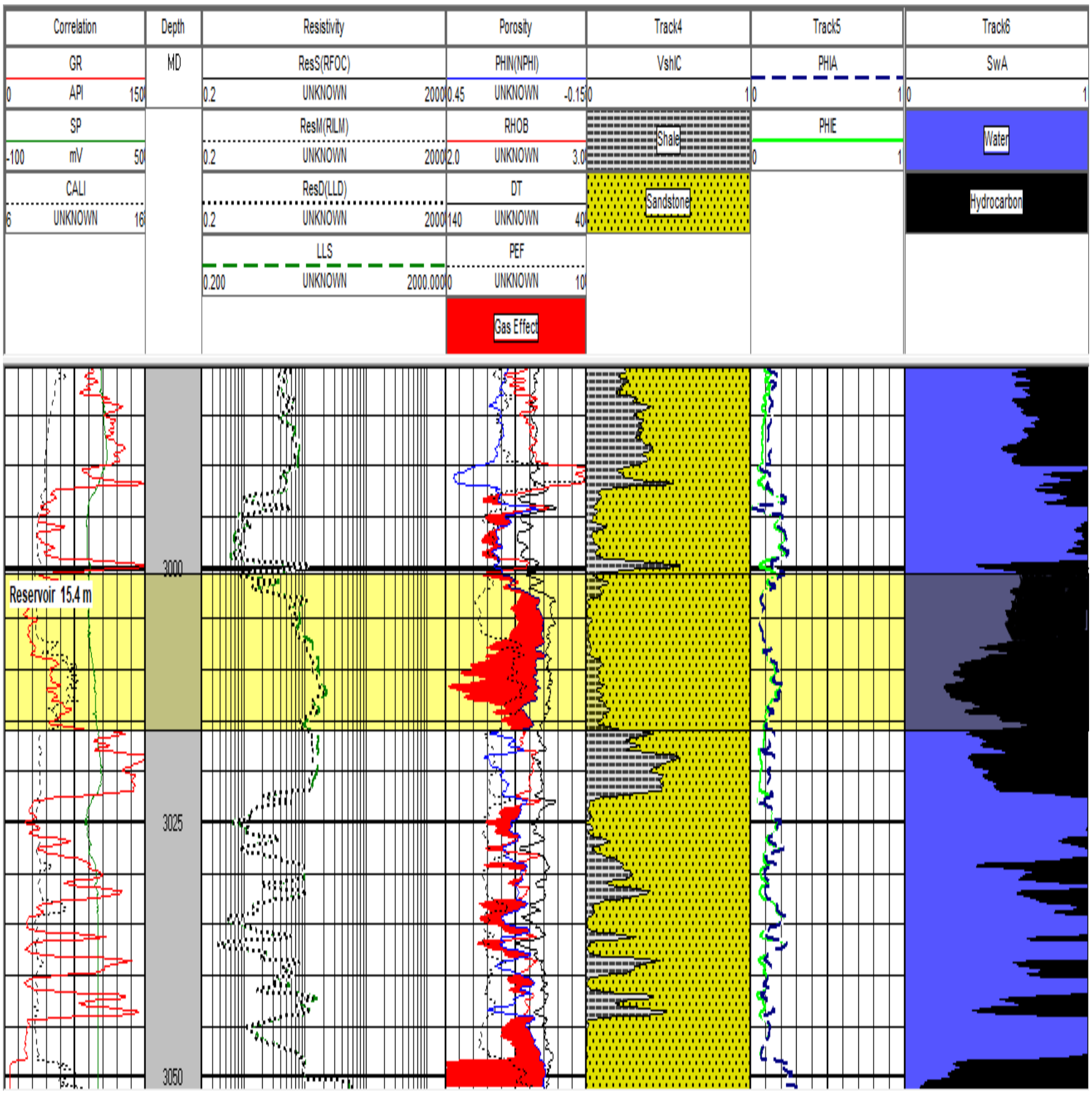


Figure 4.1: Hydrocarbon saturation calculated for Massive Sands.

In this figure, Red colour shows Gas Effect of NPHI and RHOB. Also, there is presence of sands and saturation of hydrocarbon is high. So, this could be the potential zone for commercial production of Gas.

4.2 Computation Rock Physics Coefficients for the Area

Rock physics contributes particulars about elastic parameters which in turn can be interpreted into useful geologic information. For a trustworthy interpretation at least two among the three input parameters; P-Wave Velocity, S-Wave Velocity and Density must be measured. The two available parameters are correlated to determine the coefficient which better represents the area under study (Khan, 2013).

Well logs for the area contain P Wave Sonic and density, therefore these two parameters have been correlated using Wavelets software.

In the current study the relationship between p-wave velocity which is computed from Sonic log and Density log is:

$$RHOB = 2.079 + 0.0001 * Vp$$

The computed relationship remarkably allocates the rocks of the area and therefore is used in computation of all rock physics parameters.

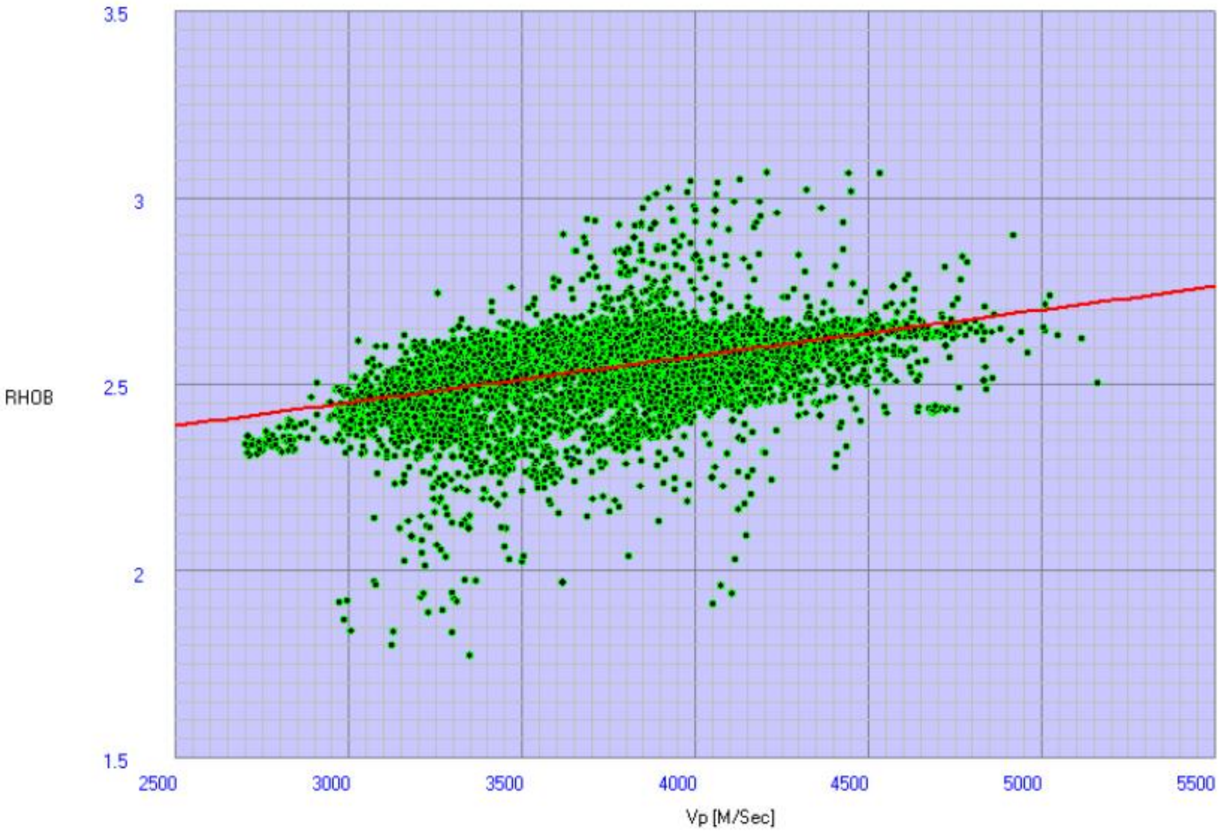


Figure 4.2: Cross-plot of P-Velocity and Density.

4.2.1 Calculation of 1D Rock Physics Parameters

1D Rock physical analysis has been done to understand the behavior of different parameters vertically with the depth. Using wavelets software this task has been achieved. Firstly, the petrophysical log file has been loaded, which is in LAS (Log ASCII Standard) format, for the specific depth range of the targeted zone. With the help of DT (sonic) log Vp has been calculated by simply inverting the log value. Then Vs will be determined from Vp using mathematical relation. Furthermore, rock physics parameters have been computerized by the software using Vp and Vs values. Figure is the brief description of the 1D rock physics parameters. Each curve assigned different colour to understand it better. Figure shows DT (Sonic log), Vp (Compressional wave Velocity), Vs(Shear wave Velocity), Ip(p-wave acoustic impedance), Is(s-wave acoustic impedance), p (calculated density), phi (porosity), BM(Bulk modulus), SM(Shear modulus), YM(Young's modulus), PWM(P-wave modulus), LC(Lame's constant) and PR(Poisson's ratio).

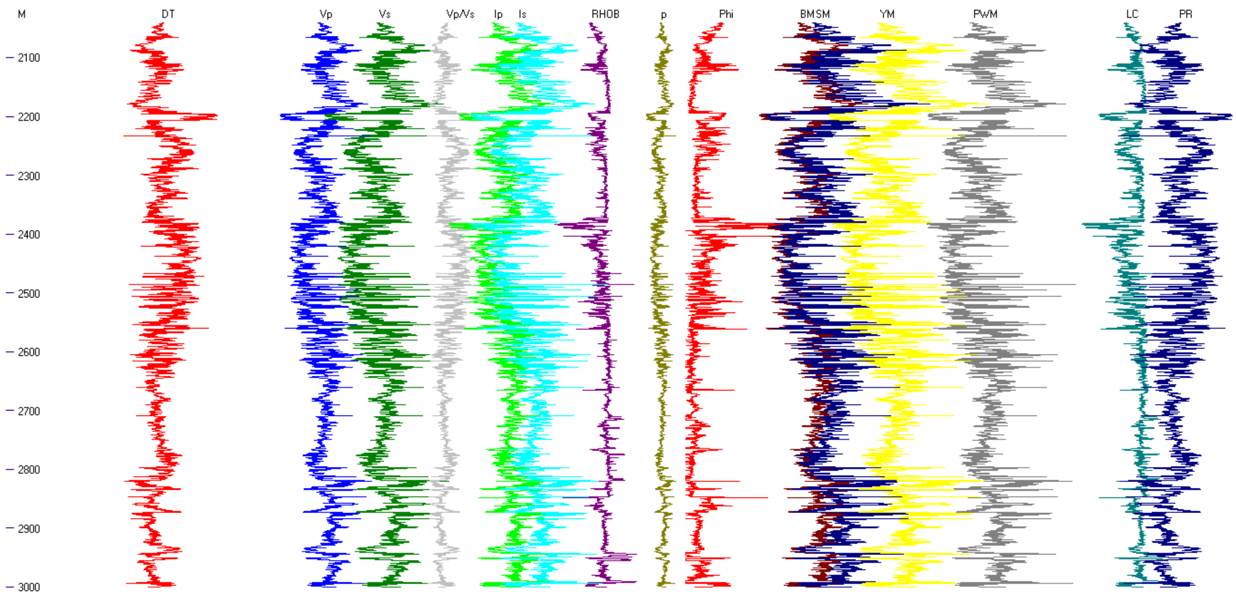


Figure 4.3 Different Rock physics parameters variations with the depth in Chak66-01 using DT log.

4.2.2 Poisson's Ratio versus Vp to Vs Ratio Cross-Plot

A common way of looking at the VP/VS ratio is to use Poisson's ratio. It has been noticed that Gas/Oil lower VP/VS and hence Poisson's ratio relative to water filled reservoir. Thus, we can also create cross-plots of Poisson’s ration and VP/VS and identify zones for Oil and Gas. Below is the generalized diagram showing relation between above mentioned ratios.

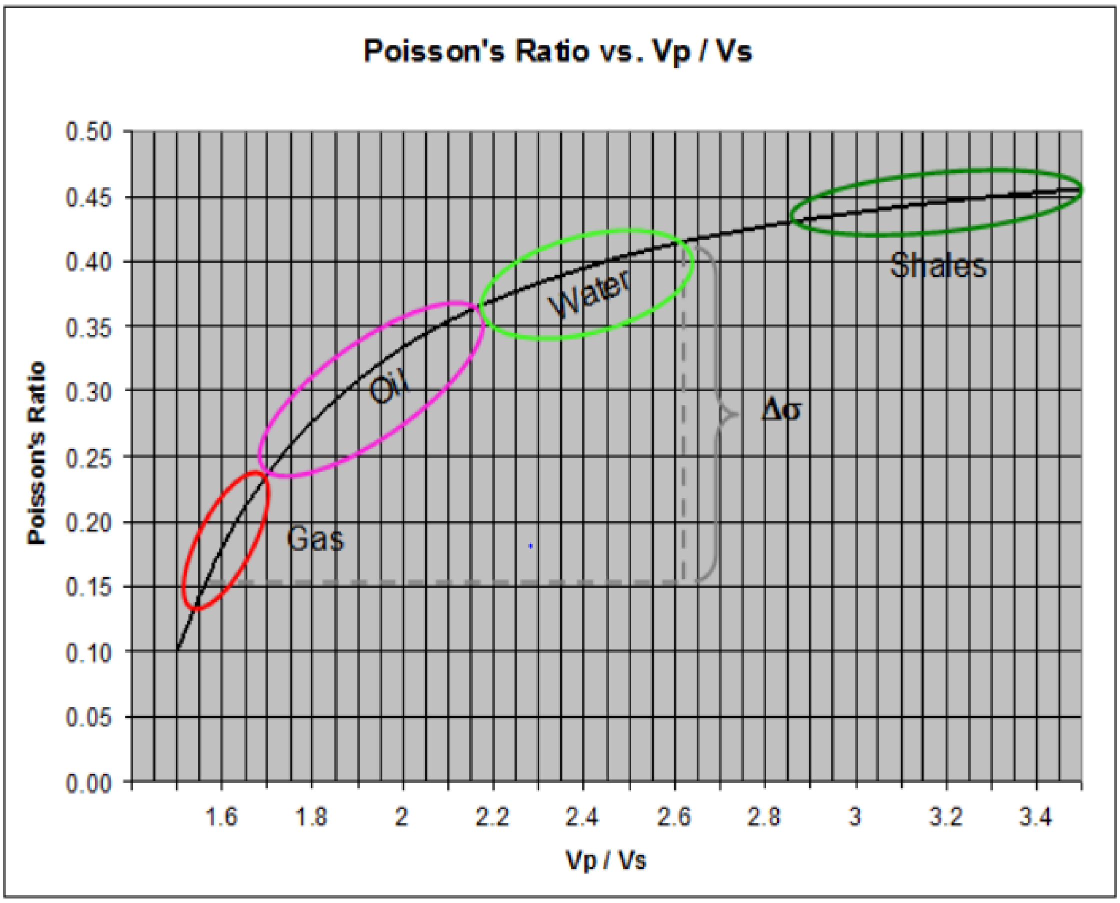


Figure 4.4: Generalized cross-plot between Poisson's Ratio and VP/VS showing the marked zone of gas, oil, water and shale in the well. (Khan, 2013)

Similarly, A cross-plot for Chak66-01 has been designed to understand the extension of the gas, oil and water zones.

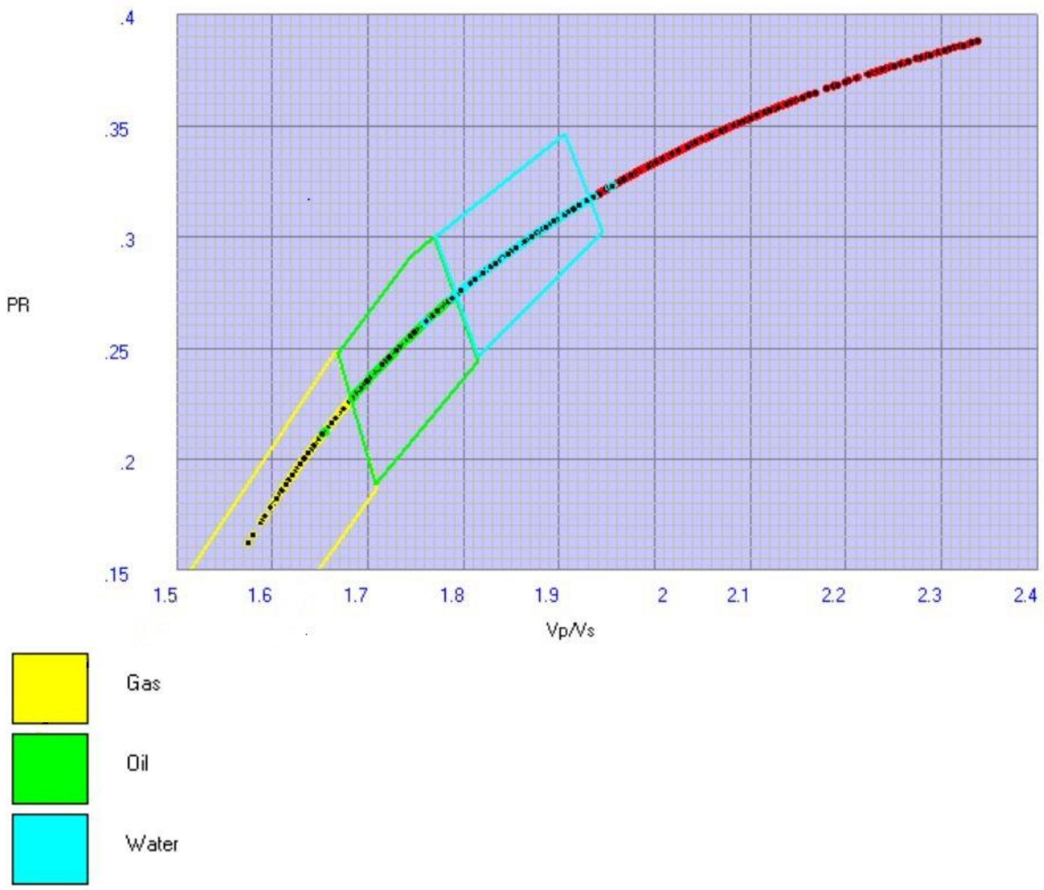


Figure 4.5 Cross-plot of Poisson's Ratio and VP/VS for Chak66-01.

4.3 Seismic Attribute Analysis

Seismic attributes are the set of properties computed from the data which consists of the amplitude. Attributes can be computed based on pre stacked data and post stacked data. The most common types of post stacked attributes are instantaneous attributes which are computed for every sample of the seismic trace.

The seismic energy is basically a mechanical energy which has two components:

- Kinetic
- Potential

Through experiment it has been found that kinetic component of the seismic energy has been measured. We need to measure the imaginary potential component for instantaneous attributes (Khan, 2010).

A measurable property of seismic data, such as amplitude, dip, frequency, phase and polarity. Attributes can be measured at one instant in time or over a time window and may be measured on a single trace or set of traces from seismic data.

4.3.1 Essential of Seismic Attributes

The increasing reliance on seismic data requires that we gain the most information possible from the seismic reflection data. It empowers interpreters to obtain more information from seismic data. Seismic geomorphology uses seismic attributes to extract geomorphologic insight using 3-D datasets. Amplitude is the default attribute of Seismic reflection data for the determination of physical parameters like reflection coefficients, velocities etc. The phase component is the principal factor in determining the shapes of the reflectors and their geometrical configurations. Fig 4.6 explains the true behavior of complex seismic trace.

Attribute computations decompose seismic data into constituent attributes. There are no rules governing how attributes are computed. They are applicable in checking seismic data quality identifying artifacts, petroleum prospect identification, hydrocarbon play evaluation and reservoir characterization. Any quantity calculated from seismic data can be considered an attribute. Thus, attributes are of many types: pre-stack, post-stack, inversion, velocity, horizon, multicomponent 4-D.

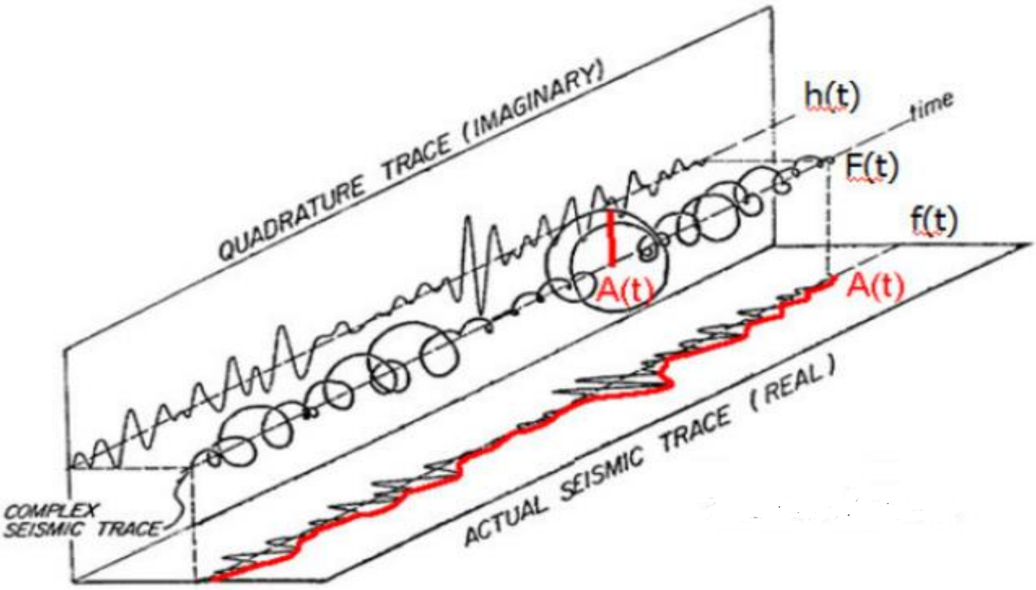


Figure 4.6 Isometric diagram for complex seismic trace showing Real (red) and Imaginary components of complex seismic trace.

4.3.2 Hilbert Transform

Hilbert Transform is introduced by David Hilbert to solve special case of the Riemann Hilbert problem for holomorphic functions. It is used in seismic attribute analysis and electrical engineering. The Hilbert transform is generally introduced as a convolution between a real signal f(t) and 1/πt as given below.

$$h(t) = \frac{1}{\pi t} * f(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{f(\tau)}{t-\tau} d\tau$$

The Hilbert transformed signal h(t) represents the imaginary part of the real signal f(t).

The imaginary component is basically a 90 degree phase rotated version of real component of seismic trace, therefore can be computed through Hilbert Transform (Taner et al. 1979).The Hilbert Transform of the real seismic trace is generates an imaginary trace and using both these traces the envelope trace is computed. Fig 4.7 shows the real trace and quadrature trace(imaginary) of complex seismic trace along with reflection strength real seismic trace. Reflection strength seismic trace which will always be positive.

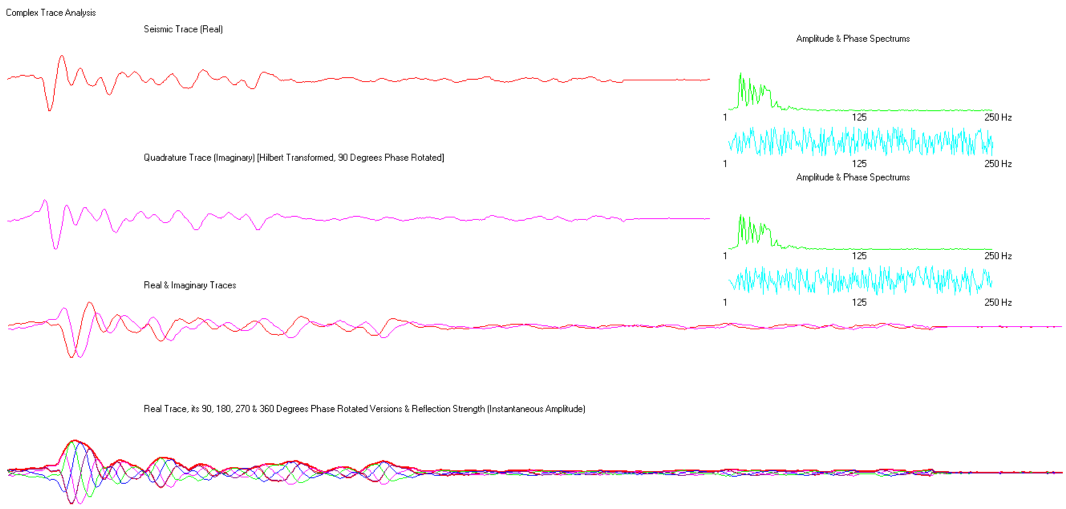


Figure 4.7 Detailed Seismic Complex Trace Analysis along with amplitude and phase spectrum (Khan & Akhter 2015)

4.3.3 Reflection Strength Attribute

Reflection strength attribute usually considered as envelop of a trace which represents the total instantaneous energy of the complex seismic trace which is independent of the phase. It is also termed as instantaneous amplitude attribute. First derivative of the envelope shows the variation of the energy of the reflected events. It is used to detect the possible fracturing and absorption effects. While the second derivative determines the measure of the sharpness of the envelop peak. Mathematically it is computed using the relation given below.

$$A(t) = \sqrt{f^2(t) + h^2(t)} = |F(t)|$$

Where A(t) is amplitude of the seismic trace, f(t) real component, h(t) quadrature component and F(t) is the amplitude of imaginary trace. The behavior of the instantaneous amplitude wavelet respective to seismic trace is shown in Fig 4.7. The envelope relates directly to the acoustic impedance contrasts. It can be used as an effective tool of distinction for the following characteristics:

- Bright spots, possibly gas accumulation.
- Sequence boundaries.
- Thin bed tuning effects.
- Major changes in depositional environment.
- Spatial correlation to porosity and other lithological variations.

The attribute is computed for seismic line SNJ-04 to see the major changes in lithologies. Even negative reflection coefficients such as limestone formation overlaid on clay formation would generate a positive response in this attribute. Fig 4.8 shows the envelope attribute map of SNJ-04. The thick (yellow) packages indicate the maximum reflection strength corresponding to the source, reservoir and seal rocks. It also shows spatial patterns representing changes in the limestone thickness and breakage due to the faults. In this case not every patch is scattered due to fault these weak reflections may because of interbedded sands or shale.

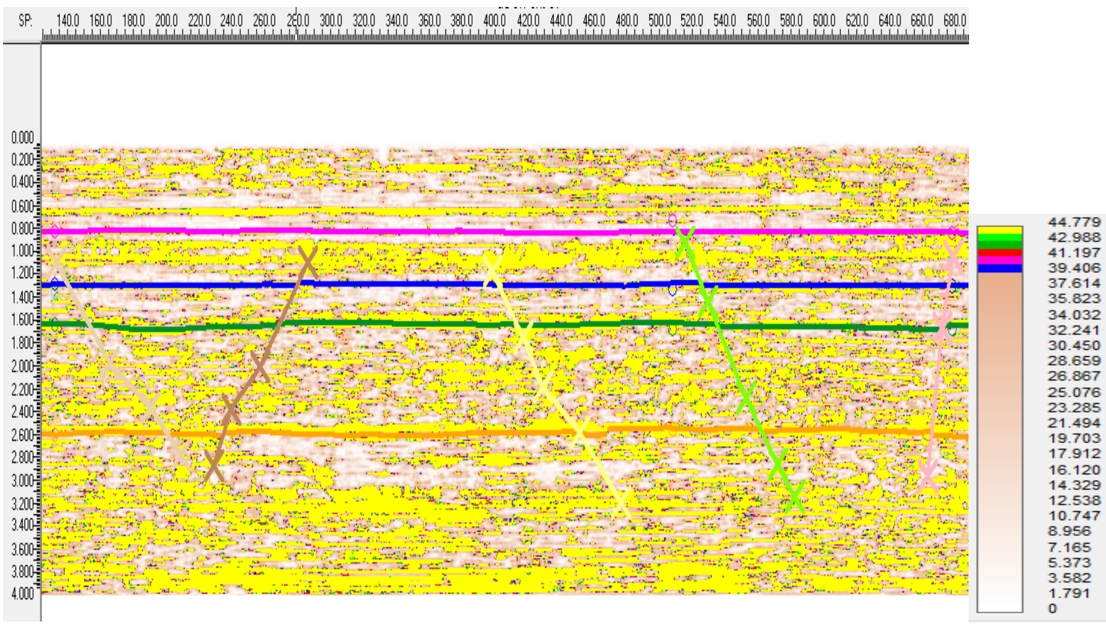


Figure 4.8 The Trace Envelope or Reflection Strength Attribute of seismic line SNJ-04 with marked reflectors and faults.

4.3.4 Instantaneous Phase Attribute

Wave fronts are the lines of constant phase, the phase attribute is one of the physical attributes and can be conveniently used for geometrical shape discrimination. It computes the phase for each seismic trace. It provides the measure of continuity of the reflector. The phase information is independent of seismic trace amplitudes and relates to the propagation of phase of the seismic wave front. It is computed from real and imaginary seismic traces using a mathematical relation as given below.

$$\Theta(t) = \tan^{-1}[h(t) / f(t)]$$

Where h(t) and f(t) are real and imaginary components of the seismic complex trace respectively.

Two different versions of instantaneous phase have been computed; one is for normalized maximum amplitude that is 1 and other is for amplitude 0.2, to clarify the independency of amplitude on phase shown in Fig 4.9 and Fig 4.10 respectively. With the decrease in amplitude the second trace shows very weak events while instantaneous phase remains undisturbed.

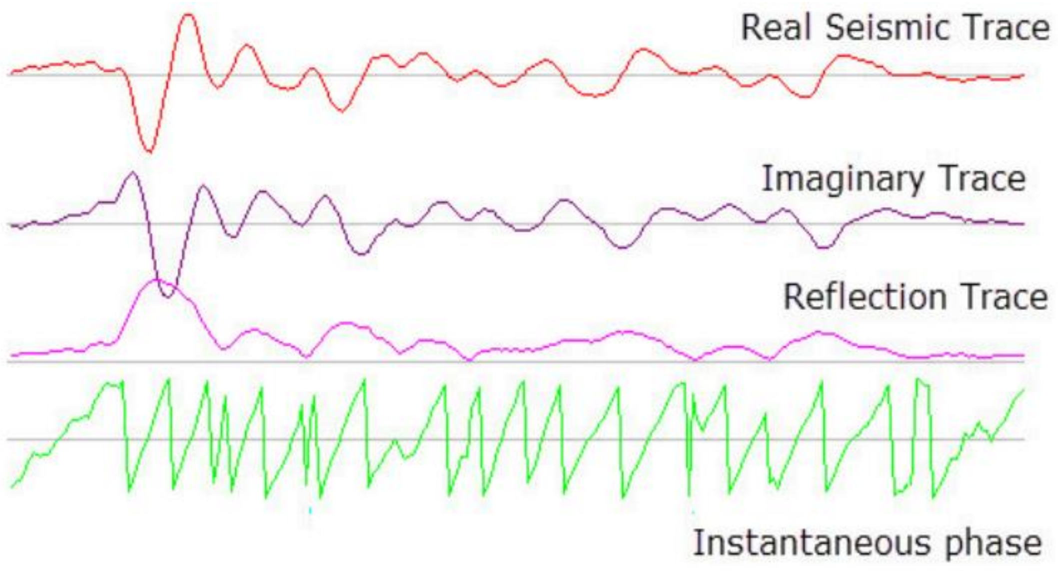


Figure 4.9 Seismic trace generated for amplitude 1 showing instantaneous phase variation respective reflection strength generated using Wavelets.

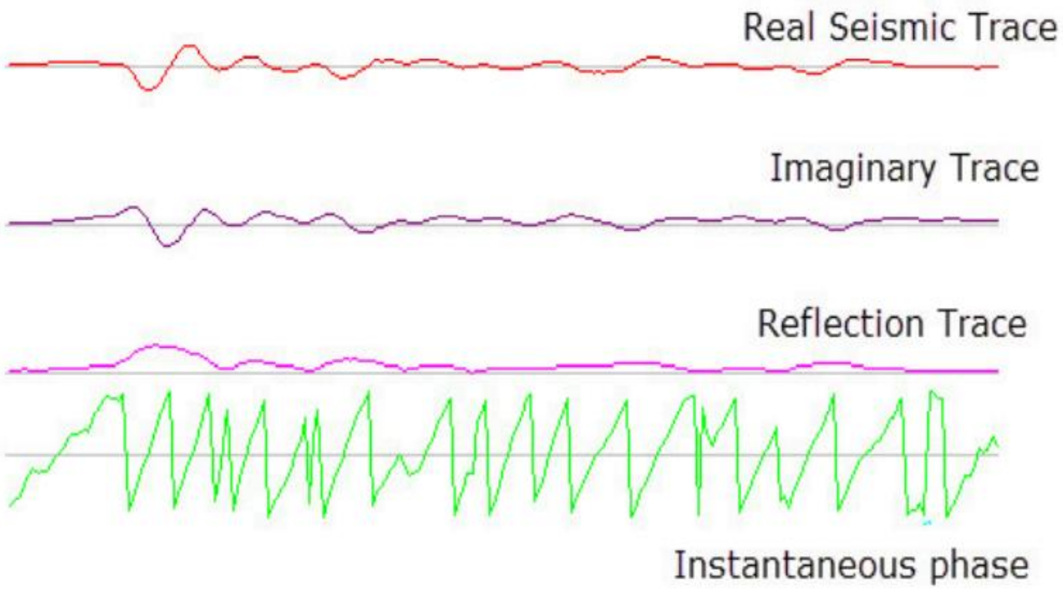


Figure 4.10 Seismic trace generated for amplitude 0.2 showing instantaneous phase variation respective reflection strength generated using Wavelets.

Now it is clear and proved that instantaneous phase is independent of amplitude. Instantaneous phase used for following purposes:

- Efficient indicator of reflector continuity.
- Relates to the phase component of wave propagation.
- Complete visualization of the stratigraphic events.

Time derivative of the phase attribute give rise to the new attribute termed as instantaneous frequency. In this attribute displays, the phase corresponding to each peak, trough, zero crossing, etc. of the real trace is assigned the same colour so that any phase angle can be followed from trace to trace. It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections. Figure 4.11 shows the instantaneous phase attribute which changes from -121.904º to +121.904º. In this display plus and minus 180 degrees are the same color (purple) because they are the same phase angle. The interpreted horizons lie over the zero phase regions indicated by different colors. In color bar negative value indicating negative phase. It can be observed in comparison to amplitude-based sections that the instantaneous phase shows much deeper horizons.

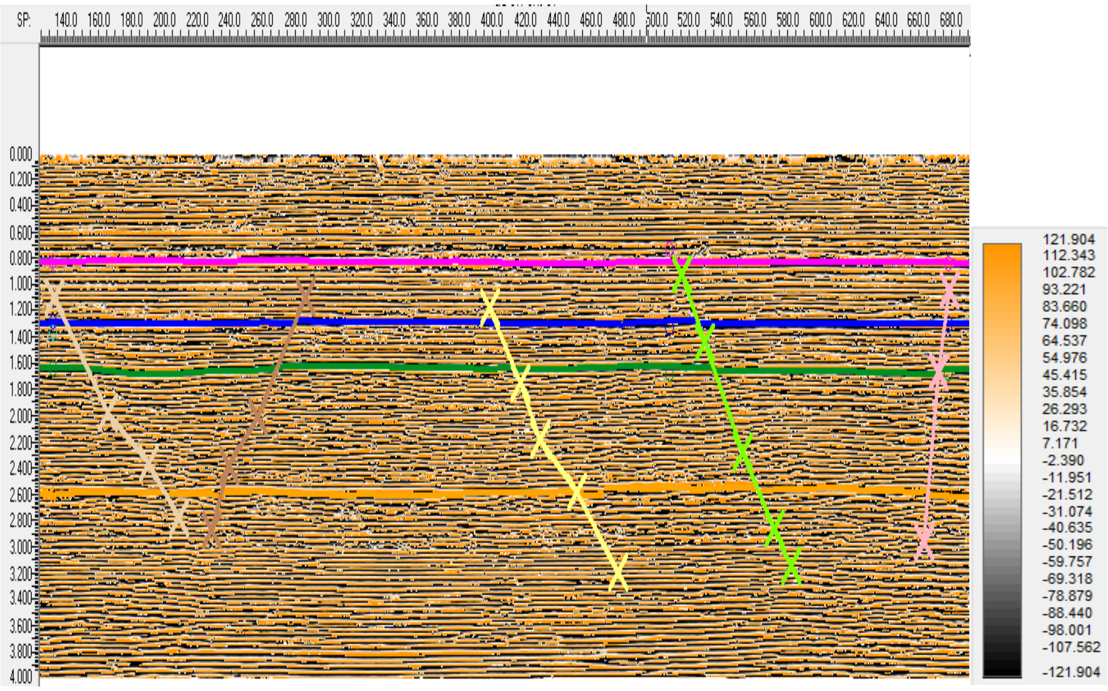


Figure 4.11 Instantaneous Phase Attribute of seismic line SNJ-04 with marked reflectors and faults.

4.3.5 Apparent polarity Attribute

Some of the instantaneous attribute like instantaneous frequency show very sharp and crispy signature therefore are difficult to interpret. Thus, wavelet attributes are computed over each cycle of the seismic trace (Khan, 2010).

Apparent polarity shows the blocky nature as it represents the average value over each cycle in the seismic trace which can be observed in Fig 4.12. Each peak in the reflection indicates the cycle.

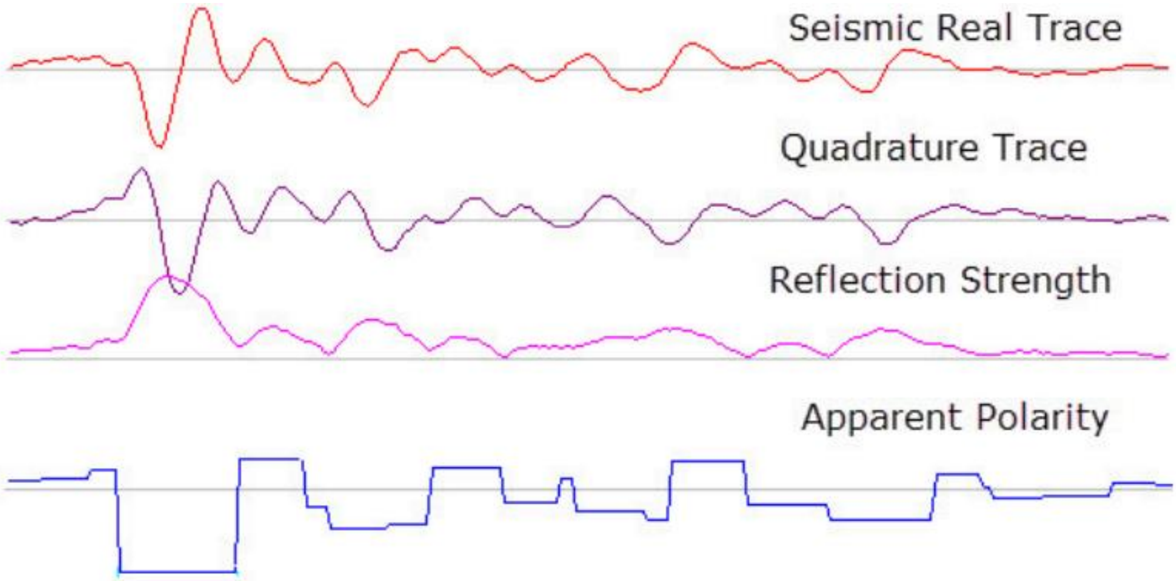


Figure 4.12 Behaviour of Apparent polarity respective to seismic real trace and reflection strength generated using Wavelets.

The procedure of obtaining the blocky behaviour is dependent of:

- Peak value of the reflection strength trace
- Nature either its peak or trough of the real seismic trace.

The wavelet attributes are calculated at the peak of the envelope, which represents the attributes of the wavelets within a zone defined by the trace envelope minima. These attributes indicate spatial variation of the wavelets and therefore relate to the response of the composite group of individual interfaces below the seismic resolution. The attribute individually highlights the seal, reservoir and source rocks as shown in Figure 4.13. Negative value in the colour bar indicating trough region of the seismic trace.

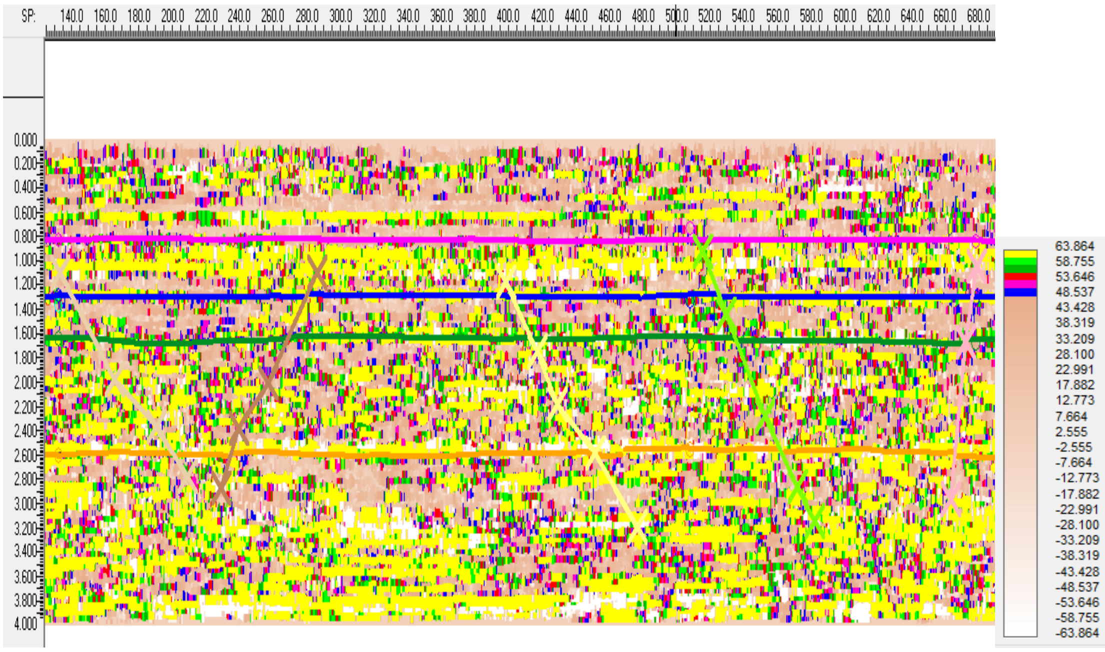


Figure 4.13 Apparent Polarity Attribute for seismic line SNJ-04 showing the reflectors and faults.

4.3.6 Basic Principles for Seismic Attributes

Using too many attributes will create problems instead of solving the issues. Review the attributes considering these following principles:

- Seismic attributes should be unique. When multiple attributes measure the same property, choose the one that works best.
- Never use seismic attribute without having knowledge about it.
- Seismic attributes represent subsets of the information in the seismic data. Quantities that are not the subsets are not the attributes.
- Attributes that differ only in resolution are the same attribute.
- Avoid overlay sensitive attributes.

Chapter 5

5 2D Seismic Modeling, Complex Velocity Model Building and AVA Modeling

5.1 2D Seismic Modeling

Structural Modeling of the interpreted digital geological cross-section of seismic line SNJ-04 was performed, to generate a synthetic 2D seismic section. It is the reverse process of seismic interpretation. In seismic interpretation we mark geological horizons whereas in seismic modeling we generate the synthetic seismic section. As this modeling is completely based on the structural data the derived synthetic section completely matches the structures. This type of modeling is commonly used to select acquisition parameters for new surveys based on existing geological cross-sections with velocities assigned to each formation. It is also used to get seismic response of stratigraphic models as well as confirmation of seismic interpretation. A synthetic source wavelet (Ricker) was generated. The wavelet generation interface along with the input parameters is shown in Figure 5.1.

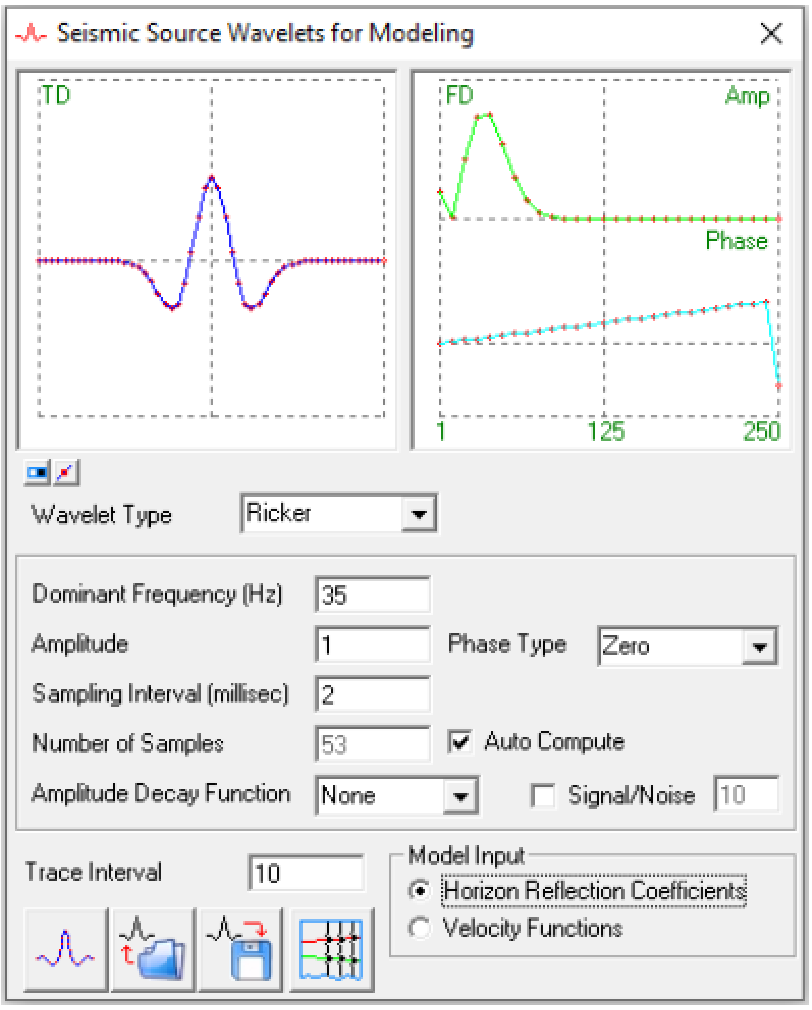


Figure 5.1 Source wavelet generation along with input parameters.

The geological section was convolved with the Ricker wavelet at CDP intervals 10 to generate a Zero Offset 2D synthetic seismic section. This section is like a migrated seismic section shown in Figure 5.2. All interpreted geological horizons were assigned reflection coefficient attributes.

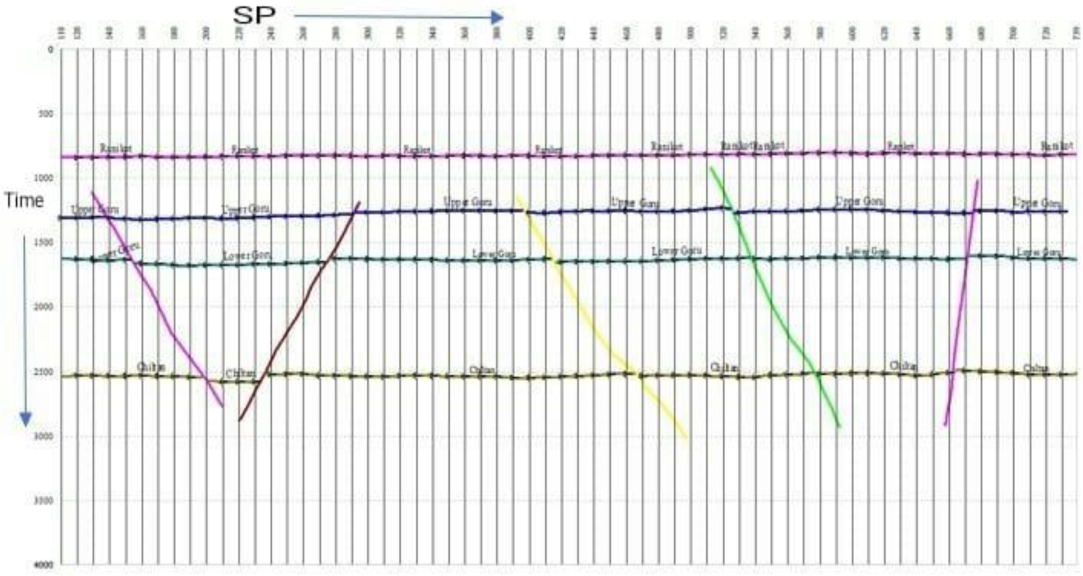


Figure 5.2 Marked geological cross section of seismic line SNJ-04 showing seismic model for each reflector.

5.2 LAYERED CAKE TIME MODEL

A Layered Cake Time Model (LCTM) consisting of flat horizons or time slices after every 100 milliseconds with nodes at every 5th CDP is generated for SNJ-04 seismic line as shown in Figure 5.3. The calibrated velocity functions are loaded and processed to generate an unsmoothed spatio-temporal velocity model. This velocity model is then used in time to depth conversion of the LCTM to generate a depth section (Figure 5.4) which shows the deformation of the LCTM in the form of pull ups & downs in the depth section due to lateral velocity variations. It can be observed that the depth section is not smooth due to fluctuations in the velocity model. Thus, a spatio-temporal smoothing with a 3x3 kernel operator is applied to generate a smoothed velocity model, which is again used in time to depth conversion of LCTM (Figure 5.5).

The resulting depth section is much smoother as compared to that in Figure 5.4. This concludes that velocity models must be smoothed to get realistic time to depth conversions. It also highlights the importance of lateral velocity variations in time to depth conversions which is ignored by some interpreters by simply averaging the velocity functions into a single function.

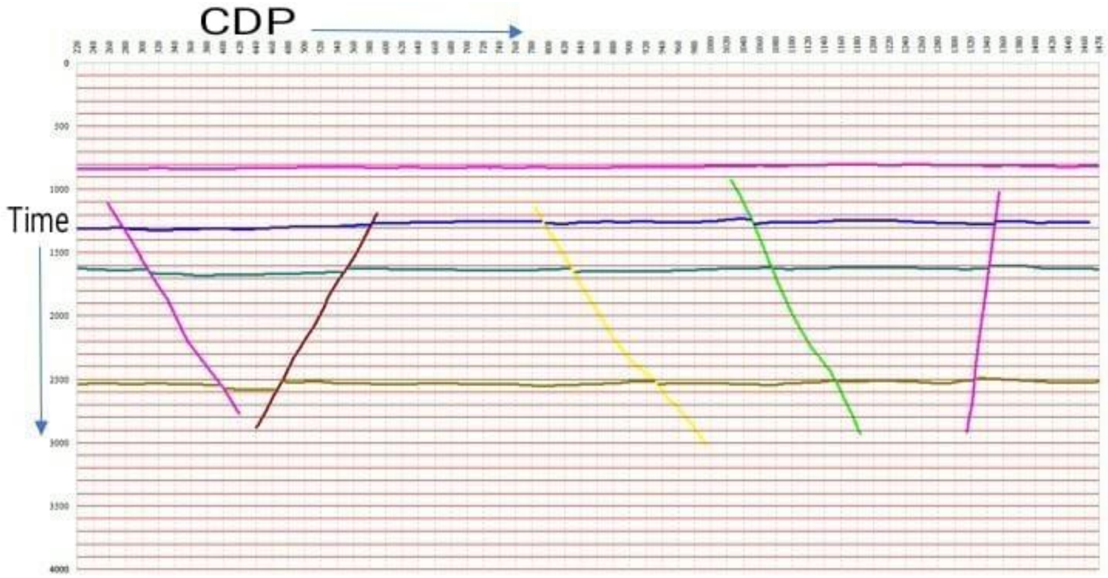


Figure 5.3: Layered Cake Time Model (LCTM) of seismic line SNJ-04.

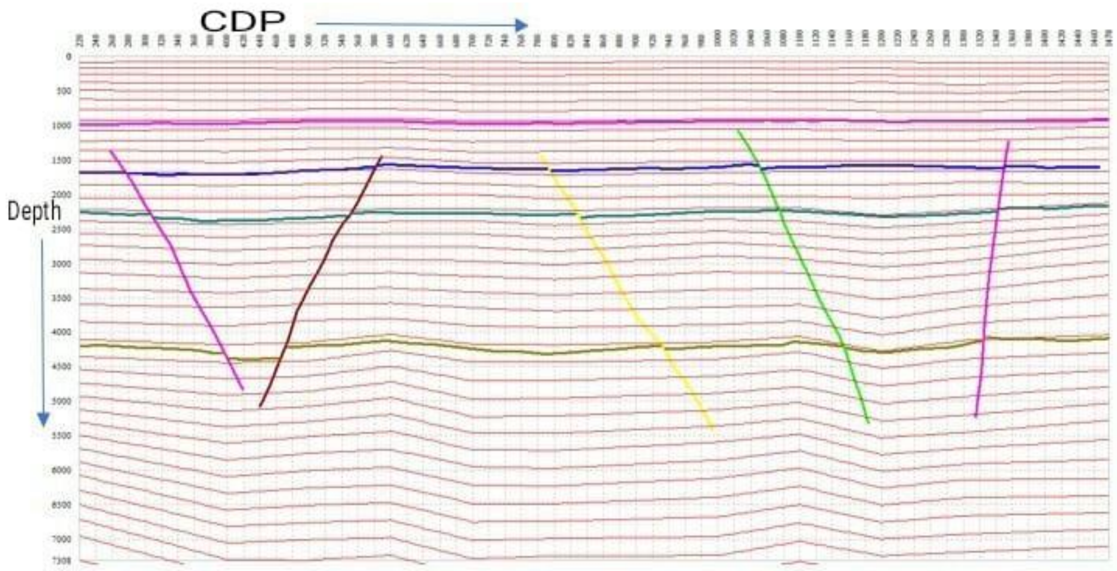


Figure 5.4: Depth converted LCTM with sharp pull ups and pull downs due to lateral velocity variations.

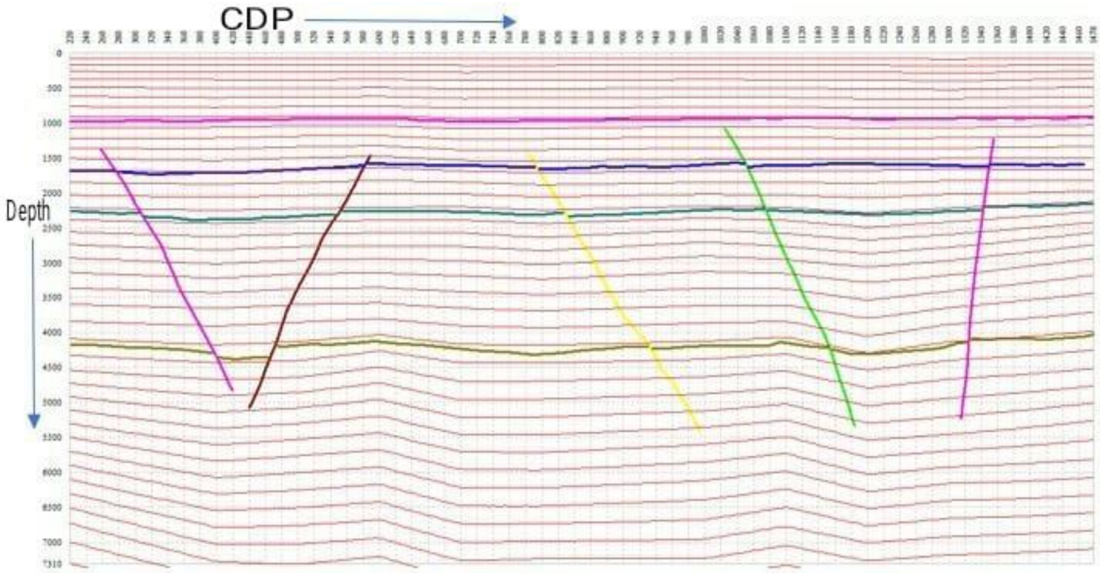


Figure 5.5: Effect of smoothed velocities on a depth converted section.

5.3 Complex Velocity Model Building

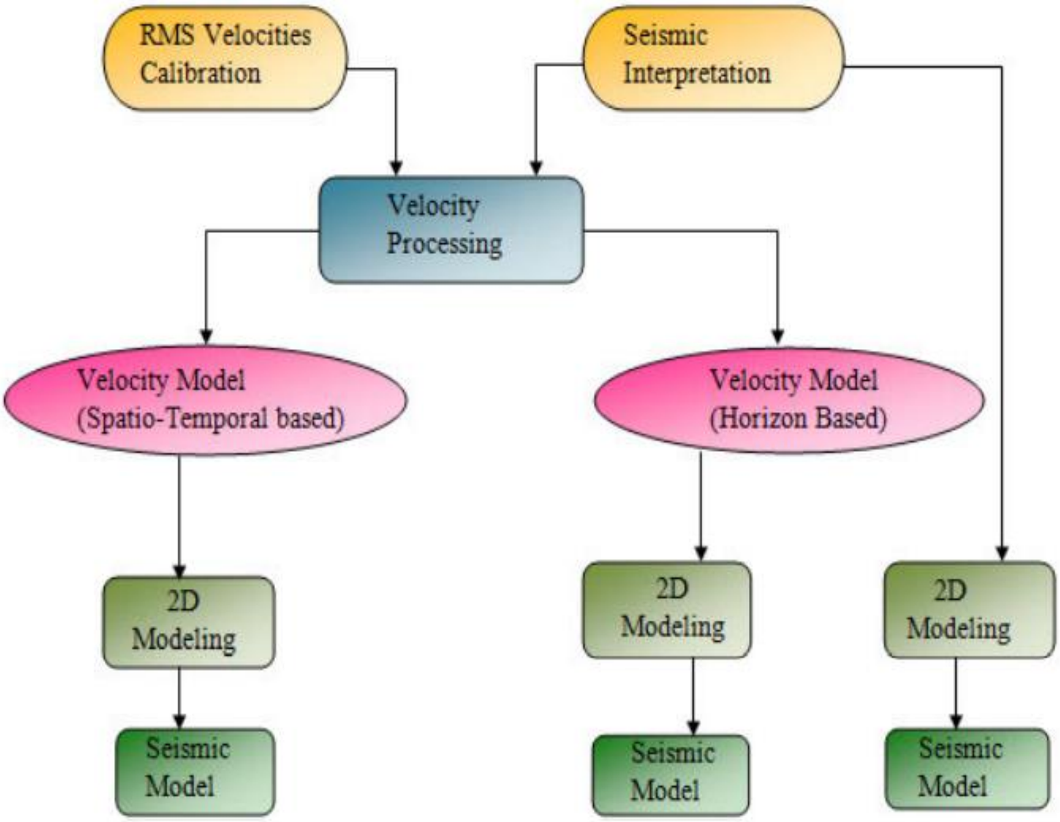
The seismic method is controlled by velocities, which is dependent of density and elastic moduli of rocks. In 1968, Penne Baker was one of the first who used velocities as a tool of interpretation. Being a drilling professional and not a geoscientist, he was interested in technological innovation problems such as drill-bit use and irregular pressure. Velocity is a macroscopic (wavelength-scale average) property of the rock depending upon the density and elastic properties of the minerals making up the lithology.

The velocities measured from any source are eventually turned into interval velocities which in turn are associated with lithologies. A velocity model is generated when interval velocities are properly associated with their corresponding lithologies. This model is further used for different applications.

We usually use velocities to stack and migration of seismic data, time to depth conversion of seismic section and time contour maps to depth contour maps. Mostly the velocities are measured from velocity analysis where stacking velocities are directly calculated from common depth point (CDP) stacks and common velocity analysis method are constant velocity stack (CVS), vertical seismic profiling (VSP) and check shot survey. (Taner & Koehler, 1969)

5.3.1 Velocity Interpolation and Modeling

The seismic velocity provides the base for seismic time to geological depth techniques. The first step towards the depth conversion is acquiring the best reliable velocity information. The velocity needs to be developed which can be used in many applications. This development is based on interpolation and smoothening of calibrated velocity functions. Workflow of velocity modeling using two interpolation techniques and their applications is described below.



5.3.2 Velocities for Modeling

2D seismic model is generated for SNJ-04 by using three techniques. Two of them are generated from the velocity, while the third is produced through interpreted seismic depth section for horizon reflection coefficient.

5.3.2.1 Spatio-Temporal Interpolation

The input RMS velocity functions are customarily velocity-time pairs (VT-Pairs) without fixed time intervals. The temporal (vertical) interpolation at 200 milliseconds is used to get velocity functions with VT-Pairs after regular time interval. The spatial (horizontal) interpolation is used to create at desired CDP for every 10th. The moving regular operator of 3 is used along each function for smoothing. This generates the spatio-temporal inserted Vrms. These Vrms (Sky-Blue) are then converted into Vint (Dark Green), Vavg (Dark Blue) velocities and Vrms nodes (Red) are shown in Figure5.6.

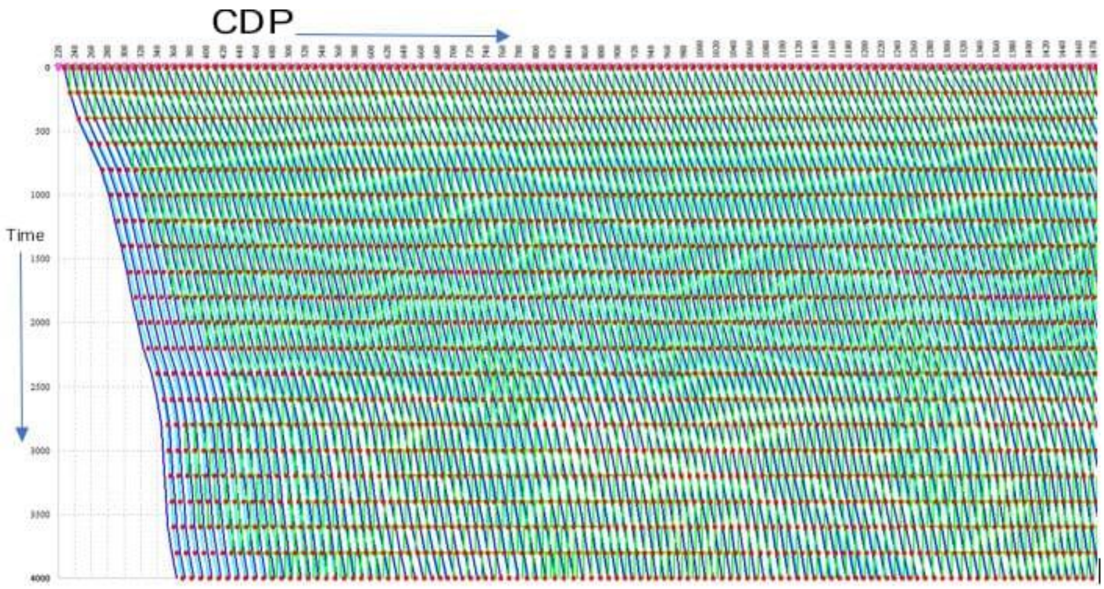


Figure 5.6 Spatio-temporal Velocity Model at temporal interpolation every 200 milliseconds and spatial interpolation at CDP interval 10 of seismic line SNJ-04.

5.3.2.2 Horizon Interpolation

The horizon interpolation is more complex criteria because it requires input of interpreted reflectors along with the velocity data. The velocity is interpolated along these reflectors. It requires computation of nodes for each reflector at the CDP interval. VT pairs are then interpolated at these nodes to create velocity functions. This type of velocity models is widely used for velocity modeling and Pre-Stack Depth Migration (PSDM). The velocity model established by this strategy closely matches the subsurface structure as shown in Figure5.7.

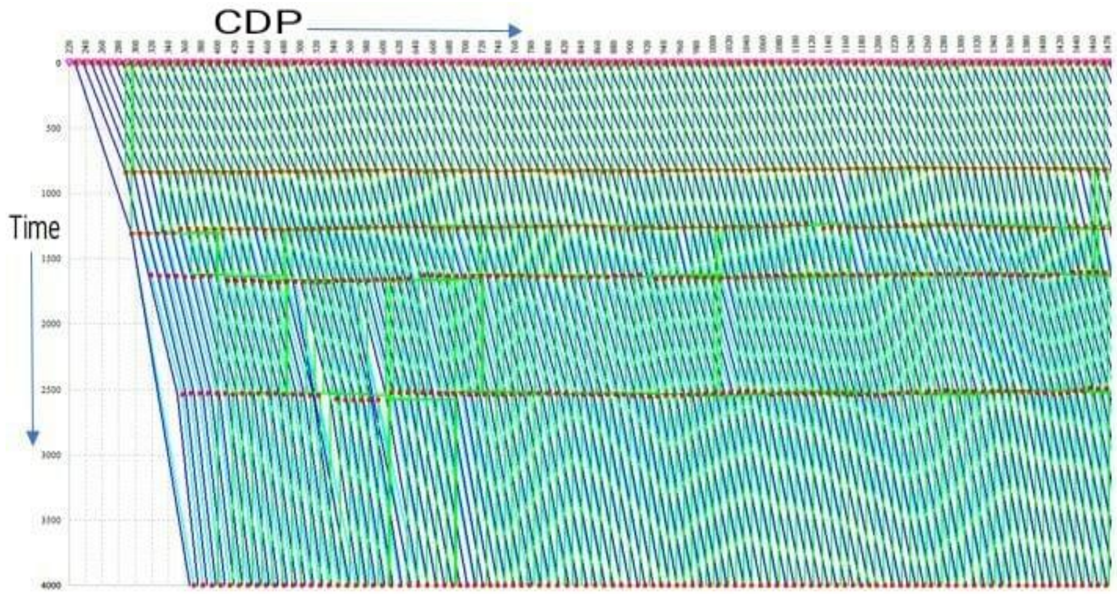


Figure 5.7 Velocity Model interpolated for velocity functions at every 10th CDP along the interpreted reflectors.

5.3.3 2D Seismic Model by Velocity

For 2D seismic velocity modeling a Ricker Wavelet of 35 Hz frequency without any amplitude decaying function is used as a source. The wavelet is convolved with velocity model on interpreted time sections at every 10th CDP to generate a seismic section.

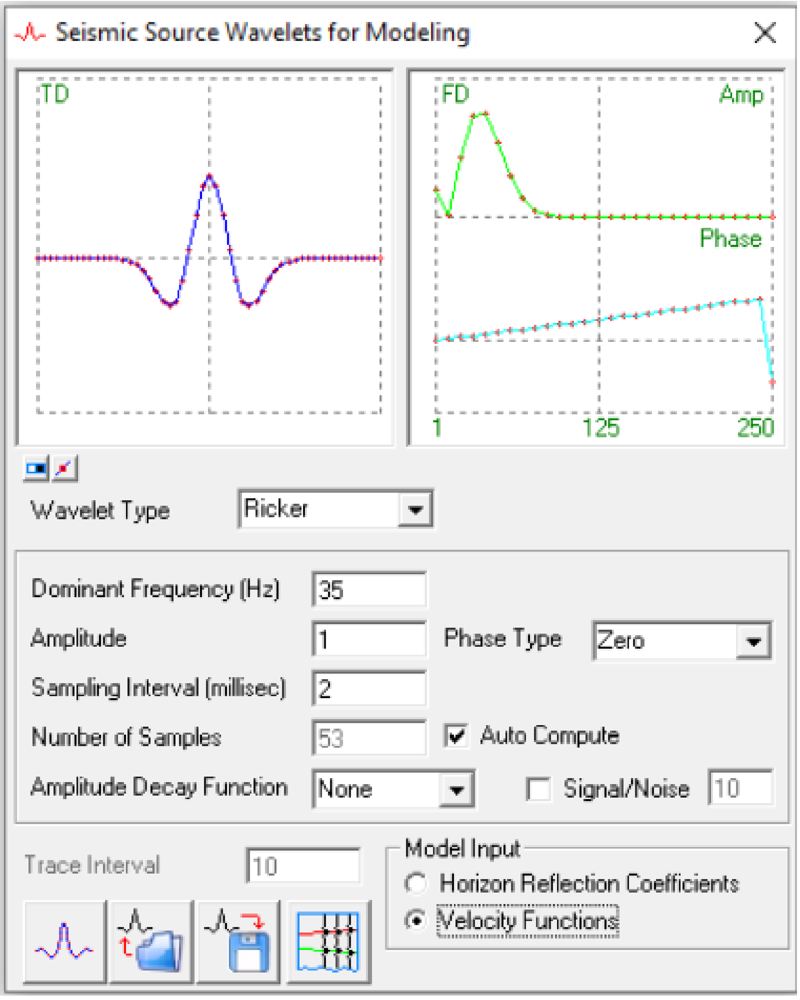


Figure 5.8 Seismic source wavelet generation at zero phase without amplitude decay function.

5.3.3.1 Seismic Model Based on Spatio-Temporal Velocity Interpolation

The spatio-temporal interpolated velocity model is used as input. The RMS velocity functions are converted into interval velocity functions. The interval velocity functions are used to generate reflectivity sequence which convolved with the source wavelet to generate seismic records developing a 2D seismic model. The seismic section generated from this technique does not display any structural feature as shown in Figure5.9. This indicates that structural information contained in original velocity functions is missing due to spatio-temporal interpolation. Thus spatio-temporal interpolated velocity model cannot be used in modeling and rock physics applications but can be used in time to depth conversion.

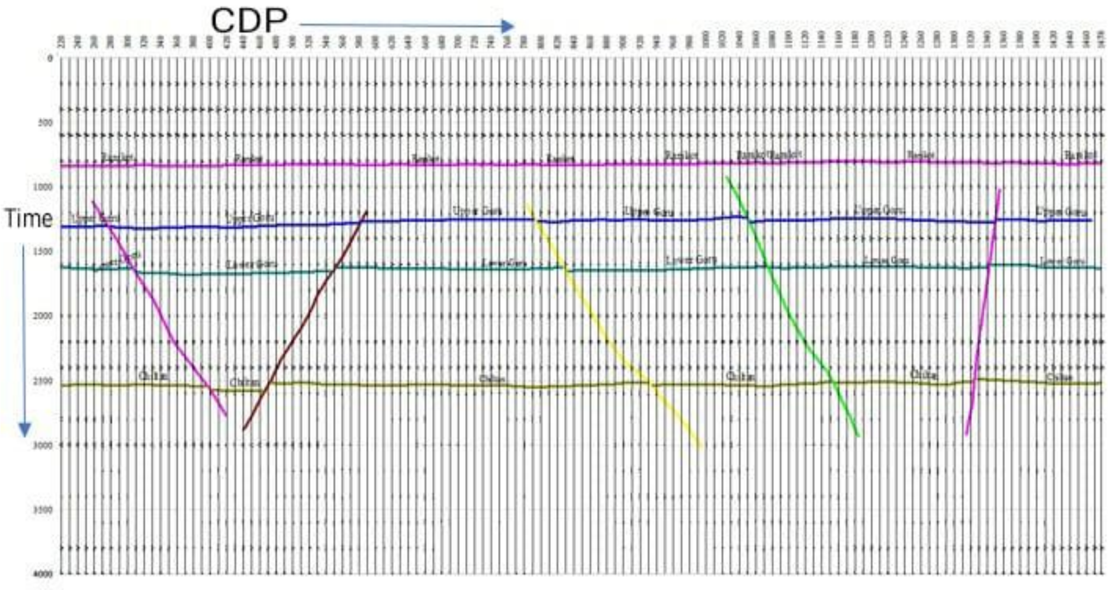


Figure 5.9 2D seismic model generated by using Spatio-Temporal velocity interpolation.

5.3.3.2 Seismic Model Based on Horizon Velocity Interpolation

The basic modeling process is the same as mentioned in the previous section, except horizon interpolated velocity model is used as input. The modelled seismic section generated by this technique is shown in Figure5.10. It can be noticed that this seismic model reveals affordable sub-surface picture clearly illustrating some structures. However, some closely packed layers are beyond the resolution of seismic velocities.

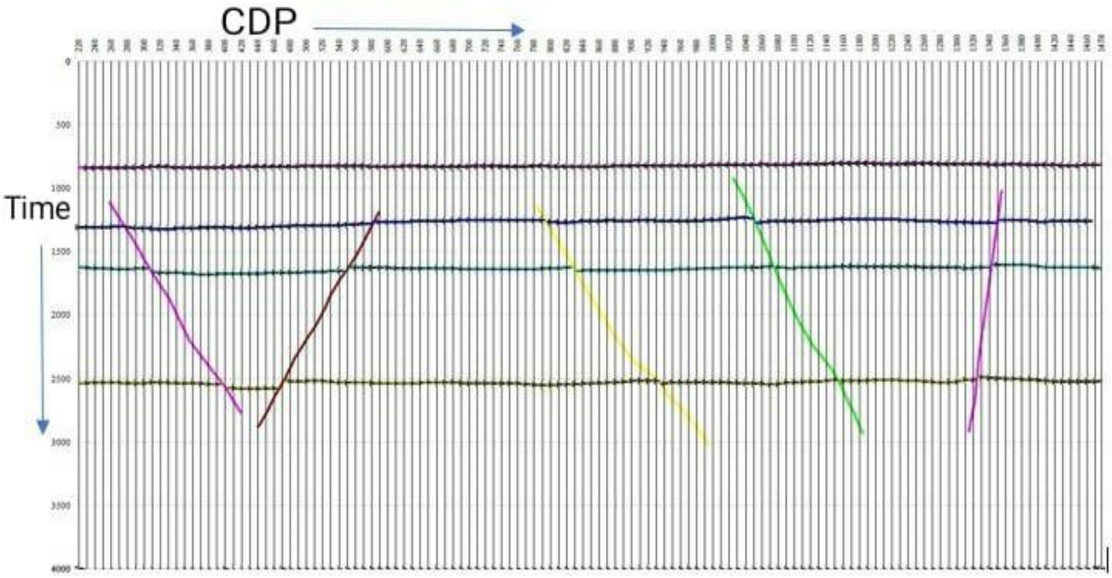


Figure 5.10 2D seismic model generated by using horizon velocity interpolation.

5.4 Conclusions

2D seismic model based on spatio-temporal velocity interpolation and horizon velocity interpolation have been generated as discussed in earlier sections. It can be observed that 2D seismic model based on spatio temporal velocity interpolation does not demonstrate subsurface structure so it can't be used in velocity modeling and rock physics analysis, though it can be used for time to depth conversion. Contrary to this, 2D seismic model based on horizon velocity interpolation displays the real subsurface structure which authenticate the interpretation.

5.5 Amplitude versus Offset/Angle (AVO/AVA)

AVO is the fingerprint of lithology and fluid. It has been found that Gas-sand reflection coefficients generally become more negative with increasing offset. High Gas Oil Ratio (GOR) light oil-saturated rocks may exhibit significant AVO anomalies. Offset is a surface data acquisition geometry based parameter we record seismic data as a function of offset, while the angle defines the subsurface direction at which the seismic ray strikes the horizon of interest, with respect to its normal. Zoeppritz equations and all its approximations are dependent on angle therefore the surface offsets (AVO) must be transformed into angle of incidents (AVA). There is a nonlinear relationship between offset and angle and the link between AVO and AVA is ray tracing in overburden as shown in Fig 5.11.

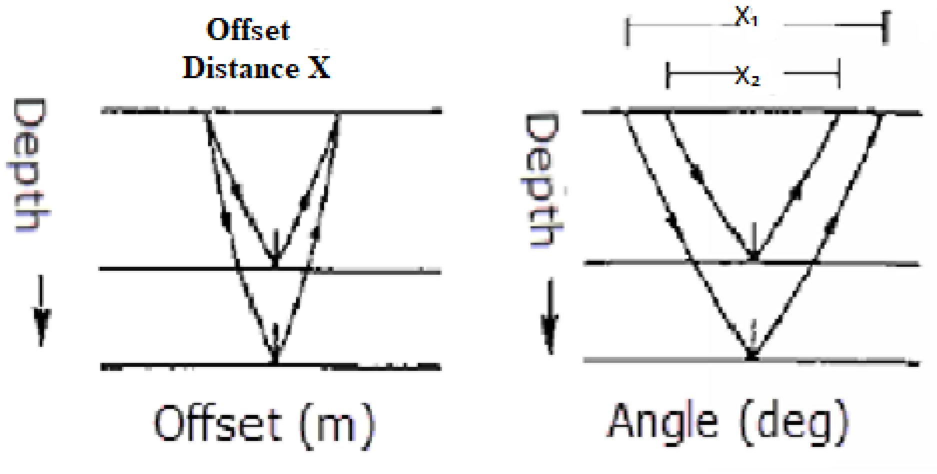


Figure 5.11 Relationship between Offset and Angle demonstrated through Raytracing.

5.5.1 Input Parameters from Petrophysical Logs

The petrophysical log of Chak66-01 has been used to calculate the Rock Physics parameters (Vp, Vs and RHOB). The LAS data is loaded in the Wavelets software for the depth range of 2700m to 3030m. Vp is calculated using the DT log and then by using the empirical relations Vs and RHOB are calculated. The input parameters for the Zoeppritz Calculator are shown in Table. By using the Blocky average tool, the average values of interval velocities are calculated as shown in figure 5.12.

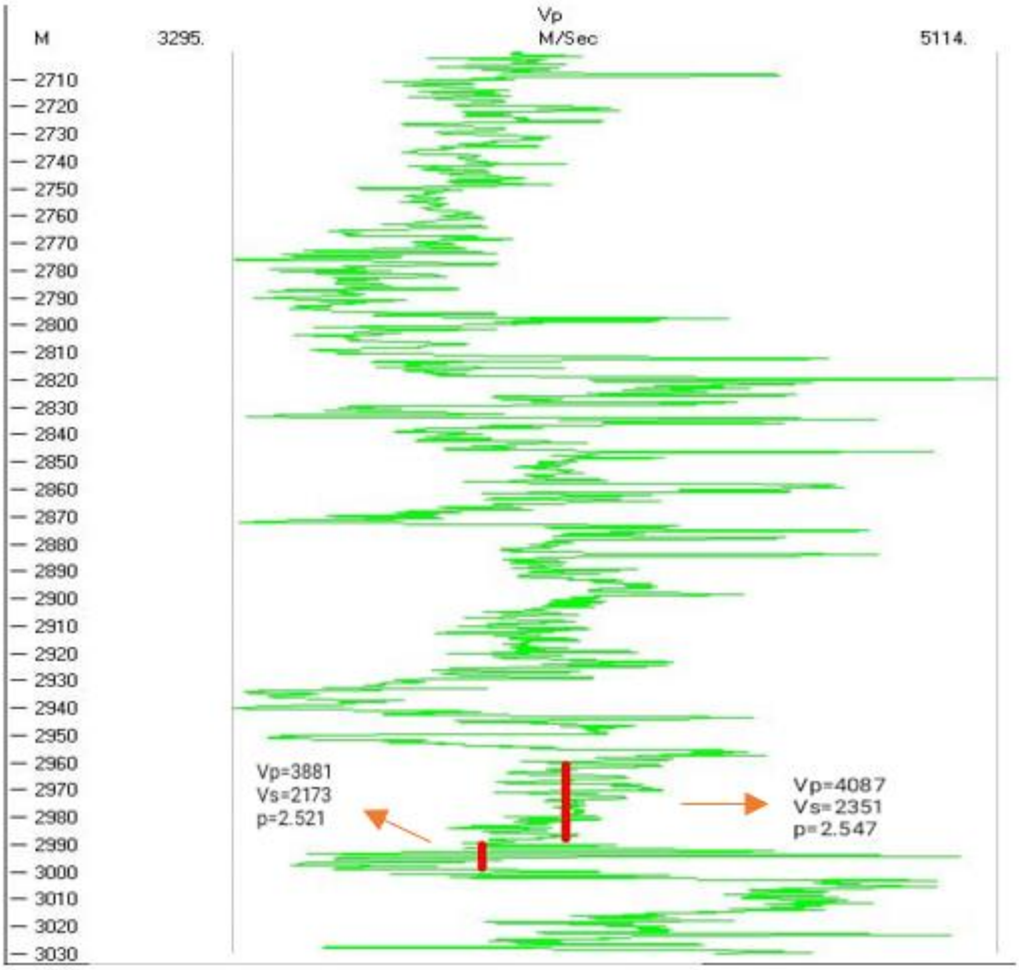


Figure 5.12 Primary velocities calculate using DT log for 2700 m to 3030 m depth range of Chak66-01 using Wavelets software.

Depth Range	Vp	Vs	RHOB
2960-2989	4087	2351	2.547
2990-3000	3881	2173	2.521

Table 5.1: The input parameters.

5.5.2 Computational Results

Zoeppritz Calculator calculates the reflection coefficients at the layer interface. It computes the reflection coefficients based on Zoeppritz energy partition equations and its various approximations for angle of incidents ranging from 0° to 90°.

Figure 5.13 shows graph of reflection coefficients versus angle of incidence (0° to 90°), computed using Shuey method is plotted on the graphics display.

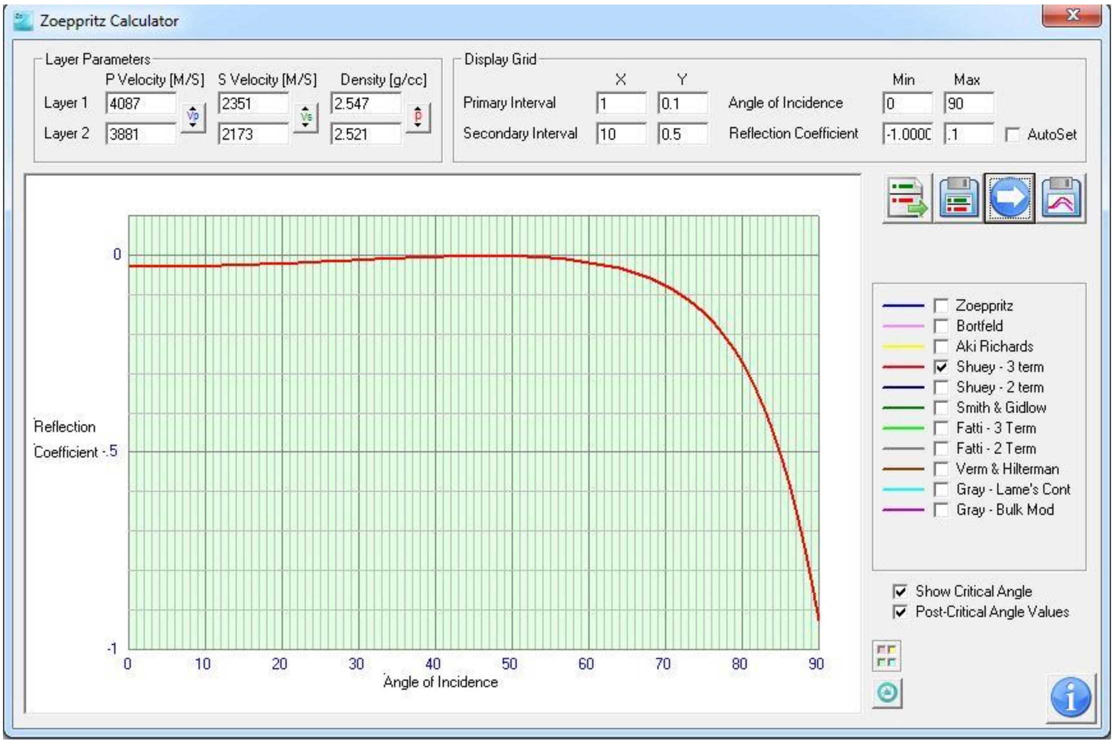


Fig. 5.13: Zoeppritz Calculator program interface showing the input parameters and the computed reflection coefficients graph.

5.5.3 Amplitude Versus Angle Modeling

AVA modeling is done using wavelets software. AVA synthetic gathers are generated using petrophysical logs and the logs calculated from these petrophysical logs. AVA synthetic gathers at the depth of 2990m clearly shows the reflection coefficients become more negative with increasing angle or higher angles. This shows the availability of Gas sand reservoir.

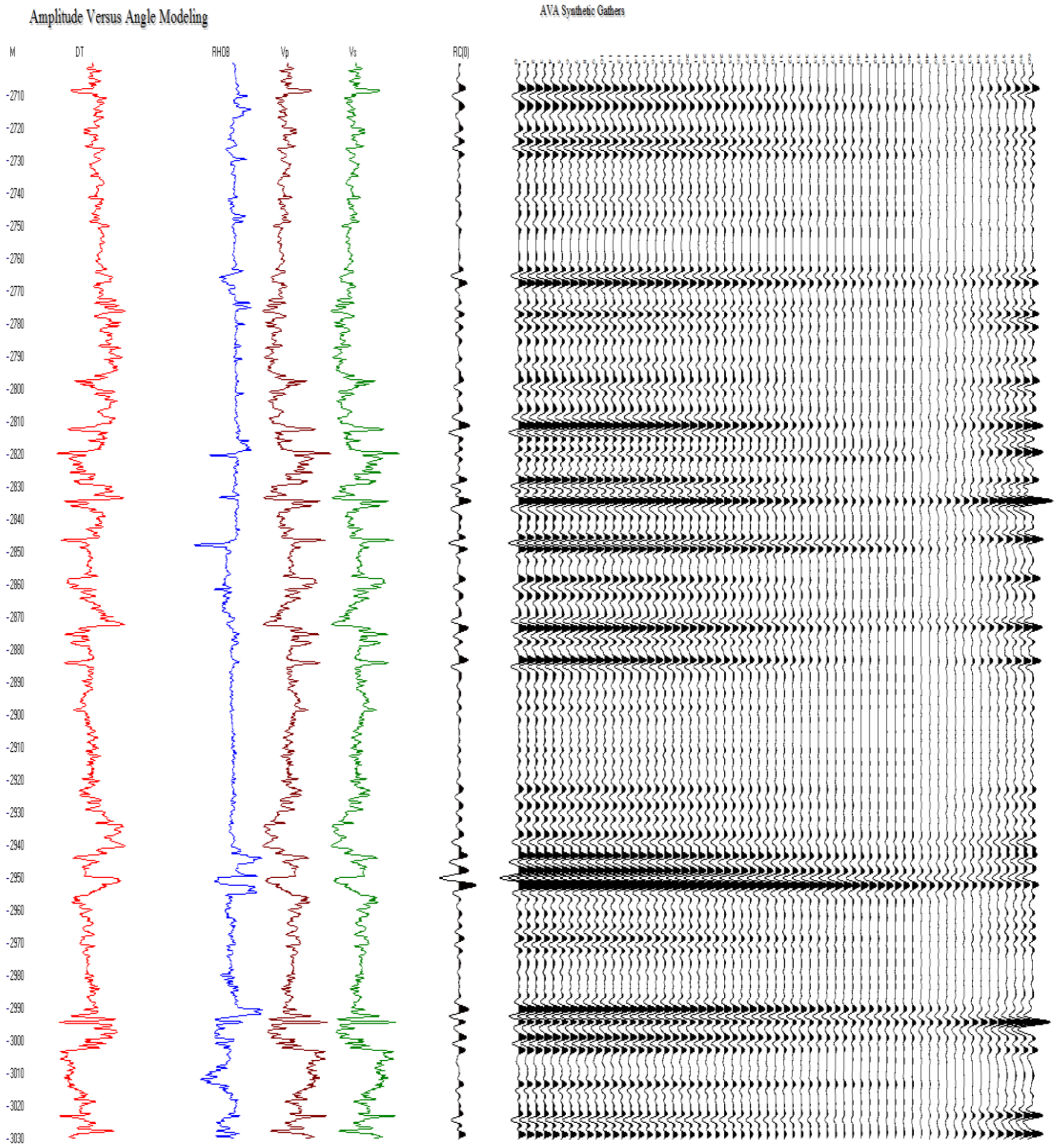


Figure 5.14: AVA modeling.

Conclusions and Recommendations

Conclusions

- Four reflectors are marked on the interpreted seismic sections using formation tops: Ranikot (Reflector 1), Upper Goru (Reflector 2), Lower Goru (Reflector 3) and Chiltan (Reflector 4).
- Study area is in extensional regime having step faulting along with horst and graben structures which is confirmed by the seismic attribute analysis.
- Velocity is generally increasing with the depth due to compaction of rocks.
- The velocity analysis of the area allows the conversion of time section to depth sections which presented the real scenario of sub surface.
- The reflection strength attribute computed across a seismic line though confirmed the reflector marking but remain unsuccessful in identifying oil-gas accumulation.
- Instantaneous phase attribute provided good results and the precise positions of faults.
- The increase of amplitudes with angle is an established indicator of hydrocarbons especially gas sands. The AVA synthetic modeling clearly indicates oil and gas sands with good deviation of hydrocarbons saturated reflection coefficient curve.

Recommendations

- Velocity analysis indicates vertical as well as lateral variations in seismic velocities which highly influence the time to depth conversion, seismic modeling and rock physics analysis.
- The spatio-temporal and horizon slice interpolation algorithms indicate that horizon interpolation generates a robust velocity model.
- Build a velocity model of the area using horizon slice-based interpolation which can be used in further analysis including Pre-Stack Depth Migrations which is very sensitive to velocity data.

References

Ahmed, N., Mateen, J., Shehzad, K. Ch., Mehmood, N., Arif, F., 2011. Shale gas potential of lower Cretaceous Sembar formation in Middle and Lower Indus Basin, Pakistan. SPE PAPG Annual Technical Conference, 22-23 November, p. 235-254.

Coffeen, J.A., 1986. Seismic exploration fundamentals, Penn Well Publishing Company, Tulsa, Oklahoma.

Dix, C. H., 1955. Seismic Velocities for Surface Measurements. Geophysics, 20, 68-86.

Dobrin and Savit.,1988, Geophysical Exploration, Hafner Publishing Co.

Gadallah, J., and Fisher, I., 2009. Exploration Geophysics, Springer-Verlag Berlin Heidelberg. DOI: 10.1007/978-540-85160-8.

Kadri, I. B., 1995. Petroleum Geology of Pakistan. Karachi: Ferozsons (Pvt) Ltd.

Kazmi [et al.] Geology and Tectonics of Pakistan [Book]. - Karachi: Graphic Publishers,1982.

Kazmi, A.H., and Jan, M.Q., 1997, Geology and Tectonic of Pakistan, Graphic publishers, Karachi, Pakistan.

Kearey, P., Brooks, M., & Hill, I. (2002). An Introduction to Geophysical Exploration. Blackwell Science Ltd

Khan, K.A., 2009. Seismic Methods, Digital Courseware Series, 2nd Edition.

Khan, K.A, 2010. Seismic The Next Step Series: Seismic Attributes, OIST, Islamabad.

Khan, K.A., and Akhter, G., 2011. Workflow shown to develop useful seismic velocity models, Oil & Gas Journal, Vol.109(16), pp.52-61.

Khan K.A. and Akhter, G., 2015, Computer-Based Experiments for Learning Seismic Signal Processing Concepts, Computer Applications in Engineering Education, Vol. 23, 959-966. Doi: 10.1002/cae.21669

Khan, K.A., 2013. Seismic-The Next Step Series: Rock Physics Analysis, OIST, Islamabad.

McQuillin, R., Bacon, M., and Barclay, W., 1984. An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road London

Shah, S.M.I., Ahmed, R., Cheema, M.R., Fatmi, A.N., Iqbal, M.W.A., Raza, H.A., and Raza, S.M., 1977. Stratigraphy of Pakistan. Geological Survey of Pakistan, Memoirs, v. 12, p.137.

Shah, S.M.I., 2009. Stratigraphy of Pakistan. Geological Survey of Pakistan, Memoirs, v.22.

Sheriff R. E., Telford W. M., and Geldart L. P., 1990, Applied geophysics, Cambridge University Press.

Taner, M.T., and Koehler, F., 1969. Velocity spectra – digital computer derivation and applications of velocity functions, Geophysics, Vol.34, pp.859-881.

Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1999, Applied Geophysics, Cambridge University Press, London.

Vermeer, Gijs J.O, (2002). 3D Seismic Survey Design Soc. of Exploration Geophysicists. Tulsa, OK.