2-D SEISMIC INTERPRETATION AND RESERVOIR CHARACTERIZATION OF TAJJAL AREA, LOWER INDUS BASIN SINDH, PAKISTAN

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SUMMARY

The dissertation pertains to locate structures favourable for hydrocarbon accumulation using seismic and well data and Petrophysical interpretation to evaluate reservoir properties. The interpretation was performed on seismic lines GT J88-206, GT J88-207, GT J89-516 and GT J89-522 and on well KADANWARI-14. For the interpretation of the seismic lines, two reflectors were marked by correlating synthetic seismogram on seismic section. As the area of study lies in the lower Indus basin, horst and graben with associated normal faults are present.

Seismic attribute (instantaneous phase) is applied to confirm the interpretation. Instantaneous phase tell us about lateral continuity and trace envelope about reflection strength of reflectors.

Petrophysics uses combined response of different logs on the basis of which we mark possible hydrocarbon bearing zones. Lower Goru formation of lower cretaceous age is present in the study area in which the sands of lower goru are acting as thin pay zones and are acting as reservoirs. We performed Petrophysical analysis and check response of different logs in the depth range of 3075m to 3500m. Two possible Hydrocarbon bearing zones were marked in this depth on the basis of Petrophysical analysis. Average effective porosity was calculated to be 13% in zone A and it is 15% in zone B, water saturation 49% in A zone and 32% in zone B. Hydrocarbon saturation was found to be 50% in zone A and that in zone B was 67%.

Chapter#1

Introduction

INTRODUCTION

1.1 Orientation of the Field Area

The area of research is situated in Tajjal region in Sindh territory of Pakistan. It is situated in Lower Indus Basin and is isolated from Upper Indus Basin by Sargodha High and Pezu elevate in the north. The field area is limited by Sargodha high in the North, Indus Offshore in the south, Indian Shield in the East and Kirthar and Suleiman extends in the West. The region is imperative for its gas fields predominantly SAWAN, MIANO, KADANWARI, PIRKOH, SUI and so on. All these fields are in stratigraphic traps. The field area lies between 27° 0' N to 27° 15 'N Latitude and 68° 59' E to 69° 22' E Longitude.

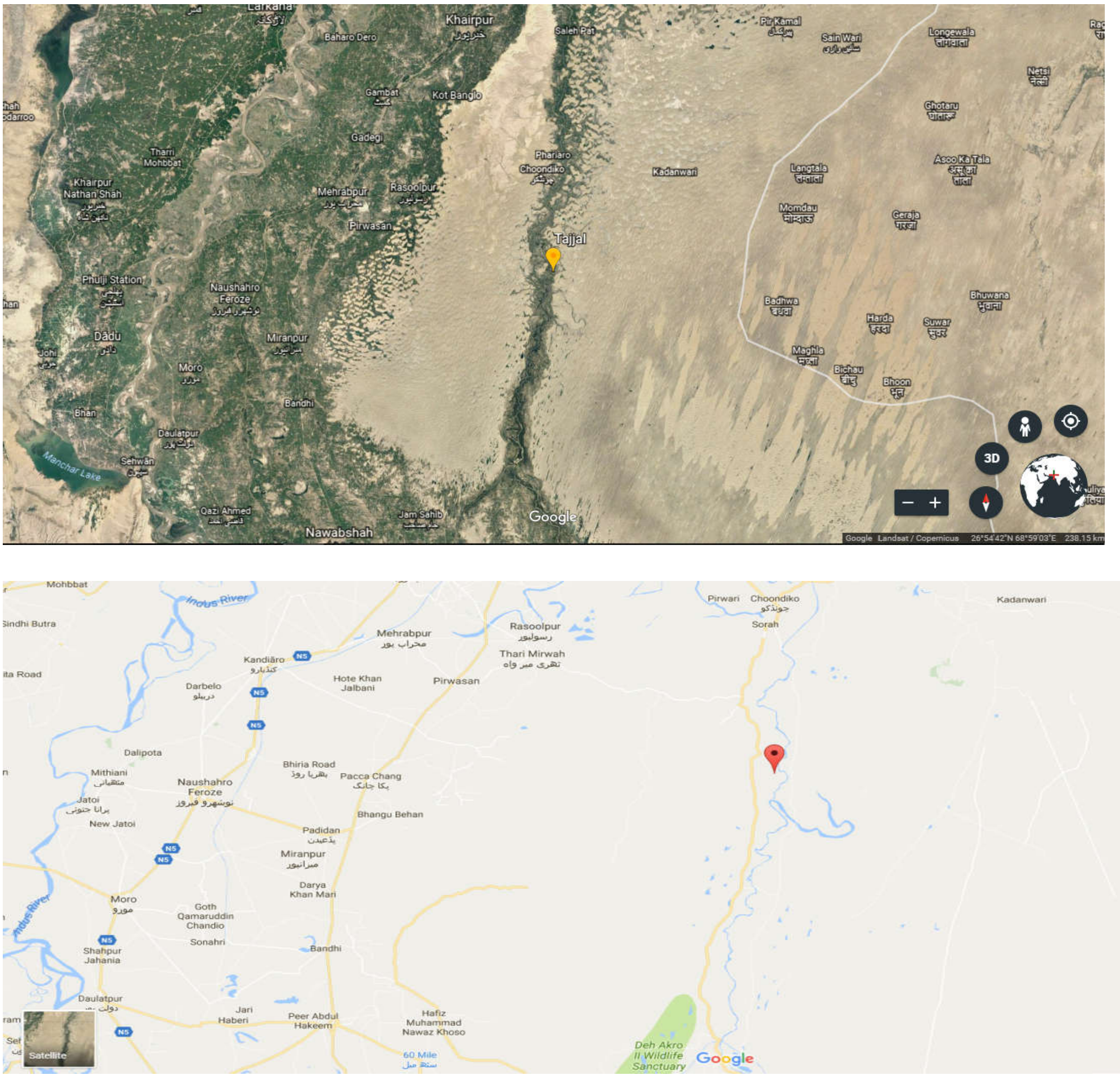


Figure 1 Location Of Tajjal Area

1.2 Exploration History of Lower Indus Basin

The Lower Indus basin is limited by the Indian shield toward the east and negligible zone of Indo-Pak plate toward the west. It is involved the Thar stage, Karachi trough, Kirtharforedeep and Kirthar overlap belt, and Indus seaward augmentation. The Badin trough situated over the southeastern flank drifts upper east southwest, going astray marginally in the south to a more north-south orientation. Various oilfields are operational in this part of Indus basin and some of the well known are listed below

- **Sui**

  Sui gas field was found in 1952 and is in the Marri-Bugti transverse elevate in Sibi locale of Baluchistan, on PPL's Sui M.L. concession. It is a mammoth gas field (52 by 12 mile), tender anticline eroded down to Lower Siwaliks. Unique stores were 8.624 tcf of gas, and 1994 generation was 712.267 MMcfd.

- **Khaskeli Field**

  This was found in June 1981, and is in the Badin trough on UTP's Khaskeli M.L. concession range in Hyderabad area of Sindh. The revelation was the primary oil found in the Lower Indus basin. Unique stores were 8.196 million bbl, and 1994 generation was 684 b/d of oil and 331 Mcfd of gas. Creating supplies are Lower Goru Upper Sand unit, A1 and A2 repositories. Normal porosity is 25%. Permeability surpasses 1 darcy.

- **Tando Alam Field**

  Opened in May 1984, is in the Badin trough of the Thar platform on OGDC's Tando Alam M.L. region in Hyderabad region, Sindh. Least areal degree is 5.5 by 2 km, and vertical abundancy is 90 ms TWT (around 120 m). Unique stores were 20.16 million bbl, and 1994 creation was 919 b/d of oil from Lower Goru.

- **Pasakhi Field**

  Found in July 1989, is in the Badin trough on OGDC's Sanghar P.L. concession in Hyderabad area, Sindh. Unique stores were 9.37 million bbl, and 1994 creation was 2,320 b/d from Lower Goru.

- **Tajjal**

  Investigation permit territory in Khairpur region of Sind. The Kadanwari revelation well, TD 3,994 m in Sembar, streamed gas on drillstem tests at rates of 11.2-28.6 MMcfd on different size gags with 133-174 b/d of water. Unique stores are 728 bcf of gas. The well is briefly suspended.

- **Kadanwari Gas Field**

  Found in August 1989, is on the Thar stage in the Lasmo gathering's.
- **Bari Oilfield**

  Found in 1992, is in the Badin trough on UTP's Laghari P/L concession zone in Hyderabad region, Sindh. Unique stores are 2.531 million bbl of oil; 1994 generation was 2,275 b/d of oil and 537 Mcfd of gas.

1.3 Infrastructure and Climate

Tajjal is open region of the Sindh territory of Pakistan which is easily accessible. In any case it needs offices and the populace per square km is none to constrained. It is a hot zone with normal temperature of 45-50°C in summer and 30-35°C in winter. Temperature diminishes forcefully around evening time.

1.4 Base Map

A base map is a map with respect to which information can be plotted. The base map is essential for translation perspective since it delineates the spatial area of seismic segment and furthermore indicates how seismic segment are interconnected. A base map ordinarily incorporates area of rent and concession limits, wells, and seismic study focuses. Base map gives the structure to forming (contouring). Contours making a closure are always indicative of some specific subsurface structure. If the time contours have greater values in their core and smaller values on the outside then it is a syncline map and if high time values are present on the outside and low values in the centre then it is anticline map. So, contouring is quite helpful in this regard. The base map, given in adjoining Figure demonstrates the orientation of seismic lines in the Tajjal area

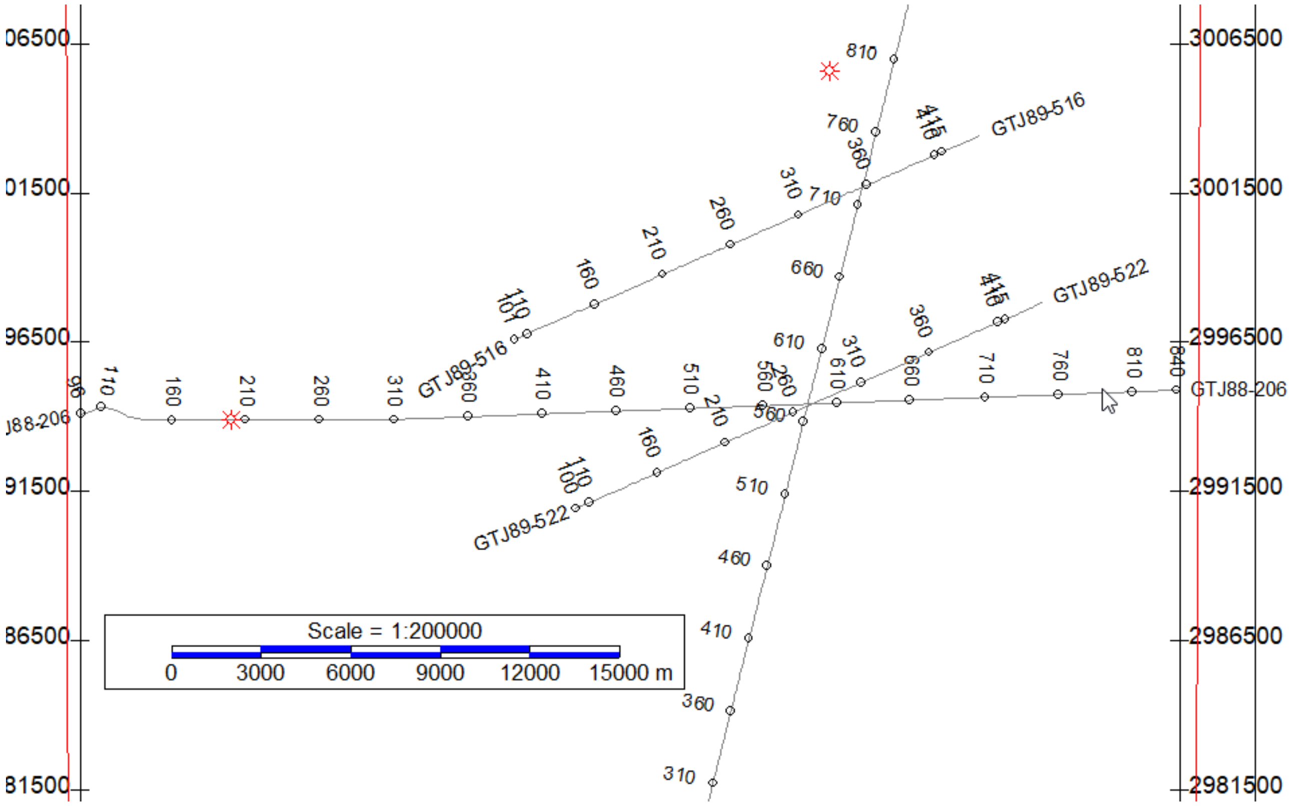


Figure 2 Base Map

1.5 Introduction to Seismic Lines

Seismic review for Tajjal region was completed in March 1988. The information procurement and handling were made on choosing fitting field parameters. This exposition relates to the understanding of CDP nominal 60 fold information. Lines GT J88-206, GT J88-207 and GT J89-516 and GT J89-522 are processed and they are interpreted along other survey lines for obtaining accurate subsurface and an attempt is made to map the structure using these lines of base map. The seismic information procurement and handling in regards to the worked lines of Tajjal area was performed by Lasmo in 1988.

Line	Orientation	Nature
GT J88-206	EW	Dip line
GT J88-207	NE-SW	Strike line
GT J89-516	NE-SW	Dip line
GT J89-522	NE-SW	Dip line

1.6 Petroleum Play In Lower Indus Basin

A range which contain hydrocarbon collections of a given sort happen frames a petroleum or an oil play. A developed source rock, relocation pathway, reservoir rock, trap and seal/top rocks are segments of oil play. These are the primary segments of a petroleum play without which a proper and economical petroleum system cannot be formed.

- **Source Rock**

  Rocks which are rich in natural organic content are vital to act as a source of petroleum and if warmed adequately, will produce oil or gas. Rocks of marine birthplace have a tendency to be oil inclined, though earthbound source rock has a tendency to be gas inclined. Sembar shale is the demonstrated source rock and Chiltan Limestone is likewise going about as a source at a few territories.

- **Reservoir Rocks**

  A subsurface geologic unit having adequate porosity and permeability to store and transmit liquids is known as a reservoir. It is a basic part of an entire oil framework. Sands of Lower Goru go about as a repository rock in this region. The plausibility of reservoir in Lower Goru overlain on Basal Sand couldn't be disregarded in spite of the fact that they have not demonstrated as repositories still now (Kadri, 1995). Hydrocarbon targets may likewise exist in the Jurassic Chiltan Limestone, Paleocene and Eocene developments.

- **Seal Rock**

  Seal or cap is an impermeable layer regularly shale, anhydrite or salt that go about as a boundary over the supply (reservoir) with the end goal that liquid can't move past the repository. Sember, Bara-Lakhra, Laki-Ghazij and Kirthar Arrangements go about as seal in Southern Indus bowl (Zaigham&Mallick, 2000).Inter-slept with Shales (Upper, Lower and Talhar) of Lower Goru development gives compelling vertical and parallel seal and go about as an essential seals. The Upper Goru shapes the top and parallel seals for the Upper Sand units of Lower Goru development. (Kadri, 1995).

- **Trap**

  Trap is a structure that is good for hydrocarbon gathering. Traps are of two sorts **Auxiliary (Structural) traps** and **Stratigraphic traps**. Those traps that are framed because of structure changes are called Auxiliary traps. In any case, A stratigraphic trap gathers oil because of changes of rock character as opposed to blaming or collapsing of the rock. The expression "stratigraphy" fundamentally signifies “the investigation of the stones and their variations”.(Rittenhouse, Gordon, Stratigraphic-Trap Characterization: Geologic Investigation Strategies, 1972). In the range of premium i.e. Tajjal, auxiliary traps are more articulated than the stratigraphic traps. Horst and Graben structures are shaped because of the extensional condition.

1.7 Aims and Objectives

- 2D structural interpretation of the region by marking different faults using seismic data.
- Preparation of time and depth sections and study their differences which are helpful in better understanding of subsurface image.
- Seismic attribute analysis to confirm interpretation.
- To study the physical behavior of reservoir zone by using Rock physics parameters.

Chapter#2

Geology of the Field Area

GEOLOGY OF THE FIELD AREA

2.1 Major Division of Indian Sub-Continent

The most remarkable certainty concerning both the physical topography and geography of the Indian locale is that it is made out of three particular units or earth –features which are as dissimilar to in their physical as in their topographical characters. The initial two of these three divisions of India have a principal premise and the particular characters of each, as we might find in the accompanying pages were urged it from an early time of its land history, since which date every territory has sought after its own particular profession autonomously. These divisions are :

- The triangular level of the Peninsula (i.e. the Deccan, south of the Vindhyas), with the island of Ceylon.
- The sloping locale of the Himalayas which outskirts India toward the west ,north, and east, including the nations of Afghanistan, Baluchistan and hill traces of Burma, known as the additional promontory (*extra-peninsula)*.
- The considerable Indo-Gangetic plain of Punjab and Bengal, isolating the two former ranges, and stretching out from the valley of the Indus in Sindh to that of the Brahmaputra in Assam (Wadia, 1952).

2.2 The Indus Plain (Characters and Peculiarities)

As said over, the Peninsula, as an earth-highlight, is totally dissimilar to the additional Peninsula. The accompanying contrasts rundowns the principle purposes of difference between these two areas. The first is stratigraphic or that associated with the topographical history of the regions. As far back as the beginning of topographical history (Cambrian period) the Peninsula has been a land territory, a continental piece of the earth's surface which since that age in the earth-history has never been submerged underneath the ocean, aside from temporarily and locally. No extensive marine residue of later age than Cambrian was even kept in the inside of this land-mass. The additional Peninsula then again, has been a locale which has lain under the ocean for most of its history (Wadia 1952).

The second distinction is geotectonic. The Peninsula of India uncovers a significant diverse sort of design of the world's covering from that appeared by the additional promontory. Peninsular India is portion of the world's external shell that is made in awesome part out of the most antiquated complex of shake beds that remain upon a firm and steadfast establishment and that have for an enormous number of ages. Sidelong pushes and mountain-building strengths have had yet little impact in collapsing or uprooting its unique cellar. The strata wherever indicate high edges of plunge, a firmly pressed arrangement of folds and other savage takeoffs from their unique primitive structure.

(Wadia, 1952).The third distinction is the differing qualities in the physiography of the two territories. The distinction in the outer or surface alleviation of Peninsular and additional Peninsular India .In the Peninsula, the mountains are for the most part of the "relict" sort ,i.e. they are not mountains in the genuine feeling of the term, however are negligible extraordinary segments of the old level of the Peninsula that have gotten away, for some reason ,the weathering of ages that has removed all the encompassing parts of the land; they are, so to state, immense valleys, with low subtle angles, as a result of their channels having drawn nearer to the base-level of disintegration. Appeared differently in relation to alternate mountains are all genuine mountains, being what are called "structural" mountains,i.e. those which owe their starting point to a particular inspire in the world's outside layer and as a result, have their strike or line of augmentation pretty much comparable to the pivot of that elevate. The waterways of this zone are fast downpour - ional streams, their disintegrating power are constantly dynamic, and they have cut profound chasms, through the mountains in the bumpy piece of their track (Wadia, 1952).

2.3 Physical Characters of the Plains of India

The third division of India, the colossal alluvial fields of the Indus and Ganges through, humanly discussing the best advantage and significance just like the foremost theater of Indian history, is, geological talking, the minimum fascinating piece of India. In the geographical history of India they are just the annels of yester-year, being the alluvial stores of waterways of the Indo-Ganges frameworks, borne down from the Himalayas and saved at the their foot. They have concealed, underneath a profound mantle of waterway dirts and residues, important records of past ages, which may have tossed much light on the physical history of Peninsular and Himalayan territories and uncovered their previous association with each other. These fields were initially a profound dejection; there is some distinction of sentiment. Burrard from a few inconsistencies in the perceptions of the avoidances of the plumb-line and other geodetic contemplations has proposed a significant diverse view. He feels that the Indo-Gangetic alluvium disguises an extraordinary profound break, or crack, in the world's sub outside, a few thousand feet profound, the empty being along these lines topped off by detrital stores. He credits to such sub-crustal breaks or fractures a central significance in geotectonic and qualities the height of the Himalayan affix to a coincidental bowing or twisting development of the northern mass of the crevice. Such depressed tracts between parallel, vertical separations are called "Fracture –Valleys" in topography (Wadia, 1952).

2.4 Structure of the Area (Ahmed et al, 2004)

Fig 2.1 demonstrates that Sulaiman Fold belt is present in the north of our field area while Kirher Fold belt is present in the southern part. Towards east is Indian Shield and towards West is Kirther Fold Belt. The Studied territory lies in Lower Indus Basin in Pannu-Aqil Graben which part of Sukkar Rift Zone which contains Mari Khandkot High, Jacobabad-Khairpur High and Pannu-Aqil Graben. This Sukkar Rift Zone partitions the Central Indus Basin and Lower Indus Basin. The region has been navigated by Normal Faults shaping Horst and Graben Structures. This implies that the region has been worked by extensional powers and is more conspicuous close to the limit between Jacobabad-Khairpur High and Panno-Aqil Graben (Ahmad *et al* 2004).

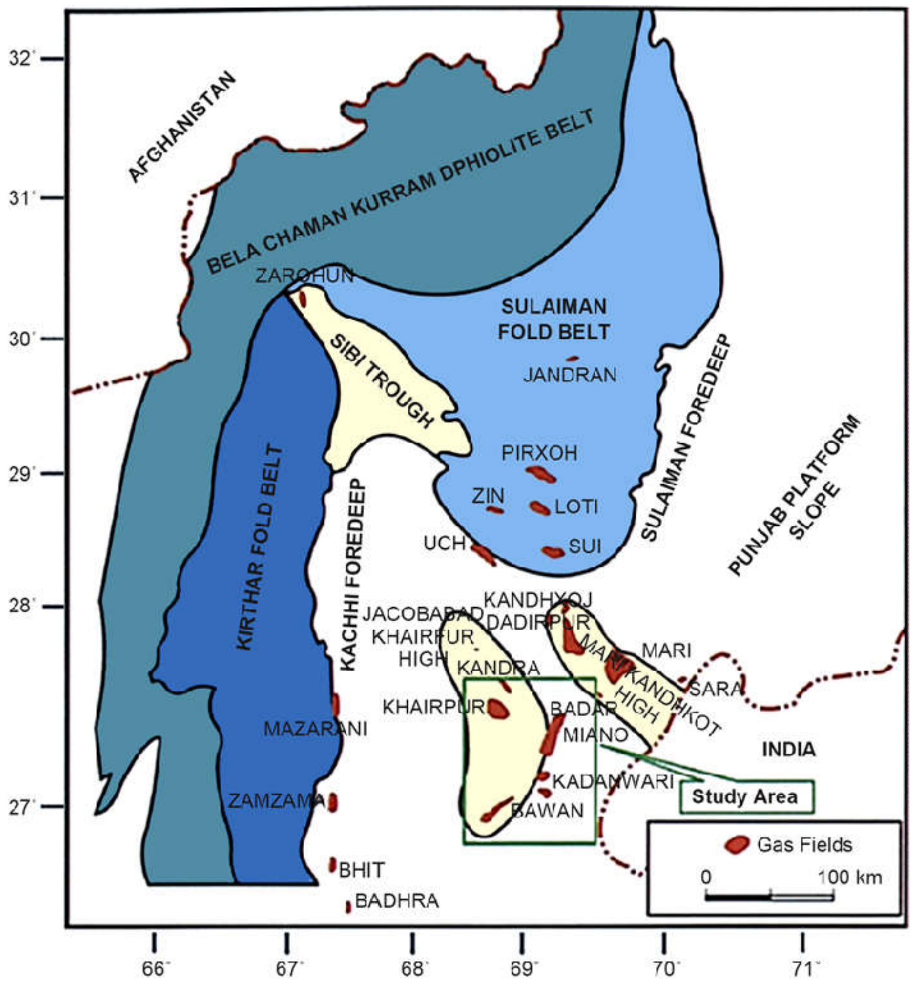


Figure 3 : Location and structure map of the studied area after Ahmad et al, 2004

2.5 Tectonic Framework of Pakistan

Pakistan is one of a kind in as much it has a place with the two areas of landmasses, i.e Tethyan Domain and Gondawanian Domain and is maintained by the Indo-Pakistan crustal plate. The northern most and western districts of Pakistan fall in Tethyan domain showing a convoluted geology and complex crustal structures (Kazmi & Jan, 1997).

As indicated by Wadia's (1960) division, Pakistan incorporates nearly the three divisions of Landmasses. On the premise of plate structural components, geologic structure, orogenic history (age and nature of disfigurement, magmatism and transformative nature) and lithofacies, Pakistan might be partitioned into following wide structural zones (Kazmi & Jan, 1997).

I. *Indus platform and foredeep.*
II. *East Baluchistan fold-and-thrust belt.*
III. *Northwest Himalayan fold-and-thrust belt.*
IV. *Kohistan-Ladakh magmatic arc.*
V. *Kakar Khorasan flysch basin and Makran accretionary zone.*
VI. *Chagai magmatic arc.*
VII. *Pakistan offshore.*

2.6 Indus Platform and Foredeep

This zone reaches out finished a zone surpassing 2500,000 km2 in southeastern Pakistan and incorporates the Indus plain and Thar –Cholistan deserts. It has over 80% of Pakistan's populace, broad coal stores, significant oil and gas fields, potential for geothermal vitality and immense groundwater supplies (Kazmi and Jan, 1997).

Gravity and Seismic overviews, bolstered by restricted drill opening information, demonstrate that in the eastern part Precambrian rocks frame a delicate westbound plunging monocline secured by finishes of Mesozoic to Cenozoic marine to deltaic residue. In any case, there are wide zones of up twist and down twist which are all around characterized by gravity studies. The sedimentary cover is generally thin in the up twist zones. The down twist contains a thick sedimentary heap, especially the foredeep at the western edge of stage slant where the sedimentary cover is up to 10,000 m thick (Kazmi and Jan, 1997).

2.7 Structural Zones

The Indus stage and foredeep contain the accompanying primary basic zones.

- Fore Deeps
  - Sulaiman foredeep
  - Kirthar foredeep
- Buried Ridges
  - Sargodha-Shahpur edge
  - Nagarparker edge
- Zones of upwarp
  - Mari-Khan dot High
  - Jacobabad-Khairpur High
  - Thatta-Hyderabad High
  - Tharparker High
- Zones of downwarp and slant
  - Northern Punjab monocline
  - Southern Punjab monocline
  - Cholistan Shelf
  - Panno Aqil Graben
  - Nawabshah slant
  - Lower Indus trough
  - Nabisar slant

It might take note of that the Jacobabad-Khairpur upwarp isolates the Indus plat-form into two portions. The **lower portion** is inclusive of the lower Indus trough. It is restricted by Nawabshah and Nabisar slants which are in flanked by Thatta-Hyderabad and Tharparker highs. The **upper portion** in Punjab is crossed by Sargodha-Shahpur edge, part it into northern Punjab monocline and southern Punjab monocline and Cholistan rack. Westbound the Indus stage forcefully steepens to shape the Sulaiman and Kirther foredeeps.

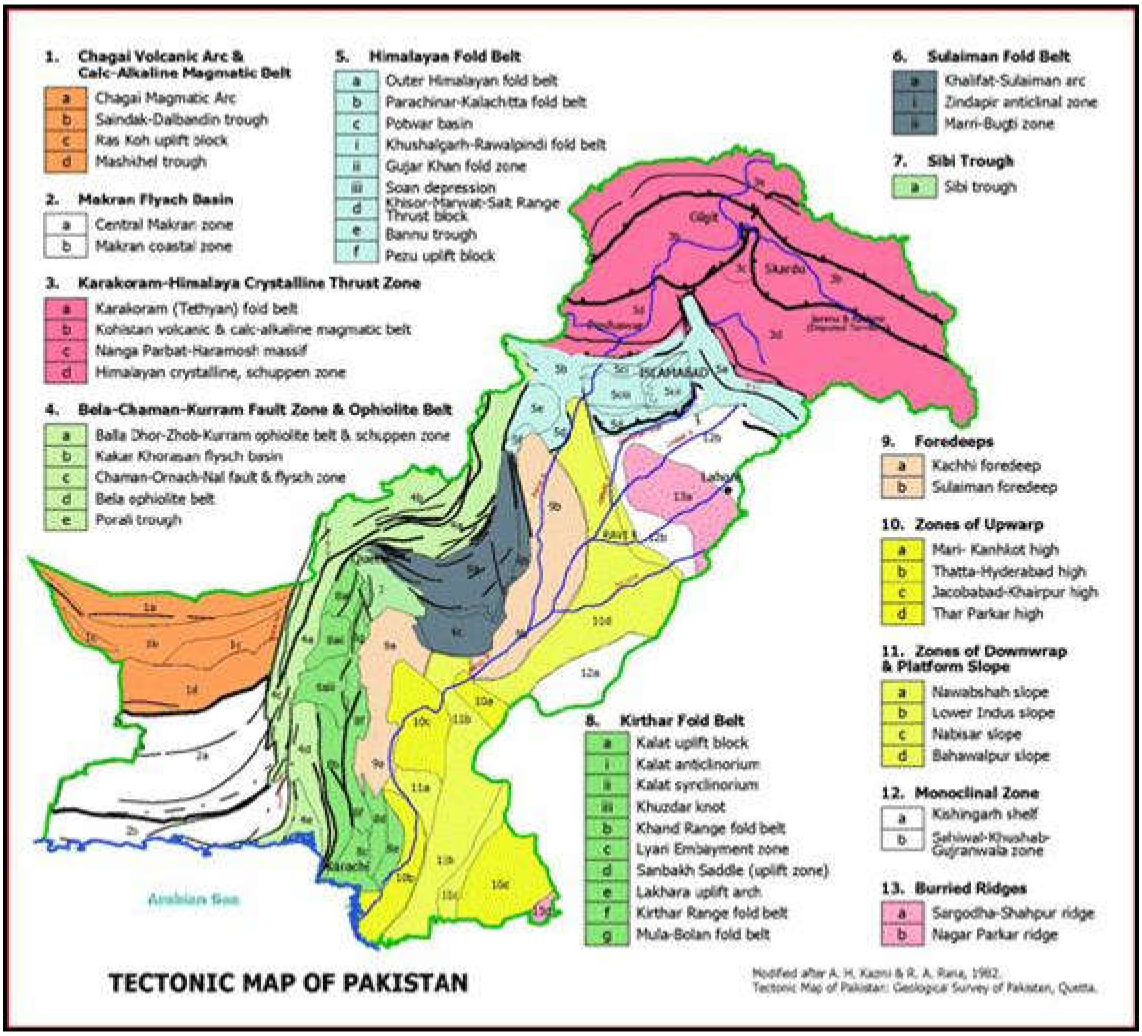


Figure 4 Tectonic Zones of Pakistan (www.gsp.com.pk)

2.8 Basins of Pakistan

Sediments get developed at certain place, they might be kept at the place of their cause or may get transported to other place by transporting operators, and the dregs saved at the place of source are called **Molasses**, what occurs with the moved residue? they are regularly saved at a place which is described by provincial subsidence and where they could get safeguarded for longer time frames, such a place is known as a **Basin**, in a bowl the repository or compartment which is the substratum of the bowl is called **Basement**, the amassed silt in a bowl are called **Sedimentary Cover**, the progressive settling of residue in a bowl is called **Subsidence**, the purpose of most extreme sedimentary collection in a bowl is called Depocenter.

As far as the beginning and diverse topographical histories, Pakistan comprise upon two noteworthy sedimentary bowls, the Indus Basin and the Baluchistan Basin, these bowls were produced amid various land scenes. There is another littler bowl which has its own particular topographical history of improvement, this bowl was created because of the crash amongst

India and Eurasia and is named the Median bowl. It is the **Kakar Khorasan** Basin which is otherwise called Pishin Basin.

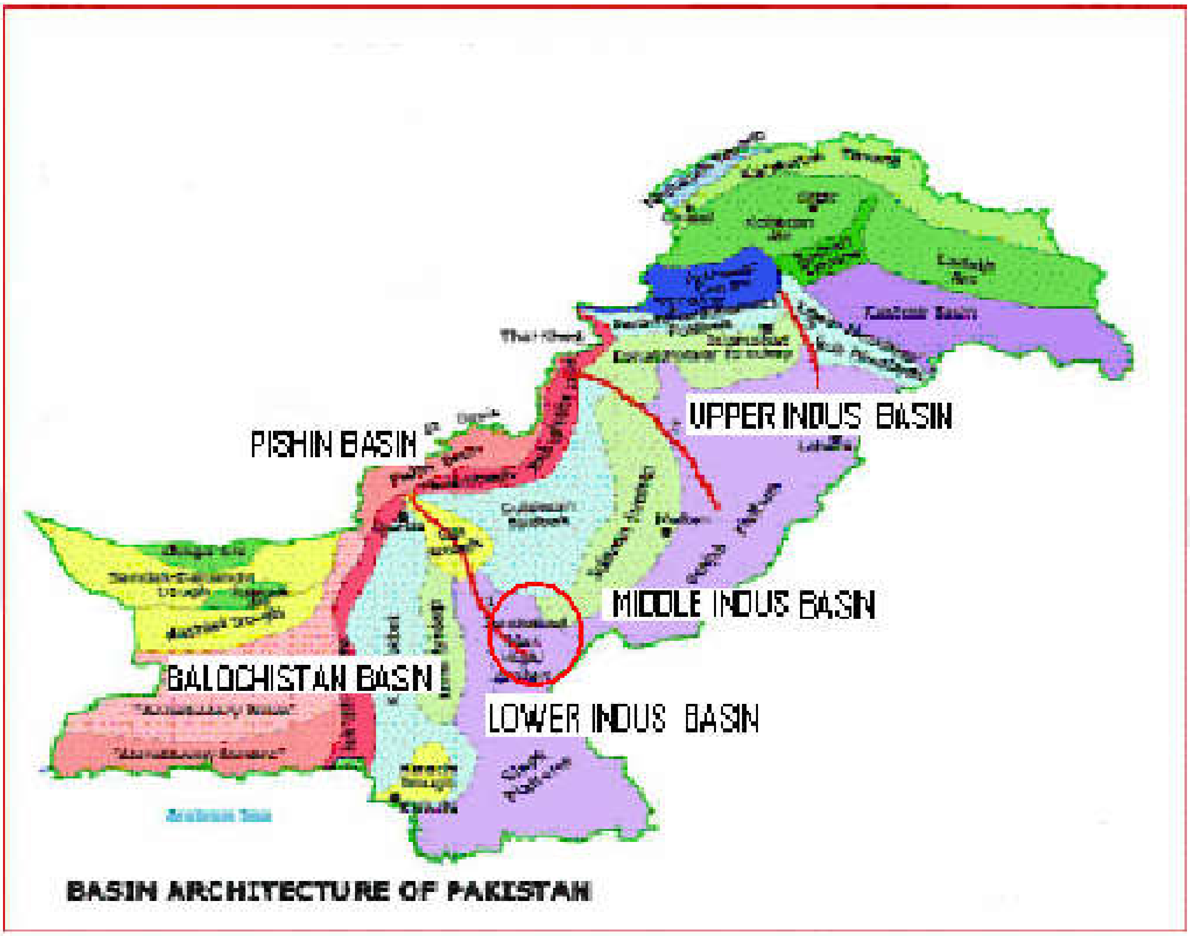


Figure 5 Basins of Pakistan

According to Fig 5, Indus Basin is characterized into the following classes.

- Upper Indus Basin
    - Kohat Sub Basin
    - Potwar Sub Basin
- Lower Indus Basin
    - Central Indus Basin
    - Southern Indus Bsin

2.9 Lower Indus Basin

This bowl is portrayed by aloof rooftop duplex-sort structure and a uninvolved backthrust along the Kirther Fold Belt, a latent rooftop push framing a front summit divider along the edge of overlap belt, and the Kirther discouragement and out-of syncline intra-molasses separations in the Kirther dejection arrangement. The Kirther and Karachi discouragements contain a few substantial anticlines and vaults and some of these contain little gas fields (Mazarani, Sari, Hundi and Kothar). The eastern piece of bowl involving the Sindh monocline is to a great extent included blamed and tilted squares of Mesozoic rocks which shape auxiliary traps overlain by Deccan Trap Basalts and Tertiary sedimentary rocks .The northern edge of Lower Indus Basin involves the Sukker Rift on which bears vast anticlinal structures and contains the Khandot and Mari Gas fields. The last is a goliath field 6.3 TCF of stores. The principle supply shakes in the Sindh Monocline are Cretaceous Lower Goru sandstone. In the Karachi melancholy generation is from Paleocene Ranikot limestone and sandstone, in Kirther despondency and Sukker Rift zone it is from Eocene Sui Main/Habibrahi limestone. The lower Indus bowl is likewise described by high geothermal inclinations which run from 2 to more than 40C/100m.

2.10 Tectonic Boundaries

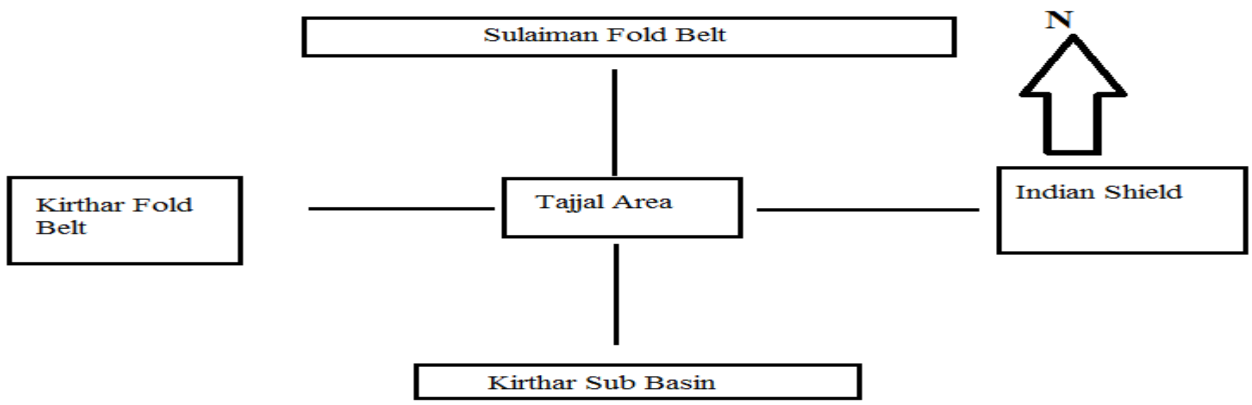


Figure 6 Tectonic Boundaries of Tajjal Area

2.11 Geographic Boundaries

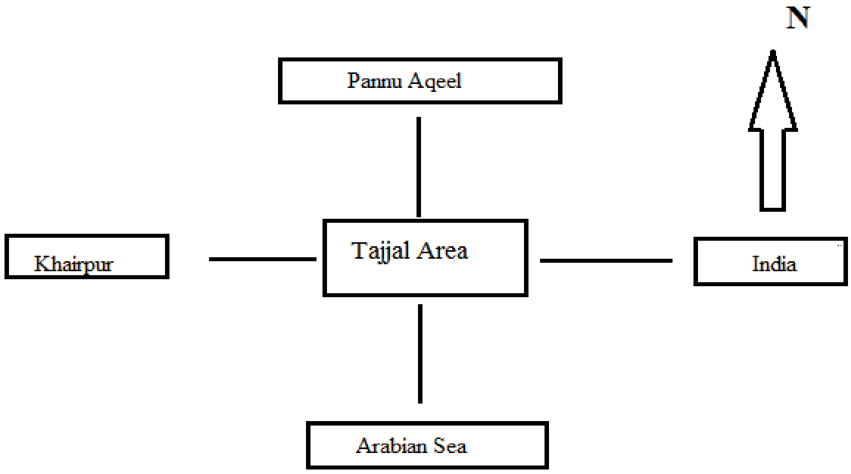


Figure 7 Geographic Boundaries of Tajjal Area

2.12 Structure of the Field Area

All of the lower Goru revelations are situated on close to the (for the most part east –to southeastward of) one or other auxiliary high (Mari high, Jacob awful khairpur high, Badin elevate, lakhra high) which has suggestions for the movement pathways, timing of the supply charge and hydrocarbon ensnarement in basic and unpretentious stratigraphic highlights. The vast majority of these structures high are reversal highlights distinguished on the local seismic lines. The main inspire scene happens close to the K-T limit, and is showed as the base Tertiary Unconformity. The Paleocene Ranikot clastics disperse towards and propagade out and thicken far from these highs. In addition, the greater part of profound storm cellar related and shallower torque –tectonics related flaws end against this unconformity. By and large, the whole cretaceous area changes character from firmly straight and single blame at beat Chilton to duplicate an echelon left-sidelong sections at lower and upper Goru levels. This structural occasion was an aftereffect of trans-tensional tectonics identified with first docking of India –Eurasia plates and experience –clockwise pivot of the Indian plate. The second inspire occasion in the center and lower Indus Basin occurred amid the late Eocene-Oligocene times. The basic high most likely experienced repetitive periods of up heaval in light of progressive periods of push stacking in the west and northwest. The last change of the states of traps and possibly the optional hydrocarbons relocation and repository charge occurred amid this period.

2.13 Stratigraphy

Detailed Stratigraphy of the study area is explained by the table given below.

	Age		Lower Indus Basin			
ERA	**PERIOD**	**EPOCH**	**Kirthat**	**Sulaiman**	**Lithology Description**	
CENOZOIC	QUATERNARY	PLEISTOCENE	LEI CONGLOMERATE		CONGLOMERATE	
	TERTIARY	PLIOCENE	SIWALIK GROUP		SANDSTONE	
		MIOCENE	GAJ FORMATION		SANDSTONE, SHALE, LIMESTONE	
		OLIGOCENE	NARI FORMATION		LIMESTONE, SANDSTONE	
		EOCENE	KIRTHAR FORMATION	DRAZINDA MEMBER		
				PIRKOH MEMBER		LIMESTONE
				DOMANDA MEMBER		
				HABB RAHI FORMATION		LIMESTONE
				BASKA SHALE		SHALE
			LAKI FORMATION	GHAZIJ FORMATION	LIMESTONE	SHALE
			SUI MAIN LIMESTONE		LIMESTONE	
		PALEOCENE	LAKHRA	DUNGHAN FORMATION	LIMESTONE, SHALE	LIMESTONE
			BARA			
			KHADRO	RANI KOT	SANDSTONE	SANDSTONE, LIMESTONE
MESOZOIC	CRETACEOUS	LATE	PAB SANDSTONE		SANDSTONE	
			FORT MUNRO MEMBER		LIMESTONE	
			MUGHALKOT FORMATION		SANDSTONE, LIMESTONE, SHALE	
		EARLY	PARH FORMATION		LIMESTONE	
			GORU FORMATION		SANDSTONE, SHALE	
			SEMBAR FORMATION		SANDSTONE, SHALE	
		LATE				
			MAZARDRIK FORMATION		SHALE	

	JURASSIC	MIDDLE	CHILTAN FORMATION	LIMESTONE
		EARLY	SHIRINAB FORMATION	SANDSTONE, LIMESTONE
	TRIASSIC	LATE	WULGAI FORMATION	SANDSTONE, SHALE, LIMESTONE
		MIDDLE		
		EARLY		
PALEOZOIC	PERMIAN	LATE	NOT EXPOSED OR DRILLED	
		EARLY		

Stratigraphy of the study area

2.14 Cretaceous Sequence

Sembar Formation

- It is the bottom most unit of cretaceous sequence in Kirther-Sulaiman Region comprising of shale blocks interbedded with silt stone and nodular, argillaceous lime stone. The silt and shale are routinely Glauconite.
- Its thickness is 133m in type area while in Mughal Kot section it is recorded to be 262m thick.
- Its contact with overlying Goru formation is gradational in nature but an unconformity at some places is reported by Williams (1959).

Goru Formation

- Goru formation comprises of shale, siltstone and interbedded lime stone.
- Lower part of this formation is more shaly and consists of very thin-bedded, light-colored lime stone interbedded with thin to irregularly bedded, calcarios, hard, splintery grey to olive- green shale.
- Upper part is mostly thin- bedded, light – colored porcellanneous lime stone with sub ordinate shale.
- Its thickness at the type locality is 538m and it grates into the overlying parh limestone.

Parh Limestone

- This is exceptionally uniform particular and persevering rock arrangement and uncovered widely in the Kirther – Suleiman area.

- It is thin-bedded with light grey, white or cream hues with a tenacious pink, purple to maroon hued band of interbeds of variegated shales and marls.
- In type area, its thickness is 268m while elsewhere it ranges from 300 to 600m
- Its contact with underlying Goru and overlying Mughal Kot formation is conformable.

Mughal Kot Formation

- This arrangement comprises of dark calcareous shale and mud stone with intercalations of arkosic sand stone and dim argillaceous lime stone.
- In the Sulaiman zone the sand stone is all around created though in Kirther territory the development is to a great extent dark, silty calcareous shale.
- In one of oil wells (Dabbo Creek) close Karachi, basalts are available though close Kahan town in Ziarat region the development is locally contains a thick arrangement of combinations with rocks and stones of basalt; (Kahan conglomerates member of Williams 1959; Bibaai formation of Kazmi 1955, 1979, 1988).
- The thickness of development ranges from around 150 m to 1170 m. The sort segment is 2 to 5 km west of Mughal Kot Post.

Moro Formation

- This sand stone in the Kirther – Sulaiman area rests conformably and gradationally on the Pab Sand Stone.
- Where the Pab Sandstone is not built up, it overlies the Fort Munro Formation conformably on the Parh Limestone.
- It by and large comprises of a Lower limestone unit, at places with volcanic aggregates, a missle marly unit with subordinate sandstone and Upper limestone unit.
- It is overlain similarly by the dungan arrangement in spite of the fact that at places the Khadro development lays on it disconformably.

Pab Sandstone

- Sand stone is uncovered in the Kirther – Sulaiman district. It lays comparably on the fort Munro Formation, yet in a few regions overlies Parh Limestone unconformably.
- It comprises for the most part of white, cream or darker thick –bedded to huge had relations with, cross slept with, medium to coarse grained quarzose, sand-stone with intercalations of subordinate argillaceous limestone and shale.
- The sort segment is west of wirahab Nai in the Pab Range where it is 490 m thick, through its thickness ranges from 240 m thick to 1000 m.

Wulgai Formation

- This arrangement is uncovered in the Baluchistan Ophiolites-and-push belt in Zhob, Kalata and Khuzdar Regions. It has been experienced additionally in wells bored in the Lower Indus Basin.
- It comprises of indurated dull dim mudstone and shale with intercalations of thin limestone and calcareous mudstone and sandstone.
- Its thickness in the sort area at Wulgai is evaluated at 1180 m, while as per Sokolov and Shah the aggregate thickness is 985 m.
- The Lower contact of the Wulgai Formation with Permian Beds is structurally portrayed in Wulgai region yet it is conformable in the Shrinab Section.
- Its Upper Contact with the Jurassic arrangement is transitional.

Shrinab Formation

- This Formation is most likely the Earliest Jurassic uncovered rock unit, extending in thickness from around 1500 m to 3000 m.
- It comprises of interbedded limestone and shale.
- As indicated by Fatmi, it is transitional descending and grades into the shaly Triassic Wulgai Formation. Infact the Shrinab Formation of HSC incorporates undifferentiated Jurassic, Triassic and even Permian rocks.
- This formation uncovered in Kalat, Queta, Zhob, Loralai Districts of Baluchistan.
- Equalant rocks in the Khuzdar District have now been renamed Ferozabad Group.

Chiltan Formation

- In the Kalat, Queta ,Sibi and Loralai Districts an enormous to thick slept with dull to-light –grey or cream shaded ,sub-litholographic oolitic limestone conformably and gradationally overlies the Shrinab Formation.
- Its thickness ranges from 750-1800m
- The sort area is along Dara Manda south of Boston.

Mazar Drik Formation

- In the Sibi, Kalat and Khuzdar Districts, the Takatu limestone is overlain comparably by the Mazar Drik Formation.
- It comprises of interbedded dim limestone and dim shale.
- The sort territory is Mazar Drik where the arrangement is around 30 m thick.

2.15 Eocene System

Khadro Formation

- It is broadly dispersed in the Kirther and adjoining locale, lies unconformably on the laki Cretaceous Pab sandstone and Moro Formation.
- The sort region is Bara Nai in the Laki Range. At the sort territory, the badalpart of arrangement comprises of limestone containing shellfish and reptiles bones.
- The thickness of the Formation is test openings at Lakhra and Dabbo Creek, thickness of 140 m and 180 m were entered.

Bara Formation

- This Formation conformably overlies the Khadro Formation and is widely conveyed in the Kirthar Range and neighboring territories.
- The sort segment is in Bara Nai in Lakhi Range. The Formation comprises of interbedded sandstone and shale.
- The sandstone is fine-to coarse-grained, calcareous, ferruginous and at places glauconitic, swell checked and cross-had relations with.
- Beds run in thickness from a couple of centimeters to more than 3 m. The shale is delicate, hearty, gypsiferous and usually carbonaceous.

Lakhra Formation

- It overlies the Bara Formation and yields out in, the Kirthar and adjoining regions.
- It comprises for the most part of dark, thin-to thick-had relations with, nodular, sandy and in places, argillaceous, fossiliferous limestone, with interbeds of sandstone and shale in the upper part.
- Its thickness ranges from 50m to around 242 m.

Laki Formation

- It overlies the Ranikot Group unconformably and is uncovered for the most part in southern Kirther Range and in southern Suleiman Range.
- The sort area is close Meting and close Mari Nai in the northern Laki Range.
- The development involves cream shaded to dim limestone, with subordinate marl, calcareous shale, sandstone and lateritic clay.

Kirther Formation

- It overlies the Laki Formation comparably in the Kirther territory.
- It is appropriated generally and coers additionally the Sulaiman region and parts of Wazirstan. In these zones it overlies the Ghazij Group comparably. The zone is in the Kirther Range.
- The Formation is principally fossiliferous limestone interbedded with subordinate shale and marl. The lime stone is thick –bedded to enormous, nodular lime-stone in a few territories, dim to white in shading and locally contains algal and corraline structures.
- The thickness of the arrangement ranges from 15 m to 30 m in western Kirther range to 1270 m in the Gaj River sort area.

Nari Formation

- It is uncovered broadly in tn Kirther and Sulaiman locale , while scattered outcrops are found in tectonoised push hinders in the Baluchistan Ophiolites –and –thrust Belt.
- In the Kirther Province it conformitably overlies the Kirther arrangement with the exception of in the Hyderabad anticlinorium where it violates and unconformably overlies the Kirther and laki developments.
- The sort area is in the Gaj River pig out in the Kirther extend.
- The Upper Part of Nari Formation is generally dark colored, fine – to-coarse-grained sand stone with interbeds of shale.
- The Lower Part comprises of interbedded dark to darker, fossiliferous sandy limestones, calcareous sand stone and shale.
- At numerous territories the Lower Part of the Formation is a dim to darker shelly, nodular, and thick-had relations with to enormous limestone which has been named the nal part.
- Its thickness ranges from 1045 m to 1820 m in the Kirther zone.

Gaj Formation

- In the Kirther and Sulaiman Ranges, the Lower Part of the Neogene comprises of marine close shore to estuarine silt of Gaj development.
- The sort territory is at the Gaj River. The Formation rests similar and transitionally finished the Nari Formation. In the Sulaiman Ranges, however, it exceeds and lays unconformably on more seasoned rocks at a few spots.

- The Gaj Formation is generally shale which is variegated, dark and gypsiferous and cross-had relations with sandstone and fossiliferous tanish, argillaceous limestone.
- In any case, in the southern piece of the Kirther extend in Karachi region , the arrangement overwhelmingly comprises of yellow – dark colored sand stone and cream-hued or pinkish-white argillaceous limestone.
- Its thickness ranges from around 90 m in Queta territory to 600 m in Kirther region.

Nagri Formation

- This Formation lays comparably on the Chinji development in many places in the Sulaiman Range, through somewhere else in the Sulaiman and Kirther Ranges it overlies the Gaj and prior arrangements unconformably. At a few places a rakish unconformity might be seen.
- The Formation is to a great extent thick –bedded to gigantic, greenish – dim, medium – to coarse-grained, salt and pepper finished, interbedded with subordinate darker to rosy sandy earth and combinations.
- The thickness of the Formation ranges from 200 m to 3000 m.
- The Formation has yielded a rich vertiberate fauna including proboscidactyles, carnivores and primates additionally been accounted for the green growth of arrangement is Early Pliocene.

Chapter#3

Seismic Interpretation and Attribute Analysis

INTERPRETATION

Interpretation is the transformation of the seismic reflection data in to a structural picture by the application of correction, migration and time depth conversion (Dobrin and savit , 1988). Thus threading together all the accessible topographical and geophysical data including the seismic and afterward coordinating them all in a solitary picture can only give a picture nearer to the reality.

Seismic data have been interpreted in two modes.

- The first mode is in territories of generous well control, in which the well data is first attached to the seismic data, and the seismic at that point supplies the coherence between the well for the zone of interest.
- The second mode is in territories of no well control in which the seismic information give both definition of structure and estimates of depositional environments. Seismic velocities and seismic stratigraphic ideas are utilized to characterize the lithology. Seismic reflection amplitudes help to detail velocities and fill in as a manual for pore constituents.

Seismic interpretation is the transformation of seismic reflection data into a structural picture, contouring of subsurface horizons and further depth conversion by applying some suitable velocities. The seismic reflection interpretation usually consists of calculating the positions, and identifying geologically, concealed interfaces or sharp transition zones from seismic pulses returned to the ground surface by reflection. The influence of varying geological conditions is eliminated along the profile to transform the irregular travel times into acceptable subsurface model. This is very important for confident estimation of the depth and geometry of the bedrock or target horizon. (Robinson & Coruh , 1988).

3.1 Types of Seismic Interpretation

There are two main approaches for the interpretation of seismic section

- Stratigraphic Analysis
- Structural Analysis

3.1.1 Stratigraphic Analysis

Stratigraphic investigation includes the subdivision of seismic sections into arrangements of reflections that are interpreted as the seismic expression of genetically related sedimentary successions. Unconformities can be mapped from the divergence pattern of reflections on a seismic section. The presence of unconformable contacts on a seismic segment gives imperative information about the depositional and erosional history of the area and on the environment existing amid the time, when the developments occurred. Reefs, unconformity, disconformity, facies changes, lenses, pinch-outs and other erosional truncations are all examples of stratigraphic traps (Sheriff, 1999). Some of the parameters used in seismic stratigraphic interpretation are:

- Reflection configuration
- Reflection Continuity
- Reflection Frequency
- Reflection Amplitude
- External Form
- Interval Velocity

3.1.2 Structural Analysis

In structural interpretation, fundamental goal is to look out basic traps containing hydrocarbons. Tectonics play a critical part in the development of these traps. Tectonic setting as a rule represents which sorts of structures are available and how the structural features are related with each other, so tectonics of the area is useful in deciding the basic style of the region and to find the traps. The most widely recognized structural elements related with the oil, are anticlines and faults (Sheriff, 1999). In Tajjal area, faults associated with the extensional regime, resulted in the formation of normal faults and series of horst and graben structures.

3.2 Stepwise Workflow of Interpretation

Stepwise workflow of interpretation process is illustrated in the figure given below

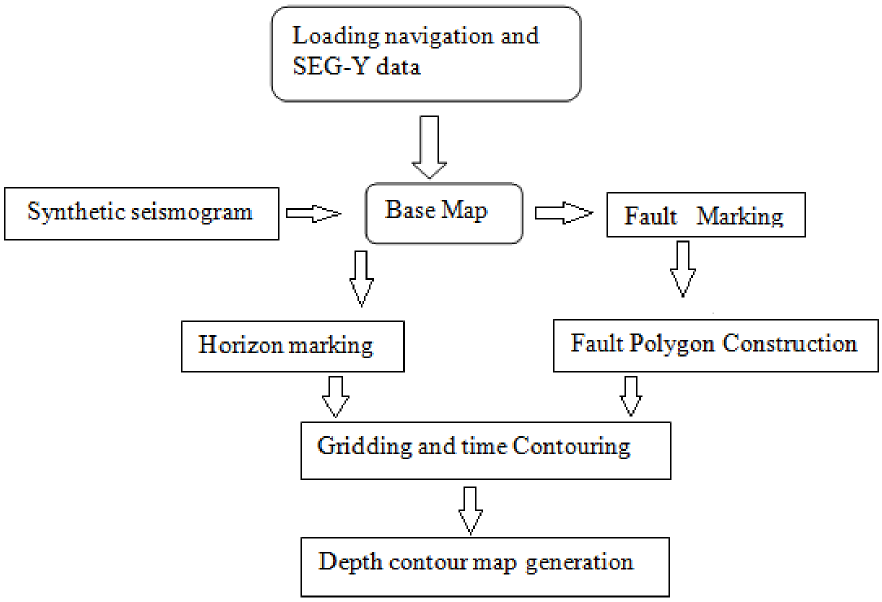


Figure 8 Interpretation Workflow

Following steps are involved in the interpretation.

3.2.1 Generation of Synthetic Seismogram

Synthetic seismogram are artificial seismic traces use to establish correlations between local stratigraphy and seismic reflections. To produce a synthetic seismogram, sonic log is required which the measure of slowness of a wave. It gives the seismic velocities of the waves that have been sent into the earth. Density log is also required but it is sometimes not given so we can also use constant density for that area. With the help of Kadanwari-14 well synthetic seismogram was constructed in order to mark seismic horizons. Following steps were followed for its generation

- Load Las file of the well in Kingdom software
- Open the project and select 'logs'
- Integrate the sonic log rescale from depth in meters to two-way travel time in seconds
- Compute velocity from sonic log for both P and S-waves
- Using velocity logs, create TD chart for the well.
- Compute Acoustic impedence log using velocity and density logs
- From this, compute reflection co-efficient (RC) from the time scaled velocity logs
- Compute the wavelet from seismic for correlation

- Convolve the RC log with this extracted wavelet to generate the amplitudes of synthetic seismogram

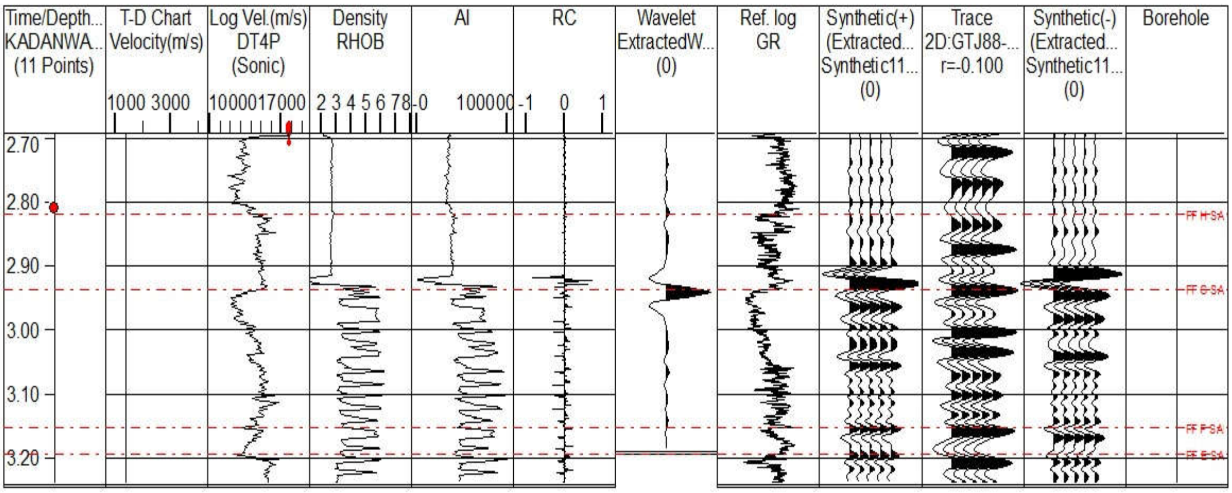


Figure 9 Synthetic Seismogram For Well Kadanwari-14

3.2.2 Horizon and Fault Marking

The initial step when beginning the interpretation procedure is to judge the reflections and unconformities, if exhibited, and also mark the faults where the reflectors seem to be discontinuous on the seismic time section. Those reflectors are chosen which are genuine, indicate great character and continuity and can be followed throughout the area (Badely, 1985).

On the Time Section horizons are marked by picking the continuous train of wavelets running across the section. Confusion emerge in denoting the continuity on the grounds that the wavelets or the follows tend to stir up or the grouping may break because of subsurface auxiliary changes or sudden lithological changes or the most well-known issue confronted is the presence of different types of noises. These clamors cause the distortion of the signal. Subsequently, with a specific end goal to choose that whether the sequence proceeds towards the upper horizon or the lower, a more extensive perspective of the interpreter, knowledge about the area and the impressive experience would help in denoting a right pick.

Two horizons namely upper goru and lower goru were picked on given Lines of Tajjal Area. These horizons were marked through the same steps and faults were also seen in the data where the data was discontinuous and one horizon was displaced from its original position indicating some fault. The geology of the study area tells us that the area commonly has normal faults which indicate the presence of extensional regime and horst and graben structures are formed in this area. Some difficulty was faced because the data was of low quality and the seismic horizons also showed very small displacement due to which it was difficult to mark them. The reflectors were not strong enough to be picked up easily due to variation in acoustic impedance that is eventually caused by changes in lithology.

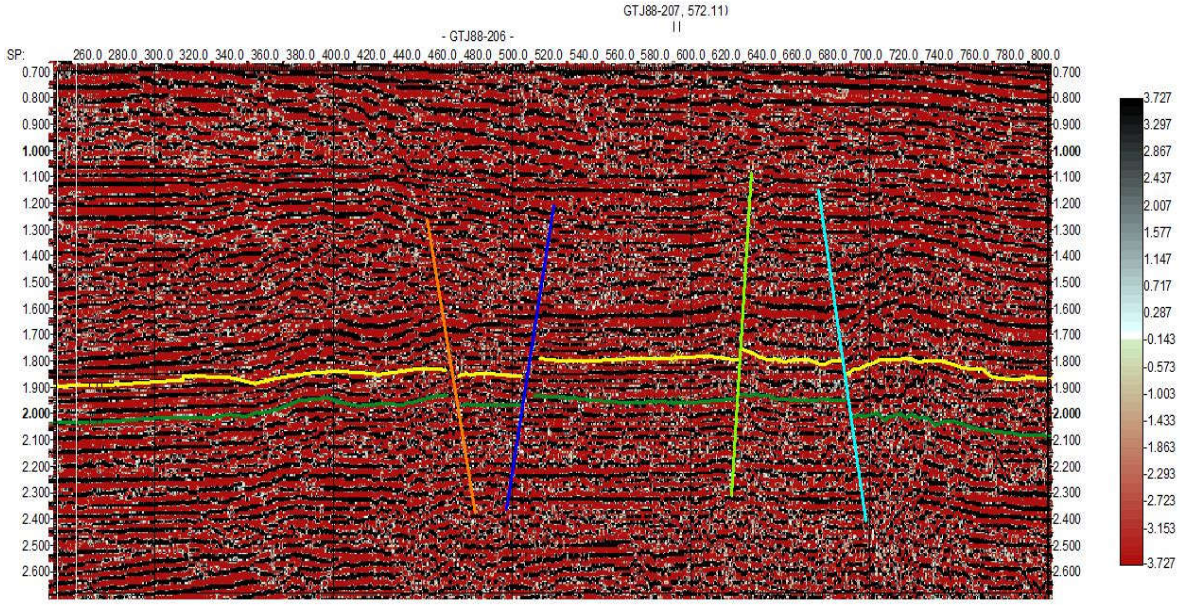


Figure 10 Horizons and Fault Marking on Dip Line GT J88-206

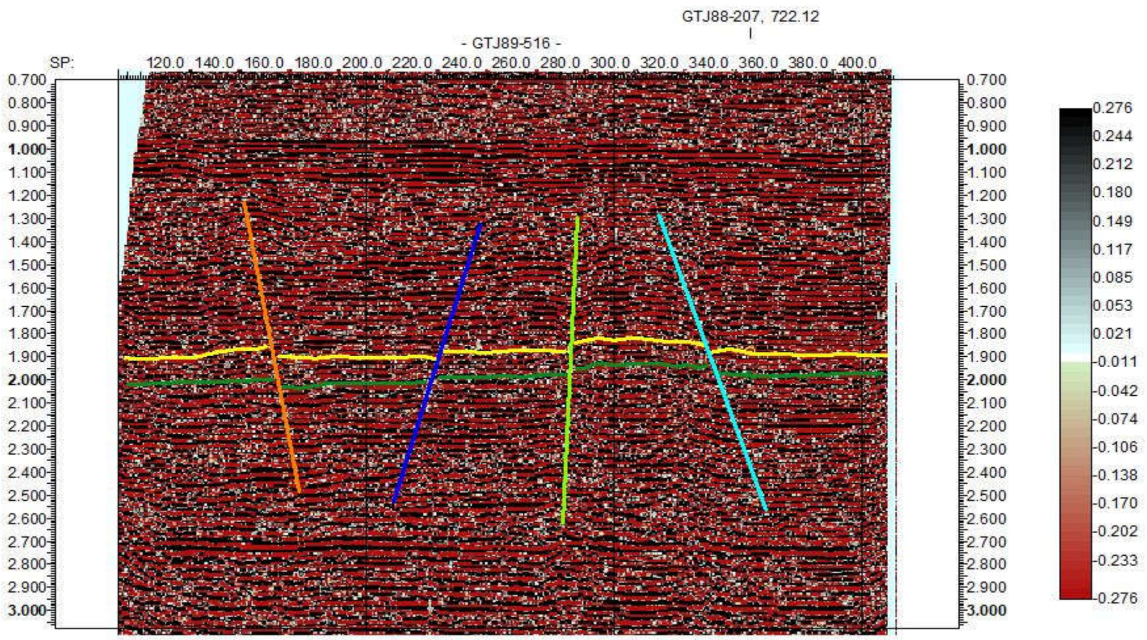


Figure 11 Horizons and Fault Marking on Dip Line GT J89-516

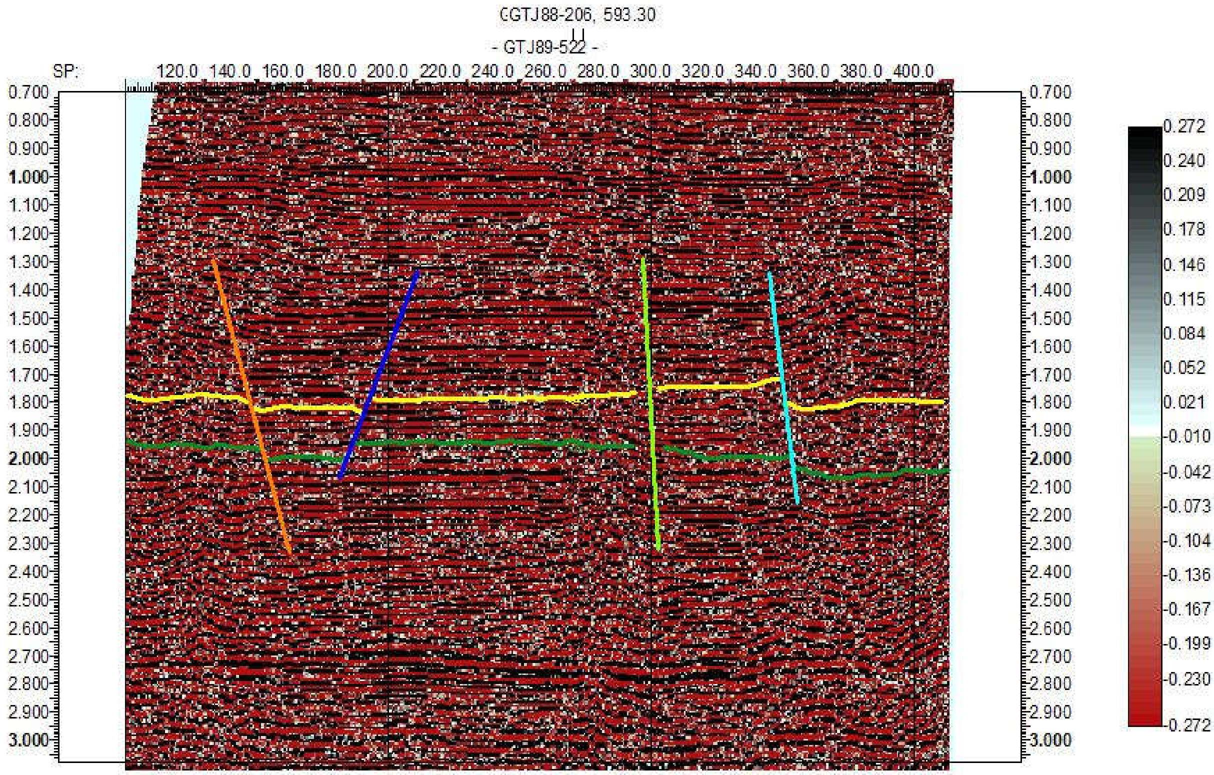


Figure 12 Horizons and Fault Marking on Dip Line GT J89-522

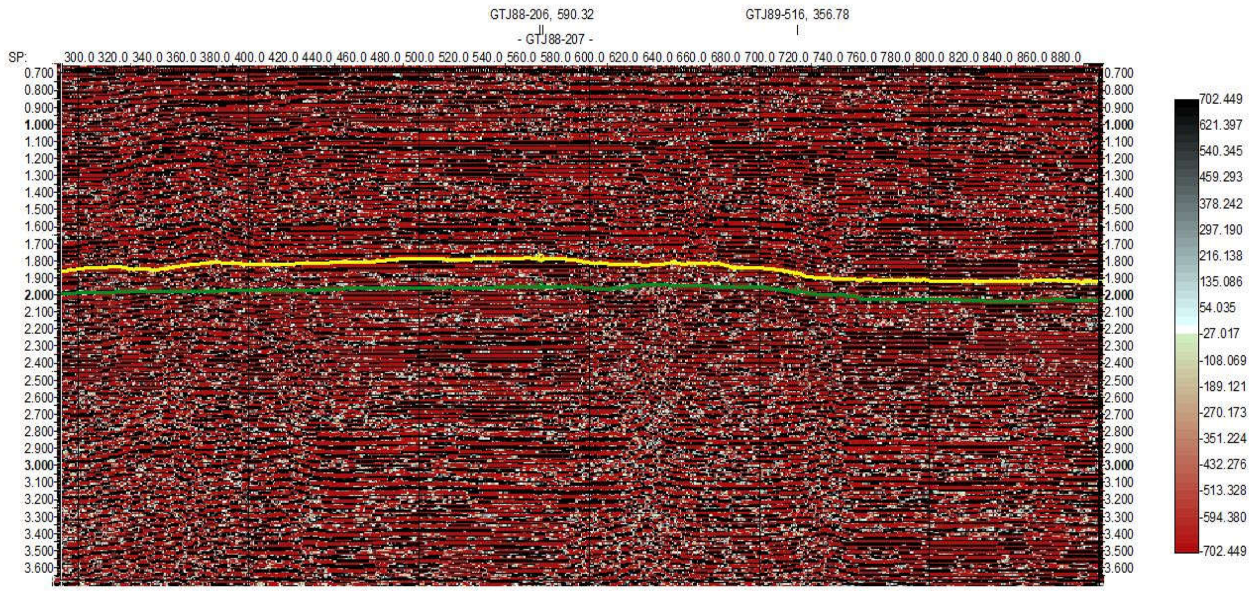


Figure 13 Horizons Marking on Strike Line GT J88-207

3.2.3 Seismic Time Section

A time section is actually a reproduction of an interpreted seismic section. It comprises of two scales; level scale comprises of VPs while the vertical scale comprises of two-way time in seconds. Time of every reflector at various vibrating focuses are noted and then the seismic time section is created by plotting the two-way travel time of the reflectors and faults on y-axis against the vibrating focuses on x-axis points.

The time section gives the position and setup of reflectors in time domain. Places of the reflections on the time section rely upon velocity contrasts and in addition on layer thickness. Three conspicuous horizons were denoted that are experienced in the repository zone alongside five faults. We can see that the area under study has been navigated by Normal Faults shaping Horst and Graben Structures. This implies that this zone has been worked by extensional forces.

3.2.4 Seismic Depth Section

Generally the depth section gives the configuration of reflectors in the same way as the time section. Expel the kinks for the horizons as much as possible with a specific end goal to get the smoother horizons. To decide the depth, the initial step is to read times of every reflector from seismic section. Utilizing the proper velocity values and time, the depth of every reflector is figured as takes after:

$S=(V*T)/2$

Where;

S= Depth of the reflector

V= Average Velocity

T= Two way travel time read from seismic section

Time is two way travel time of seismic wave i.e. from surface to the reflector and then back to surface where it is recorded. We are interested in the time taken by the wave from surface to the reflector to find its actual depth so we convert this two way travel time into one way by dividing it with 2.

Generally the depth section gives the configuration of reflectors in the same way as the time section, the distinction is that it demonstrates the subsurface structure in depth domain. For the most part the maps of seismic reflection are set up in time sections yet at some point the speed pull ups and pull downs disturb the subsurface structure that is the reason it is fundamental to make the depth section along the time maps and thicknesses of the reflectors can be calculated from the profundity segment.

3.2.5 Construction of Fault Polygons

Construction of fault polygons are very important in seismic data interpretation as far as time and depth contouring of a particular horizon is concerned. Any mapping software requires all faults to be converted into polygons prior to contouring. This is because if a fault is not converted in a polygon, the software will not recognize it as a discontinuity thus making any possible closures against faults represents false picture of subsurface. Their construction on the lines is indicating high and low areas on a particular horizon more prominently. Moreover, associated color bar helps in giving information about dip directions on a fault polygon if dip symbols are not drawn.

Fault polygons constructed for the lower and upper goru are shown below.

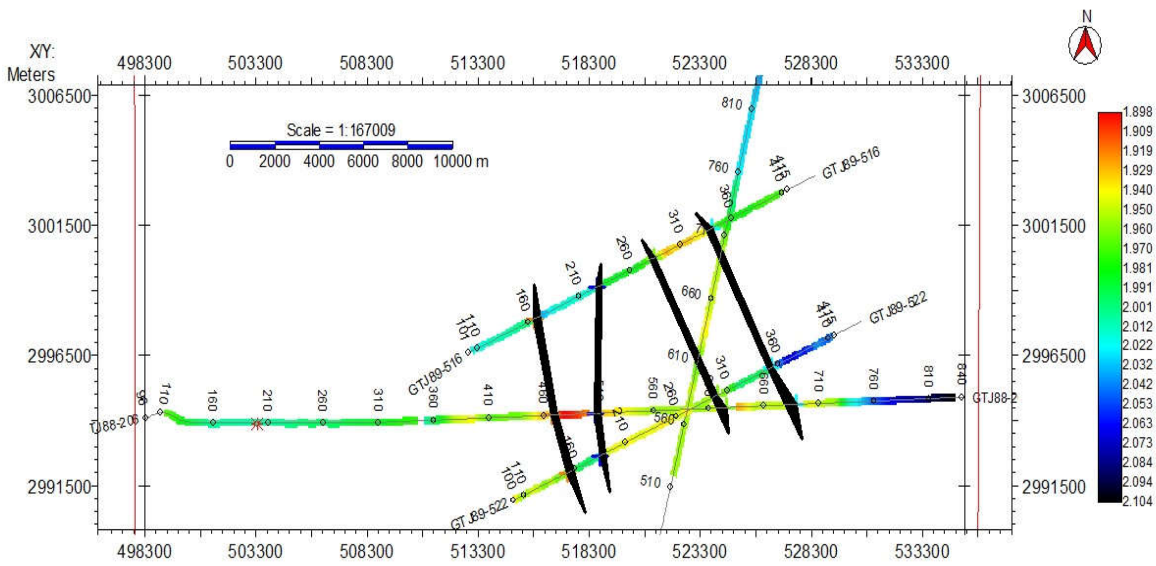


Figure 14 Fault Polygons of Lower Goru

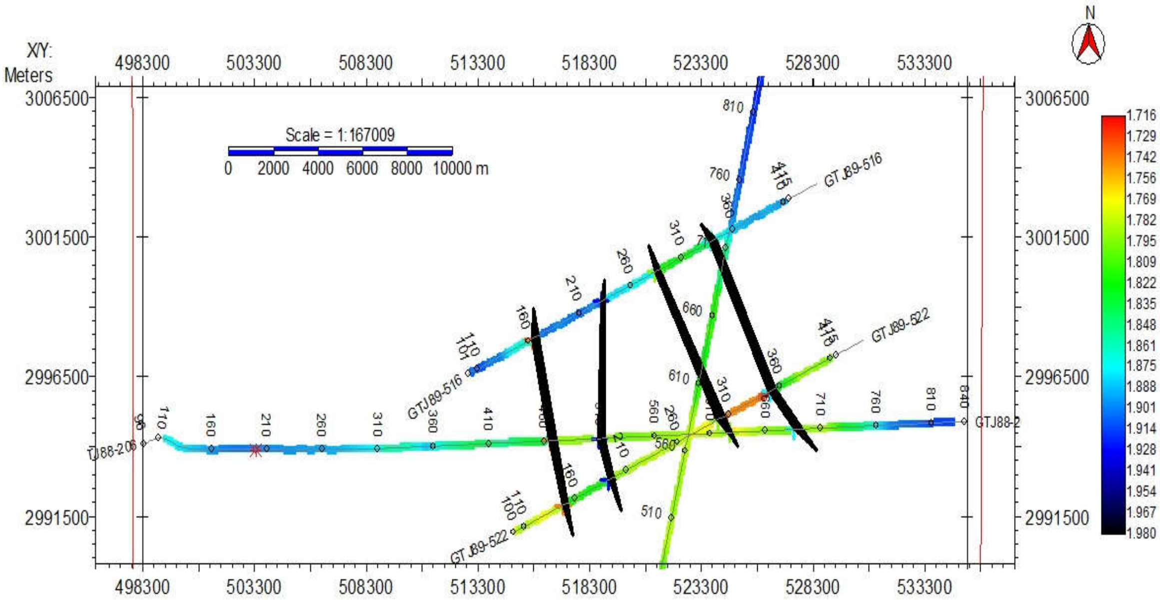


Figure 15 Fault Polygons of Upper Goru

3.2.6 Contour Maps

A line that connects the line of equal values is called a **contour line**. A map that uses contour lines as its vehicle for illustration is called a **contour map**. Contouring is the main tool in seismic interpretation. After contouring it becomes obvious that what sort of structure is forming at a particular horizon. A formation is selected for the purpose of constructing contour maps. The contours must break when passing through a fault polygon and this breaking of a contour is confirmed by the colour contrast right along the boundary of a fault polygon. There are two types of contour maps.

1.Time Contour Maps

These maps show lateral as well as vertical variations with respect to time at the level of horizons. Time contour map is constructed at upper goru and lower goru respectively which are shown below. Colour variation clearly showing the horst and grabben geometry of the reflectors in subsurface. Lighter colour show relatively shallower part while darker colours indicate deeper parts. Blue colour shows deeper portions that are grabben and lighter or shallower portion is interpreted as horst.

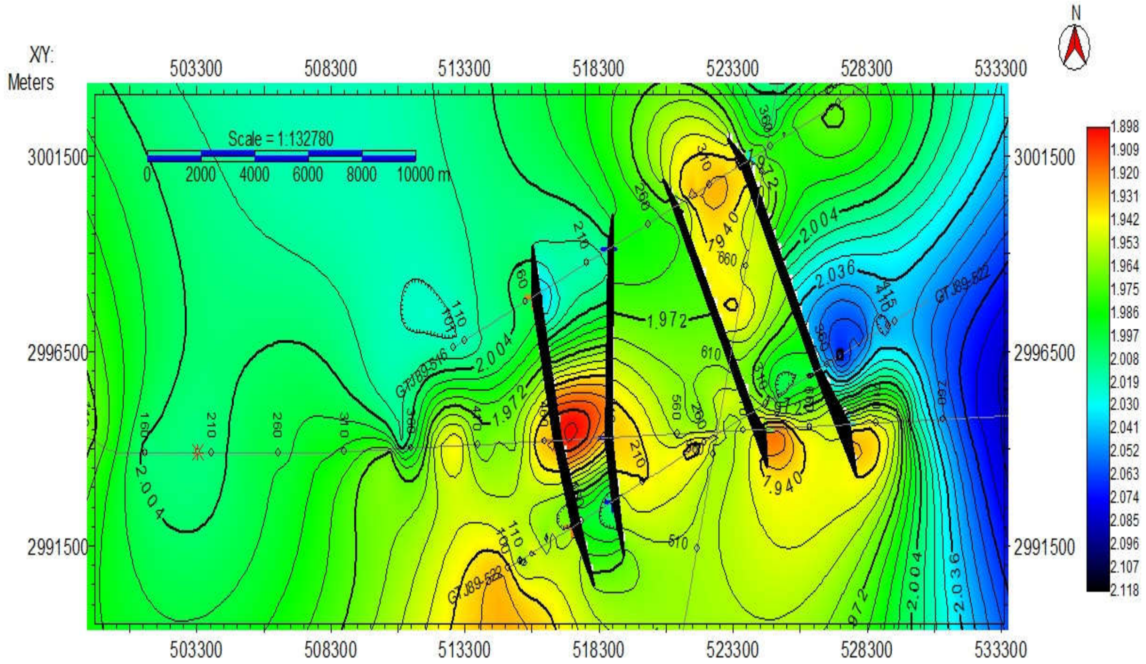


Figure 16 Time Contour Map Constructed for Lower Goru

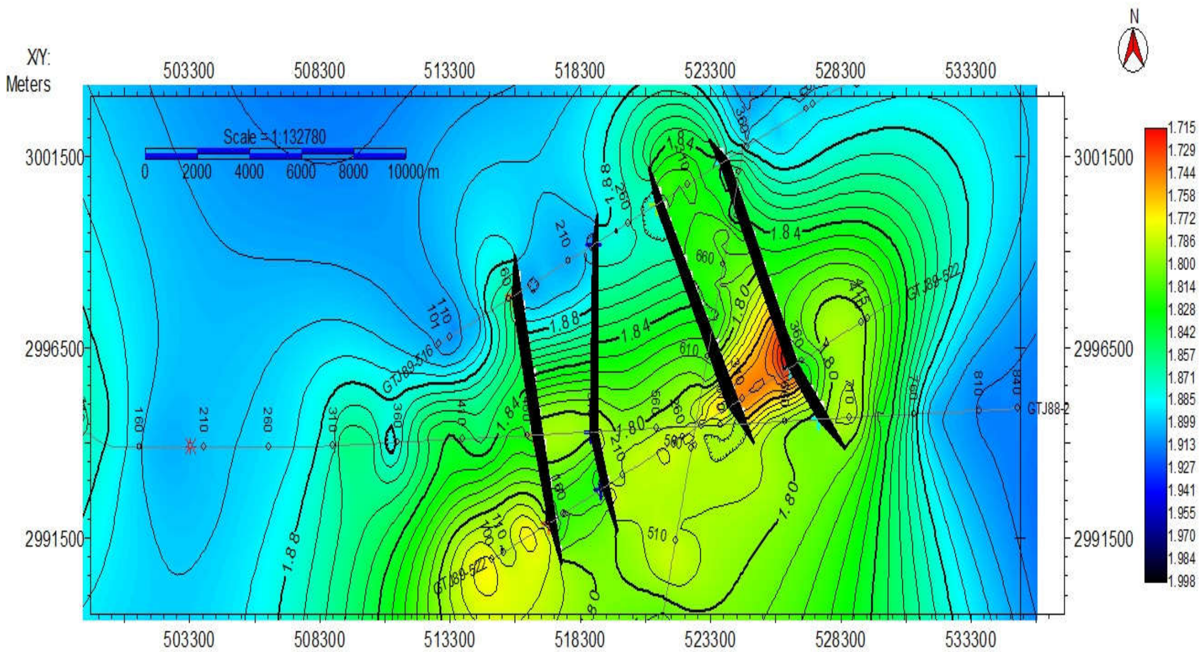


Figure 17 Time Contour Map Constructed for Upper Goru

2. Depth Contour Maps

Use of well point velocity generates depth contour maps. They show vertical variation with respect to depth. Trend of depth contour map is the same as that of time contour map. The adjoining figure of depth contour map confirms the normal faulting and formation of horst and grabben geometry in the study area. This explains the extensional regime of tajjal area.

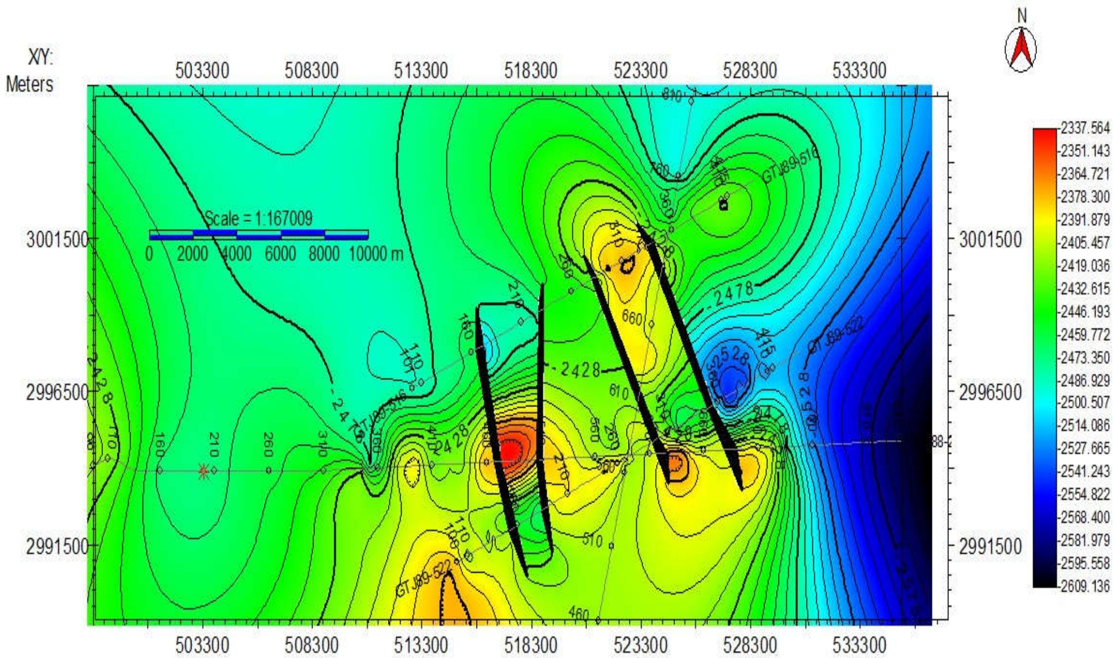


Figure 18 Depth Contour Map Constructed for Lower Goru

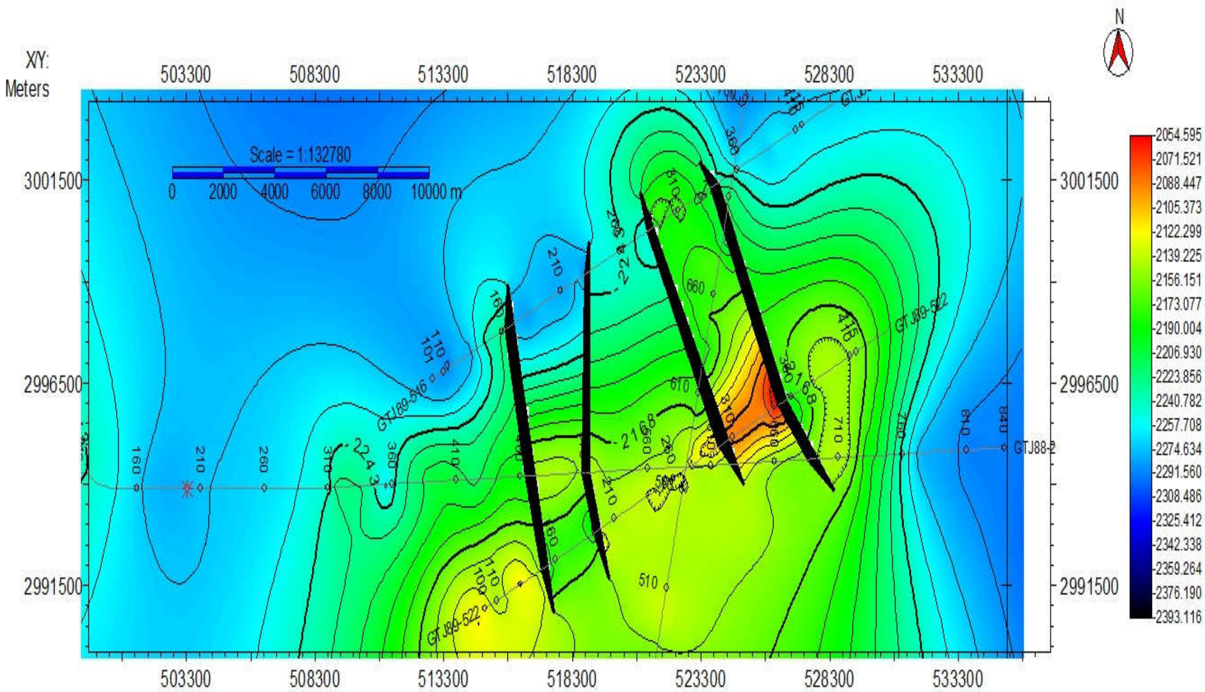


Figure 19 Depth Contour Map Constructed for Upper Goru

3.3 Seismic Attributes

3.3.1 Introduction

Seismic attribute is defined by as a measurement derived from seismic data. Such a broad definition allows for many uses and abuses of the term. Countless attributes have been introduced in the practice of seismic exploration (Brown, 1996 and Chen et al, 1997). Many of these attributes play an exceptionally important role in interpreting and analysing seismic data (Chopra et al, 2005). Some particular attribute applications are considered i.e. Instantaneous phase and Average Energy.

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

3.3.2 Classification

The Seismic Attributes are classified basically into two categories.

- Physical Attributes
- Geometrical Attributes

3.4 Physical Attributes

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

3.5 Geometrical Attributes

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

3.6 Instantaneous Phase

Instantaneous phase is measured in degrees ($-\pi,\pi$). It is independent of amplitude and shows continuity and discontinuity of events. It shows bedding very well. Phase along horizon should not change in principle, changes can arise if there is a picking problem, or if the layer changes laterally due to "sink-holes" or other phenomena. This attribute is useful as (Chopra et al., 2005)

- Best indicator of lateral continuity.
- Relates to the phase component of the wave propagation.
- Has no amplitude information, hence all events are represented.
- Detailed visualization of bedding configuration.
- Used in computation of instantaneous frequency and acceleration.

This attribute is marking clear cut continuity of the reflector as showen in the below figure.

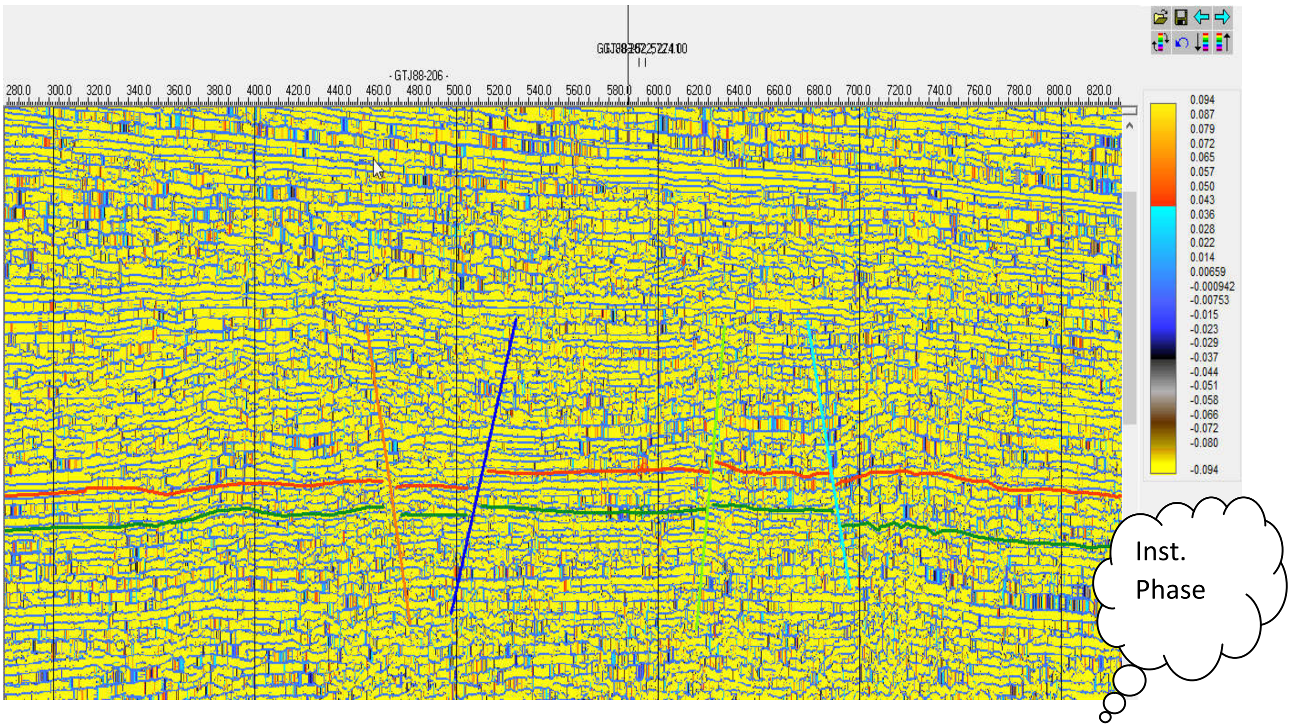


Figure 20 Instantaneous Phase Attribute Applied on Seismic Line GT J88-206

3.7 Conclusion

After all interpretation it is concluded that in my study area there are horst and graben structures. The horst and Graben structures are formed in the results of the normal faulting which are also confirmed in the above interpretation and by the seismic attribute. Hence we have favourable structures formed as the result of the normal faulting for accumulation of the hydrocarbon in the Tajjal area.

All models shown above represent clear horst and Graben structures which can act as a very good structural trap in the petroleum play point of view. From stratigraphic column discussed in previous chapter and Petroleum Plays in study area sands of the lower Goru formations have potential for hydrocarbons and faults in the area are major migration pathways for hydrocarbon and in most places are acting as traps. Time and depth contour maps show that the faulting in the area is making favourable geometry for the accumulation of hydrocarbons. Seismic instantaneous phase attribute shows that the marked reflectors are continuous and this continuity confirms that the marked reflectors are correct

Chapter#4

Petrophysical Analysis

PETROPHYSICS

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

4.1 Data Set

Key parameters in the calculation of petrophysics are given below.

- Volume of Shale
- Porosity Calculation
- Water Saturation
- Hydrocarbon Saturation

Before going to calculate these properties, we must have to know about different types of logs and their characteristics which are mentioned below.

4.2 Classification of Geophysical Well Logs

Different classification and short explanations of geophysical well logs is given below. These are explained according to the tracks in which they are run.

4.3 Lithology Track

In lithology track, following three logs are displayed.

- **Gamma Ray Log:** It is the measurement of a formation's radioactive contents. Since radioactive contents are present in shale thus it deflects owing to the presence of radioactive content. This is why it has been considered as best log for lithology identification. It is also called the 'shale log'.
- **Spontanious Potential Log:** SP log measures naturally occurring potential of geological formations where no artificial currents are injected. It gives deflection opposite to the permeable beds since shale is impermeable so it gives straight line

opposite to shale known as 'shale base line'. It is used to indicate permeable zones, calculate volume of shale, and to calculate resistivity of formation of water.

- **Caliper Log:** Used to measure the borehole size. It helps to identify the cavities and washouts and breakouts. Hence this log is also called the quality check for other logs because if there is any washout then in front of the wash out, porosity and resistivity log will not give correct readings. Thus this log is quite vital in petrophysical analysis.

4.4 Porosity Logs

Sonic Log (DT), Density log (RHOB) and Neutron porosity logs (NPHI) are porosity logs that are used to calculate pore volume of formations. With the combination of resistivity logs, they are used to calculate water saturation in different formations.

- **Sonic Log:** Sonic log produce compressional waves and measure the transient travel time ofwaves. Where travel time is higher it is indication of porous media because wave is name of progressive disturbance of media.
- **Density Log**: Gamma rays are bombarded on formation these are scattered from formation's electrons higher the scattering higher the electron density and this electron density is related to bulk density of rocks. Lower the density higher the porosity of medium.
- **Neutron Log**: Neutron log tool emit high energy neutron and the only resistive substance to neutron are hydrogen ions. If value of this log is high it means high hydrogen ions concentration is present. Since hydrogen ions are present in pore space so neutron log measures porosity. If gas is present than value of log is low because concentration of hydrogen ion is low.

4.5 Resistivity Log

Basically there are different types of electrical Resistivity Logs. Logs of LLS and LLD can separate only when (oil) high resistive fluid is present in the formation. In case of water, values of resistivity are lower and for hydrocarbons, resistivity is larger. It includes:

- **Laterelog Deep:** Laterelog is used for deep investigation of the undisturbed zone (Uninvaded zone) and it is called Laterelog deep (LLD). This log is also used for saline muds also in case of fresh mud. This log is generally used for measuring the formation resistivity. IT having deep penetration as compared to the (LLS).

- **Laterelog Shallow:** Laterelog shallow (LLS), used for shallow investigation of the transition zone / invaded zone. Because the depth of the investigation is smaller than the LLD.

4.6 Petrophysical Analysis

The major purpose of performing petrophysical analysis is to confirm the presence of hydrocarbons and determine how much, hydrocarbons are present in the formation of interest. This is done with the help of logs to determine different properties of the reservoir formation. The geophysical well data including the logging data of gamma ray, resistivity, caliper, sonic,spontaneous potential, neutron and density is used to identify hydrocarbons in the reservoir formation. We use Archie's equation to estimate the Petrophysical parameters including porosity, volume of shale, saturation of water, permeability etc.

The petrophysics analysis has been carried out in order to measure the reservoir characterization of the Tajjal area using the borehole data of KADANWARI-10.

The following figure shows the workflow for Petrophysical analysis. Different logs are used in different tracks to evaluate the reservoir properties. Petrophysical interpretation is performed using SMT kingdom software.

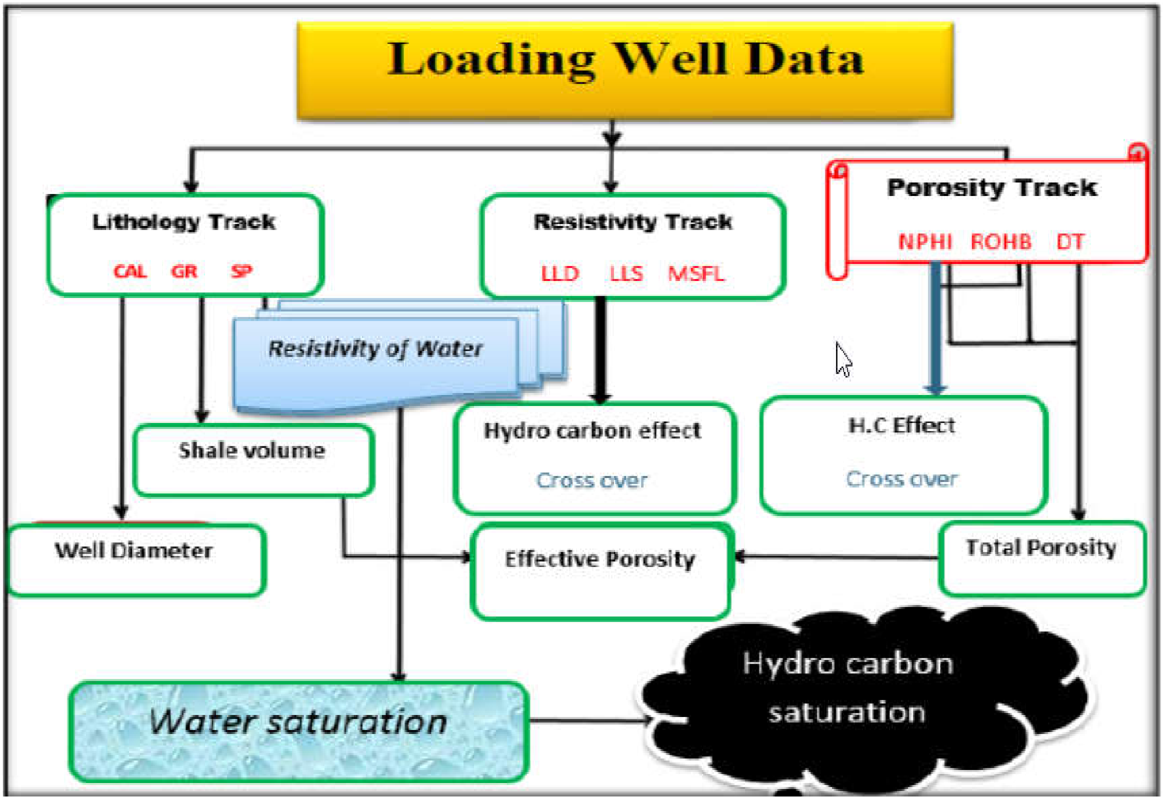


Figure 21 Workflow for Petrophysical Analysis

4.6.1 Estimation of volume of shale

It is defined as the presence of shale or clay in formation. Not only the Shale formations contain the clay minerals, carbonates and sand formations also contain it. Volume of shale ranges from 0 to 1i.e. it is in fractions. It is **0** for **clean carbonate or sand** and is **1** for **clean shale**. Shale content determination is necessary of reservoir characterization because volume of shale affect the porosity of reservoir formation.

The volume of shale can be estimated from the response of Gamma ray log. The response of Gamma ray must be known through different lithologies. The gamma ray log is the passive logging because we measure the Formation properties without using any source. Actually it measures the Formation's radioactivity. The gamma ray emits from the Formation in the form of electromagnetic energy which are called the photons. When a photon collides with the Formation electron hence they transfer the energy to the Formation electron so the phenomenon of the Compton scattering occurs. Now these emitted Gamma rays reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray.

Volume of shale is calculated using the following equation.

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

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

The average volume of shale in lower Goru formation of Kadanwari-10 well is about **33%** that has been calculated from the given data.

4.6.2 Porosity Estimation

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

- **From Sonic Log:** Sonic log device consists of a transmitter that emits sound waves and a receiver that picks and record the compressional waves as it reach the receiver. This log is a recording verses depth of time (t) which is required by a compressional wave to go across 1 feet of Formation, called interval transient time Δt, while it is the reciprocal of the velocity of sound wave. This time (Δt) is depended upon lithology and porosity of the Formation (Asquith and Gibson, 2004). Sonic log can also be used for the following purposes in combination of other logs as given by (Daniel, 2004).

$$\Phi sonic = \frac{\Delta t_{log} - \Delta t_{matrix}}{\Delta t_{fluid} - \Delta t_{matrix}}$$

- **From Density Log:** In the density logging gamma ray collide with the electron in the Formation and scattered gamma ray (Compton scattering) received on the detector which indicate the density of the Formation increase in the bulk density of the Formation causing the decrease in the count rate and vice versa. Bulk density which is obtained from the density log is considered the sum of the density of the fluid density and the matrix density of the Formation. Average density porosity of Lower Goru formation is **13%**
- **From Neutron Log:** This is the type of porosity log which measure concentration of Hydrogen ions in the Formation. Neutron is continuously emitted from chemical source in the tool of the neutron logging. When these neutron collide with nuclei in the Formation and results in loss of some energy. Hydrogen atom has same mass as that of neutron, maximum loss of energy occurs when electron collides with hydrogen atoms.

  Hydrogen is an indication of the presence of the fluid in the Formation pores; hence loss of energy is related to the porosity of the Formation. The neutron porosity is very low when the pores in the Formation are filled with the gas instead of the water and oil; the reason is that gas having les concentration of the hydrogen as compared to water and oil. This less porosity by the neutron PHI due to the presence of the gas called the gas effect (Asquith and Gibson, 2004).
- **Total Porosity:** It is simply the average of porosities measured by DT, RHOB and NPHI.
- **Effective Porosity:** It is the measurement of interconnected pores of formation. Since shale is impermeable so it is calculated after removing the effect of shale from total porosity.

  $$\boldsymbol{PHIE = (\Phi_{total}) * (1 - v_{shale})}$$

  Its average value is **10%**

4.6.3 Water Saturation

Water saturation is the percentage of pore volume in rock that is occupied by water of Formation. If it is not confirmed that pores in the Formation are filled by hydrocarbons, it is assumed that these are filled with water.

For the KADANWARI-10 well, water saturation was found by using Archie Equation

$$(\boldsymbol{S_{water}})^{\boldsymbol{n}} = \frac{\boldsymbol{a}}{(\Phi)\hat{}\boldsymbol{m}} * \frac{\boldsymbol{R_{water}}}{\boldsymbol{R_t}}$$

Where;

S water = Water saturation

n = Saturation Exponent = 2

a = Lithological Coefficient = 1

m = cementation factor = 2

R water = Resistivity of water = 0.05

R t = True Resistivity

The values of the factors a, m, and n come from the core analysis of the data. We assume these three values to be constants and their values are mentioned against them.

By putting values of these parameters and simplifying the above equation, we calculate the water saturation and it is multiplied by 100 to get the results in percentage. Archie equation is used because it gives direct relationship between resistivity of water and true resistivity with water saturation. It is more realistic than any other equation. Finally, this water saturation is subtracted from 100% to give hydrocarbon saturation.

The average value of saturation of water is **51%**

4.6.4 Hydrocarbon Saturation

Water saturation is used to find out the hydrocarbon saturation. As we know that the sum of the water saturation and hydrocarbon saturation is always equal to 1 because both are fraction of the water or hydrocarbon in the total volume of the pore spaces. So, Hydrocarbon saturation can be calculated from this by using following relation.

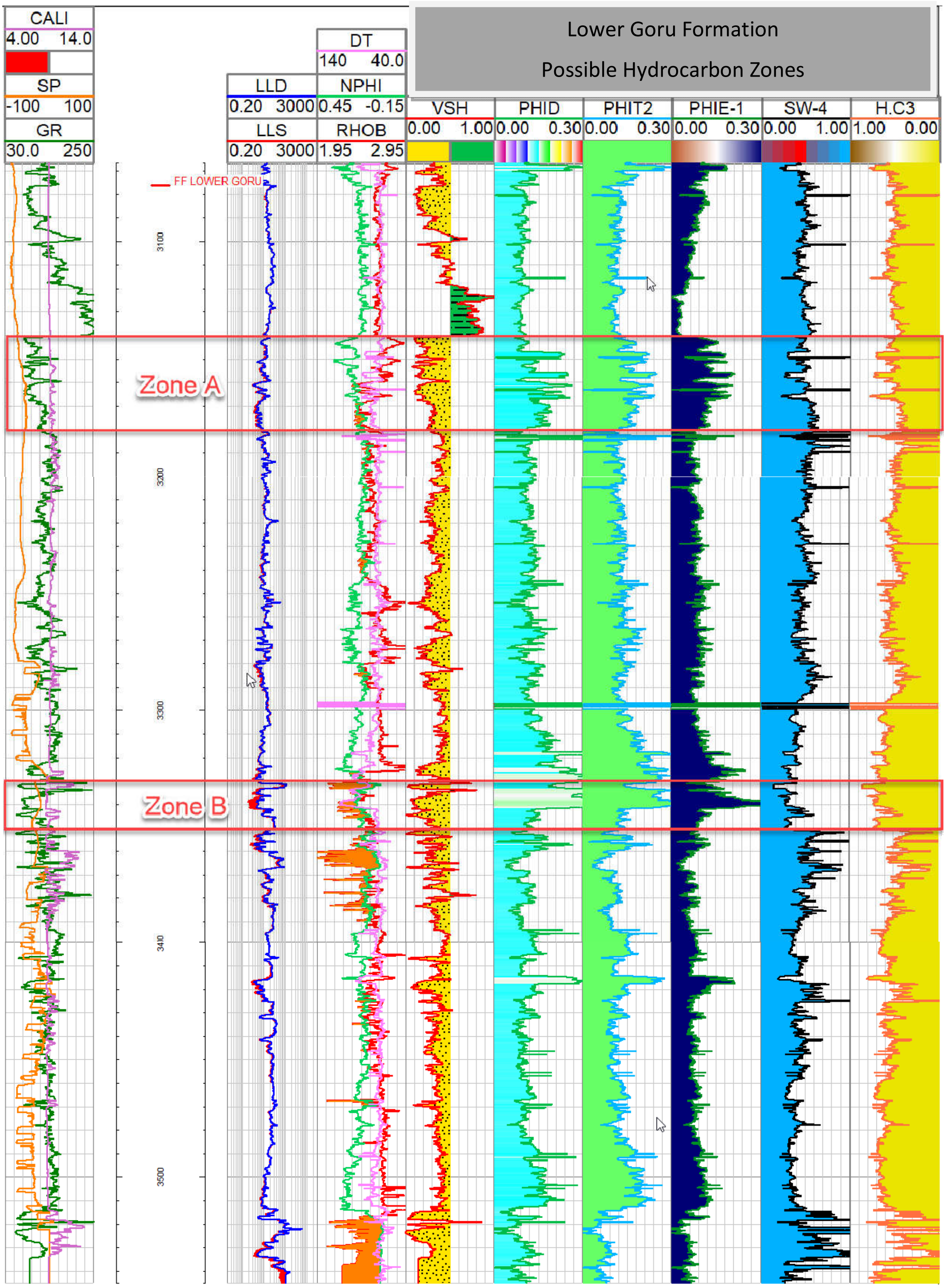
$$HC = 1 - s_{water}$$

Average value of hydrocarbon saturation is **49%** in the lower goru formation.

4.7 Well Log Interpretation of Kadanwari-10

Petrophysical analysis of area is performed by using the well data. Once well is drilled we run different log to evaluate reservoir properties. Different logs have different working principal and depending upon this they show their effectiveness to calculate the reservoir properties.

The interpretation of Kadanwari-10 is shown in figure given below. The Lower Goru Formation is encountered at the depth ranges from (3075m-3545m). It is confirmed as a reservoir by different results obtained from well log. The other logs like Gamma ray log shows low value of Gamma ray readings and resistivity logs shows high values. The volume of shale is far less than 50%. The neutron log shows good porosity values and density and sonic logs shows low values as well. These results are satisfactory thus we can interpret that Lower Goru act as a reservoir. There are two possible hydrocarbon zones in this well. They are named as zone A and zone B.



Lower Goru Formation
Possible Hydrocarbon Zones
CALI
4.00 14.0
SP
-100 100
GR
30.0 250
LLD
0.20 3000
LLS
0.20 3000
DT
140 40.0
NPHI
0.45 -0.15
RHOB
1.95 2.95
VSH
0.00 1.00
PHID
0.00 0.30
PHIT2
0.00 0.30
PHIE-1
0.00 0.30
SW-4
0.00 1.00
H.C3
1.00 0.00
FF LOWER GORU
Zone A
Zone B

4.7.1 Zone A

The first possible hydrocarbon zone in Lower Goru formation is marked as zone A ranging from 3140m to 3180m in depth. Here the GR log shows a decrease indicating sand and porosities are on the increase suggesting the presence of a porous sub surface reservoir. Water saturation is lower than hydrocarbon saturation which is good enough to call it a pay zone.

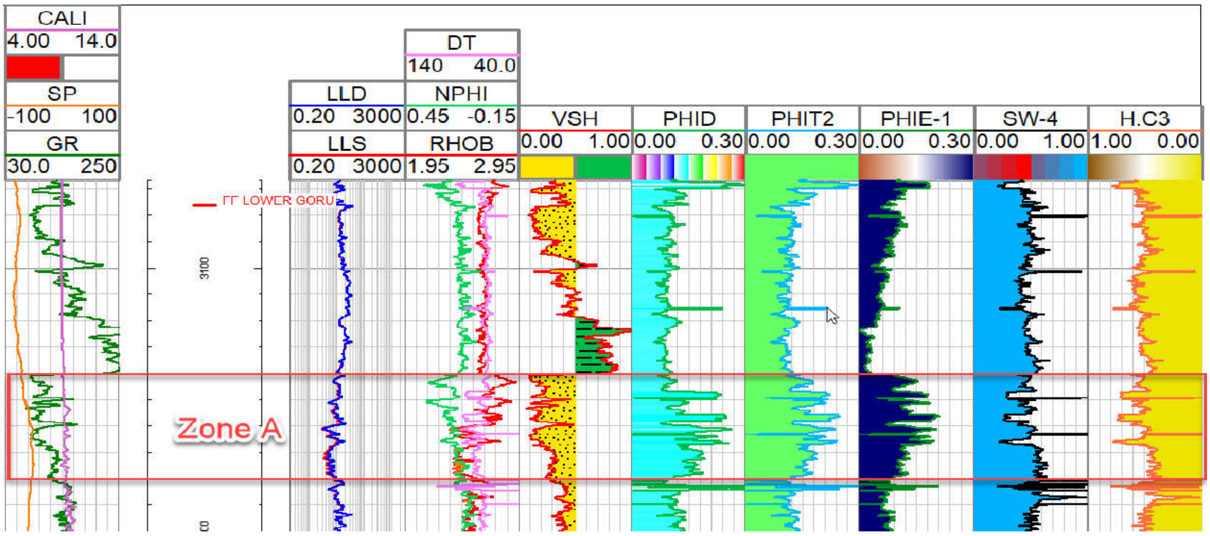


Figure 22 Kadanwari-10
Lower Goru Formation Zone A

Depth Range (3140m-3180m)

Parameters	Avg. % in zone A
Volume of Shale	23
Effective Porosity	13
Water Saturation	49
Hydrocarbon Saturation	50

4.7.2 Zone B

Second possible hydrocarbon zone is at a depth range of 3330m to 3350m. This is a small pay zone where the log curves show an increase in porosity and an increase in resistivity values. There is a cross over between LLD and LLS and hydrocarbon saturation is also fair enough to consider it as a pay zone.

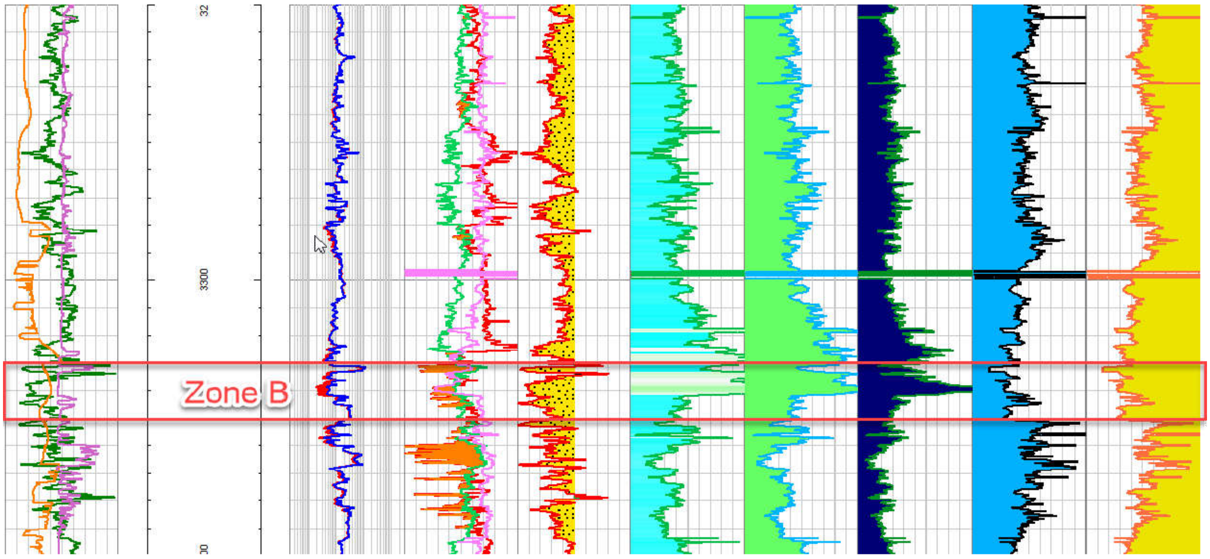


Figure 23 Kadanwari-10
Lower Goru Formation Zone B

Depth Range (3330m-3350m)

Parameters	Avg. % in zone B
Volume of Shale	22
Effective Porosity	15
Water Saturation	32
Hydrocarbon Saturation	67

4.8 Moved and Unmoved Hydrocarbons

4.8.1 Unmoved Hydrocarbons

It is the difference between bulk volume moved water and the effective porosity. It represents the portion of pore space adjacent to the boreholes in which hydrocarbons remain.

4.8.2 Moved Hydrocarbons

It is the difference between bulk volume of water and bulk volume moved water. It represents the zone adjacent to the borehole that is invaded by mud fluid.

4.9 Conclusions and Discussion

- Seismic Interpretation results have identified Horst and Graben structures in the area of study which are favourable structures for the accumulation of hydrocarbons.
- Normal faulting and formation of such structures indicate the extensional regime of the study area.
- On the basis of time and depth contour maps, different probable zones are observed in the study area.
- Due to limitation of data control seismic attribute analysis only confirm the interpretation at some locations but not give any reliable location to identify hydrocarbons.
- Petrophysical Analysis of the well Kadanwari-10 leads us to two probable zones of hydrocarbon potential that are zone A and zone B.
- Zone A is thicker then Zone B but hydrocarbon saturation in Zone B is greater than in zone A.

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