A Summer Training report on

"3-D SEISMIC & WELL LOGS DATA INTERPRETATION OF LOWER VINDHYAN GROUP OF SON VALLEY, VINDHYAN BASIN"

OIL AND NATURAL GAS CORPORATION LIMITED (VINDHYAN BLOCK, FRONTIER BASIN)

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Declaration by the scholar

I hereby declare that this report submission on the project titled "**3-D SEISMIC AND WELL LOGS DATA INTERPRETATION OF LOWER VINDHYAN GROUP OF SON VALLEY, VINDHYAN BASIN**" carried out during 1st July, 2019 to 30th July, 2019 is my own work and that to the best of my knowledge and belief, it neither contains any material previously published or written by any other person, nor any material which has been accepted for the award of any other Degree or Diploma of the University or any other Institute of Higher Studies, except where due acknowledgement has been made in the text.

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CERTIFICATE

This is to certify that Mr. Rishabh Kumar, a student of 3rd Year Integrated M.Sc. Applied Geology at IIT Kharagpur has successfully completed his summer training on the topic **"3-D SEISMIC AND WELL LOGS DATA INTERPRETATION OF LOWER VINDHYAN GROUP OF SON VALLEY, VINDHYAN BASIN"** from 1st July to 30th July, 2019 at Frontier Basin, KDMIPE Campus, ONGC, Dehradun. He has been exposed to Seismic Interpretation of subsurface data using PETREL software which is vital in identifying prospective areas of Hydrocarbon.

During his training he has maintained excellent discipline, punctuality and code of conduct. I wish all success for him.

30/07/2019

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ABSTRACT

The report deals with the integrated interpretation of 3-D seismic data to bring out some G&G evaluation of the area of interest. The objective of seismic data interpretation is to extract all available subsurface information from the processed seismic data. Key interpretation skills, which include synthetic seismogram generation, well-to-seismic tie, well logs correlation, fault interpretation, seismic horizon interpretation and mapping, being performed with PETREL software.

Project started with loading and QC of well data and a volume of 3-D seismic data in the PETREL software. Further step involves well logs interpretation and generation of Synthetic Seismogram. After picking prominent reflections in the seismic profile that depict the probable mappable horizons of our interest. Based upon these interpreted horizons further calibration and tracking are made. After the picking of the horizons, horizons are correlated over the given 3D seismic data.

In the present work, horizons **Basement, Kajrahat Limestone, Jardepahar Porcellanite, Charkaria Olive Shale, Mohana Fawn Limestone, Basuhari Shale, Lower Rohtas, Middle Rohtas, Upper Rohtas** were correlated and picked throughout the seismic data. After that with the help of one of the 'Make Surface' feature of PETREL, the Time Thickness map and Time Structure map of Lower Vindhyan were prepared.
This exercise has given an exposure to the various practices of the G & G data interpretation for identification of prospective areas for exploration of hydrocarbon.

ACKNOWLEDGEMENTS

On the successful accomplishment of this summer training, I would like to take this opportunity to extend my deepest sense of gratitude and appreciation towards those who extended all support and facilities without which this report would not have seen the day light. I deem it a proud privilege and feel immense pleasure to acknowledge all those who are directly or indirectly involved. First and foremost, I am grateful to **Mr. Tarun Shah**, ED-Basin Manager, Frontier Basins, Dehradun for having provided a chance to work in Frontier Basins. I extend my deepest gratitude to **Mr. Vinod K. Arya**, **CGM**-Block Manager, Vindhyan Block for providing a nice working environment for successful completion of my project work in Frontier Basins. I also thank **Dr. Sanjay Ojha, Chief Geologist** for exposing me to the working processes of a geologists in ONGC.

I consider myself fortunate and privileged to have worked under the supervision and guidance of **Mr. Sandeep Kumar (Sr. Geologist),** Frontier Basin, ONGC Ltd., Dehradun. His dedication to research, meticulous planning, counsel and unreserved help served as a beacon light throughout my summer training. With deep sense of gratitude, I thank him for his unflinching and invaluable inspirations, the introspective guidance and active persuasion throughout my summer training. His professional expertise, ideas and passions in science exceptionally inspire and enrich my growth as a student and a researcher. Some words of acknowledge will never substitute for the knowledge I have acquired from him.

I am also thankful to **Mr. Subhagya Kumar Patel (Sr. Geologist), Mr. Rajeev Ranjan Prasad (Sr. Geophysicist), , Mr. Abhishek Mishra (Sr. Geophysicist), Mr. Suryansh Suyash (Sr. Geologist), and Mr. Ram Singh (Geophysicist)** of Frontier Basin, ONGC, Dehradun for their enthusiastic help throughout the Summer Training work and enabled me to complete this summer training work comfortably.

CONTENTS

INTRODUTION

The Vindhyan Basin is situated in the central part of in India. The Vindhyan Basin is a classic example of Proterozoic arcuate shaped Intracratonic basin developed in the central part of the Indian shield along with several other basins such as Cuddapah, Chattishgarh etc. The Vindhyan Basin containing Max. 5000m thick sequence of mostly sandstones, shales and limestones, occupies an area of about 1,62,000 sq.km of shallow marine sedimentary sequence of Proterozoic age of which about 80,000 sq.km extends in the Ganga valley in the north and northeast beneath the Tertiary sediments of Himalayan foredeep. In the southwest, the Vindhyan rocks are covered by Deccan volcanic. The basin is spread over the states of Rajasthan, Madhya Pradesh, Uttar Pradesh and Bihar. The basin is bounded on the northwest by Delhi Aravalli orogenic belt (the Great Boundary Fault of Rajasthan) and on the south and southwest by the Son Narmada Lineament. The basin is divided into two parts – **Chambal Valley** area in the west and **Son Valley** in the east. Bundelkhand Massif is situated in the north central part of the basin. The southern part of Chambal valley covered under the Deccan Trap.

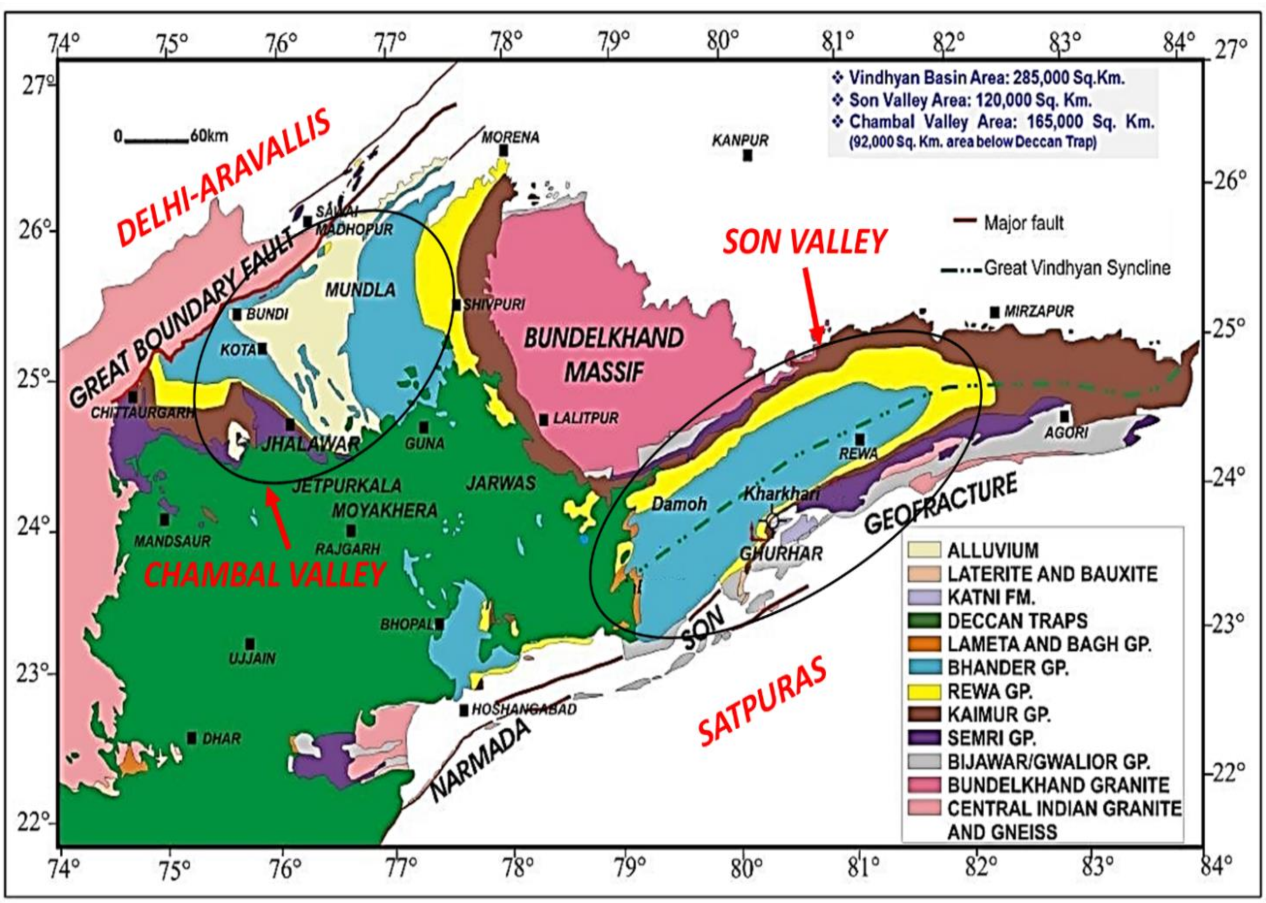


Fig1: Geological map of Vindhyan Basin and its two subdivisions-Chambal and Son Valley

Area of Study:

Southern part of Son valley of Lower Vindhyan Basin has been attempted and the aim was to carry out a regional study based on well log data integrated with seismic inputs for hydrocarbon perspectivity analysis of Vindhyan Basin.

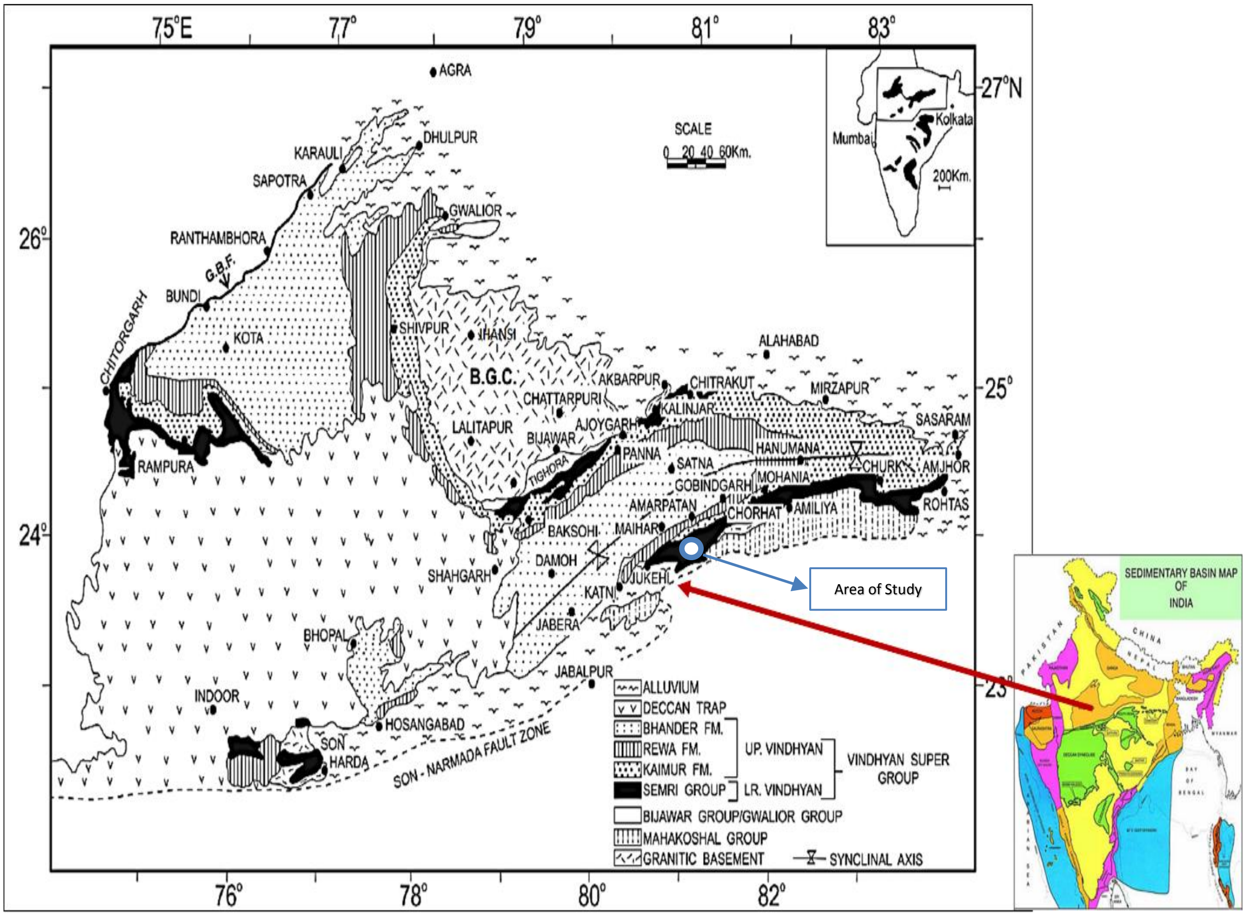


Fig2: Geological map of Vindhyan Basin showing its position in Indian Sub-continent and the associated major lithounits

Regional Geology:

The Vindhyan Basin extends from Dholpur in the north to Khandow in the south and from Sasaram in the east to Chittorgarh in west. The greater part of the basin in Chambal valley is covered by Deccan Trap flow erupted during cretaceous to Oligocene in the south & southwest of the basin. Basin bordered by the Precambrian Gneisses and metasediments in the east and southeast while to north it extends beneath the Gangetic alluvium. In Son Valley the Lower Vindhyan rocks have been fully developed and well exposed in the southern part of the basin. In Son Valley area the Vindhyan supergroup tectonically less disturbed, flat lying with a gentle slope towards the South.

Tectonic setting of Vindhyan Basin:

Vindhyan Basin, a Proterozoic basin, covering an area of more than 2 lakh sq.km and containing 3-6 Km thick shallow marine clastic and carbonate sediments, is the largest sedimentary basin in the peninsular India, in terms of areal extent and sedimentary thickness. The tectono-sedimentation limit of Vindhyan Basin in south and south-east is marked by the Son Narmada Lineament (SNL), which demarcates Vindhyan Basin from the Satpura Basin towards south. The western margin of the basin is marked by the Great Boundary Fault (GBF), separating the basin from the Aravalli-Delhi orogenic belt. The northern limit of the basin is marked by the Bundelkhand Massif and Indo-Gangetic plains, while in the east the Vindhyan outcrops extend up to Sasaram and are bounded by Monghyr-Saharsa ridge. Substantially thick Vindhyan equivalent rocks have also been recognized under the Gangetic alluvium. The south western part of the basin is covered by Deccan Trap.

The Bundelkhand Massif, located in the north-central part of the basin, divides the Vindhyan Basin in to two sectors: Chambal-Valley in the west and Son-Valley in the east. The basin fills in Son-Valley constitutes a considerable thickness (2-6Km) of unmetamorphosed, varyingly deformed sedimentary succession, which is divisible into carbonate dominated Lower Vindhyan (Semri Group) and clastic dominated Upper Vindhyan (Kaimur, Rewa and Bhander Groups) sequences, separated by a large hiatus. While, in Chambal-Valley sector of Rajasthan, the sequence is dominated by clastics and no major hiatus has been observed between Upper and Lower Vindhyan. Early phase of tectonic evolution of Vindhyan Basin is controlled by basement related rift tectonics which formed a number of horst and grabens along planes of weakness. Two main fault trends are evident, faults parallel to the SNL (E-W to ENE-WSW) as well as NW-SE aligned oblique faults. The major half grabens are located along the down thrown side of these rift related faults. Some of these faults show syn-sedimentary vertical movements. In later phase of evolution, compressional reactivation of pre-existing extensional faults under the influence of wrench related strike–slip movement along the Son-Narmada Lineament (SNL) resulted in the formation of inversion structures like Damoh, Jabera and Kharkhari. Major oblique faults divide Son-Valley into a number of tectonic blocks, notable among them are the Udaipur-Tendukhera block, Jabera-Damoh block and Satna-Rewa-Kaimur block.

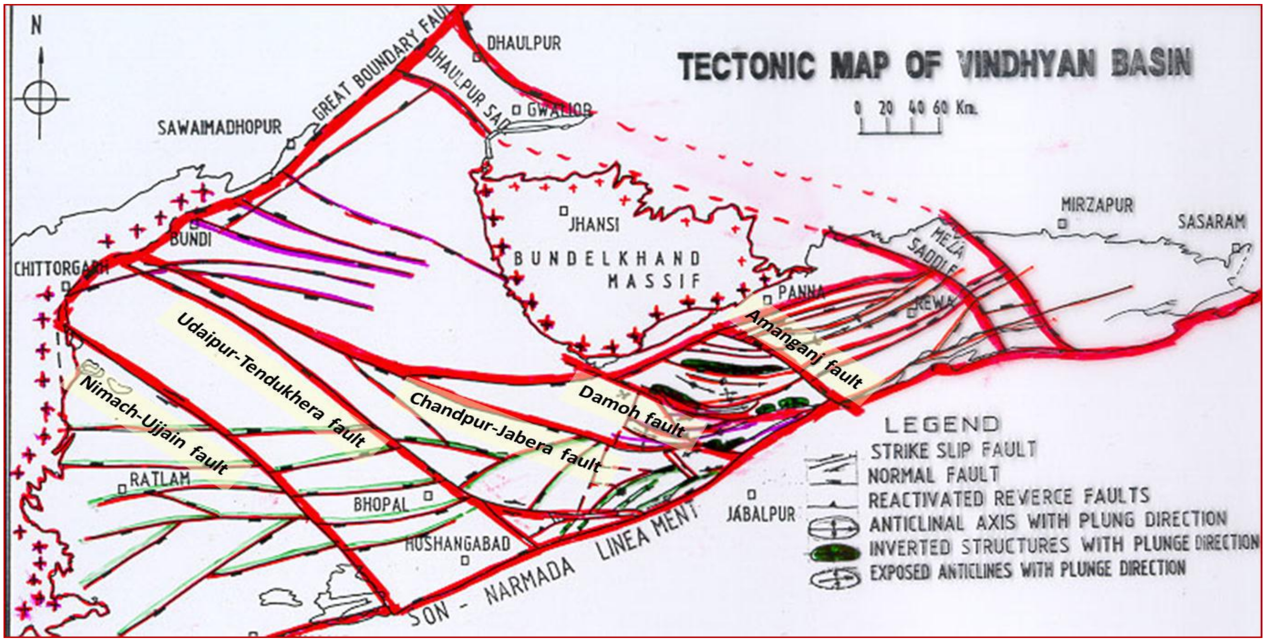


Fig 3: Tectonic map of Vindhyan Basin

Basin Evolution of Vindhyan:

The Vindhyan Basin was formed as a result of a large crustal down warp in the northern part of the Indian Platform, after the Delhi orogeny. The initial transgression of the sea from the north is inferred to have taken place in the eastern part of the basin over the Bijawars. The shallow sea appears to have established lagoonal conditions near the coastal part during the subsequent regressive phase. Initially, the Son-Narmada Lineament was dormant, but at the onset of Vindhyan sedimentation later, the fault system along this down warp became active with the formation of the southern limit of Vindhyan deposition. After the deposition of Kajrahat Limestone, the Son-Narmada Lineament again became active resulting in emission of volcanic material, which was deposited as the Jardepahar Porcellanite. In the subsequent regression, the shore line shifted towards northwest. The Fawn Limestone was deposited over the shelf in a tidal flat environment. This was followed by shallowing of the basin as is evident from the overlying Glauconitic Sandstone. The fresh marine transgression resulted in the deposition of marine shales followed by Rohtas Limestone.

Stratigraphy:

Vindhyan Basin in north-central India was a site for middle Proterozoic shallow marine sedimentation that comprises of about 5000m to 6000m of sediments ranging in age from 1400ma to 550ma. The entire sequence is known as the **Vindhyan Supergroup** and is considered as one of the best-preserved Proterozoic sequence of India. It consists of stratified, marine, unmetamorphosed rocks with sandstone, shale and limestone as the main rock types.

The Vindhyan Supergroup is divided into the **Lower Vindhyan Group** and **Upper Vindhyan Group**, the two being separated by a well-marked unconformity (Hiatus~500ma) at places and have gradational contact elsewhere.

In general, the Vindhyan sediments rest over the Bijawars with a prominent unconformity and at places the contact between the two faulted mainly along the southern margin and along major fault.

Sedimentation in the Vindhyan basin took place in two major depocenters one is Son valley in the east and another is Chambal valley in the west.

The rocks of Vindhyan Supergroup are divided into four groups:

1: Semri group

2: Kaimur group

3: Rewa group

4: Bhander group

The Upper Vindhyan rocks consist mainly of sandstone and shale deposited under shallow marine condition while the Semri Group (Lower Vindhyan) is shallow marine in origin and comprise mainly limestone, shale and sandstone.

In the Son Valley, sedimentation started with the deposition of basal clastic cycle of **Kharaundhi Arenite** having variable thickness. It is generally composed of conglomerate, pebbly and gritty sandstone and siltstone. Kharaundhi arenite also deposited along the down thrown side of the major oblique faults. The **Kajrahat Limestone** conformably overlies the Kharaundhi Arenite formation, and is unconformable on Bijawar. Kajrahat limestone consist of mainly stromatolitic limestone and attains a maximum thickness of 1338m. The **Jardepahar Porcellanite** Formation has conformable contact with underlying Kajrahat Limestone and consists of porcellanite, shale, and sandstone with occasional claystone, siltstone, and argillaceous limestone. The formations belonging to Kheinjua subgroup are Charkaria Olive Shale, Mohana Fawn Limestone and Basuhari

Glauconite, which are conformably overlain in ascending order. **Charkaria Olive Shale** is made up of shale and fine-grained sandstone. **Mohana Fawn Limestone** is represented by argillaceous limestone with algal matter and sandstone. It conformably overlies the Charkaria Olive Shale. **Basuhari Glauconitic sandstone** is composed of dolomitic limestone and fine-grained sandstone with ripple marks and cross bedding.

The **Rohtas formation** in the Son Valley area conformably overlies the Kheinjua subgroup and consists mainly of Limestone, which grades to shale and sandstone with limestone at the top. In the Son Valley area, the Upper Vindhyan Group is essentially arenaceous as compared to Lower Vindhyan (Semri) and it is divided into three subgroups namely Kaimur, Rewa, Bhander. The Kaimur Group of rocks has gradational contact with the underlying Semri Group of rocks and also shows unconformable contact (erosional unconformity) at certain places.

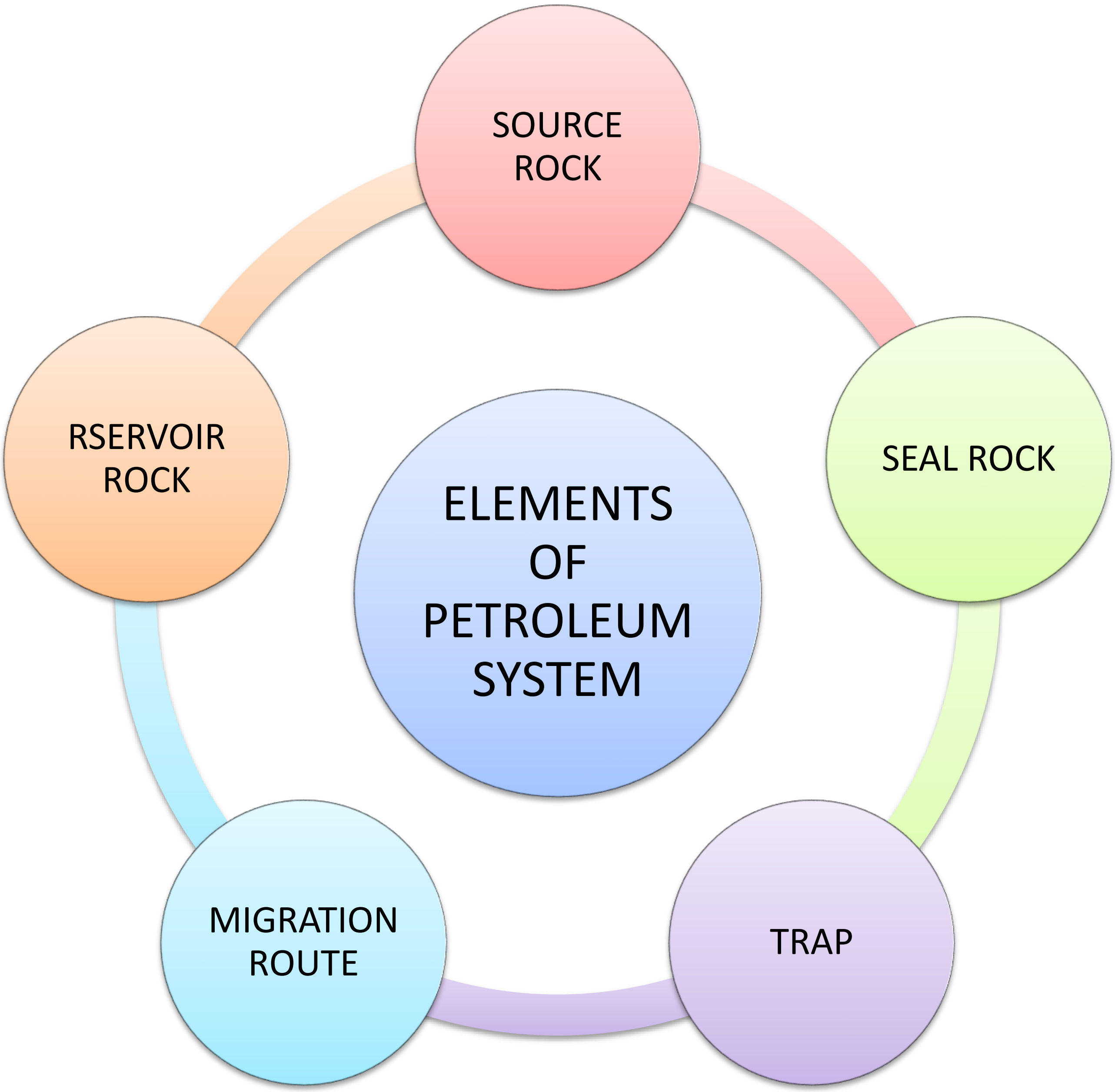
The **Kaimur Group** of rocks consist of conglomerates with pebbles of jasper and chert, quartzites, quartzitic sandstone, ferruginous current bedded sandstone, claystone and pyritiferous organic shales. The rocks of Rewa Group have conformable contact with underlying Kaimur as well as with the overlying Bhander rocks. The rocks of this subgroup are composed of alternate layers of ferruginous sandstone and shale. The sandstone is fine to medium grained, thick cross bedded, blanket type ferruginous quartz arenite.

The Bhander Group overlies conformably the rocks of Rewa Group but is overlain unconformably by Deccan Trap, Lameta and Bagh beds. Siwalik sediments in the Ganga Basin and recent alluvium also unconformably overlie it. The Bhander Group comprises mainly of stromatolitic limestone, shale, siltstone and sandstone. Mud cracked shales with intercalations of rippled fine sandstone layers are present.

Lithostratigraphy of Vindhyan Supergroup

Stratigraphic Nomenclature, Son Valley (ONGC)			
AGE	GROUP	SUBGROUP	FORMATION
MESO TO NEO PROTEROZOIC	UPPER VINDHYAN	BHANDER	MAIHAR SANDSTONE
			SIRBU SHALE
			NAGOD LIMESTONE
			GANURGARH SHALE
		REWA	REWA SANDSTONE
			JHIRI SHALE
		KAIMUR	KAIMUR SANDSTONE
UNCONFORMITY			
PALEO PROTEROZOIC	LOWER VINDHYAN	SEMRI	ROHTAS LIMESTONE
			BASUHARI SHALE
			MOHANA FAWN LIMESTONE
			CHARKARIA OLIVE SHALE
			JARDEPAHAR PORCELLANITE
			KAJRAHAT LIMESTONE
			ARANGI SHALE
			KARAUNDHI ARENITE
UNCONFORMITY			
EARLY PROTEROZOIC	BIJAWAR GROUP		
ARCHEAN	BUNDELKHAND GNEISS		

Petroleum System



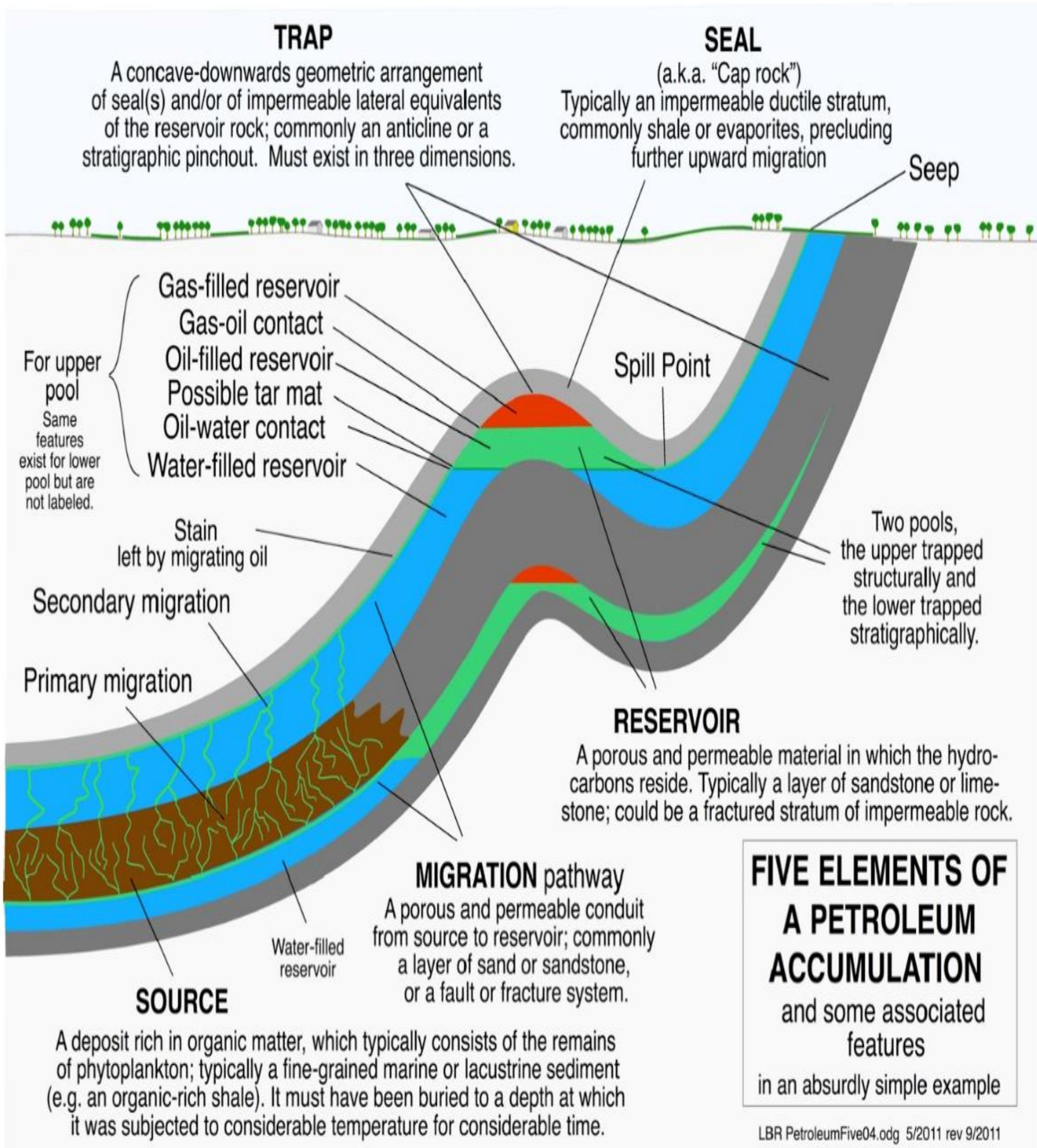


Fig 4: Elements of Petroleum System

Source rock:

Source rock is Lower Vindhyan shales, particularly, Hinota and Pulkova shales.

Reservoir rock:

Sandstones and limestones of Lower Vindhyan and Upper Vindhyan sequences are potential reservoir rocks.

Survey carried out for HC Exploration

Magnetic Survey:

The purpose of magnetic survey is to measure the field strength over the area of interest. The recorded variations of the field strength will be due to changes in the earth's magnetic field and to the volume and magnetic susceptibility of the underlying rocks. These variations can be eliminated by removing the fluctuations recorded by a fixed station in the survey area. The residual values are then directly related to the rocks beneath. Magnetic surveys can be carried out on the ground or on-board ships, but taking the readings from the air is far more efficient. In aeromagnetic surveys, a plane trails a magnetometer in a Snode attached to a cable and flies in a grid pattern over the survey area. The spacing of the survey lines will vary according to the nature of the survey and the budget, but the lines may be as close as 1 km with crosstie lines on 5 km spacing. Magnetic surveys may also be carried out from satellites. Data acquired by these various methods may be used to construct a map that contours anomalies in the earth's magnetic field in gamma units. It helps in:

- It gives idea about the orientation of basement, highs and lows
- Faults may show up more spacing or abrupt change in orientation of contours
- To differentiate basement from sedimentary cover is possible when there is a sharp contrast in magnetic susceptibility of both and is laterally persistent.
- It helps to plot depth to magnetic basement map
- It indicates igneous plugs, intrusive, lava flows which are the area to be avoided

Gravity Survey:

Gravity surveys can be carried out on land and at sea, both on the sea floor and aboard a ship. In the latter case, corrections must be made for the motion of the ship and for the density and depth of the seawater. Airborne gravity surveys are also now feasible. When the latitude free-air, Bouguer, and terrain corrections have been made for the readings at each station in a gravity survey, they can be plotted on a map and contoured in milli gals. It helps in:

It shows broad architecture of the basin. Generally, depocenters of low-density sediments appears as negative anomaly while ridge of basement appears as positive anomaly. It helps to locate salt domes (negative anomaly) and reefs (positive anomaly).

When used in combination, a far more accurate basement map can be prepared than when they are interpreted separately. Aeromagnetic and gravity surveys can be integrated with one another, or with seismic surveys. Once well control becomes available, the true depth to basin is known.

Then, the surveys can be accurately calibrated and more reliable depth-to-basement maps redrawn.

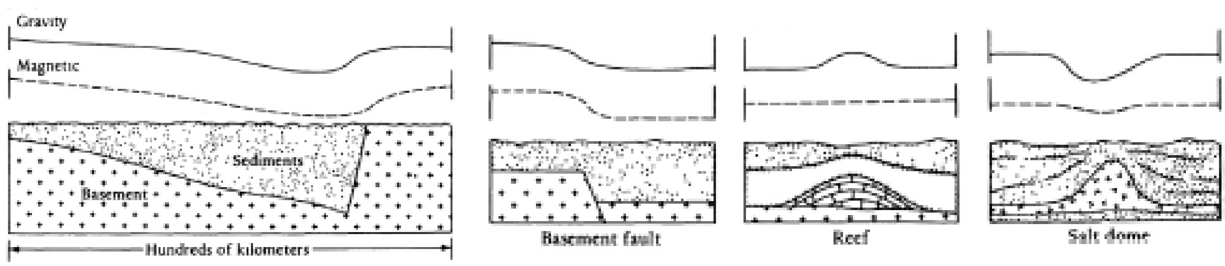


Fig 5: Gravity and Magnetic Anomalies
(Source: Kearey. P, and Brooks .M, An introduction to Geophysical Exploration)

Resistivity Survey:
The electrical geophysical methods are used to determine the electrical resistivity of the earth's subsurface. Once resistivity data have been acquired, the resistivity distribution of the subsurface can be interpreted in terms of rock type and geological structure. Resistivity data are usually integrated with other geophysical results and with surface and subsurface geological data to arrive at an interpretation. In this a known direct current (DC) moves in the subsurface from one electrode to an electrode return at some measured distance away. Two potential electrodes measure the potential drop, that is, the force needed for the current to overcome the resistance of the subsurface earth materials. We know the current we put into the subsurface, we measure a voltage, and with Ohm’s Law, we then calculate a resistance (voltage divided by current). Given the geometry of our four-electrode array, we can calculate an apparent resistivity of the subsurface. By changing the geometry of the electrodes, we measure an apparent resistivity at a different depth in the earth. It helps in:

- Provide indication of pore fluid type
- 2-D resistivity exploration has been used extensively for exploration in the oil sands and, more recently, for very shallow gas exploration (less than 400 m below ground surface).
- Identify changes in lithology not expressed as variations in acoustic impedance
- Investigation of stratigraphy and structure, in particular as an adjunct to seismic data and in those areas where seismic data are poor or unreliable.

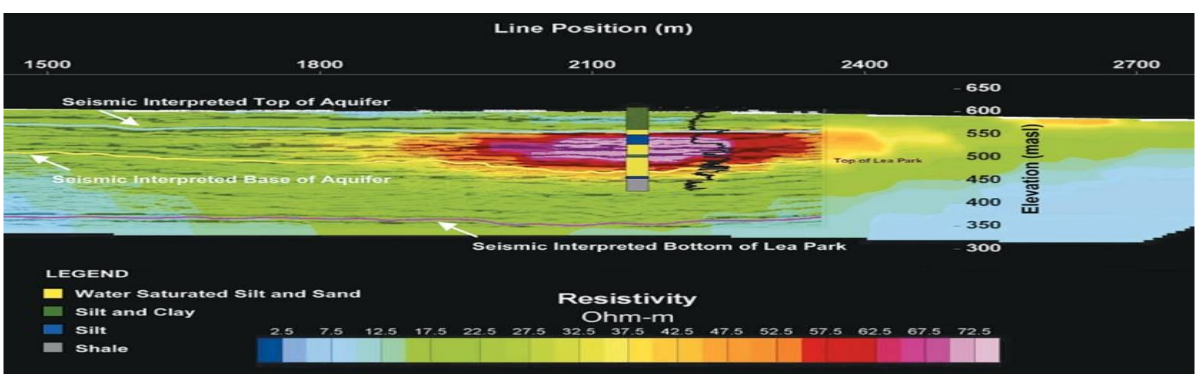


Fig 6: Resistivity Survey
(Source: www.mdpi.com/20171-1050/9/12/2320)

Magneto telluric Survey:

An electromagnetic method is used to map the spatial variation of the Earth's resistivity by measuring naturally occurring electric and magnetic field at the earth surface. In this, the horizontal component of the electric field and all the three components of the magnetic field are measures at the earth surface. The measurement is used to determine specific ratios of electric to magnetic field components called tensor impedance. It is of importance in areas where seismic survey is difficult because of severe topography or high impedance volcanic rock near the subsurface (Basalt). While MT cannot be used to detect oil directly, the identification of favorable rock types and the presence of geological structure capable of trapping hydrocarbons is critical to successful exploration.

Seismic Survey:

Seismic survey is a program for mapping geologic structure by observation of seismic waves, especially by creating seismic waves with artificial sources and observing the arrival time of the waves reflected from acoustic impedance contrasts or refracted through high velocity members.

The methods are also used, on a smaller scale, for the mapping of near-surface sediment layers, the location of the water table and, in an engineering context, site investigation of foundation conditions including the determination of depth to bedrock. Seismic surveying can be carried out on land or at sea and is used extensively in offshore geological surveys and the exploration for offshore resources.

Types of Seismic Survey

2D Survey (when source is in line with receiver): Sets of receiver group (spread) are laid along the lines and sources are shot into them. After one is short into, the spread and source are moved along the line to provide the desired subsurface coverage. In this the reflection point lies within the vertical section containing the survey line.

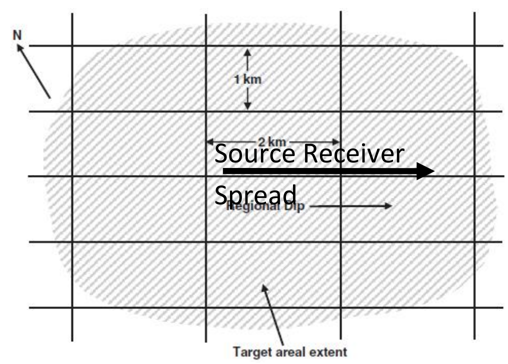


Fig 7: 2D Seismic Layout
(Source: Kearey.P, and Brooks .M, an introduction to Geophysical Exploration)

3D Survey (source and receivers are placed along orthogonal lines): The receivers are laid down in the direction of the maximum dip (inline direction) of the reflector and the source lines are orthogonal to it (cross line direction). Reflection points on the subsurface are spaced at half the group interval along inline direction and half the source or line interval along cross line direction. In this the reflection points are distributed over an area hence CMP is a zone rather than a point. Thus, this provides greater spatial sampling.

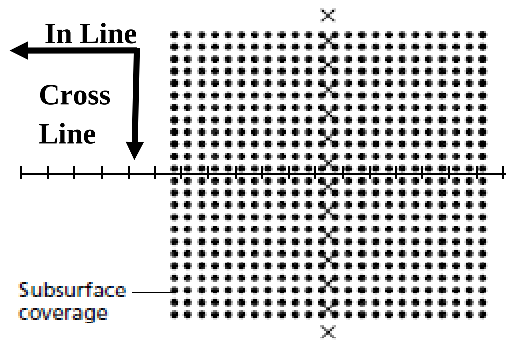


Fig 8: 3D Seismic Layout
(Source: Kearey.P, and Brooks .M, an introduction to Geophysical Exploration)

Fundamentals and Principles of Seismic Survey:

Wiggle:

Seismic reflection profiling is an echo sounding technique. A controlled sound pulse is issued into the Earth and the recording system listens a fixed time for energy reflected back from interfaces within the Earth. The interface is often a geological boundary, for example the change of sandstone to limestone.

Once the travel-time to the reflectors and the velocity of propagation is known, the geometry of the reflecting interfaces can be reconstructed and interpreted in terms of geological structure in depth. The principal purpose of seismic surveying is to help understand geological structure and stratigraphy at depth and in the oil, industry is ultimately used to reduce the risk of drilling dry wells.

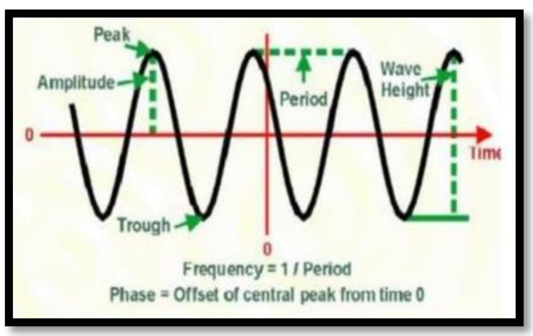


Fig. 9: Wave and its parameters
(Source: www.google.com/search?q=wave&source=lnms&tbm=isch&X&vwave/)

Seismic wave propagation:

For small deformations rocks are elastic, which is they return to their original shape once a small stress applied to deform them is removed. Seismic waves are elastic waves and are the ‘disturbances’ which propagate through the rocks.

The most commonly used form of seismic wave is the P (primary)-wave which travels as a series of compressions and rarefactions through the earth the particle motion being in the direction of wave travel. The propagation of P- waves can be represented as a series of wave fronts (lines of equal phase) which describe circles for a point source in a homogeneous media (similar to when a stone is dropped vertically onto a calm water surface). As the wave front expands the energy is spread over a wider area and the amplitude decays with distance from the source. This decay is called spherical or geometric divergence and is usually compensated for in seismic processing. Rays are normal to the wave fronts and diagrammatically indicate the direction of wave propagation. Usually the shortest ray-path is the direction of interest and is chosen for clarity. Secondary or S waves travel at up to 70% of the velocity of P-waves and do not travel through fluids. The particle motion for an S-wave is perpendicular to its direction of propagation (shear stresses are introduced) and the motion is usually resolved into a horizontal component (SH waves) and a vertical component (SV waves).

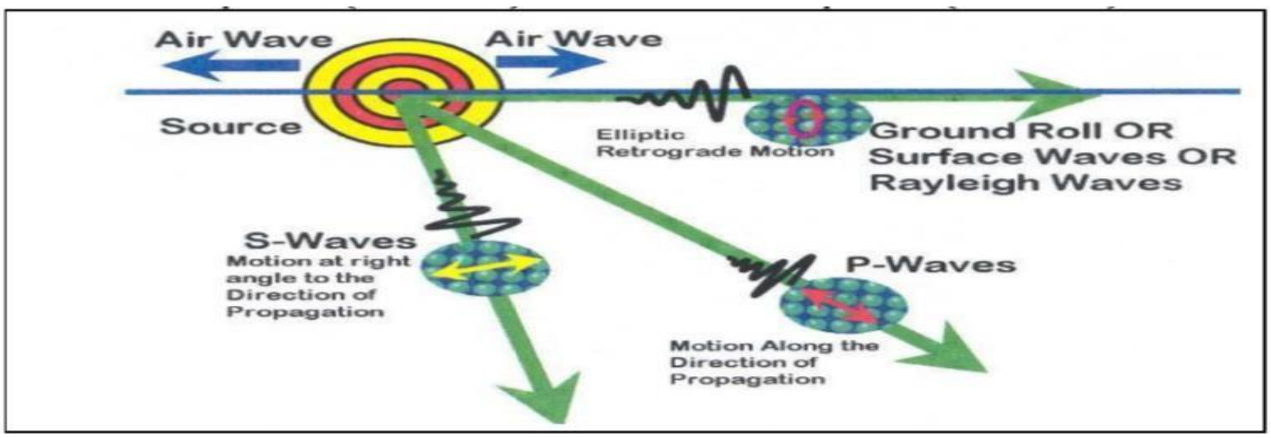


Fig 10: Seismic Wave propagation
(Source: https://earthscience.stackexchange.com/questions/2130/wave-conversion)

Reflection: The energy or wave from a seismic source which has been reflected from an acoustic impedance contrast (reflector) or a series of contrasts within the earth.

Refraction: The change in direction of a seismic ray upon passing into a medium with a different velocity. The mathematics of this is defined by Snell’s law.

Diffraction: The bending of a wave around the edges of an opening or an obstacle. Ex: Fault edges. Diffraction effects are generally most pronounced for waves whose wavelengths are roughly similar to the dimensions of the diffracting objects.

Principles:

Snell's Law - The mathematical description of refraction or the physical change in the direction of a wave front as it travels from one medium to another with a change in velocity and partial conversion and reflection of a P-wave to an S-wave at the interface of the two media. Snell's law, one of two laws describing refraction, was formulated in the context of light waves, but is applicable to seismic waves.

Huygens Principle - The Huygens-Fresnel principle states that every point on a wavefront is a source of wavelets. These wavelets spread out in the forward direction, at the same speed as the source wave. The new wavefront is a line tangent to all of the wavelets. The wave front can be viewed as the line tangent to all of these circular waves. These results can be obtained separately from Maxwell's equations, though Huygens principle (which came first) is a useful model and is often convenient for calculations of wave phenomena.

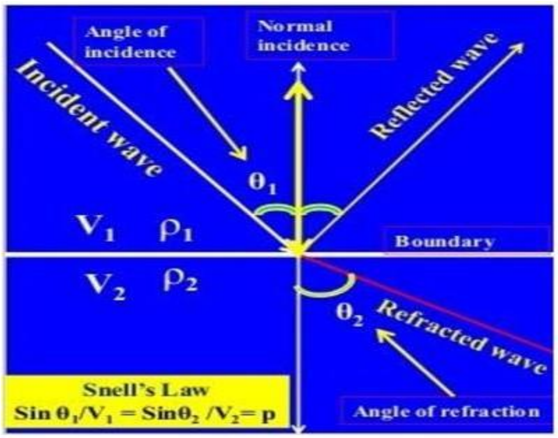


Fig. 11: Snell's Law
(Source: http://byjus.com/snells-law-formula/)

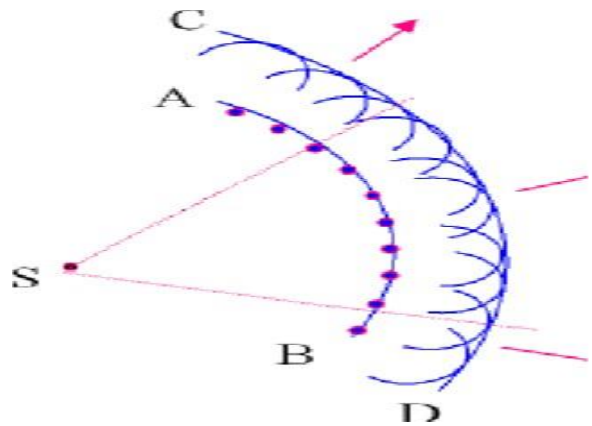


Fig 12: Huygens Principle
(Source: http://byjus.com/huygens-principle/)

Seismic Reflection: Below figures how's a simple earth model and resulting seismic section used to illustrate the basic concepts of the method. The terms source, receiver and reflecting interface are introduced. Sound energy travels through different media (rocks) at different velocities and is reflected at interfaces where the media velocity and/or density changes. The amplitude and polarity of the reflection is proportional to the acoustic impedance (product of velocity and density) change across an interface. The arrival of energy at the receiver is termed a seismic event. A seismic trace records the events and is conventionally plotted below the receiver with the time.

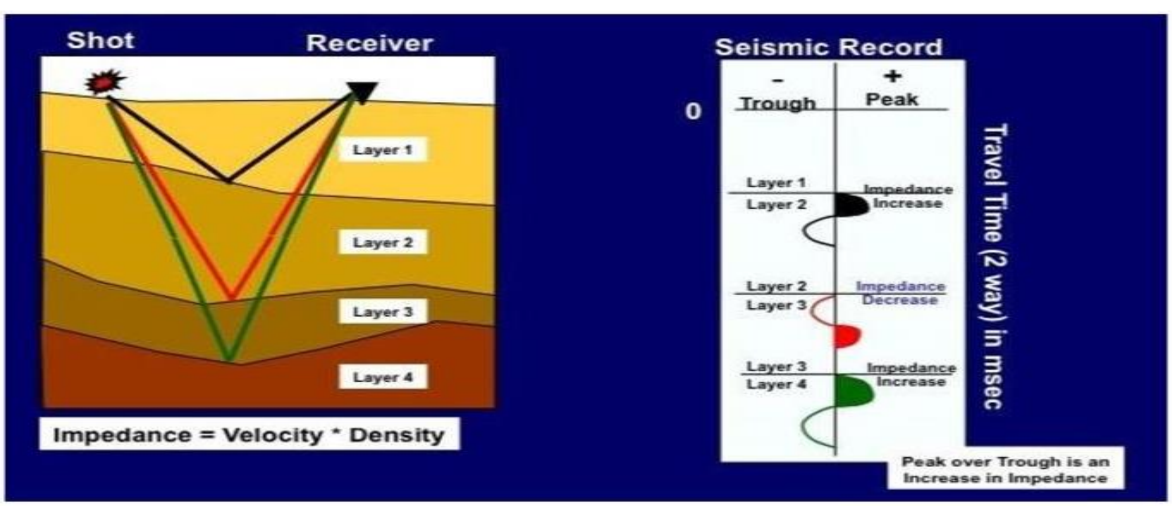


Fig. 13: Reflection from multiple layers due to Impedance contrast

Seismic Data Acquisition

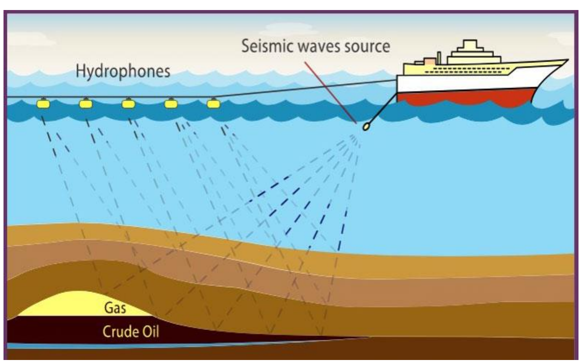
Elements of acquisition include:

- Energy Source that imparts seismic waves having appropriate amplitude and frequency
- Receiver to detect the energy that returns after subsurface interaction & convert it in electrical signals
- Precise location of Source and Receiver and their spatial arrangement

Source: choice of source depends on location of acquisition. Data can be acquired on:

- **Land**: continental region up-to shoreline. The source includes:
  - Explosives: blasted in shot holes.
  - Vibroseis generate sweep signals vibrations of low amplitude & continuously varying frequency
  - Mini-Sosie, a hammer-based source that imparts low amplitude signals.
  - Weight drops and Hammer; Shotguns, Buffalo guns and Rifles
- **Transition Zones**: Region extending beyond the shoreline up to zone of very shallow depth that limits the ship
- **Marine**: Water bodies with sufficient depth to facilitate ship. The source includes:
  - Airgun and Watergun, Marine Vibroseis

Receiver: The sourced signals after subsurface interactions return to the surface and are recorded by the geophone (in land surveys) and hydrophone (in marine surveys). Recording must be properly timed relative to source must be accurate in the order of milli second. From the group of detectors, the data is recorded, amplified and digitized.



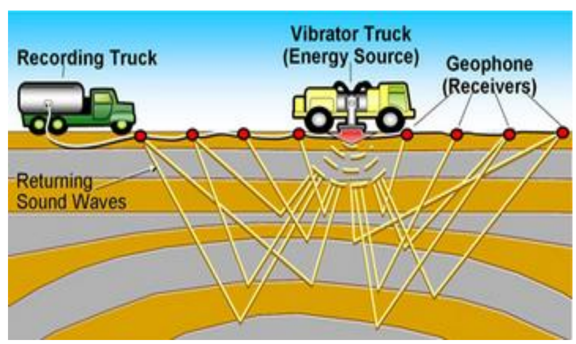


Fig 14: Acquisition of data on land and in marine

Seismic Data Processing

Data processing converts the field recording into meaningful seismic sections. The Data acquired is composed of both signal as well as the noise. However, the noise component has different characters in terms of amplitude, frequency and phase. The noise component decreases the resolution of imaging which may result in misinterpretation. Thus, there is a need to remove the noise component which is achieved by processing. Thus, processing focuses on increasing the SNR. The three major aspects of Processing are Deconvolution (deals with time factor), Stacking (deals with offset factor) and migration (deals with CDP factor).

- **Deconvolution**: It is process that improves the vertical resolution by compressing the basic wavelet. It also helps in attenuating multiple reflection. It is generally applied before stacking but sometimes also after stacking. Convoluted seismic trace has primary reflection, multiple reflection and other noises. If the basic wavelets are compressed fully and multiples are all attenuated then we will only get the reflectivity of earth on a seismic trace. This is called deconvolution.

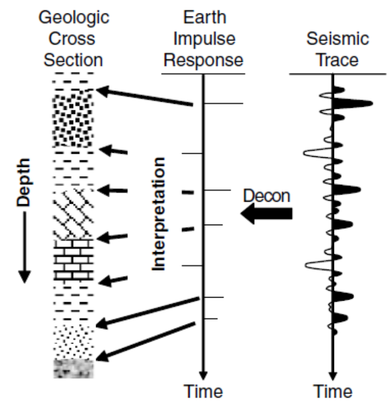


Fig 15: Deconvolution

- **Stacking:** Once velocity of layer is known, trace in CMP can be corrected for NMO so that each trace is corrected to equivalent zero offset trace. This will result in same reflected pulse at the given time but different random and coherent noise. Combining all the CMP together along the offset axis will average out the noise thereby increasing SNR.

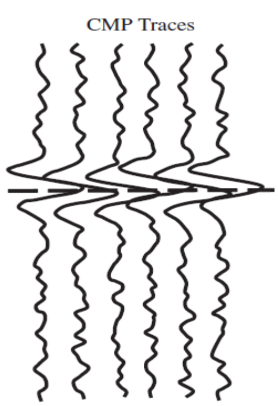


Fig 16: Stacking
(Source: Kearey.P, and Brooks .M, an introduction to Geophysical Exploration)

- **Migration**: It is done when the reflection point shifts up dip from the CDP. This is characteristic of dipping reflector. In 2D surveys the actual reflecting point is displaced in the up-dip direction of the CDP in the same vertical section (corrected by 2D migration) while in 3D surveys if dip is across the survey line then it is displaced out of the plane of vertical section (corrected by 3D migration). Thus, migration is the process of reconstructing a seismic section so that the reflection events are repositioned under the correct surface location and at corrected vertical reflection time. It improves the resolution by focusing the energy spread over Fresnel zone. Hence, it works as a spatial resolution because we are moving CDPs to a confined point i.e. we are shrinking. Migration is carried out in two domains:

- *Time Migration*: Migrated sections has time as vertical dimension. It helps to get RMS velocity.
- *Depth Migration*: Migrated section has depth as vertical dimension and are obtained by converting migrated reflection time to depth using appropriate velocity info. It helps to get Interval Velocity.

The assumption in migration is 'zero offset' and hence the reflection point is assumed to lie vertically beneath the source-detector. However, it may be offset anywhere on a semicircle with radius as 2-way reflection time. So, if we reconstruct arcs of circle (wavefront segment) through all mapped reflection points we'll get actual reflector geometry or migrated section.

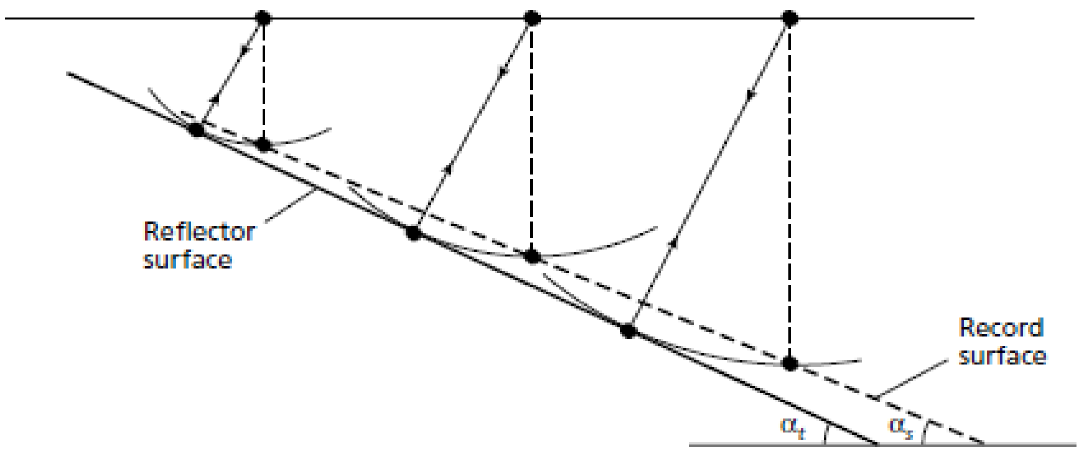


Fig 17: Migration
(Source: Kearey.P. and Brooks .M. an introduction to Geophysical Exploration)

In each of the domain there is possibility of both Pre as well as Post stacking. In pre stack we first do stacking followed by migration while in post stack we first do migration followed by stacking. Out of these Pre-Stack is more efficient as it cancels out few noises prior to migration. Thus, it gives rise to four possible combinations viz.

PSTM (Pre-Stack Time Migration) PosSTM (Post Stack Time Migration)

PSDM (Pre- Stack Depth Migration) PosSDM (Post Stack Depth Migration)

Seismic Interpretation

It provides assessment of a prospect's hydrocarbon potential and identifies location of drilling exploratory well. It makes use of Migrated seismic section, well logs, time structure maps, structural contour maps etc. Interpretation in seismic is 2 folds:

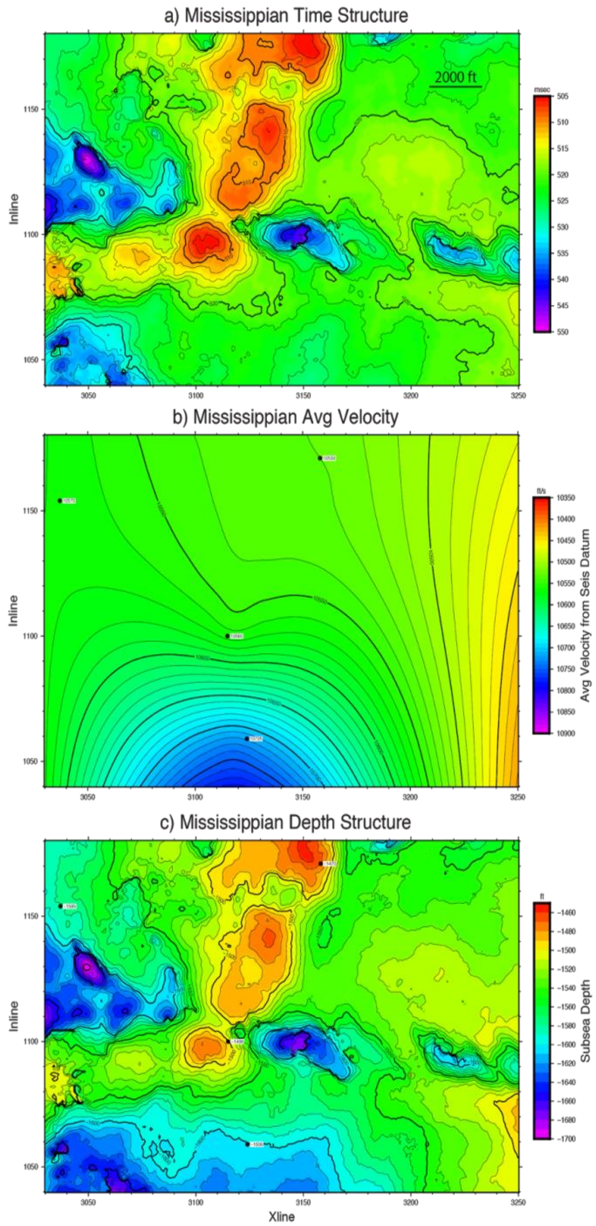
Structural Analysis:

It deals with the study of reflector geometry on the basis of reflection time. It involves Horizon tracking and fault picking.

Structural interpretation is carried out in 2 ways reflection time rather than depth i.e. Time structure map is constructed to display the geometry of selected reflection event by means of contour representing points of equal reflection time. Using appropriate velocity (derived from reflection survey or sonic log data from borehole) we can convert reflection times into depth i.e. Time structure map to Structure contour map can be-made. Time structure map is similar to structure contour map but is not exactly the same because Time structure maps are subjected to distortion because of subtle change in velocity laterally or vertically in the subsurface interval lying above the reflector.

The Closure guides to propose a well location. There are four types of closure enlisted below:

1. 4 Way closure: It is a domal structure represented by closed contours.
2. 3 Way closure: 2 faults and a closing contour forms a 3-way closure
3. 2 Way closure: A fault with closed by contour forms 2 -way closure



4 Way closure has the highest Geological Chance of Success while 2 ways has the least.

Stratigraphic Analysis:

It deals with analysis of reflection sequence as seismic expression of lithologically distinct depositional sequence. It involves study of amplitude, frequency and phase.

Principle involved:

1. Reflections (due to the contrasting impedance of vertically adjacent layers) are taken to define chronostratigraphic units.
2. Representation of Onlap, Downlap, Toplap and erosion.

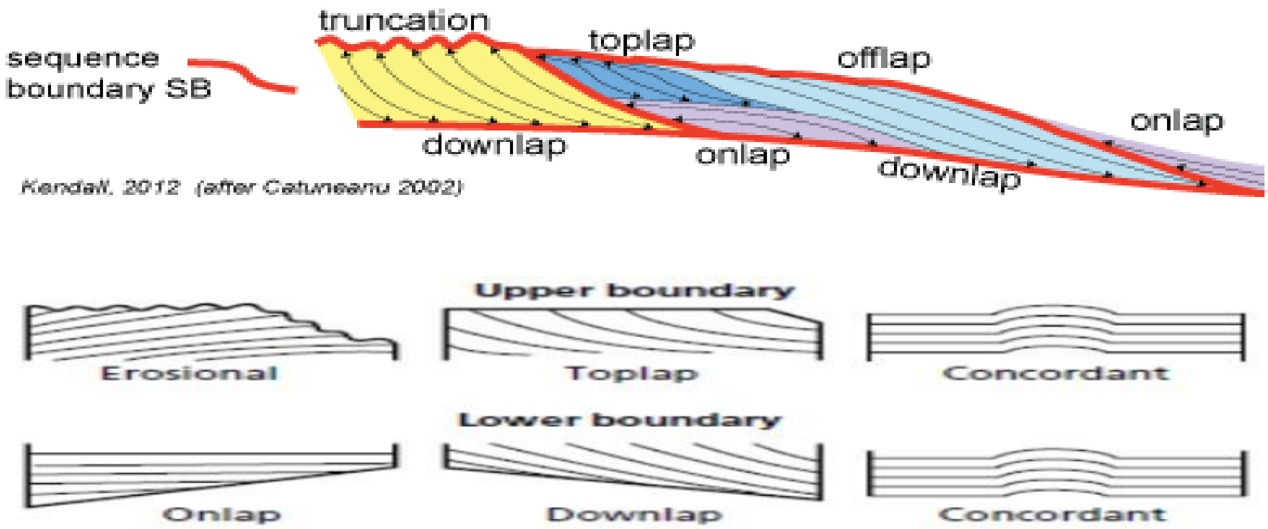


Fig 19: Different type of geological boundary defining seismic sequence
(Source: Kearey.P, and Brooks .M, an introduction to Geophysical Exploration)

Toplap: Termination of strata against an overlying surface, representing the result of non-deposition and/or minor erosion.

Erosional or Truncational: this implies the deposition of strata and their subsequent tilting and removal along an unconformity surface.

Onlap: A base-discordant relationship in which initially horizontal strata progressively terminate against an initially inclined surface, or in which initially inclined strata terminate progressively up dip against a surface of greater initial inclination.

Downlap: a relationship in which seismic reflections of inclined strata terminate downdip against an inclined or horizontal surface.

We carry out seismic facies analysis by dividing the seismic section into seismic sequence and each sequence is analyzed in terms of internal disposition of reflection events and their character which indicates depositional environment responsible for the formation of seismic sequence. e.g.: Parallel reflection indicates shallow water shelf environment; sigmoidal or oblique cross bedded units indicates Deep water shelf edge and slope. Hummocky indicates shallow marine influenced by storms etc. Major seismic sequence across broad continental margin indicates global sea level changed from aggrading, prograding and retrograding sequences. Major progradation sequences are high probability targets for HC generation and accumulation.

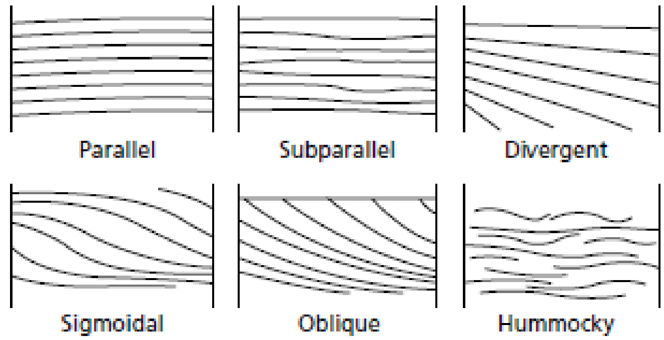


Fig 20: Seismic facies within sedimentary sequence
(Source: Kearey.P, and Brooks .M, an introduction to Geophysical Exploration)

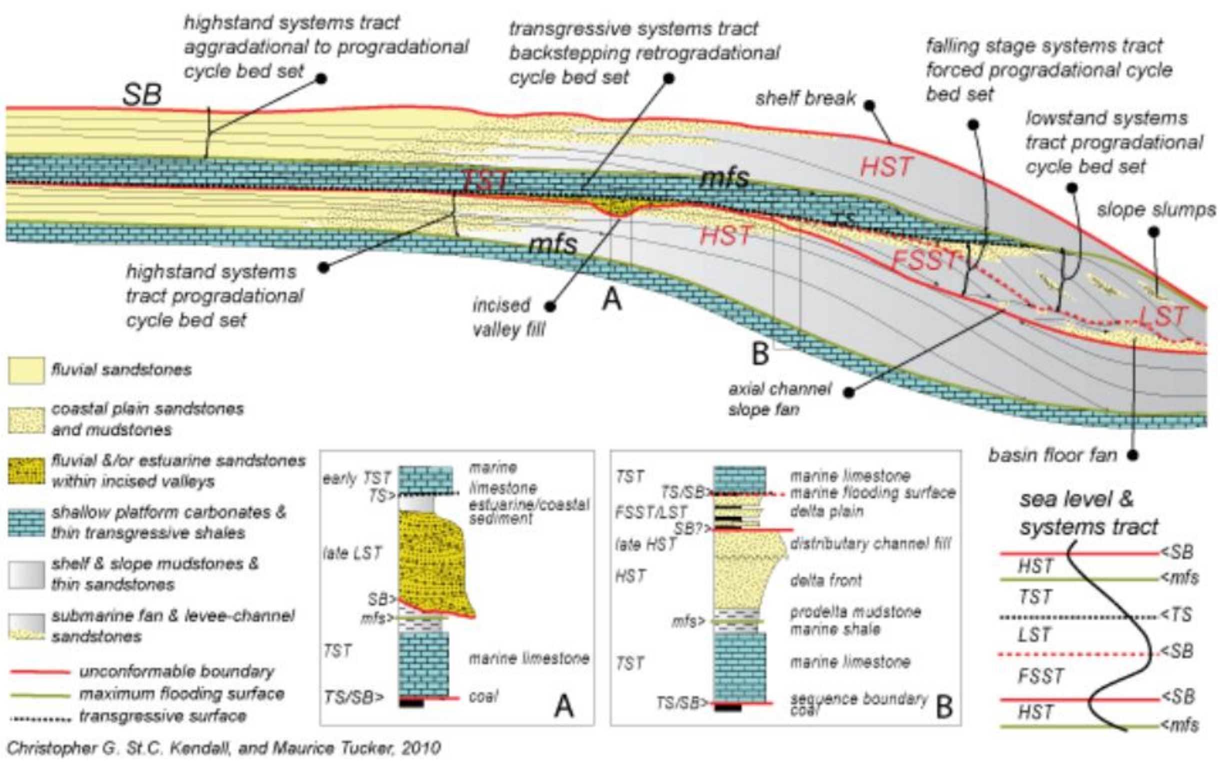
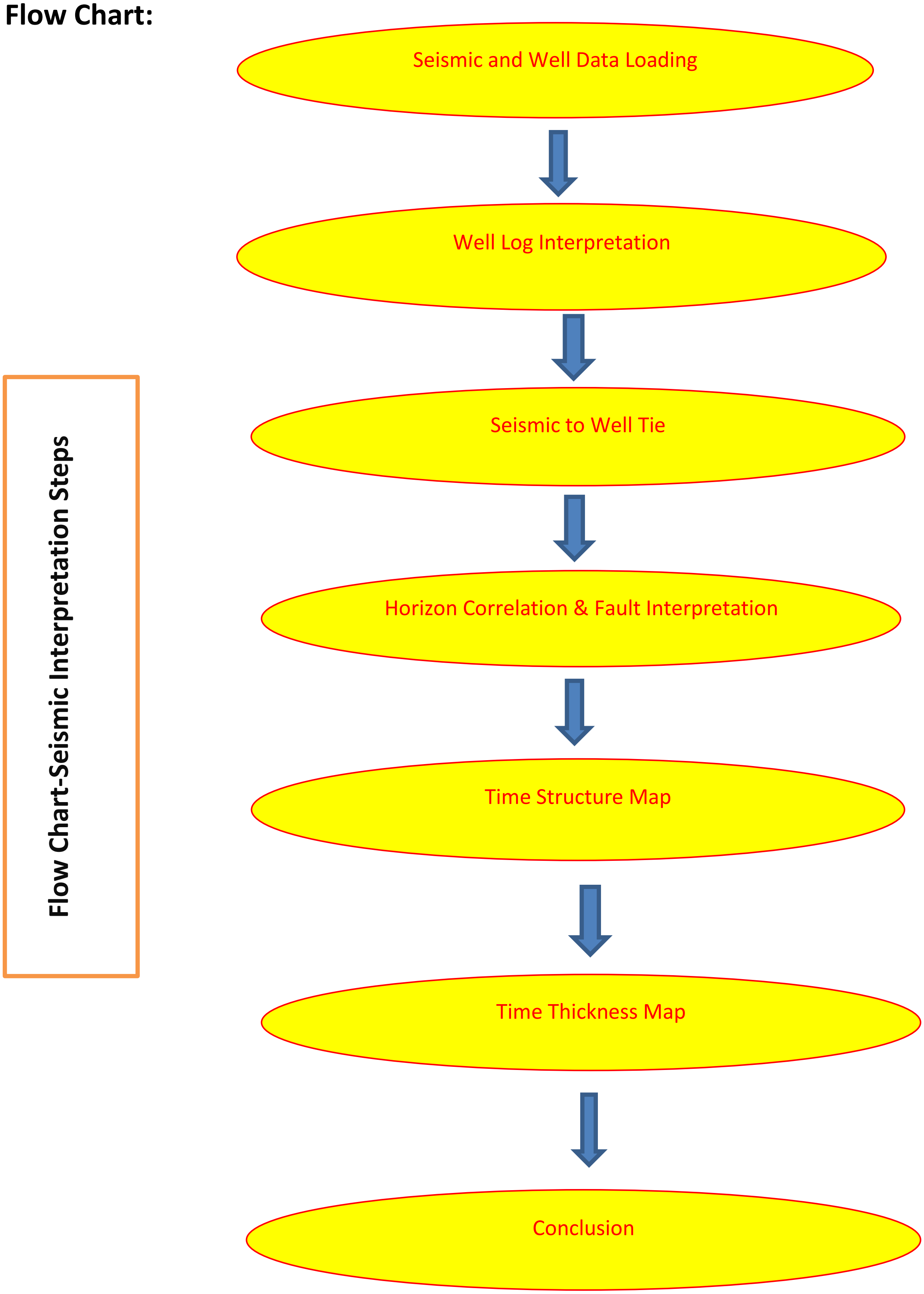


Fig 21: An overall sequence stratigraphy model

Flow Chart:


Flow Chart-Seismic Interpretation Steps
Seismic and Well Data Loading
Well Log Interpretation
Seismic to Well Tie
Horizon Correlation & Fault Interpretation
Time Structure Map
Time Thickness Map
Conclusion

Methodology

The initial step of interpretation includes the loading of processed data in the required format. SEG-Y and ASCII/LAS formats are the two major types used in most of the software. Seismic data is loaded in SEG-Y format and well data is loaded in ASCII or LAS format.

Petrel software is used in the present study to interpret well log data and seismic data. Interpretation is carried out after the desired formats are imported in the software. Firstly, LAS files are imported in the software which displays all the available wells and well logs. The well top is put above each formation by correlating the signatures of different well logs. The facies of various formations are then interpreted using the available well logs (Caliper, SP, Gamma, Resistivity, Sonic and Neutron-Density log).

Following synthetic generation and horizon correlation, generation of maps and seismic interpretation are carried out. The seismic interpretation starts with well to seismic tie i.e. the identification of prominent seismic reflectors from well ties.

Post horizon marking, fault identification on the seismic sections is made. Most of the faults are easily recognizable, where some only showed traces.

Post this, fault polygons are generated using horizon settings where their throws are maintained (if required). The horizon surface is prepared using 'make surface' tool in a 3-D window. This horizon surface along with prepared fault polygons is then incorporated within a map template where scale and other features are set accordingly to give us desired Time Structure map or Two-Way Time (TWT) map.

Well Log Interpretation

Well drilled within the study area has been studied and the tops of each formation has been picked based on the log character of Gamma ray, Caliper, Self-Potential, Resistivity, Sonic, Neutron and Density logs.

- From the 'Gamma-ray log', we inferred the lithology of the formations as the variation is as follows: shale> sandstone > limestone. Shale has high gamma-ray because of the presence of radioactive elements (K, Ur, Th). Sandstone generally forms a mud cake against the caliper log, which is not the characteristic in carbonates.
- From the 'Resistivity log', the variation is as follows: Shale<sandstone<limestone. More over gas has more resistivity than oil. If all the resistivity logs intersect each other, it is indicative of a tight limestone/sandstone. If they don't lie along the same line, it means that the lithology is porous.
- Density log interpretation: sandstone<shale<limestone. But the bulk density also depends on the effective porosity (both primary and secondary) of the rock. In case of highly porous rock, the density will decrease.
- Neutron porosity log interpretation: sandstone< limestone< shale. Compact shales have less porosity. Limestone is generally more porous than sandstone because of the creation of secondary porosity via dissolution, etc.
- The effective porosity of the rock is generally dependent on both the density log and porosity log. The lithology is grossly identified on the basis of all these above-mentioned logs.

Presence of reservoir facies is inferred when there is a crossover of neutron log and density log in a sand pack lithology. If the resistivity in that region is high, then it will be hydrocarbon bearing sand but if the resistivity is normal (with respect to the general base line trend), then it will be water bearing sand.

The fluid in the sand in comparison with the base line can be interpreted using the following criteria:

1. Very high resistivity, large neutron-density crossover: Gas bearing sand
2. High resistivity, neutron-density crossover: Oil bearing sand
3. Normal resistivity, neutron-density crossover: Water bearing sand

Simply we can say that, when the lithology of the reservoir is continuing but we observe the sudden fall in $\mathbf{R_t}$ **log**, we infer that this deviation is due to OWC.

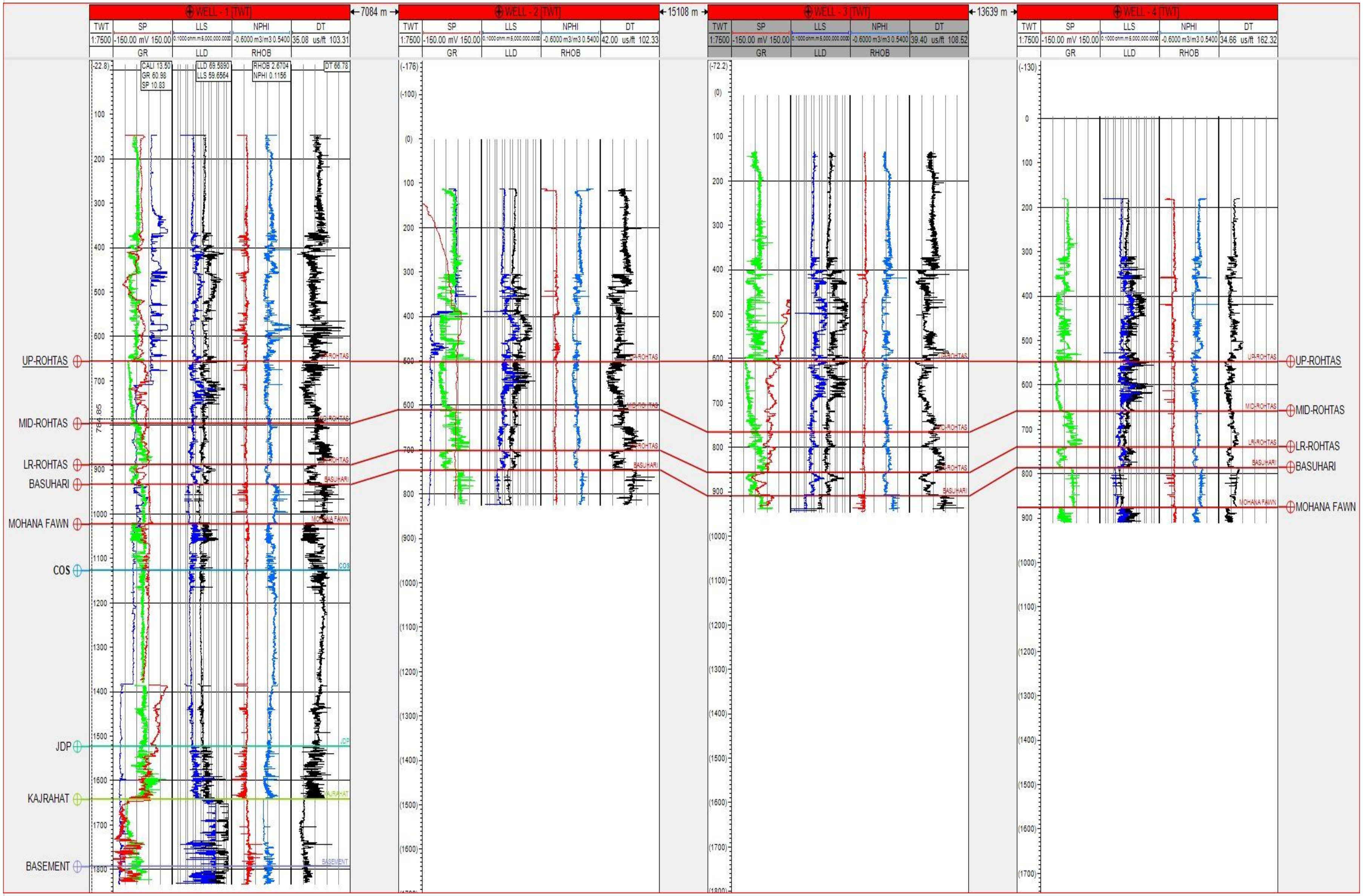


Fig 22: Well Log Correlation of four wells using open hole logs to understand the variation in fluvio deltaic

Seismic to Well Tie (Generation of Synthetic Seismogram)

Since the stacked seismic trace is in time domain so there's need for it to be converted to depth domain. This is achieved by tying the well log which in depth domain to the seismic trace. The output of this is a time depth curve and serves the purpose of matching horizon from well log to seismic. This can be achieved in three simple steps:

1. Multiply the velocity log with the density log to get impedance log.
2. Impedance log is convolved to Reflectivity function to generate synthetic seismogram.
3. This synthetic seismogram is the tied to the stacked seismic traces i.e. we adjust the stacked seismic trace with respect to the log.

The ratio of amplitude of the reflected wave to the incident wave, or how much energy is reflected. If the wave has normal incidence, then its reflection coefficient can be expressed as:

The reflectivity is defined as the ratio of change in AI at the interfaces of two media to the twice of the average of AI at that interface. i.e.

$$R = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 - \rho_1 V_1}$$

Where ρ and v are density and velocity respectively. And the suffixes are the indicator of respective mediums. Now after built up of the reflectivity series a wavelet of desired frequency is convolved with it and the synthetic seismogram is prepared. The need for a perfect (or at least near so) synthetic seismogram that ties well with the recorded seismic data cannot be over emphasized, if we are to have much confidence in our interpretation. The synthetic seismogram is constructed from well logs (density and sonic to be specific); to achieve a reasonably accurate synthetic seismogram the well logs should be well processed, edited and conditioned. It is equally important that the seismic data is as close as possible to a true representation of the real stratigraphy and rock properties; this can only be achieved by implementing the right processing flow. The sonic and the density logs from the well data act as the input for generating the impedance log. From this impedance log we get the reflectivity series for the strata near the well we are working on. The reflectivity series is a seismic expression of the geological succession which lies beneath and varies with depth as the velocity increases and also change in density and that of lithology. The link between the "ground truth" (well logs) and the recorded seismic data is the seismic wavelet. Therefore, wavelet extraction is very important in the seismic-to-well tie.

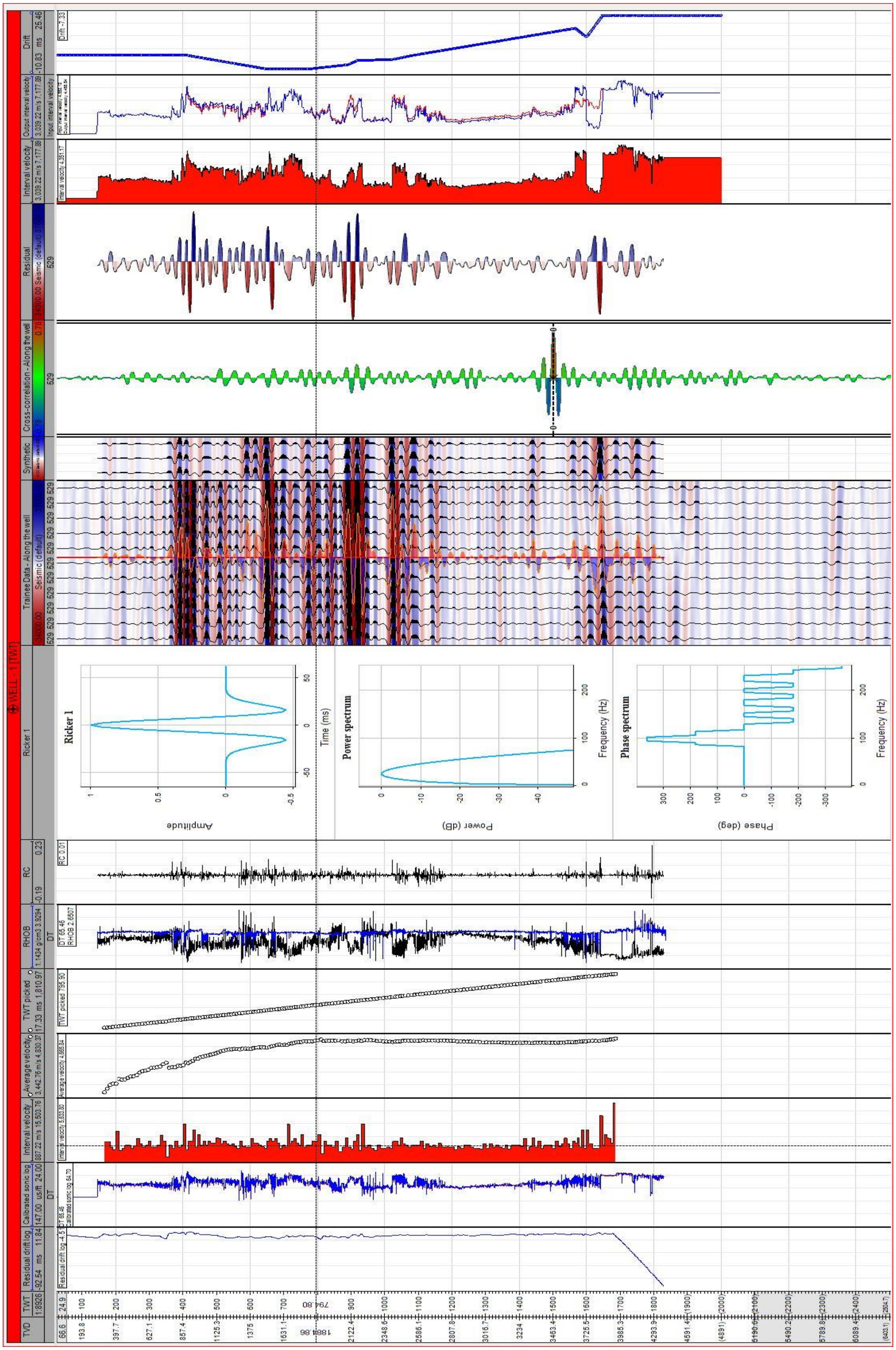


Fig 23: Seismic to Well Tie (Generation of Synthetic Seismogram)

Horizon Correlation

After having good correlation between synthetic seismogram and real seismic, time-depth function generated is used for converting well depth to the time domain, The Well for which synthetic is generated is then hanged to the seismic section passing through the well. Along this section respective horizons are picked for correlating horizons in seismic sections along lines and/or traces in time domain. In the present study, horizons have been marked in along Seismic lines of study area, out of which one along the dip direction and another along the strike direction have been shown below.

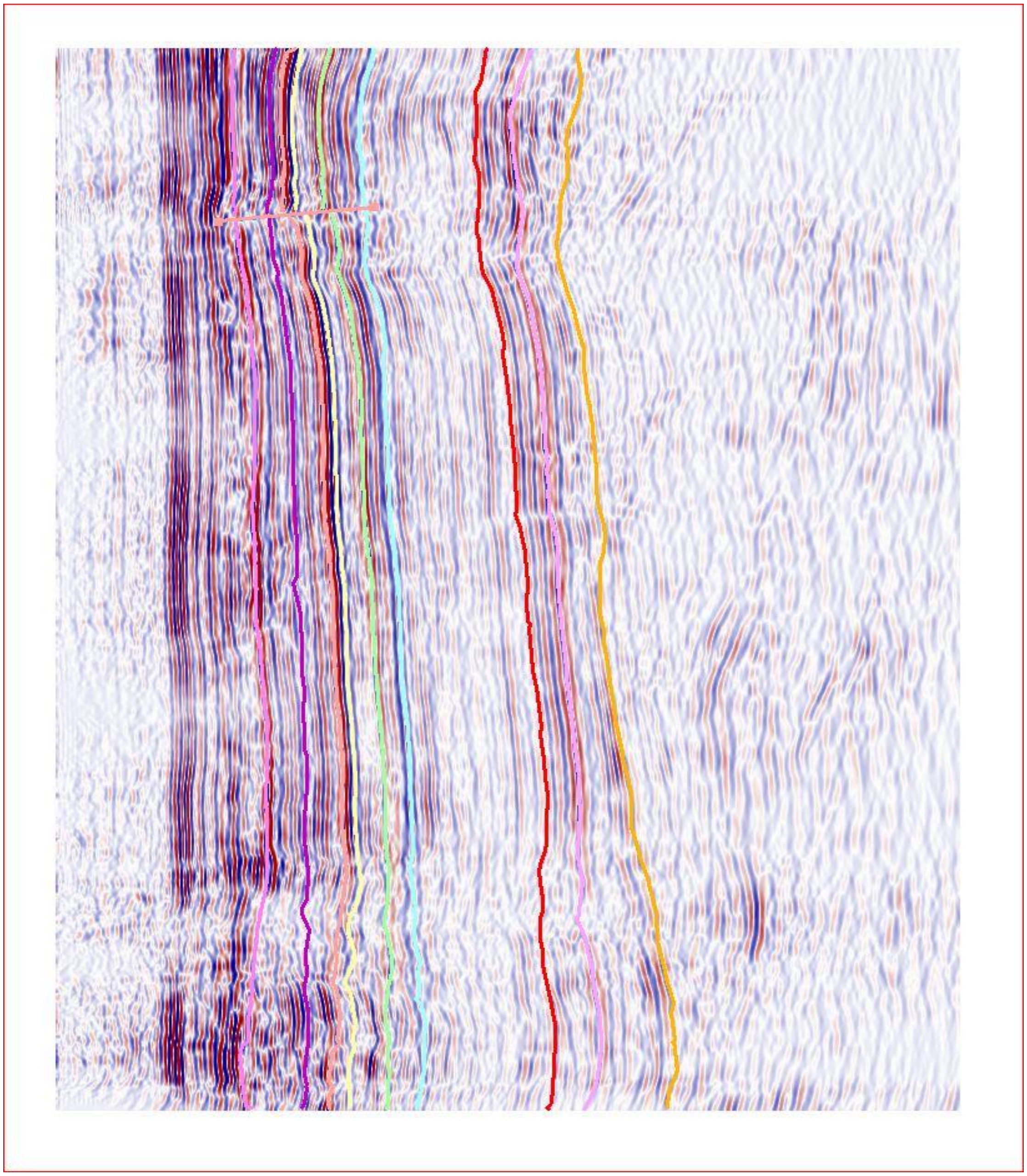


Fig 24: Horizon Correlation along the Dip (Inline Section)

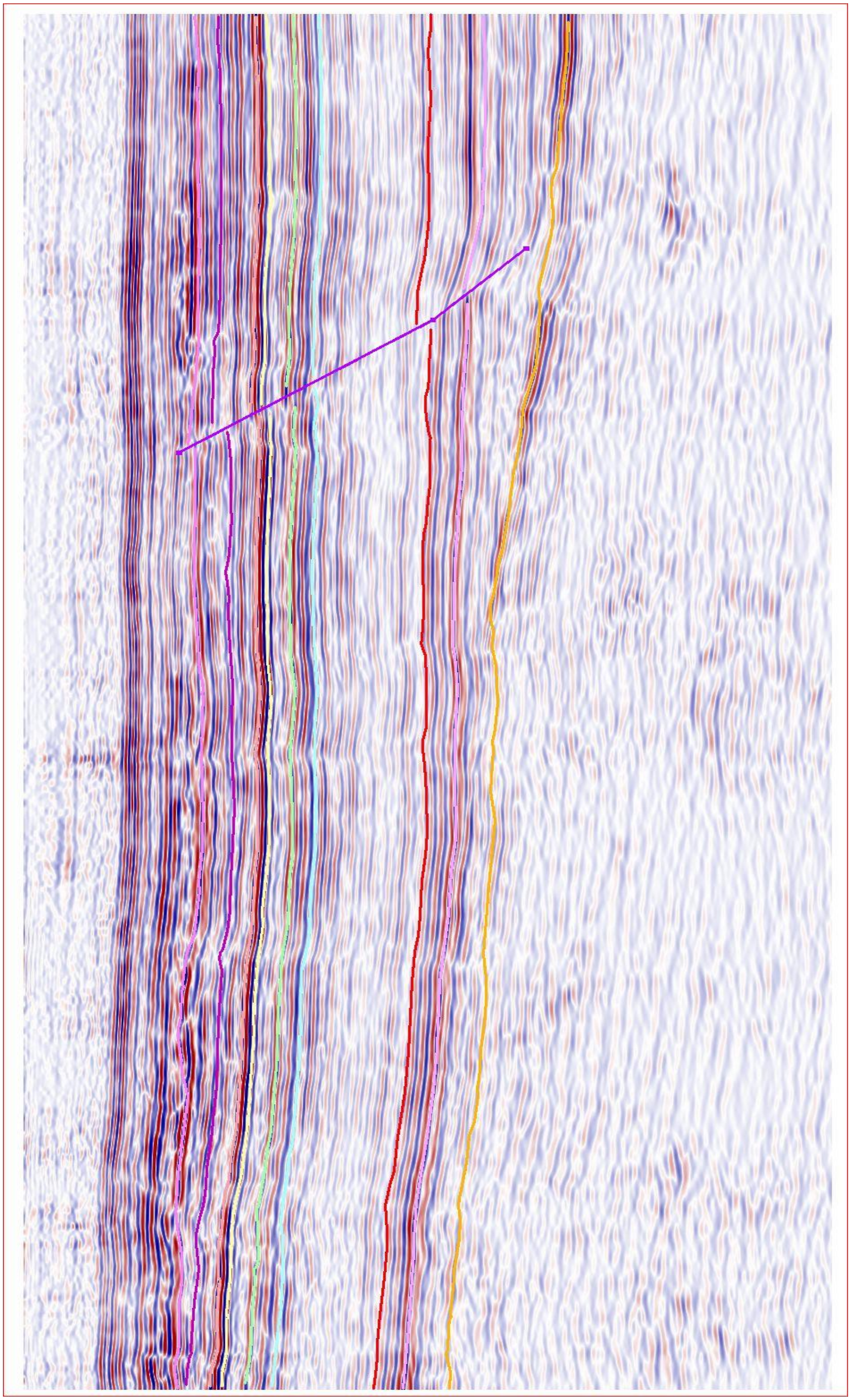


Fig 25: Horizon Correlation along the Strike (Xline Section)

PREPARATION OF TIME STRUCTURE MAPS OF INTERPRETED HORIZONS

The Geological structure of an area can be best delineated by Surface modelling or by preparation of TWT contours which is first step of interpretation. To prepare these contours few concepts are required such as contour interval, grid parameters, search radius etc.
Settlement of above-mentioned parameters demands the geological knowledge of that area, such as if the target is large enough then one can choose a large contour interval or in the case of small target, the interval should fine to make a clear sampling.

Upon those parameters we should make our first discussion on grid parameters. It is simply defined as a set of regularly distributed points that are calculated or estimated from an input set of control points. Control points represent real data that has been collected and is not regularly distributed. The gridding methods are designed to work with point data, grids, digitized contours, Seismic lines, or other line-oriented data. The next parameter is the search radius which determines how far from a node the gridding method should look to determine the value assigned to the node. The default radius is half the diagonal of the grid being calculated and is usually much larger than necessary.

Although it is better for the radius to be too large rather than too small, a large radius increases gridding time. Since only the closest points are used, significantly more data are looked at than are actually used to calculate a node’s value. Most users have found that significantly reducing the default value for the Search Radius is the easiest way to speed the gridding process. This is one of primary parameters for controlling how far extrapolations are carried away from data. The next parameter is sampling parameter and is based on horizon sampling and the areal extent of it.

Lastly the contour parameters are set in which we decide the difference between two contours which is dependent upon the size of the area and nature of study to be performed.
The annotations are also fixed so as to give an idea about the actual values of the contours. So, based on above mentioned parameters a TWT contour is prepared and according to that interpretations are made. The contours can be depicted as line contours or the area in between them can be filled by solid colour according to the selected colour bar.

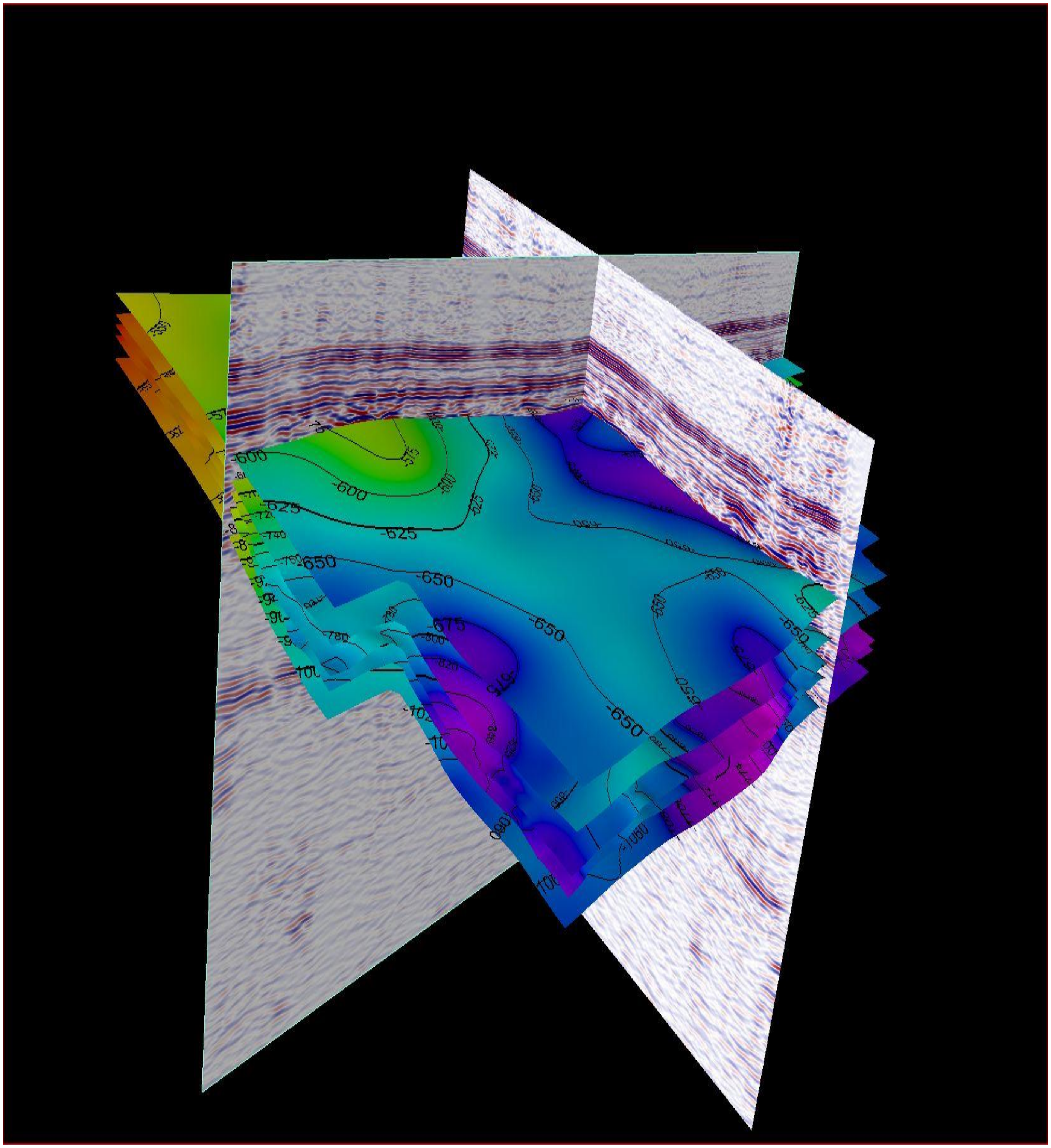


Fig 35: 3-D View of Time Structure Map of the picked horizons with Inline & Xline Section

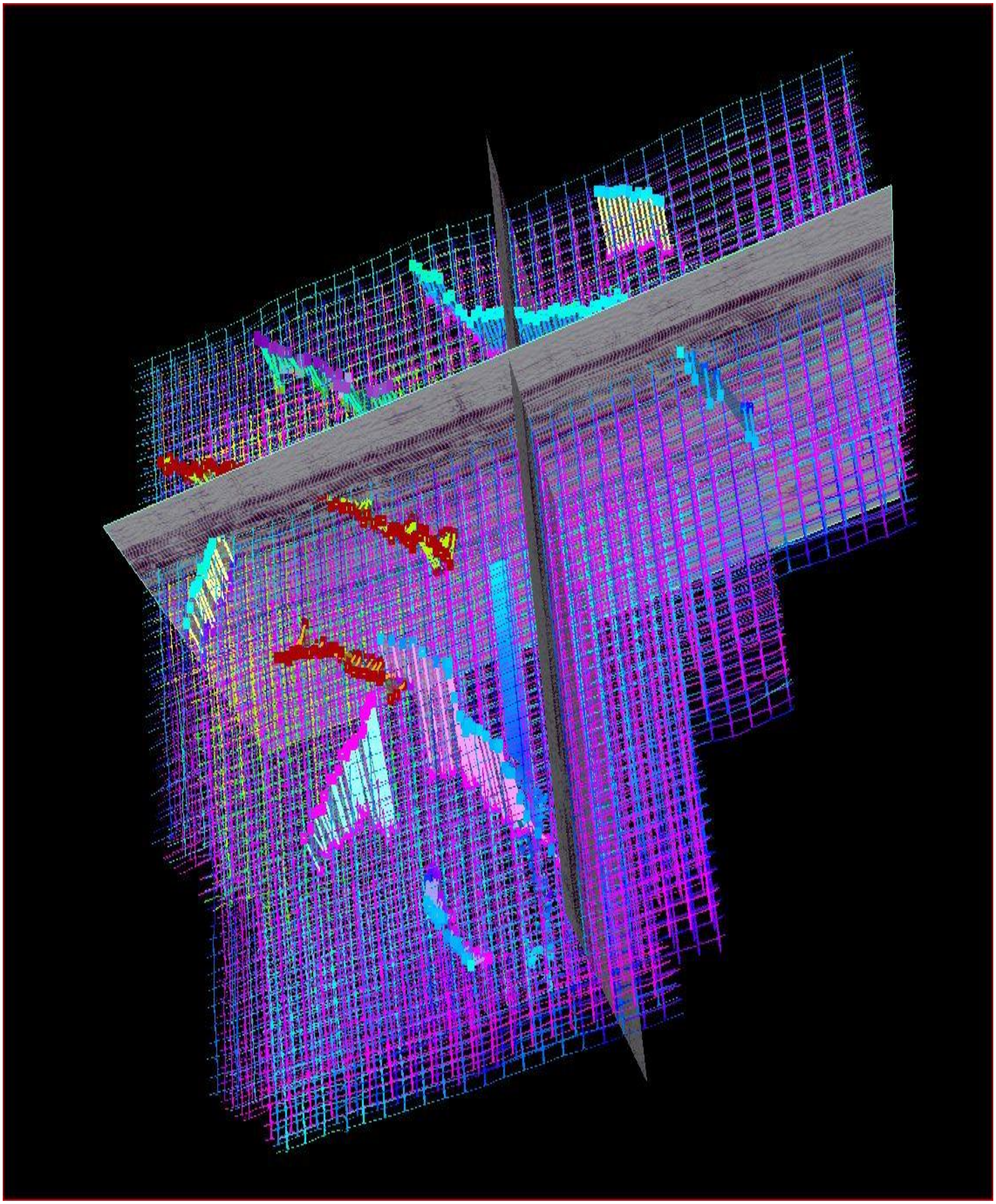


Fig 36: 3-D View of horizons picked and fault mapped with Inline and Xline Section

CONCLUSION

The work related to the summer training has been successfully completed on the topic ‘3D- Seismic and Well Logs data Interpretation of Lower Vindhyan Group of Son Valley, Vindhyan Basin’. The objective was to understand the geological and geophysical aspects of hydrocarbon exploration using seismic data. The work elaborates the complete work flow of seismic interpretation and integration with other Geoscientific data incorporating the following:

- Analyzing Well log data and seismic tie up through generation of synthetic seismogram.
- Correlation of the major horizons across the provided seismic data
- Preparation of Time Structure and Time Thickness map to bring out the present subsurface configuration of the study area.

Integrated analysis of available 3-D Seismic and Well Logs Data of part of Lower Vindhyan Basin have been evaluated. Based on study of Lower Vindhyan Basin, two structurally high areas were identified in view of hydrocarbon prospectivity i.e. in the North and North western part.

SUMMARY OF WORK

One-month training in ONGC has been a great learning experience for a student like me. I have been exposed to the various techniques which are used in the oil and gas industry in the exploration process. For an entire month, I have been acquainted entire exploration gamut in a single basket which usually covers highly sophisticated scientific G&G interpretation and engineering techniques. At the outset, I was exposed to API of Exploration involving precise geophysical and geological techniques. I had the opportunity to interact with highly sophisticated and précised interpretation software in “work station” module and generate relief and time map by myself using this work station facilities. The basic objective of doing any work, its implication and desired outputs have been inculcated in our mind before taking up that assignment. Interpreting the maps and using them to extract the maximum geological information for its effective interpretation is an art where, I would like to excel in the time to come. Nonetheless, it has been a great way to begin.

Before coming to ONGC, I had very basic knowledge of these concepts. College is a great place to learn the basics of a subject but it is in the industry that one gets a chance to learn its application. I have also had a chance to be exposed to the wonderful work culture of this prestigious organization. This knowledge has significantly improved, thanks to the all the mentors in ONGC who have helped and guided me on every step. I am confident that the knowledge that I have gained will help me becoming a very good geologist in the future. I shall make sure that my hunger for knowledge will remain intact and I shall always strive for more and its effective utilization by proper assimilation.

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