Petrophysical Evaluation of Zamzama well 3, Zamzama Block, Southern Indus Basin, Sindh-Pakistan.

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I would also thanks to all my teachers who gave me guidance and knowledge throughout my B-S program. I am grateful to my friends and class fellows for their support and encouragement.

ABSTRACT

The study area Zamzama belongs to BHP. The research area is about 120 Sq. Kms, includes the well logs of Zamzama well 3. The area has been identified as compressional regime and is characterized by major Kirthar Fold Belt (KFB).

Study was carried out to highlight the reservoir area of the Zamzama well which included the selection of the zone of interest followed by well log interpretation. The volume of shale, sand, porosity and saturation of water were interpretated followed by the preparation of isopach maps and well correlation between different wells. The porosity map of Pab Formation was also generated in the study area.

A field study was also included in this dissertation in Mughal Kot area in order to observe different features of source Sembar Formation and Reservoir Pab Formation.

On the basis of Petrophysical Evaluation it was noted that the reservoir has mud dominated facie having porosity but low permeability. The hydrocarbon saturation is also low which further makes the well uneconomical and hence it was abandoned.

On the basis of Petrophysical Evaluation, it was suggested that the well may be drilled further for possible hydrocarbon exploration as in the surrounding area deeper horizon i-e Goru Formation is producing hydrocarbons.

1. Introduction

The Zamzama field was discovered in April 1998 by BHP. The Zamzama well 3 was drilled by BHP Billiton in 2002 in Zamzama Field. The comprehensive log, core, well test data, Interference test and production data acquired from Zamzama-1/ST1 and Zamzama-2 has defined the reservoir properties for the primary Pab and secondary Khadro reservoirs and the productivity of the primary Pab reservoir.

The Study Area lies in the Lower Indus Basin and is a part of the Kirthar Foredeep, a product of the ongoing rotational collision between the Eurasian and Indian Plates The western margin of the Indo-Pakistan continental plate is characterized by the past extension tectonics resulting in rifting protocontinent and new oceanic crust created during sea floor spreading. The deformation of the basin and mountain ranges in the west are the result of the combined effect of the northward movement and the counterclockwise rotation of the Indo – Pakistan continental mass. In Study Area and surrounding, some anticlinal structures are located on the eastern side of the Kirthar sub basin that has been evaluated for hydrocarbon prospects. In the area Tertiary- Mesozoic sedimentary section indicate the adequate source, potential reservoir and cap rocks.

In this dissertation wire line log analysis have been done in order to define the possible reservoir zone within the Zamzama well 3 as well as see the petrophysical properties of the formations encountered.

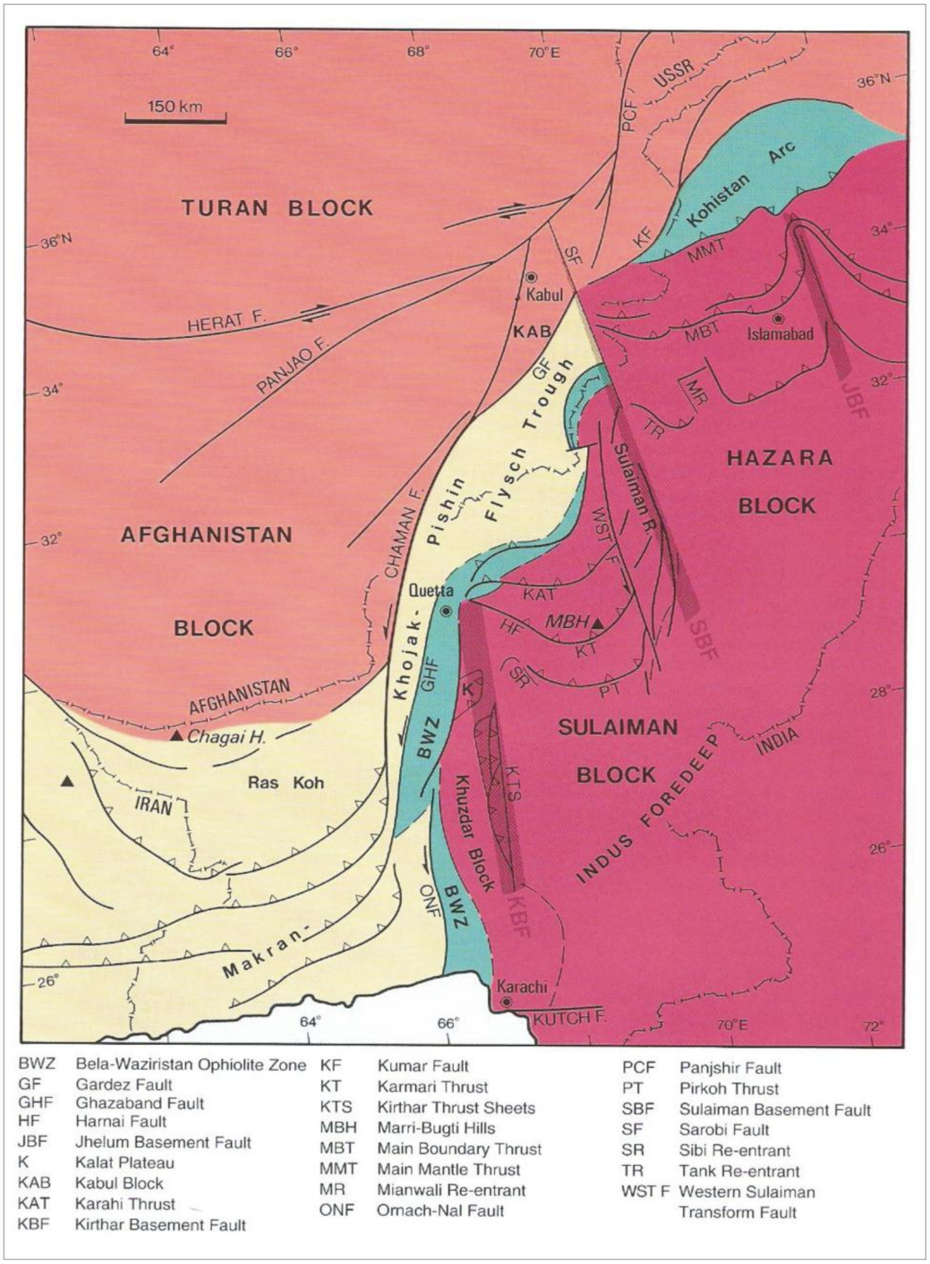

Figure.1. Map showing the collision boundaries of Pakistan, (Bennert et al, 1992)

1.1 Location

Zamzama Field is located in Located in Dadu District Sindh Province Pakistan. The location of Zamzama well 3 has Longitude 67^{o} 39’ 16.2522” E and Latitude 26^{o} 40’ 32.1545” N. The field is in the foreland of the Kirthar fold belt, approximately 200 km north of Karachi and 10km west of the Sui Southern Gas Company Dadu Compressor Station.

Figure 1.1 Map showing the location of the Zamzama Field. (BHP 2001)

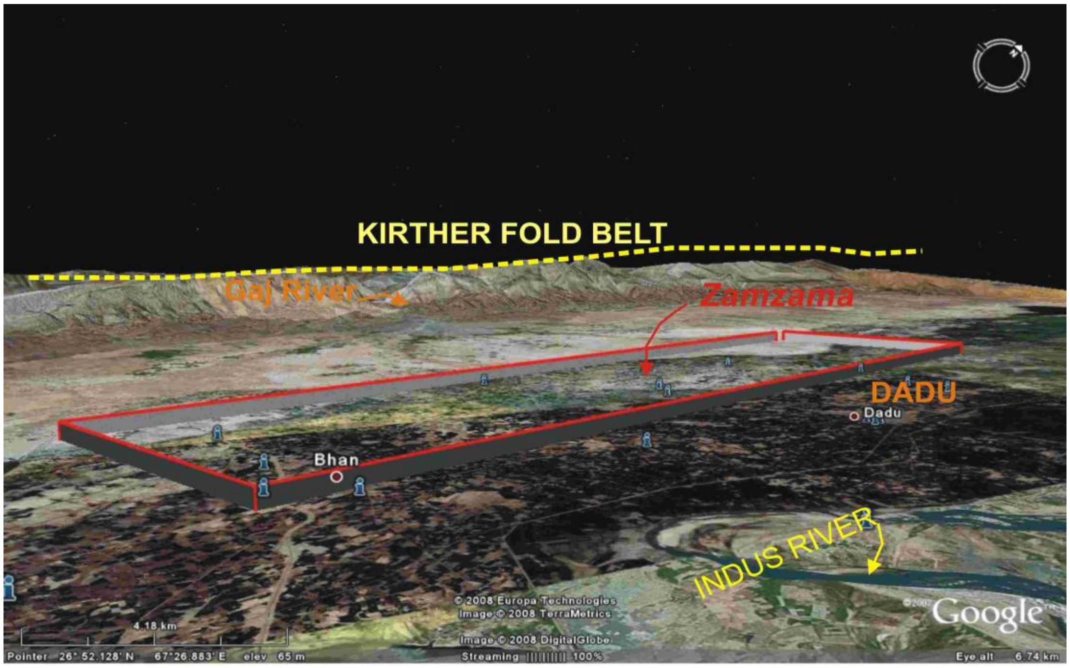

Figure 1.2 Satellite image showing the boundary of the study area (Zamzama)

1.2 Well Data

The following wells have been used to carry out this study in order to generate porosity maps, isopach maps and correlation diagrams.

Well's Name	Latitude	Longitude
Zamzama 3	26.675598	67.654514
Zamzama-01	26.734464	67.661978
Zamzama North-01	26.863892	67.654083
Zamzama East-01	26.756808	67.670181
Zamzama-02	26.705519	67.670061
Zamzama-05	26.667657	67.670613

Table 1.1 showing Wells Locations Used in study

2. Physiography of Study Area

The Study area lies in the Dadu District, Sindh province of Pakistan, approximately 200km north of Karachi. The area is covered by alluvium deposits, having buried anticlines. Dadu district is mineral rich area of Sindh Province (Figure; 2.1).

The study area is bounded by Kirthar mountain ranges in the west, Sukkar in the north east, Hyderabad district in the south east; Indus River in the east and Karachi is in its south (Fig 2.2). The Manchor Lake is just south of the Study area, near to the Indus River runs in the east.

The Kirthar mountains in the west of the study area comprises a 560km long and 130 to 220km wide complex belt of north-south oriented mountain ranges, intervening valleys and basins.

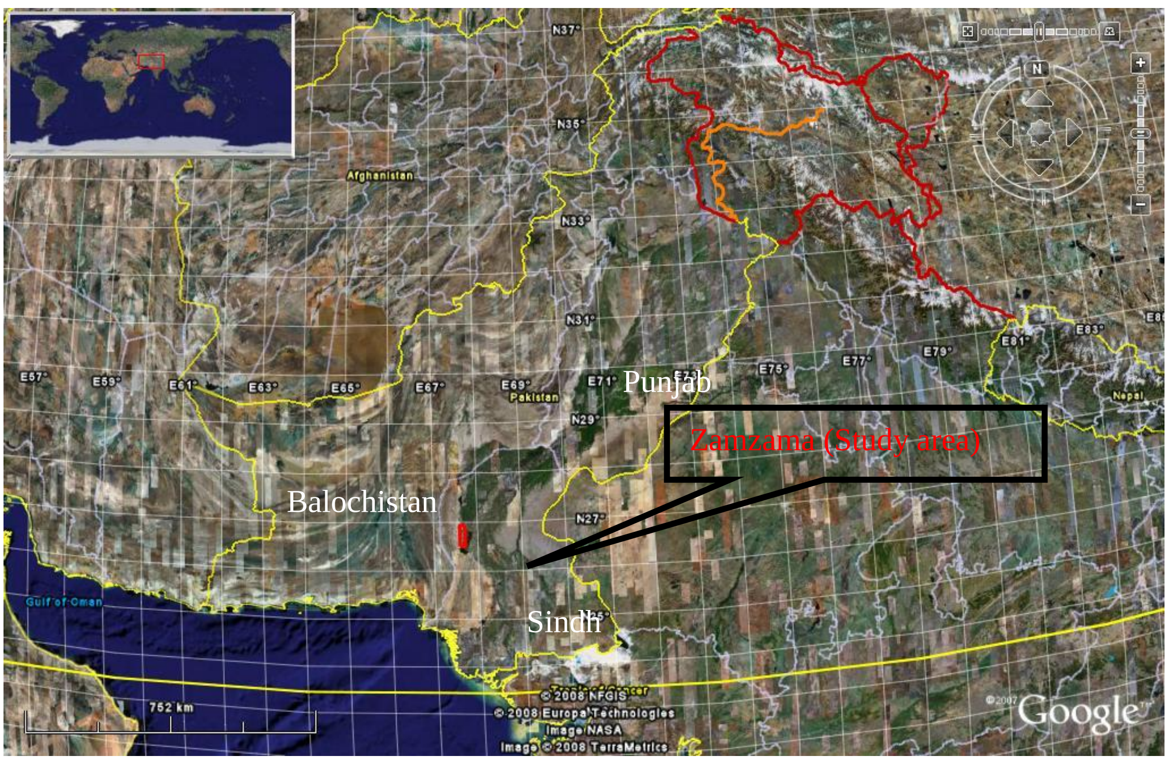

Figure 2.1. Satellite Imagery showing the location of study area.

	Latitude	Longitude
A	26.950000	67.600000
B	26.950000	67.716667
C	26.533333	67.716667
D	26.533333	67.600000

Table 2.1 showing the coordinates that bounds the study area

The Geoprovince of the study area is the Lower Indus Basin. Tectonically, the study area is bounded by Kirthar Fold Belt in the West, Karachi Trough and Sanbakh-Lakhra uplift zone in the South, Indus River in East and by Jacobabad High in the North East..

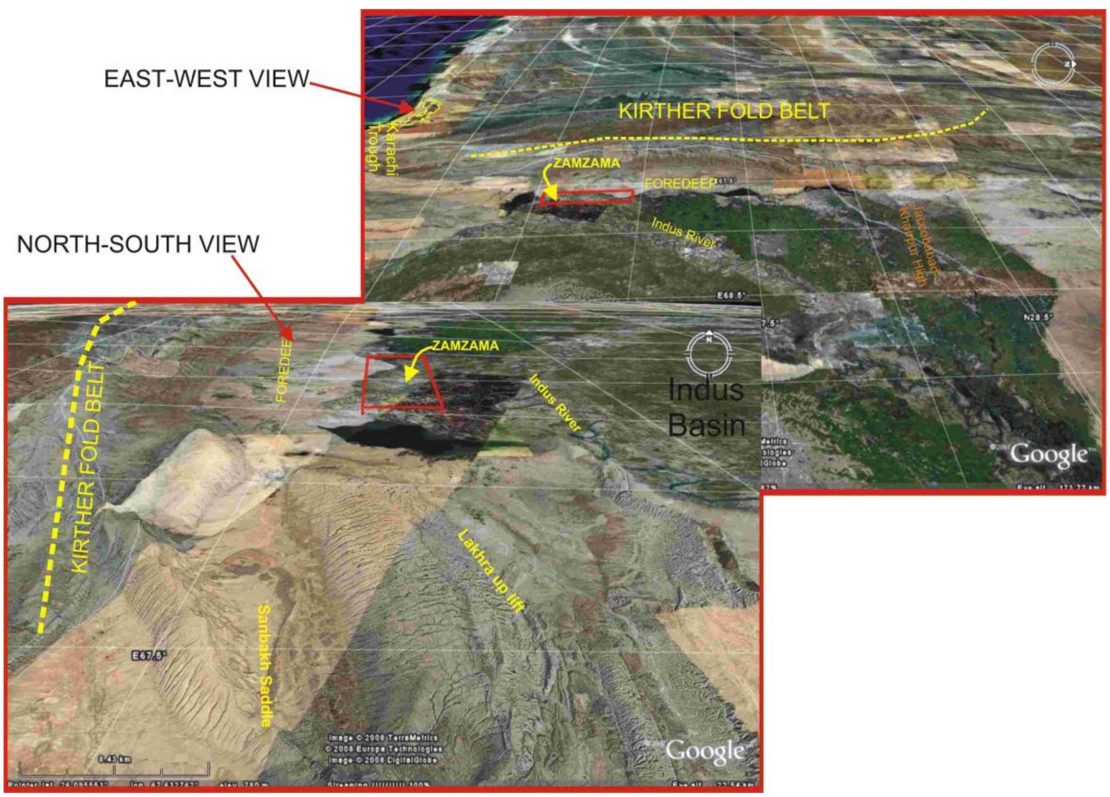

Figure 2.3: Satellite imaginary representing the geological boundaries of the study area

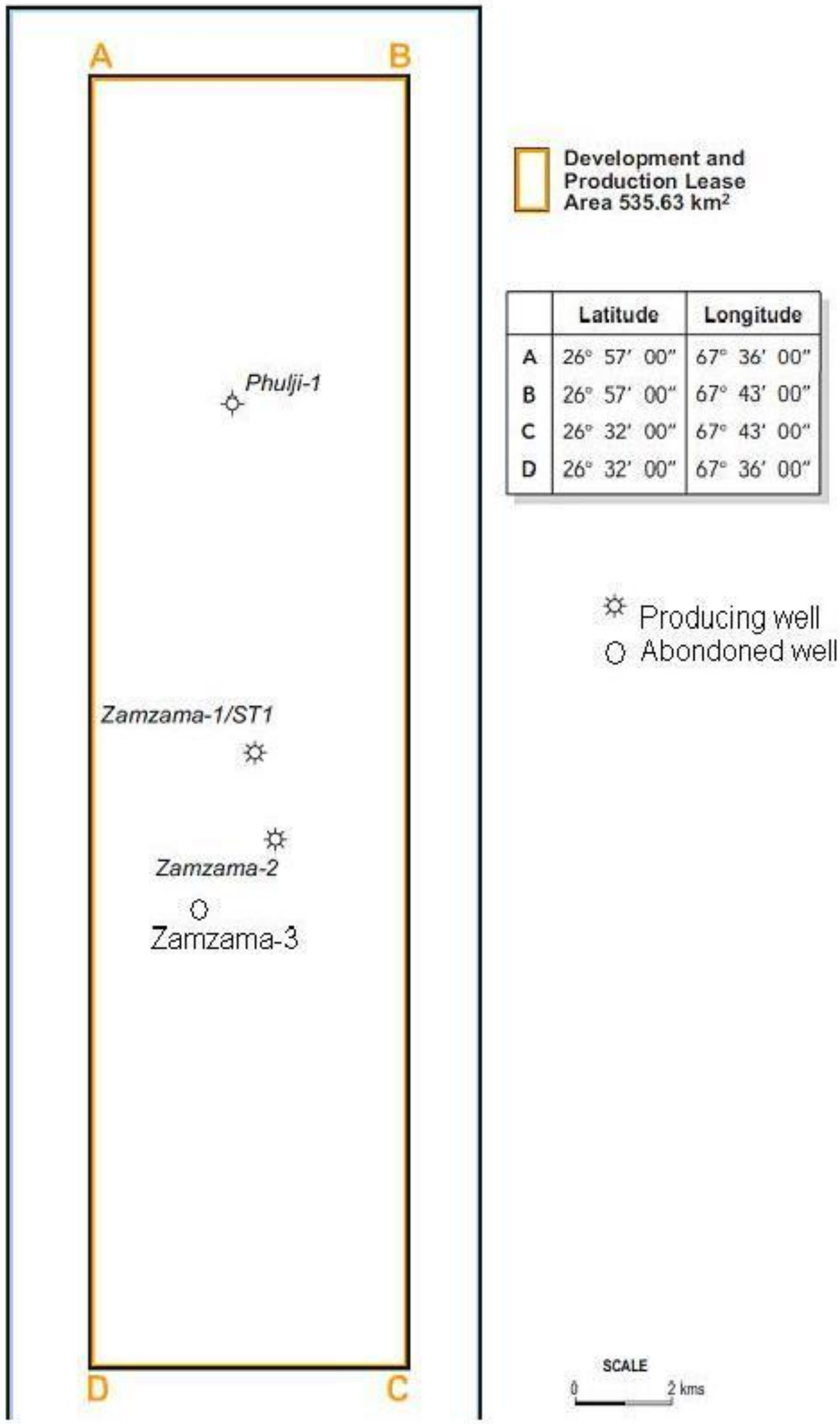

Figure.2.4 Diagram showing Lease area along with coordinates.

3. Regional Geology and Tectonics

Pakistan lies along the part of the Tertiary convergence zone and is involved in the interaction of three lithospheric plates. Its territorial limits straddle the indo- Pakistan, Arabian and Eurasian plates with their triple junction located to the north west of Karachi. It has a large sedimentary area with proven petroleum potentials (Kazmi & Jan, 1997). Northward movement of the Indian plate accompanied by the anticlockwise rotation, resulting sea floor spreading and collision and bulldozing of the Indian plate against the Eurasian were the major tectonic events (Figure. 3.1) which gave rise to the local tectonics and influenced sedimentation in the sub basin (Raza et al, 1990).

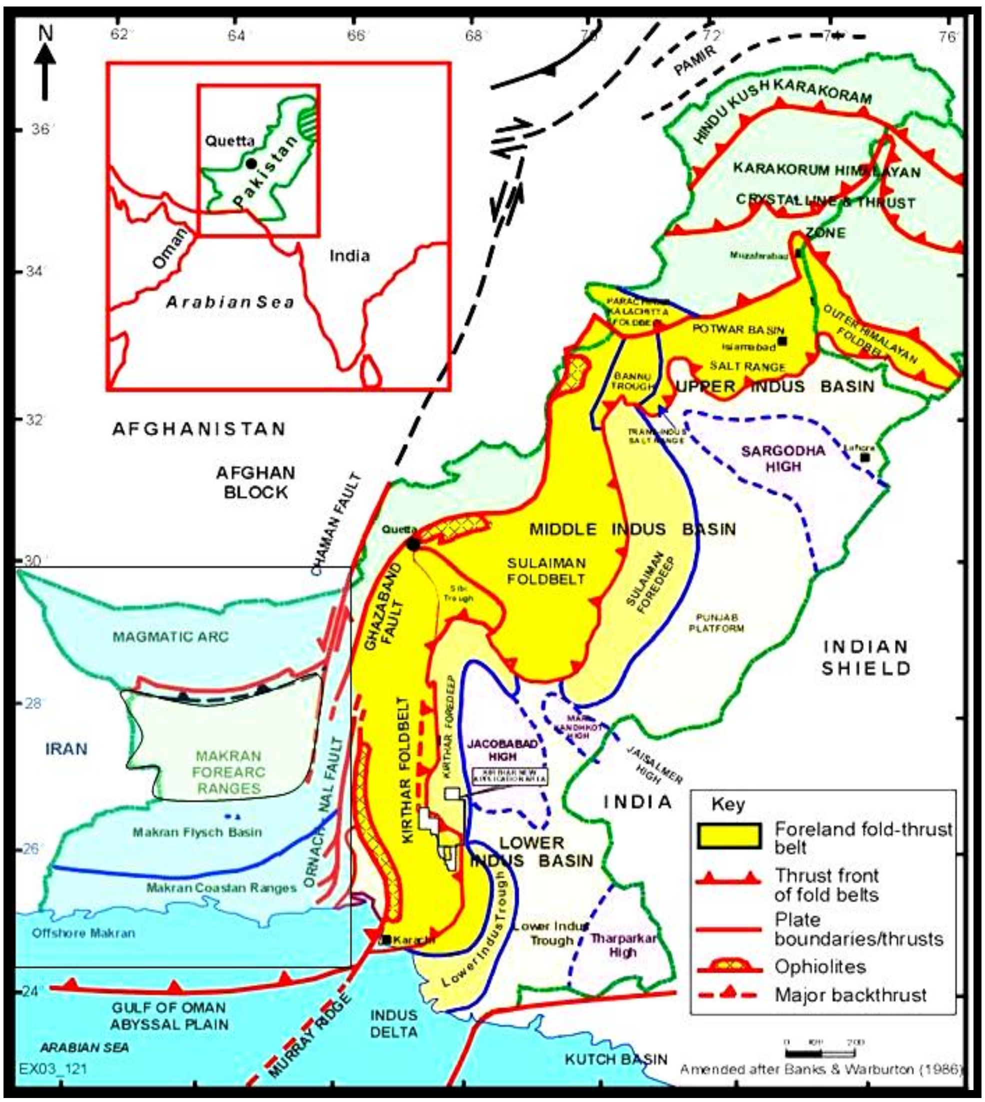

Figure. 3.1 Map showing collision boundaries of Pakistan (GSP)

The Tertiary collision between Eurasian and Indian plates brought about intense compressive folding and crustal shortening.

Pakistan comprises two main sedimentary basins, Indus basin and Balochistan basin, which evolved through different geological episodes and was finally welded together during Cretaceous/Paleocene along Ornach Nal/ Chamman strike slip faults. Geological setting of a sedimentary basin controls hydrocarbon migration and entrapment (Fig. 3.2).

The Indus basin can conventionally be delineated into the following sub basins (Kadri, 1995):

- Upper Indus Basin
- Lower Indus

The Upper Indus Basin is the northern extremity of the Indus basin. The main boundary thrust marks its northern limit and is scattered up to the Sarghodha High in the south. The Kohat- Potwar depression immediately lies southward of NW- Himalayas of Pakistan, is the northern potential zone of the upper Indus Basin. This area owes its origin to compressional tectonics and the northern margin of the Indian and Eurasian plates (Farah et al, 1984).

The Lower Indus Basin is subdivided into central and southern Indus basin

- Central Indus Basin
- Southern Indus Basin

From east towards the west, the central Indus basin comprised of Punjab Platform, Sulaiman depression and Sulaiman Fold- belt.

The lower Indus basin is located just south of the Sukkar Rift (Fig 3.4 & 3.5), a divide between Central and Southern Indus Basin (Kadri, 1995)

- Thar Platform

- Karachi Trough
- Kirthar Foredeep
- Kirthar Fold Belt
- Offshore Indus

The lower Indus basin is identified as an extension basin resulting from drifting and rifting of Indian plate during Cretaceous. The lower Indus basin is characterized by horst and graben structures, together with a system of transcurrent faults. The association of seismicity events and basement crustal features suggests that Tertiary reactivation of individual segments of the inferred rift structures has deformed overlying sequences of the Indus Basin and also surrounding areas, particularly the fold and thrust belt of Pakistan on the western side of the basin (Zaigham & Mallick, 2000).

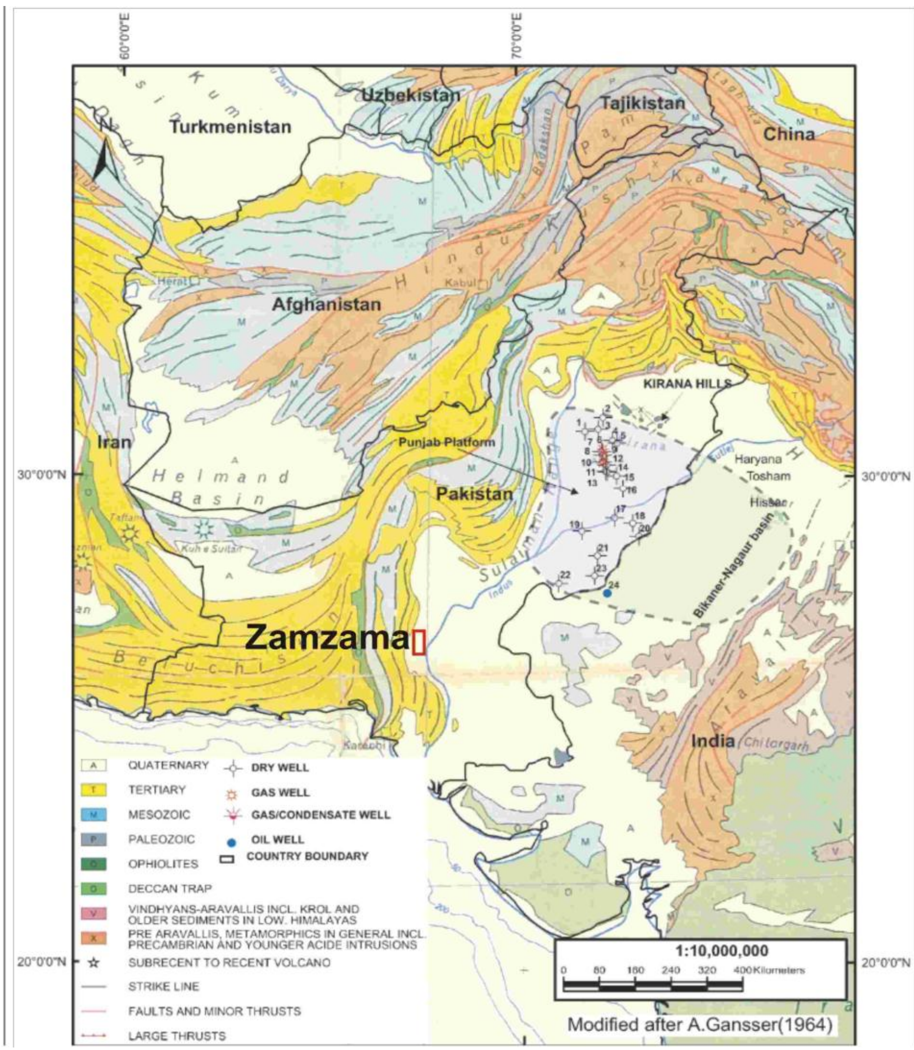

Figure.3.2 Geological map showing the Surface Geological w.r.t. faults and thrusts (BHP 2001)

The hydrocarbon discoveries associated with southern Indus Basin and surrounding areas are like Bhitt gas fields (recently explored fields on the western limb of the southern segment of the Indus Basin) (Zaigham & Mallick, 2000).

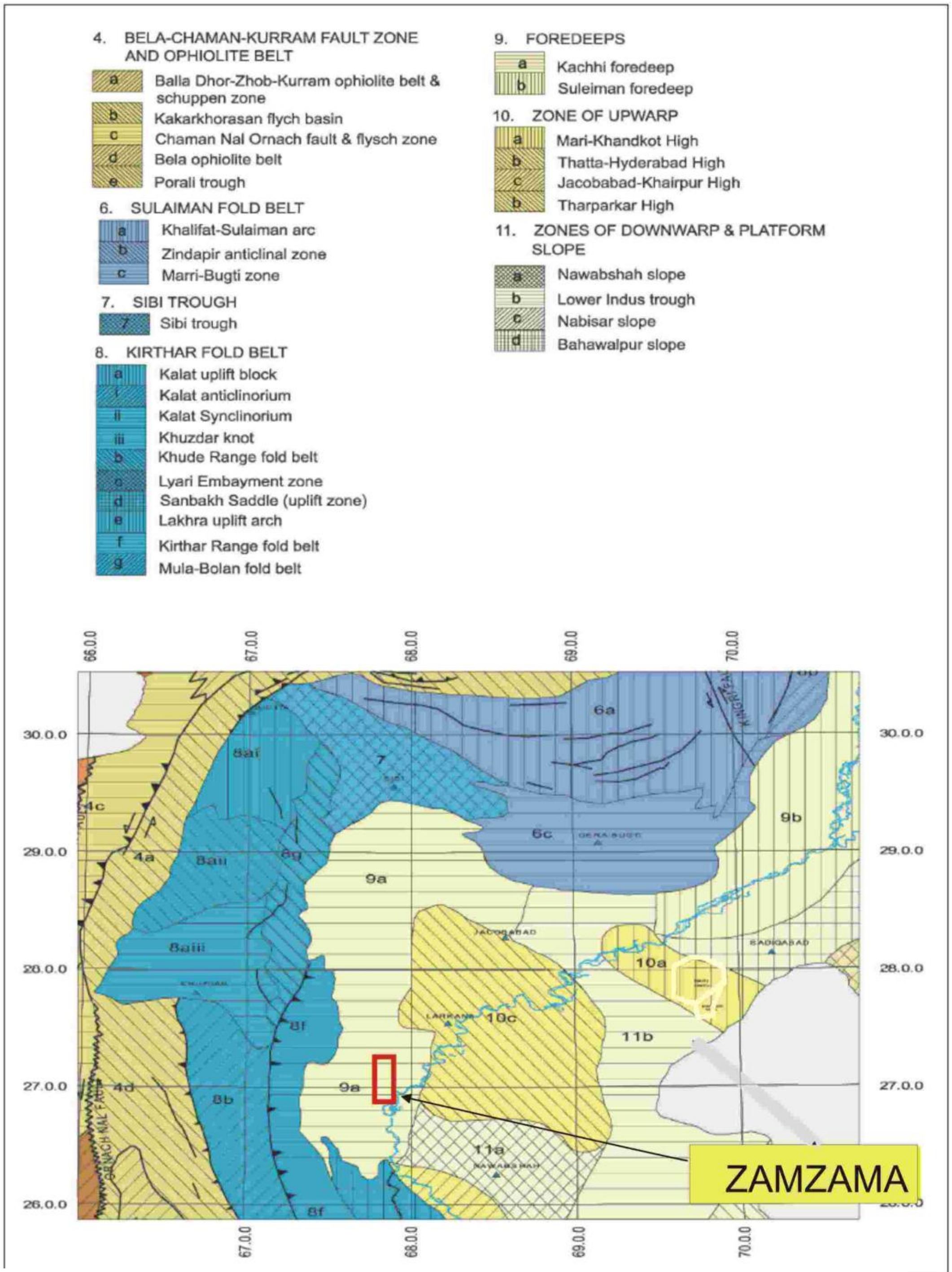

Figure.3.3 Schematic Tectonic map around Zamzama Area (PPIS)

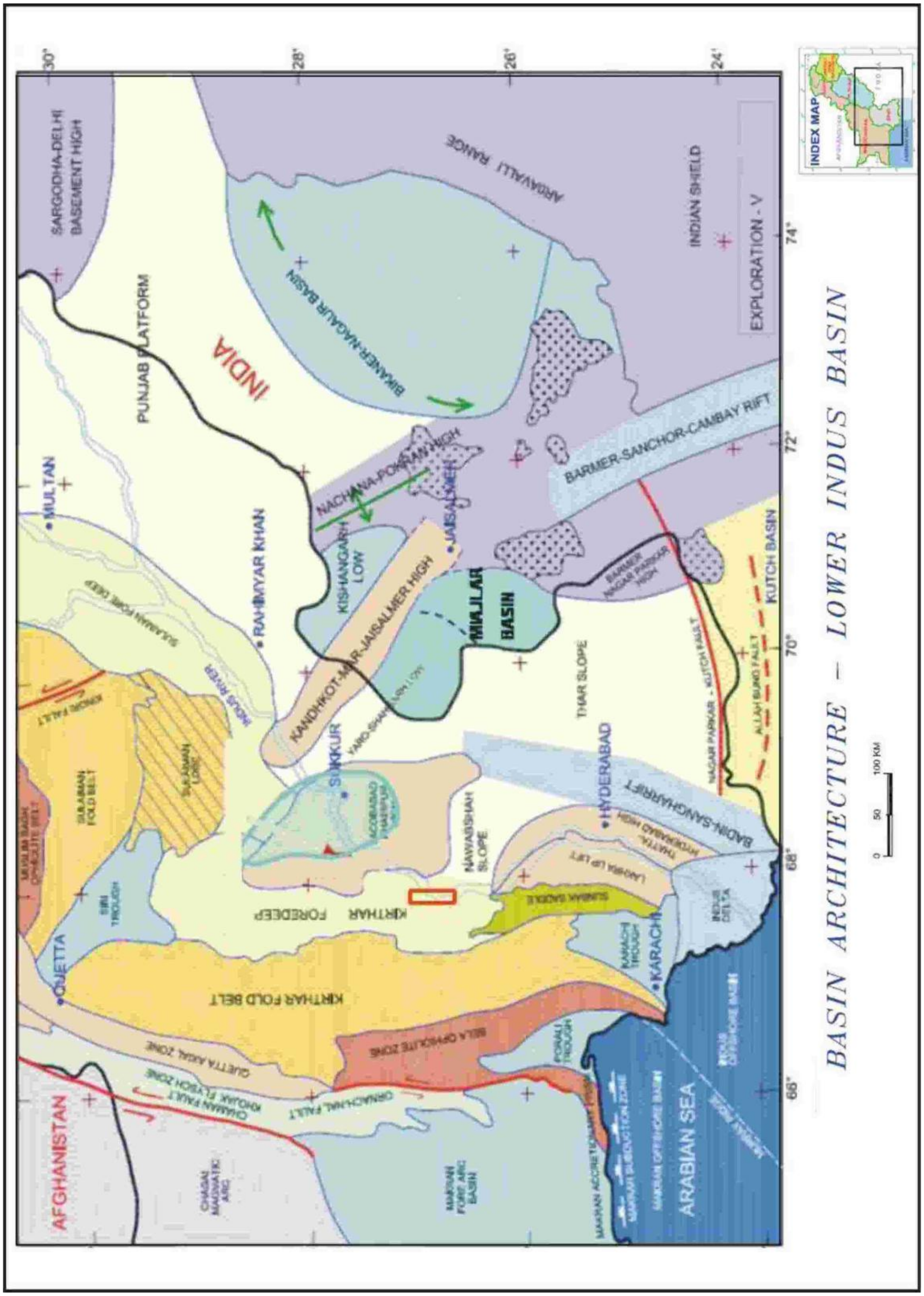

Figure 3.4 Showing the Basin architecture of Lower Indus Basin. (BHP2001)

3.1 Zamzama Structure

The Zamzama structure consists of a large N-S orientated, eastward verging thrusted anticline. The degree of thrusting and folding increases westward of Zamzama as progressively older sediments of the Lower Indus Basin are exposed in the Kirthar Fold Belt.

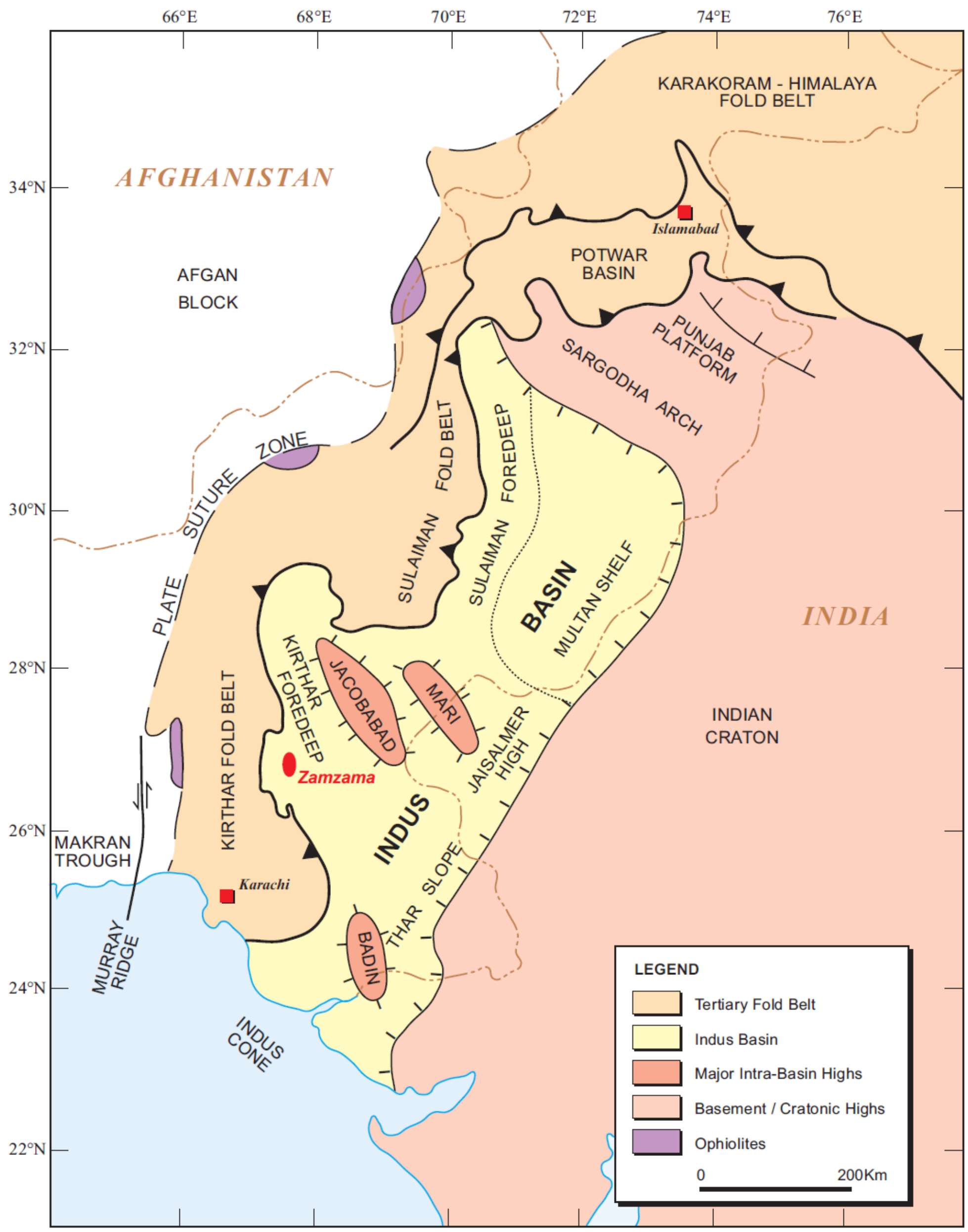

Figure 3.5 Map showing Zamzama Structure (BHP 2001)

The Kirthar Foredeep is believed to be the primary source of the Zamzama gas discovered in the hanging wall of the thrust fold.

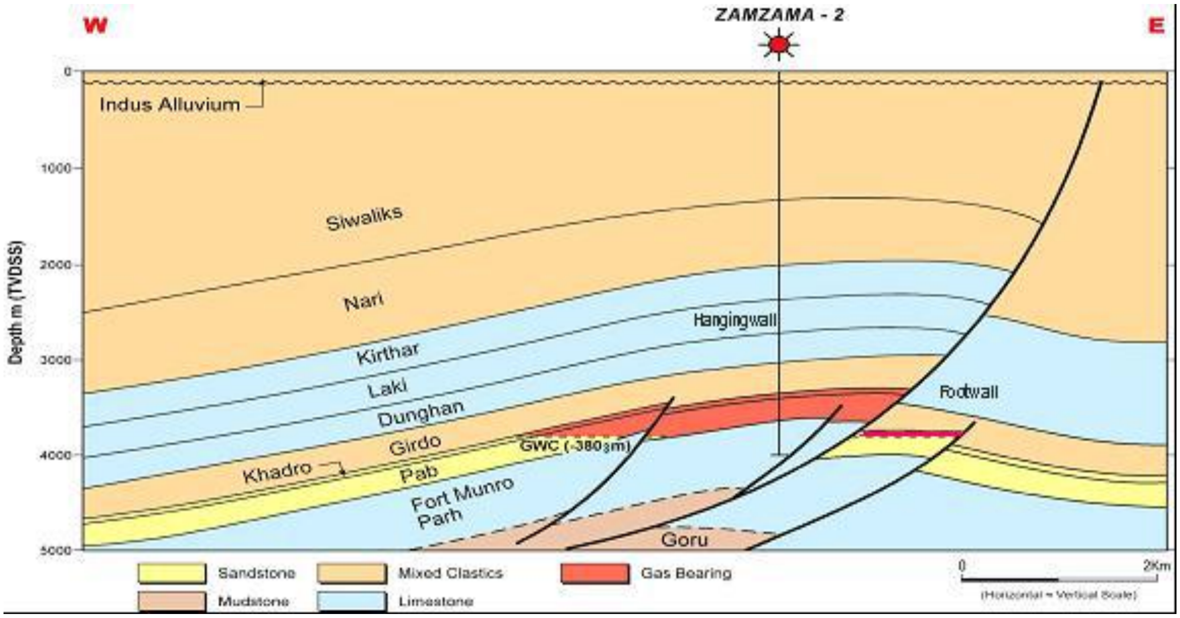

Figure 3.5a Map showing Zamzama Structure as seen in Zamzama Well 2 (BHP 2001)

3.2 Kirthar Fold Belt and Foredeep

The N-S trending Kirthar Foredeep received sediments of around 15,000m. On the eastern side it has a faulted boundary with Thar Platform. The Kirthar Fold Belt is also an N-S trending fold belt which also marks the closing of Oligocene-Miocene seas. The western part of it has contact with Balochistan Basin and is highly deformed.

Kirthar sub basin is the southern part of the Indus Extra-continental Trough Downwarp basin, which was developed on the Indian Plate (Raza et al, 1990). Subsurface seismic profiles indicate that in the foredeep zone and in the Jaccobabad –Kandkot zone some of the faults are likely to be the post Eocene (Oligocene) and post Miocene (Kazmi and Jan. 1997). Most of the late cretaceous basement faults and rift structures are likely to be associated with the detachment of the Indian plate from Gondwanaland, whereas the Tertiary faults may have resulted from bending of the crustal plate due to collision and rebound relief tension or compression release. The western margin of the foredeep is seismically active and contains a number of active faults (Kazmi and Jan. 1997).

As a consequence of left lateral transform movements from west along Ornach-Nal-Chamman fault to the eastern part of the Kirthar fold belt (Figure.3.6), a number of anticlinal structures were created on the eastern side of the Kirthar fold belt resulting from plate collision during Oligocene- Miocene time (Ahmad, R. & Ali, S.M., 1991). The decollement features within Eocene sediments has been developed by wrench-related compression. Towards north, the eastern side of the fold belt has left lateral oblique convergent wrenching (Gokurt & Sanni Anticlines). Divergent features caused by left lateral divergent wrenching lies in the southern part (Sunbakh Anticlinal Trend & Lakhra Anticline). Foreland dipping thrust regime with left lateral strike slip component exit in between the above mentioned regimes (Miangun Anticline lies in left lateral convergent-foreland dipping thrust regime and Mazarani Anticline & Phulji Anticline falls in foreland dipping thrust regime and with left-lateral divergent regime are the Bhit Anticline and Badhra Anticline). The anticlines in the eastern part of fold belt are narrow, strongly elongated, often doubly plunging (Ahmad, R. & Ali, S.M., 1991).

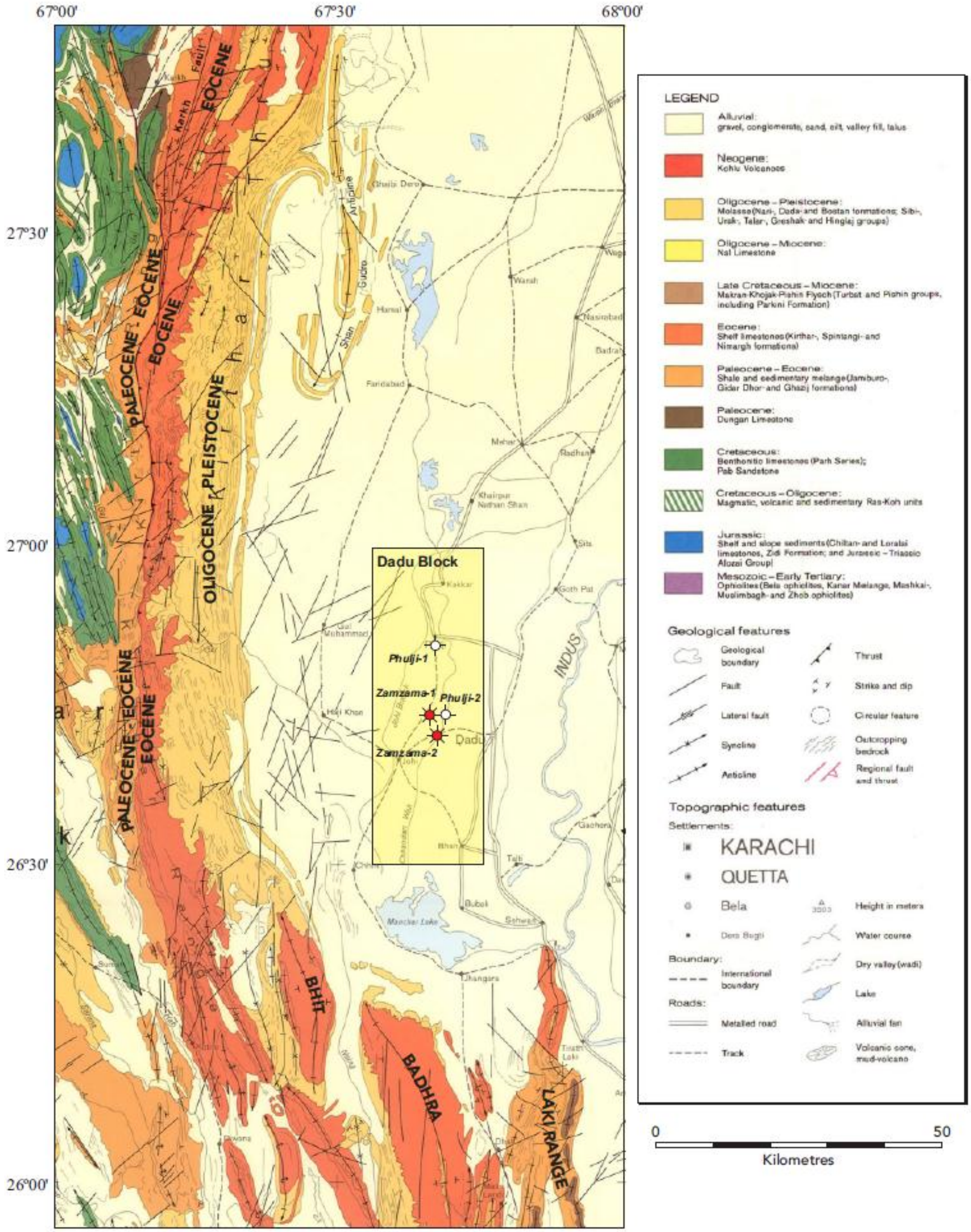

Figure.3.6: Structural Map of Zamzama Block (BHP 2001)

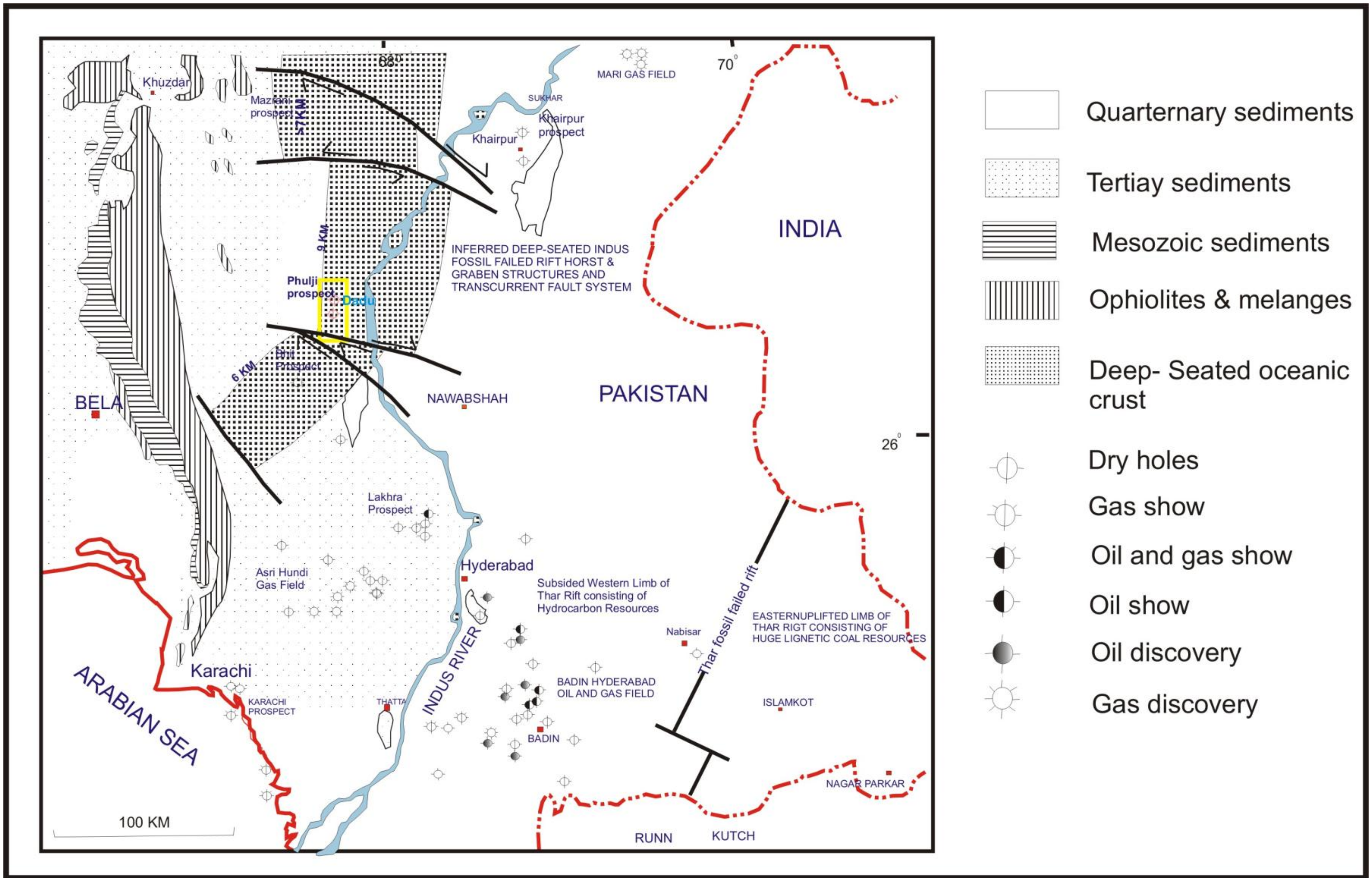

Fig 3.7: Hydrocarbon Prospects and their tectonic association in Lower Indus Basin and surrounding areas (Phulji Prospect).

Modified after Zaigham A. and Mallick K.A., 2008.

3.3 General Stratigraphy

The Lower Indus Basin consist a molasse Foredeep of Oligocene to Quaternary age overlying Mesozoic to Eocene passive margin clastic and carbonates deposits that predate the Tertiary orogenesis of the Kirthar Fold belt. The oldest rocks encountered are of Triassic age.

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The stratigraphy encountered in the Lower Indus Basin is as follows:-

Mesozoic:

Wulgai Formation (Shale and sandstone) of Triassic age and Shirnab Formation (shale and sandstone with rare limestone) and Chiltan Formation (limestone) of Jurassic age are overlain in an upward direction

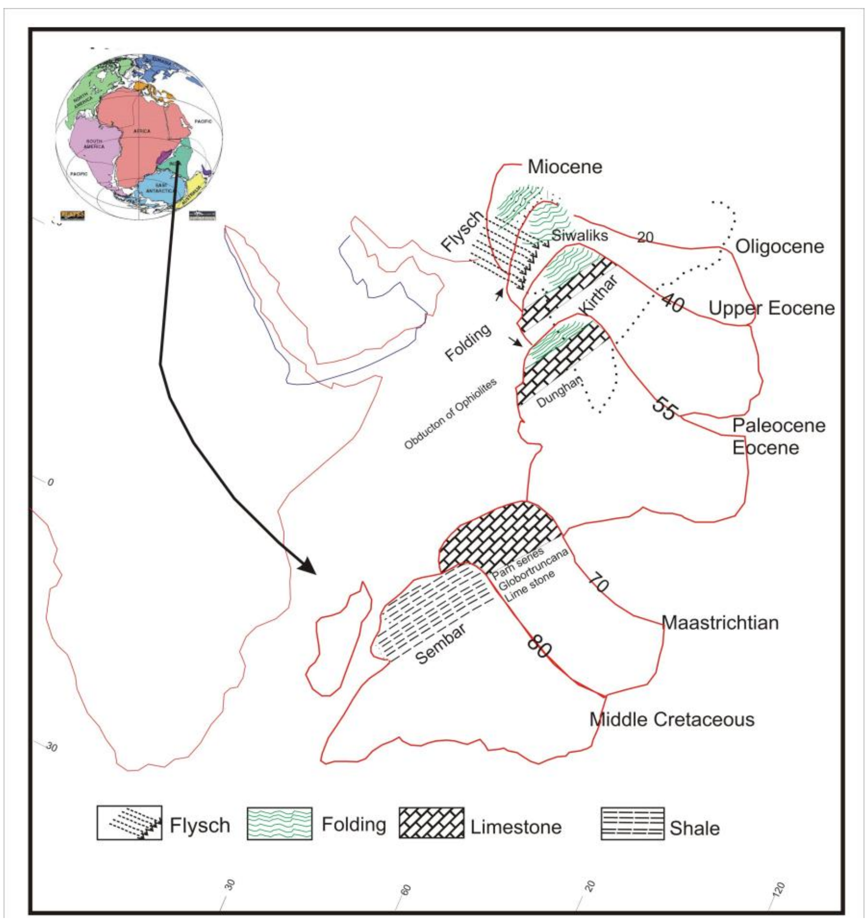

Figure.3.8 Drift of the Indian Plate according to McA Powell (1979), in relation to the Mesozoic and Cenozoic sediments in Pakistan

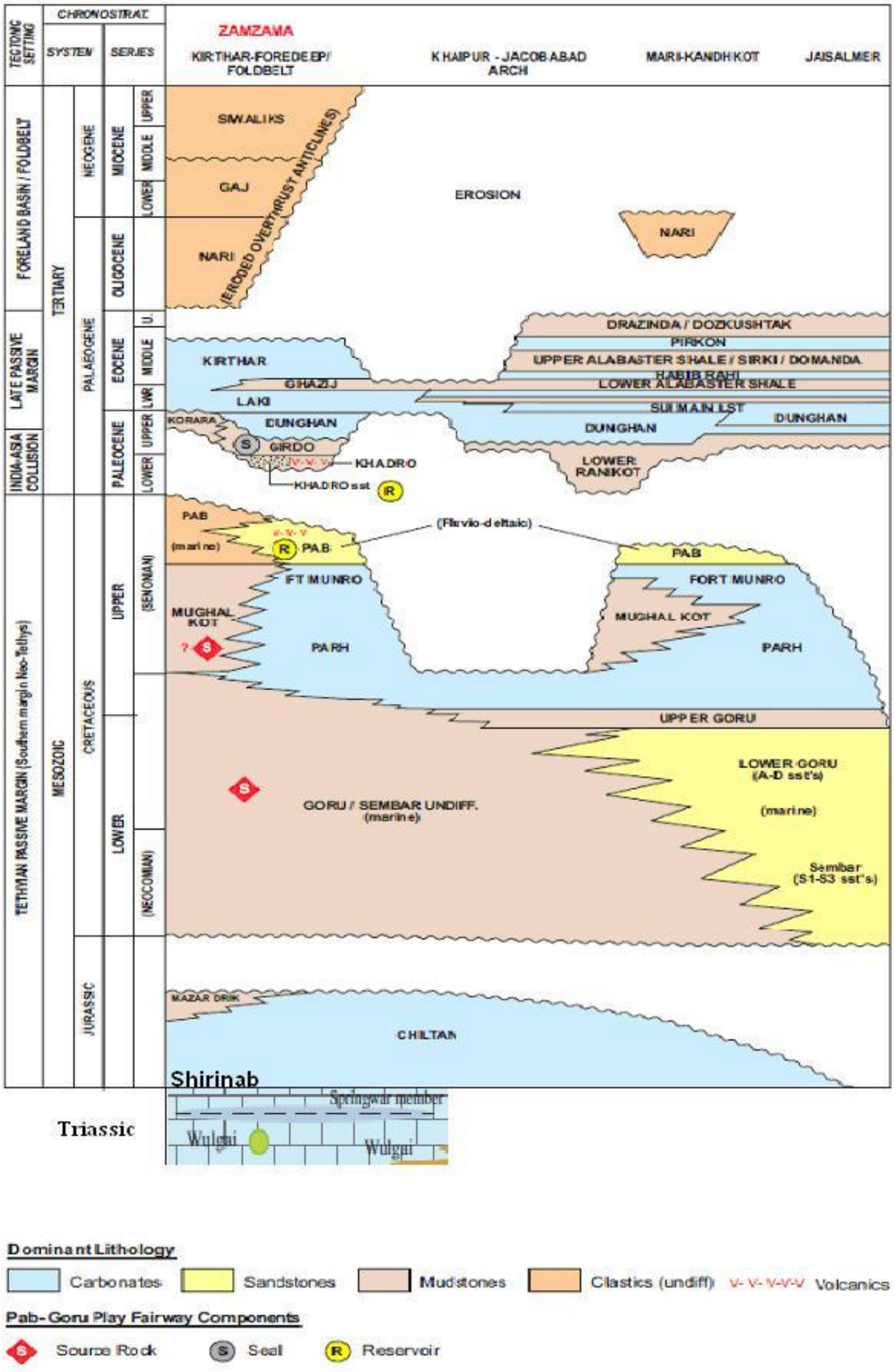

Figure.3.9 Stratigraphic Column of Lower Indus Basin (BHP 2001)

Followed by Sembar and Goru of Lower Cretaceous which is underlying Parh, Mughal Kot and Fort Munro as well as the Pab reservoir of Upper Cretaceous.

Tertiary:

Khadro Formation (sandstone), Bara Formation (sandstone and shale) and Lakhra Formation (limestone and shale) form the Paleocene succession. Eocene is limestone dominated sequence comprising Laki Formation (limestone and shale), Gazij Formation (shales), Kirthar Formation (limestone and subordinate shale). Oligocene – Miocene sequence comprises Nari (shale, limestone and sandstone) and Gaj (shale, sandstone and limestone) Formations. Post- Miocene section is mainly continental and contains fluviatile clastic overlain by alluvium.

3.4 Petroleum Prospect

Source Rock

The main source for Zamzama field is considered to be shales of Cretaceous Sembar and Goru Formation. Sembar is deposited on a broad shelf while Goru fauna shows pelagic environment.

The Sembar was deposited over most of the Lower Indus Basin in marine environments. The TOC values from the Sembar in two Badin area wells in the foreland portion of the Lower Indus Basin have TOC's ranging from 0.5 to 3.5 percent and averaging about 1.4 percent. Sembar is mainly type-III kerogen, capable of generating gas. Sembar ranges from thermally immature to overmature (Wandrey C.J. et al)

Reservoir Rock

Pab Sandstone of Cretaceous age is the primary reservoir for Zamzama Field. It is deposited in fluvio-tidal to shallow marine environment. The Pab comprises an extremely sand rich braid delta / coastal plain depositional system.

Cap Rock

Paleocene shales of Lower Ranikot (Girdo) act as a cap for Pab Sandstone

Trap

It is a large North-South oriented Eastward verging thrusted anticline is the main structure in the Zamzama area.

4. Logging Tools

Wireline log measurements respond to rock properties and the properties of the fluids in the pore space. The main purpose of well logging is to:

- provide data for evaluating petroleum reservoirs.
- aid in testing, completion and repairing of the well.

Logs can provide a direct measurement or give a good indication of:

- Porosity, both primary and secondary
- Permeability
- Water saturation and hydrocarbon movability
- Hydrocarbon type (oil, gas, or condensate)
- Lithology
- Formation dip and structure
- Sedimentary environment
- Travel times of elastic waves in a formation

These parameters can provide good estimates of the reservoir size and the hydrocarbons in place.

4.1 Caliper Log

Caliper Log is used to measure hole diameter. A caliper is lightly extended against the sides of the hole, and this distance is converted by an electromechanical device into an electronic signal suitable for recording. Changes in borehole diameter are related to both drilling technique and lithology, because borehole diameter is affected by borehole condition, mechanical strength of formation, permeability.

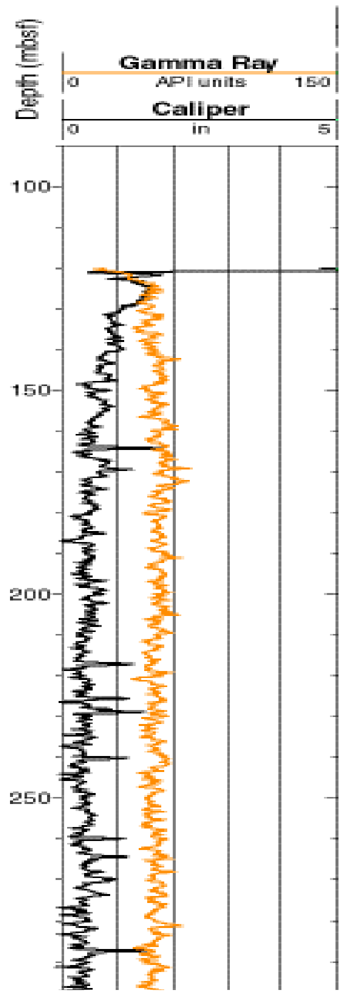

Figure 4.1 Representation of Gamma Ray Log

4.2 Gamma Ray Log

The gamma-ray log measures the natural radiation of uranium, potassium, and thorium. It shows high value in Shales while low values are observed in clean formations like Sandstone and Carbonates. It is expressed in API.

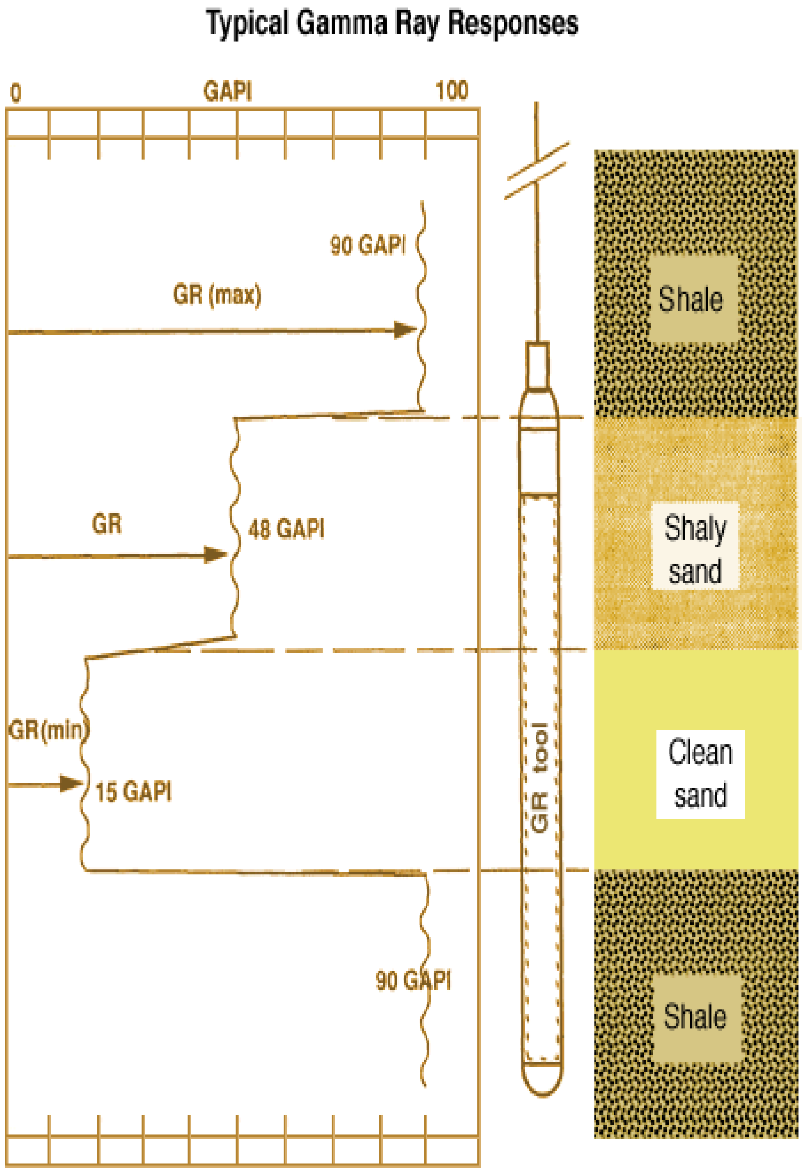

Figure 4.2 Representation of Gamma Ray Log

4.3 Spontaneous Potential Log

The SP log records the difference in electrical potential between a fixed electrode at the surface and a movable electrode in the borehole. The hole must contain conductive mud in contact with formation, and so the tool cannot be used in oil-based muds, empty holes, or cased holes. Measurement is in millivolts. The log essentially measures differences from a shale (mudstone) line (maximum deflection). The minimum deflection of the SP is clean, permeable, and water-bearing sandstone is called the static SP.

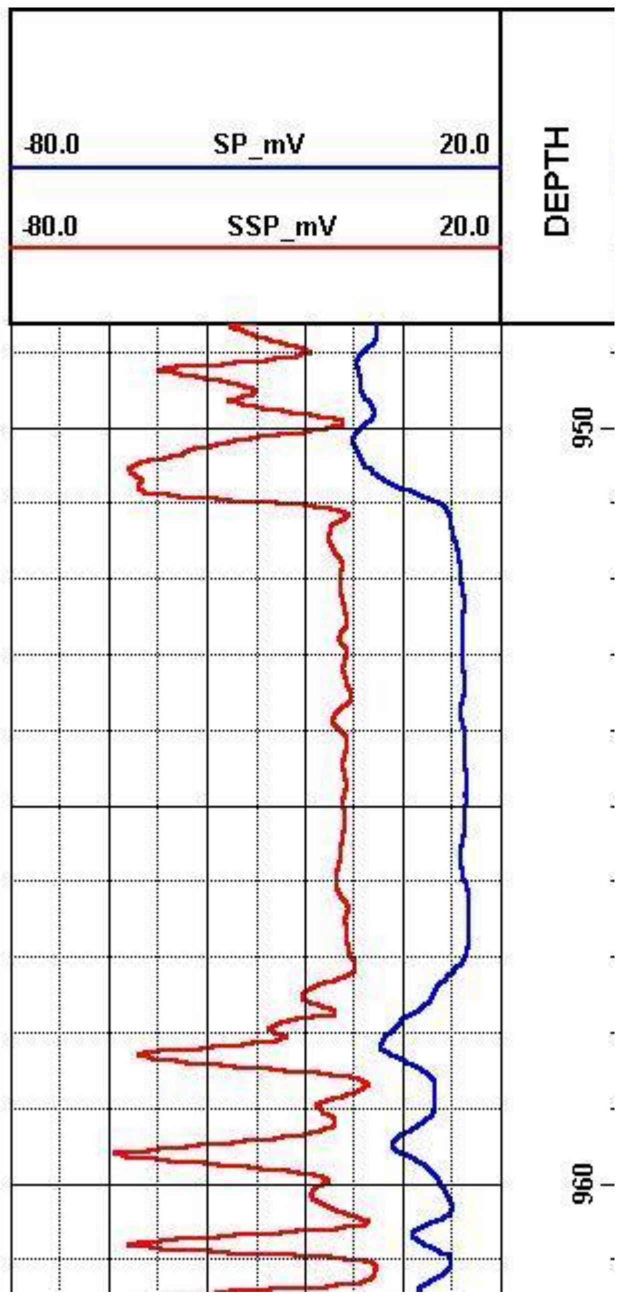

Figure 4.3 Representation of SP Log

4.4 Induction Logs

Induction tools belong to the resistivity tool family and attempt to measure true formation resistivity, Rt. They work like metal detectors by inducting currents in the formation. It is presented in ohm-m. Three logs are typically run:

- a deep investigation,
- a shallow investigation, and
- a micro device that investigates the area immediately around the well bore.

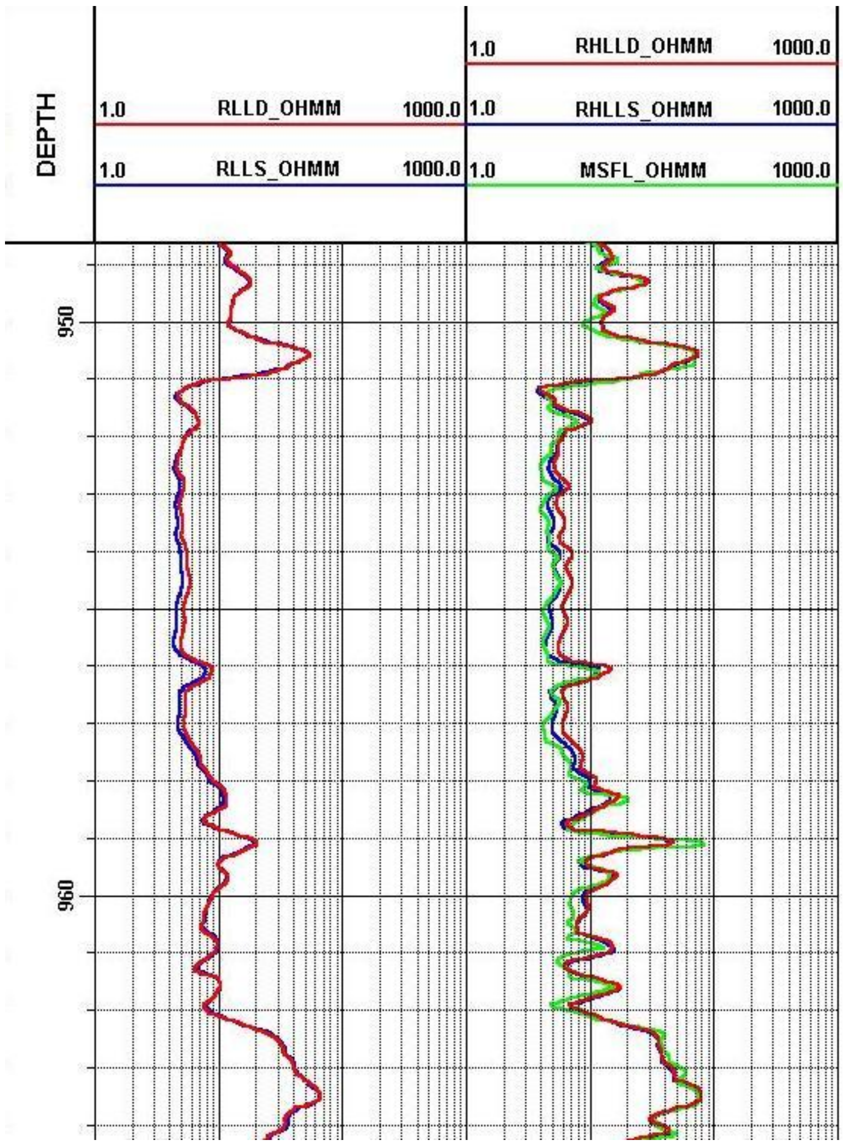

Figure 4.4 Representations of Induction Logs

4.5 Density Log

The formation density tool measures the electron density of a formation. It comprises a gamma ray source and detector. Gamma rays are emitted into the formation, where they interact with electrons and are scattered. The scattered gamma rays that reach the detector are counted as a record of formation (electron) density and the electron density can be related directly to bulk density. Unit of density log is g/cm^3

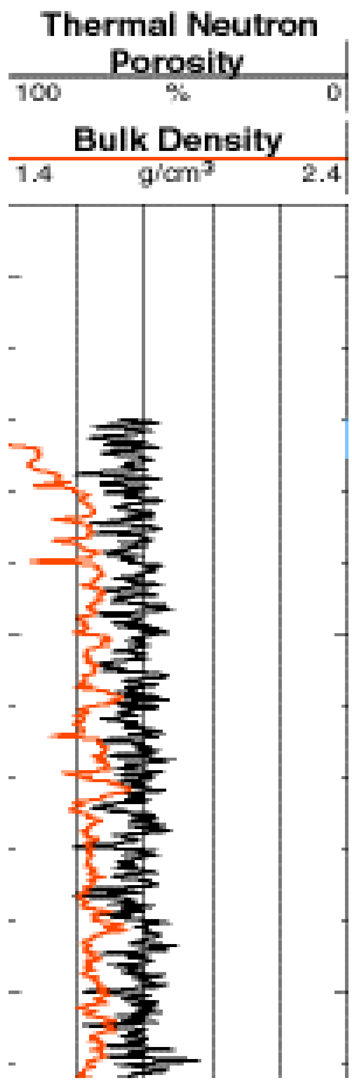

Figure 4.5 Representation of Density Log

4.6 Neutron Log

Neutron logs determine the hydrogen atom concentration in a formation. The neutron tools emit neutrons that lose energy as they collide with atoms in the host formation. Because of their similar size and mass, the most energy is lost when the neutrons collide with hydrogen atoms. Thus the maximum loss in energy equates to the highest volume of fluid-filled pores. Neutron porosity is expressed in percentage.

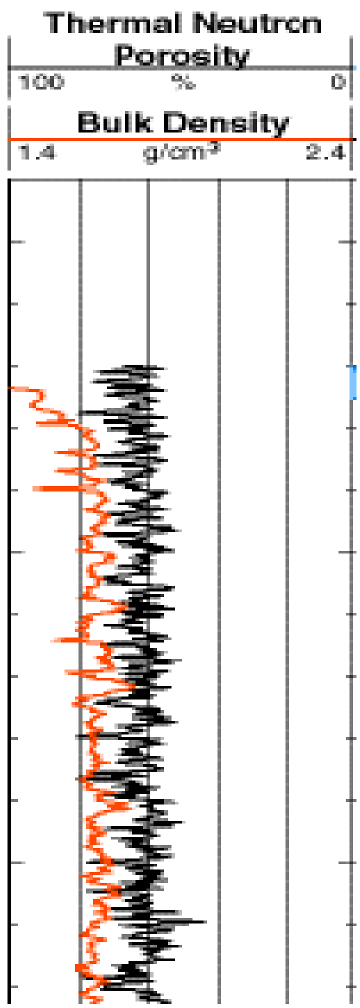

Figure 4.6 Representation of Neutron Log

4.7 Sonic Log

The sonic tool works by sending a sound pulse into the formation and measuring the time taken for the sound wave to return to a receiver located further up (or down) the tool. Typically, the distance between the transmitter and receiver is a few meters. The transit time in tight (nonporous) sandstone or limestone is short: in porous formations it is longer, and in mudstone longer still. Its main use is in the evaluation of porosity in liquid-filled holes. It may also be used to provide a calibration to a well for seismic data. Sonic Log is expressed in microseconds/feet.

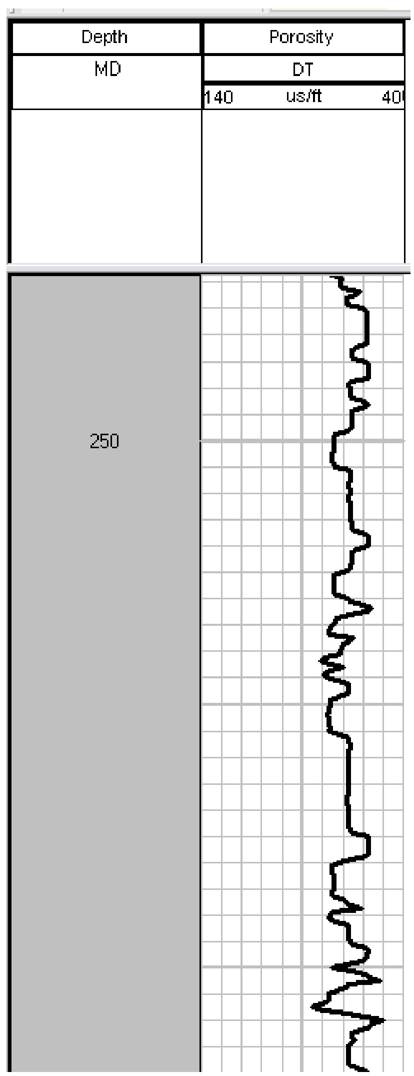

Figure 4.7 Representation of Sonic Log

5. Source and Reservoir Observations in Field

A 2 day field was done for the observation of the source and reservoir rocks. The area of study was Mughal Kot approximately 160km from Dera Ismail Khan. Both the Pab and Sembar Formation is very well exposed along with its upper and lower contacts. The location of the area is 31^{o} 24’ 02” N and 70^{o} 03’ 07’’E.

5.1 Field Observation of Pab Sandstone

A thick sequence of Pab Sandstone could be observed in the Mughal Kot Section. The lower part of Pab Sandstone was medium to thick bedded highly compacted quartzose sandstone. The sandstone was very hard. Sole marks and thinly cross laminations could be observed in it. Around 20m interval a shaly horizon was seen which consisted of 6m thick sands and shales alternate beds. Channelized beds of sandstone were observed. After 6m interval i-e total 32m again alternate beds of shale and sandstone were observed with no channelized beds in sands marking a facie change. Here Flaser Bedding was observed i-e shales were deposited in the depressions of ripples. After 2m interval (total 34m) cross bedding along with very thin beds of shales were observed. After 25m interval (total 59m) burrows were seen on surface of the sandstone which was followed by channelized bedding along with shales. After 15m interval (total 73m) organic shales with Sulphur followed by medium to thick bedded sandstone with load castes was observed. For the next 250 m (total 323) the same sequence as discussed appeared with only one difference i-e pyrite which appeared in the top of Sandstone body. Flaser bedding is formed when the tidal current diminishes, hence the fine particles gets deposited within the depression of the ripple formed by the current. Channelized beds are formed in the channels within the delta while burrows and cross bedding is the characteristic of shallow marine environment.

Figure 5.1 Photograph showing channelized sands (marked red) within the Pab Formation.

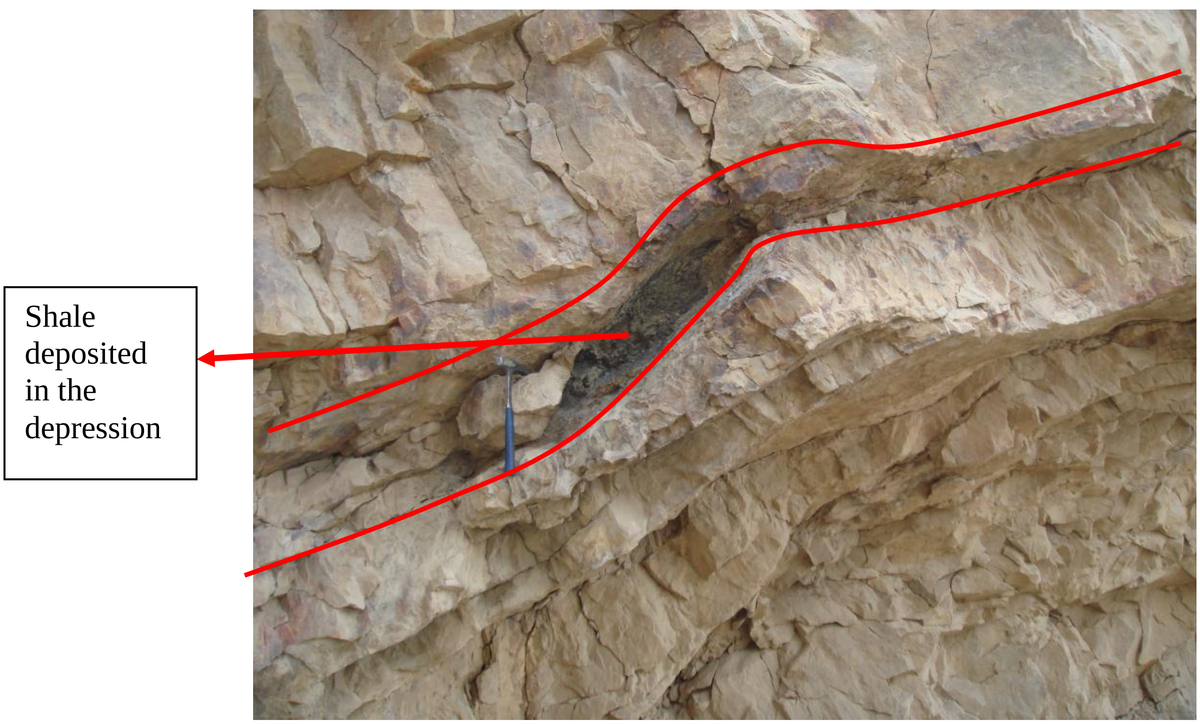

Figure 5.2 Photograph showing Flaser bedding

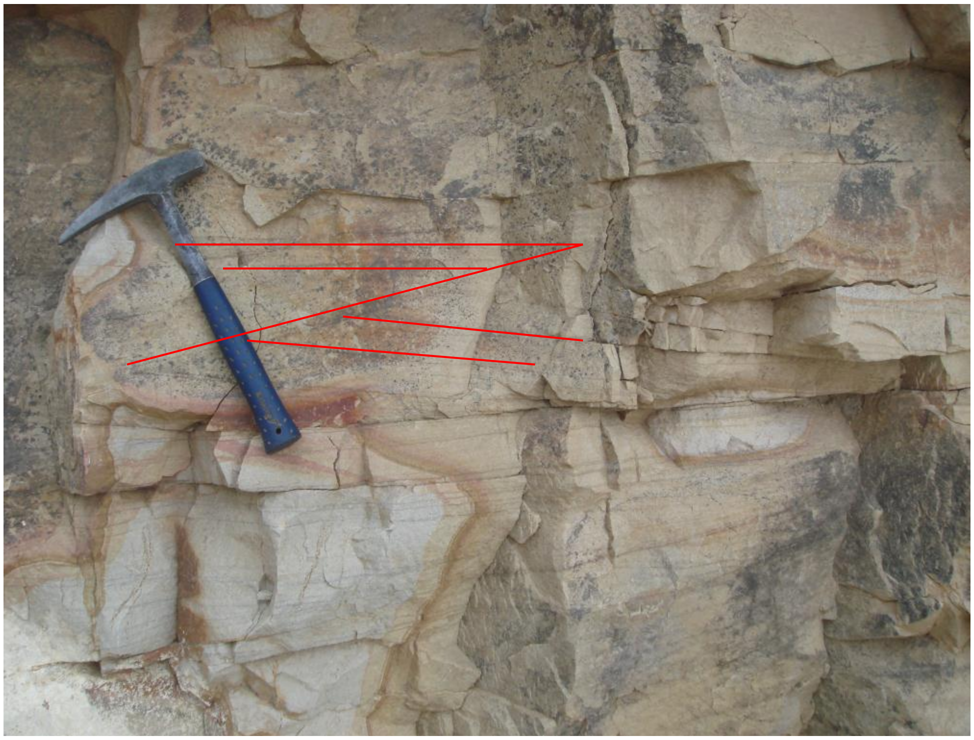

Figure 5.3 Photograph showing cross laminations in Pab Formation

Figure 5.4 Photograph showing burrows in Pab Formation

5.2 Field Observation of Sembar Formation

The formation observed consisted of black splintery shales. The shale was highly compacted in nature as it was embedded between Suleiman Limestone (lower contact of Sembar Formation) and Parh Limestone (upper contact of Sembar Formation). Belemnites were seen in the Sembar Formation. The shales were dark black due to the organic content. Phosphate was associated with Belemnites. Oil seepage was also observed within the Sembar Formation.

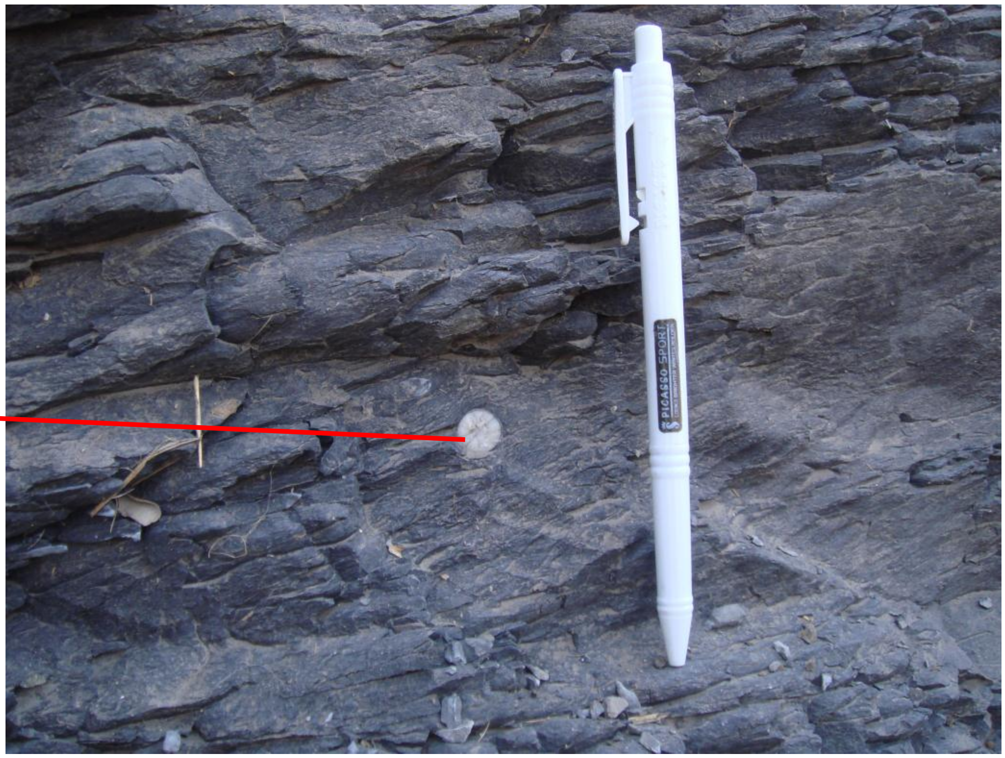

Figure 5.5 Photograph showing Belemnite in Sembar Formation

Figure 5.6 Photograph showing Belemnite with phosphate in Sembar Formation

Figure 5.7 Photograph showing Oil seepage in Sembar Formation

6. Maps and Cross Section

Different Maps and cross sections were prepared using Zamzama well 1, 2, 3, 4, 5, Zamzama East 1 and Bhan 1. The Base Map of the well can be seen in the below mentioned figure 6.

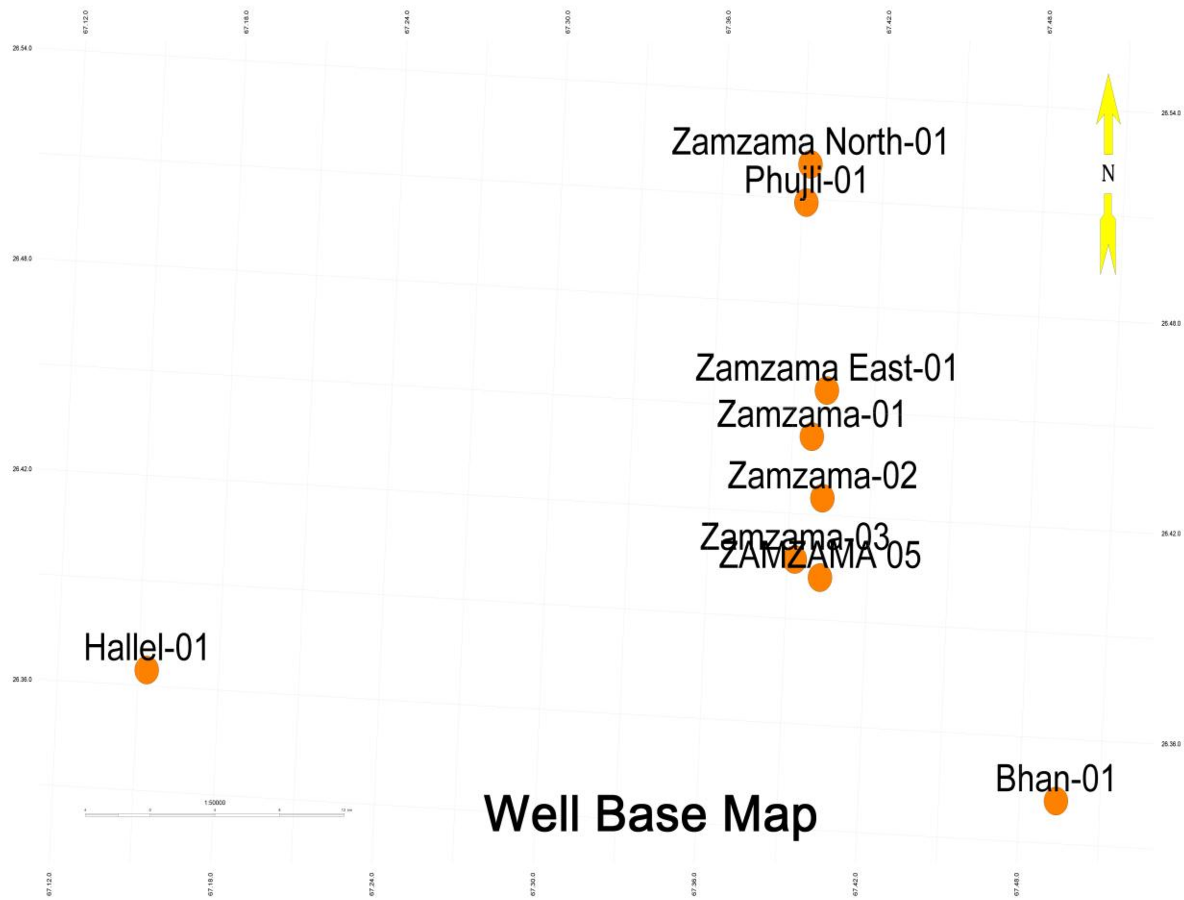

Figure 6 Map showing wells used for cross section and Maps generation.

6.1 Isopach Maps

Isopach is a line on a map of the Earth's surface connecting points where a rock stratum has equal thickness .The stratigraphy and history of the subsurface sediments in this area was well-constrained by well-log data, and this provided a source of information for study.

Ghazij Formation

The Map shows that Ghazij Formation has increasing thickness in the North-East and South-West direction and thins out in the South-East and North-West but the trends shows that comparatively the thickness is decreasing in the S-E direction more than the North-West. Contour interval was 5m. Thickness varies from 200m -130m in study area.

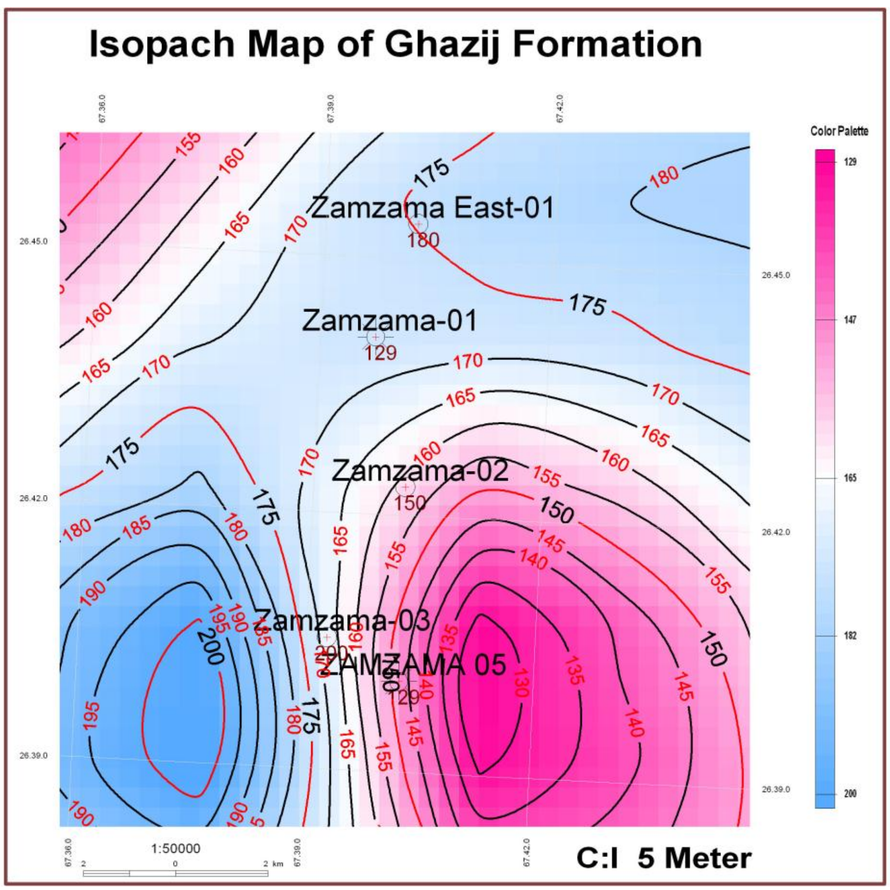

Figure 7.1 Isopach Map of Ghazij Formation

Pab Formation

From the isopach Map we can deduce that Pab Formation depocentre lies in some part of the northern sides while in all other areas the formations thins out. Thickness varies from 430m to 220 m in the study area.

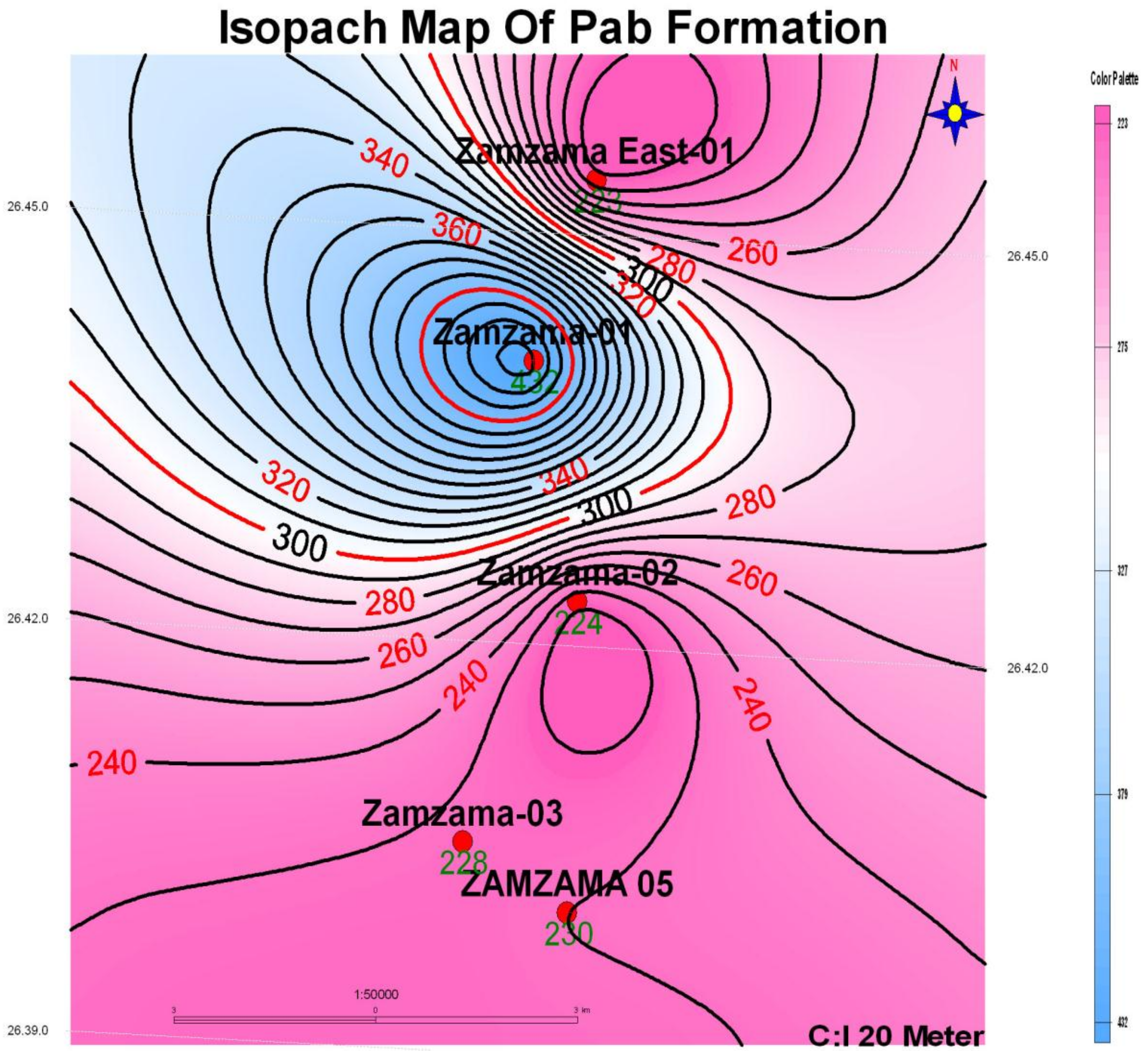

Figure 7.1b Isopach Map of Pab Formation

Fort Munro Formation

The Map shows that Fort Munro is deposited with maximum thickness in the North-West and South-West direction while it thins out in the North-East and South East Direction. Thickness varies from 270m to 50m in the study area.

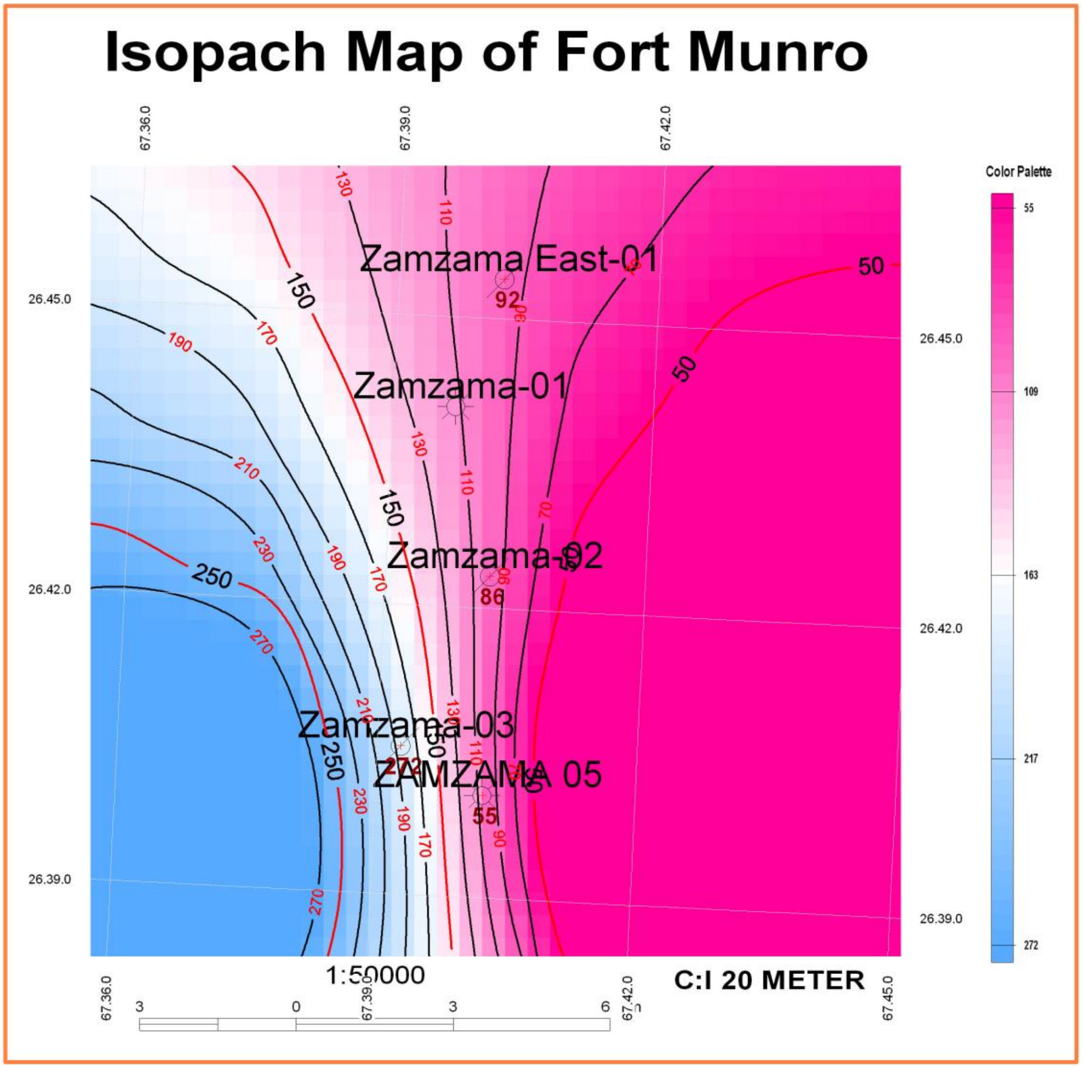

Figure 7.1a Isopach Map of Fort Munro Formation

6.2 Stratigraphic Correlation

The correlation generated (Figure 6.2) was hanged on Kirthar Limestone due to its presence in each well. It shows the depositional trend of the Formations encountered in the wells. Rock formations below the surface of the Earth are almost never perfect flat that are truly seen in the cross section which created the traps present in the area due to folding and tilting.

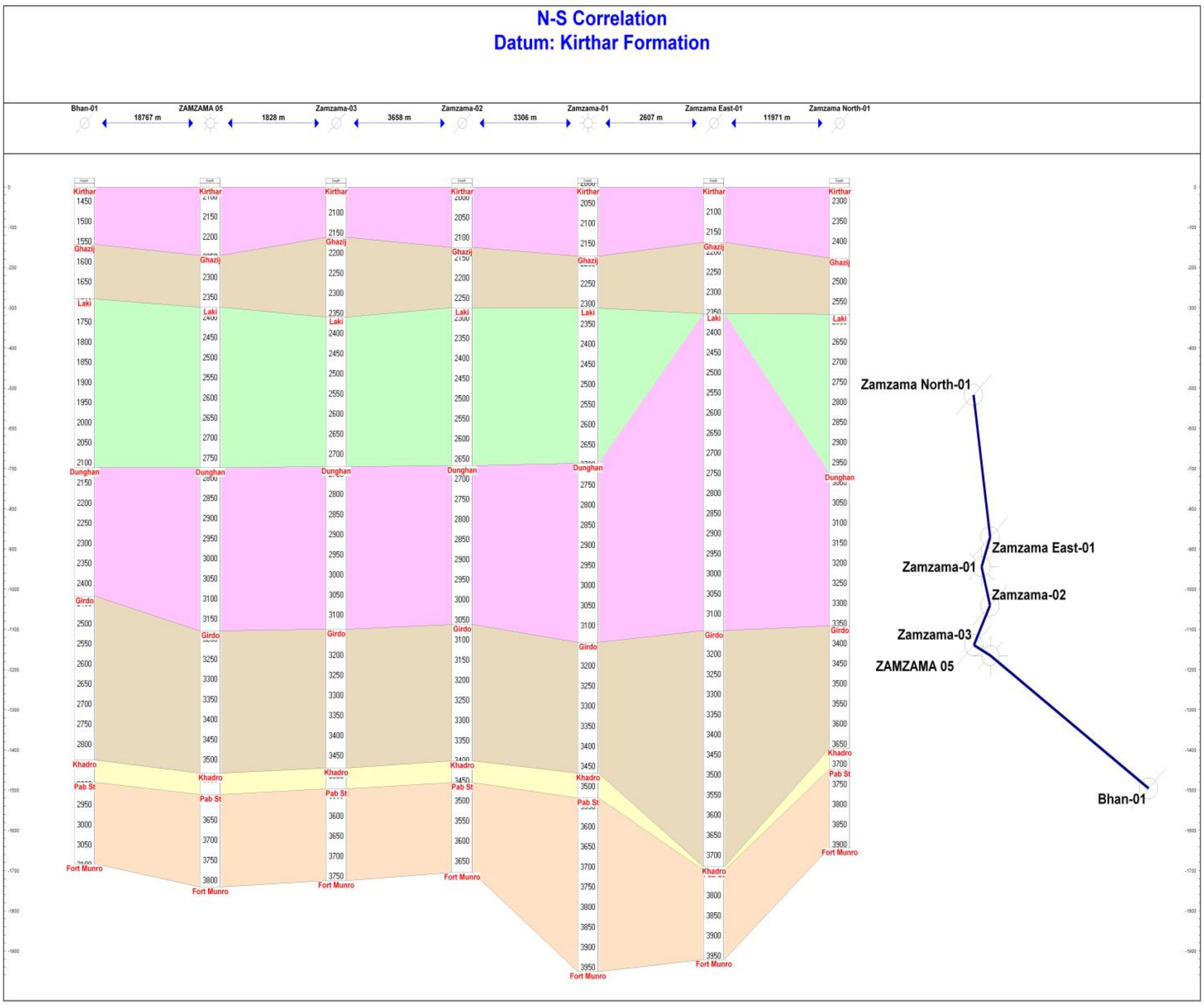

Figure 6.2 N-S Stratigraphic correlation in the study area

6.3 Pab Porosity Map

The porosity map was generated using Zamzama East 1, Zamzama 1, 2, 3 and 5. From the map it can be deduced that the porosity is increasing on the South Eastern and South Western side while it has a decreasing trend in the opposite direction. The possible reason of decreasing porosity on northern side may be due to the mud dominated facie within the Pab Formation.

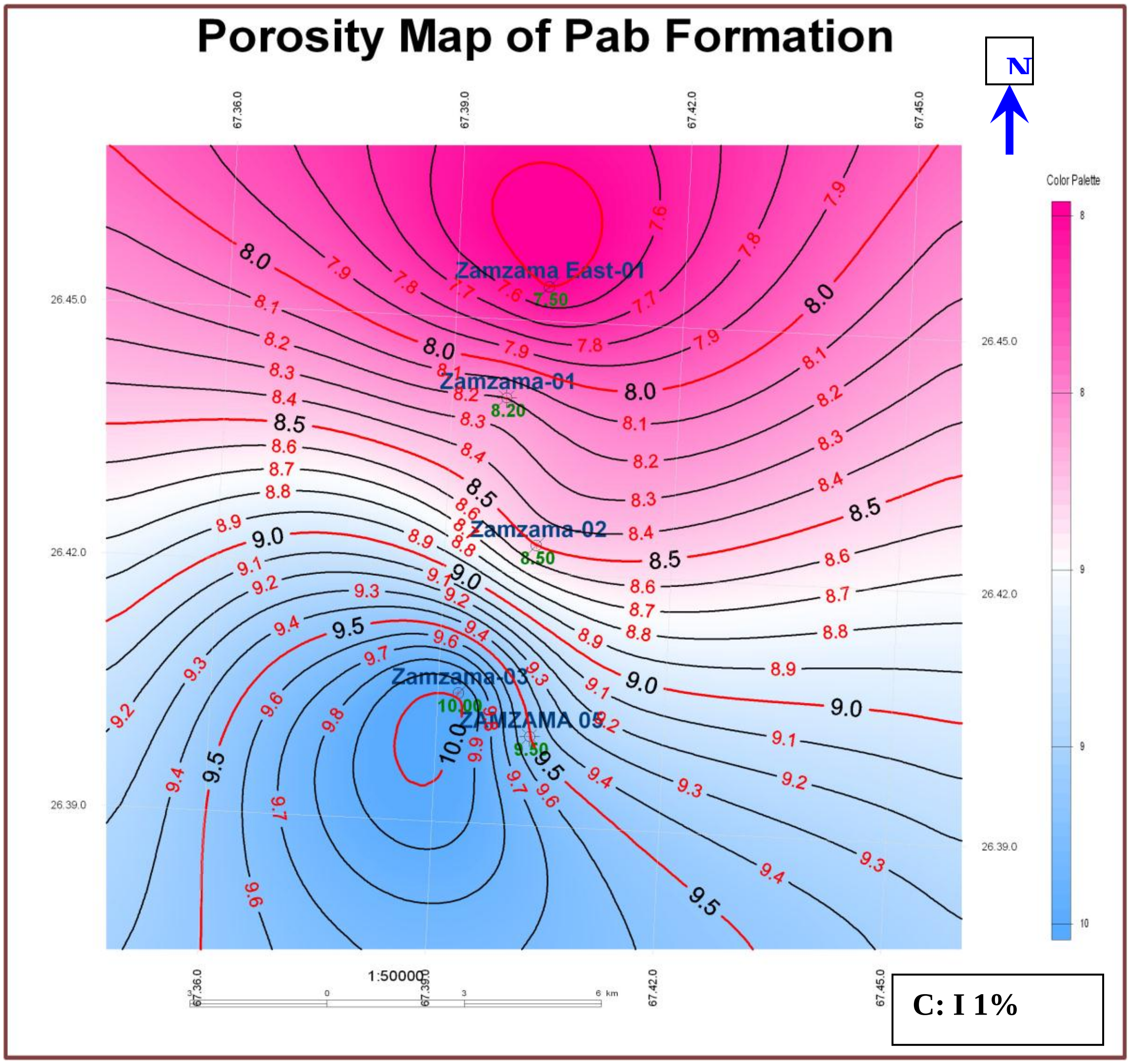

Figure 6.3 Porosity Map of Pab Formation

7. Petrophysical Evaluation

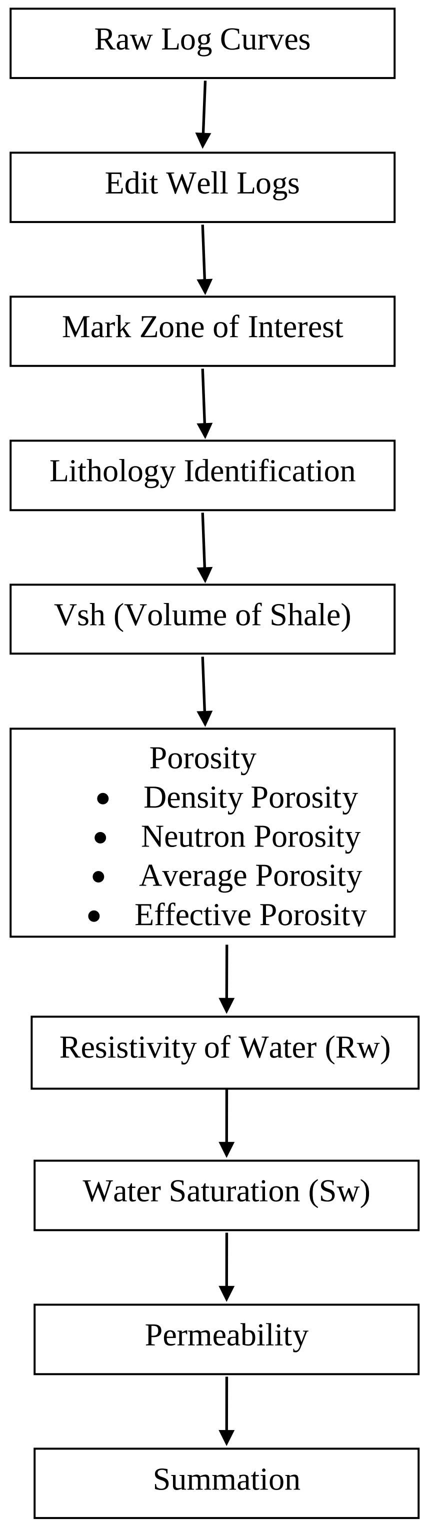

Figure 7.1 Diagram showing workflow chart

7.1 Log Interpretation Flow Chart

The work done on log can be summarized in the Figure 7.1 on page 41.

7.2 RAW LOG CURVES

Raw log curves included all the log curves, which are given us to study and find out the values of all parameters. Each log curve gives value of one parameter at different depths

7.3 EDIT WELL LOGS

The edit well logs involve in the following steps:

- End effects removal
- Sp Base shift
- Depth shift
- Sonic Despiking
- Curve Rescaling
- Curve Splicing
- Curve Merging

7.4 ZONE OF INTEREST

The zone is marked on basis of Neutron and Density Logs where there was a cross over between them indicating the presence of Hydrocarbons in the reservoir (Pab Formation). Following zones of interest were marked

Zone	Starting Depth (m)	End Depth (m)	Thickness (m)
1	3673	3735	62
2	3738	3795	57
3	3798	3873	75
4	3875	3938	63

Table 7 showing Zones of interest

7.5 LITHOLOGY

Lithology is confirmed by well to well correlation of Zamzama 1, 2, 5 and Bhan 1 and later confirmed by Gamma Ray Log character.

7.6 VOLUME OF SHALE (Vsh)

GR log was used for volume of shale determination. In the quantitative evaluation of shale content, it is assumed that radioactive minerals are absent in clean rocks and are compared to shaly rocks.

For example

$$\text{Volume of shale (VSH)} = GR_{log} - GR_{max} / GR_{max} - GR_{min}$$

The result of different zones was plotted in Figures 7.6a, 7.6b, 7.6c and 7.6d.

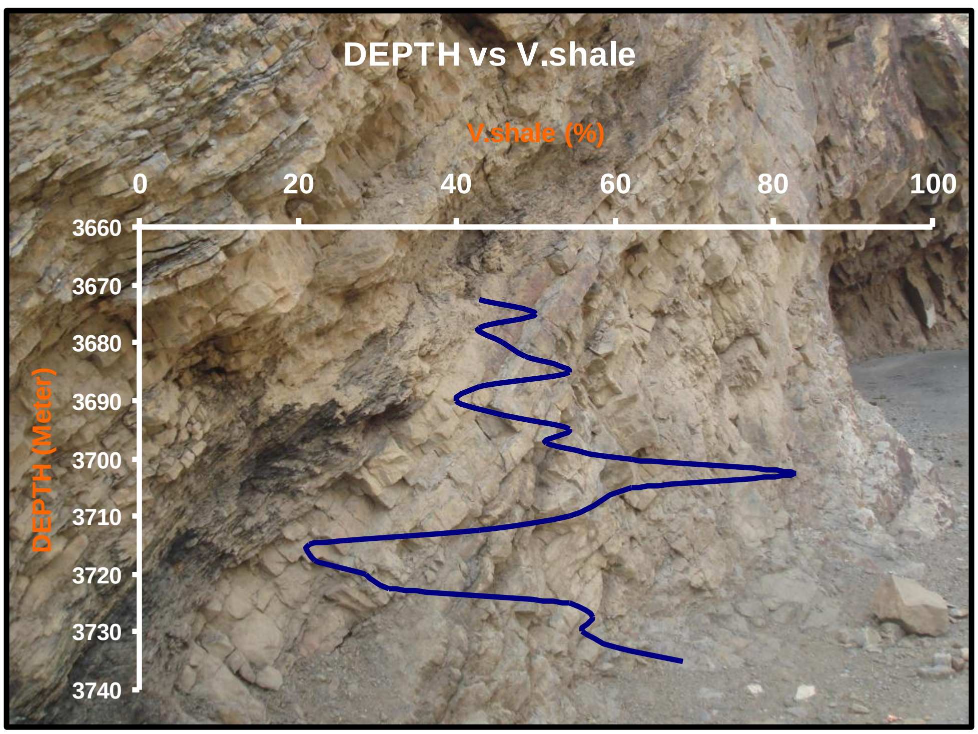

Figure 7.6a Graph showing Vsh of Zone 1

At zone 1 the volume of shale lies between 40-60% except for depth at 3700-3710m where it is around 80%

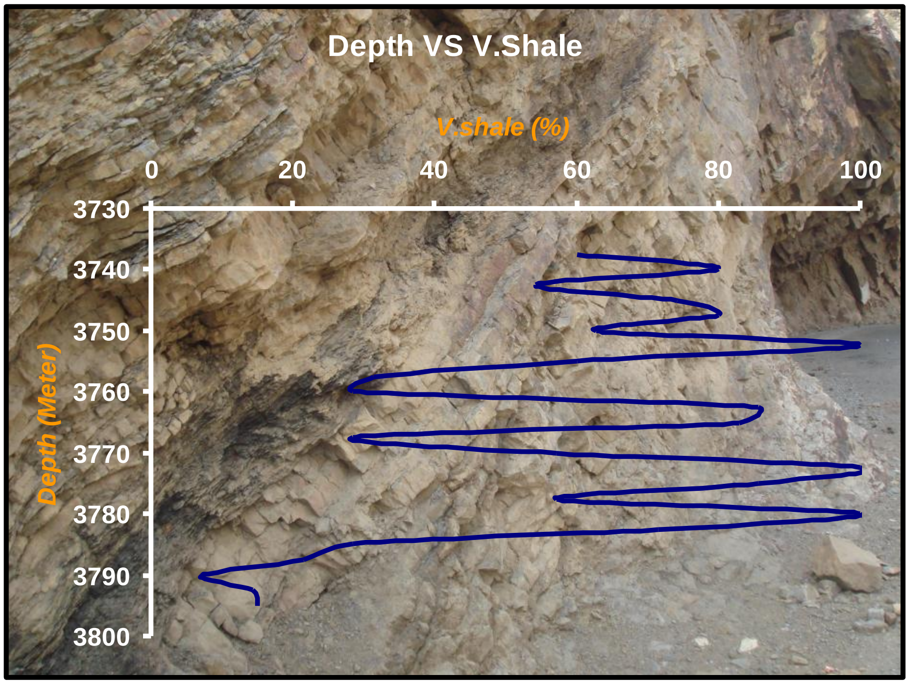

Figure 7.6b Graph showing Vsh of Zone 2

At zone 2 the volume of shale is well above 60% except at depth of 3760m and 3770m and 3780m onward where it lies below 60%.

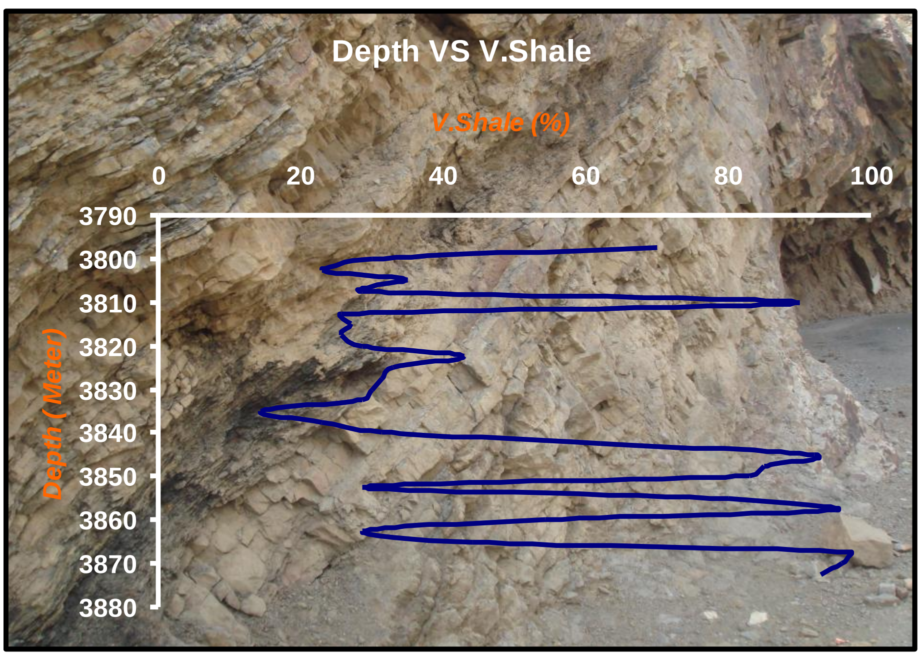

Figure 7.6c Graph showing Vsh of Zone 3

At zone 3 the volume of shale is below 60% except for depth 3810m,3840m,3850mand 3860 where its is upto 90%.

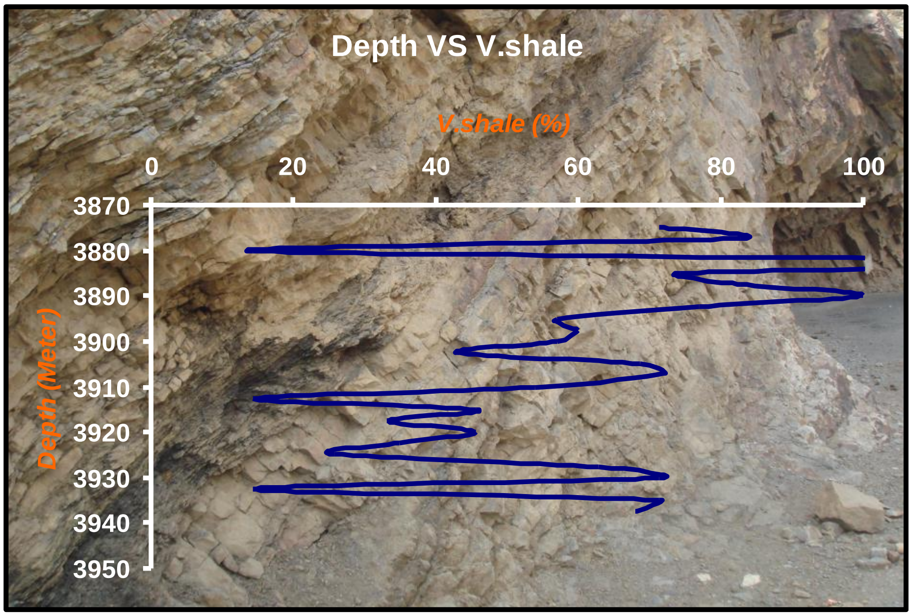

Figure 7.6d Graph showing Vsh of Zone 4

At zone 4 the volume of shale lies above 80% in upper part of 3870-3890m, in deeper part i-e 3900m onwards the value is below 60%

7.7 POROSITY CALCULATION

Porosity is space that is not occupied by the rock framework. These are spaces between grains, within the grains or formed due to dissolutions of grains due to fracturing of rocks. It can be defined as fraction of total volume of the rock that is not occupied by the solid constituents, or the ratio of pore volume to the bulk volume of rock. Porosity is denoted as φ:

$$\varphi = Vp / Vb$$

Where,

φ = Porosity

Vp = volume of rock,

Vb = volume of bulk rock

Porosity is denoted as "φ" and expressed either as percentage or decimal (metric units). The fraction of interconnected void spaces to bulk volume is considered as ***effective porosity***. Primary porosity is formed between the grains.

Porosity in sandstone is dependent on compaction, grain size and orientation, sorting, packing, roundness and sphericity and digenesis. Digenetic processes destroy most of the primary porosity. Secondary porosity is also developed through digenetic processes, e.g., dissolution, packing, pressure solution, tectonic forces etc.

First of all the porosity was calculated from both Density and Neutron Log of all the zones from which average porosity was then determined. Effective porosity was our final product. The porosity was calculated as follows:-

Density porosity = density $_{matrix}$ – density $_{log}$/ density $_{matrix}$- density $_{fluid}$

Neutron Porosity= Value of Neutron Log.

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

Effective Porosity= Porosity $_{avg}$ * V_{sand}

Volume of Sand= 1-V_{sh}

The result of different zones was plotted in Figures 7.7a, 7.7b, 7.7c, 7.7d, 7.7e, 7.8f, 7.8g and 7.9h.

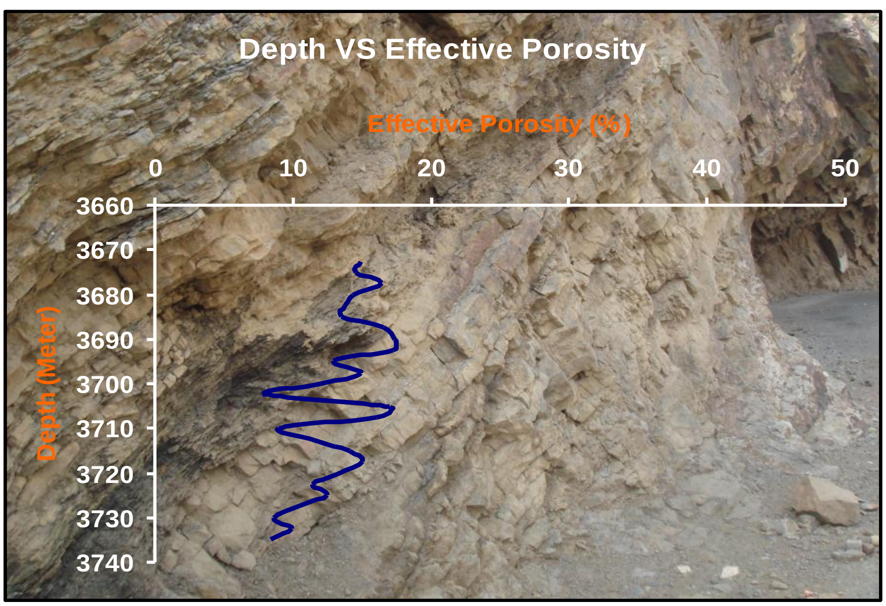

Figure 7.7a Graph showing Effective Porosity vs Depth of Zone 1

The effective porosity of zone 1 lies between 10-20% as seen in fig 7.7a.

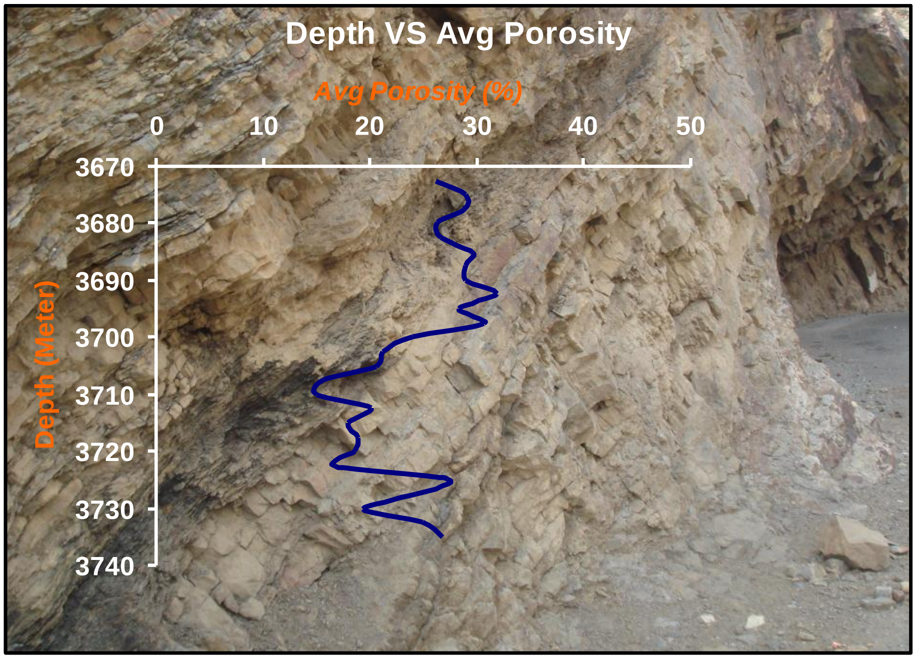

Figure 7.7b Graph showing Porosity (avg) Vs Depth of Zone 1

The porosity (avg) in zone 1 ranges from 20-30% as seen in fig. 7.7 b.

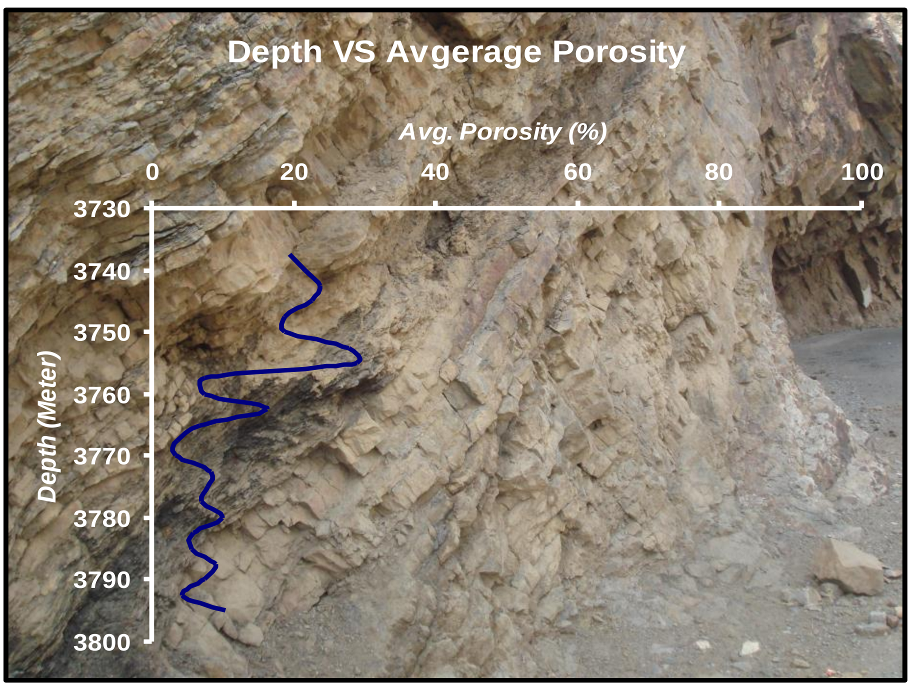

Figure 7.7c Graph showing Porosity (avg) Vs Depth of Zone 2

The porosity (avg) lies below 20% in this zone.

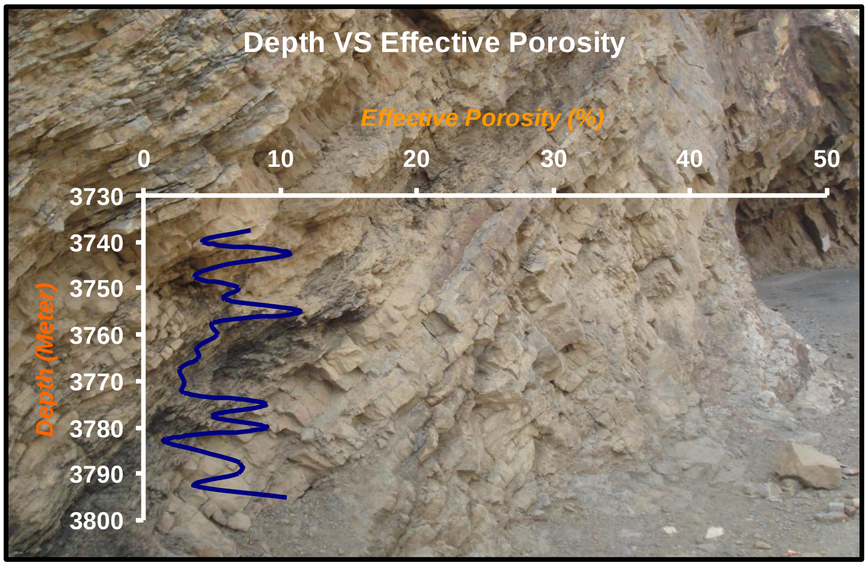

Figure 7.7d Graph showing Effective Porosity Vs Depth of Zone 2

The effective porosity of zone 2 ranges from 2-10% as seen in the graph.

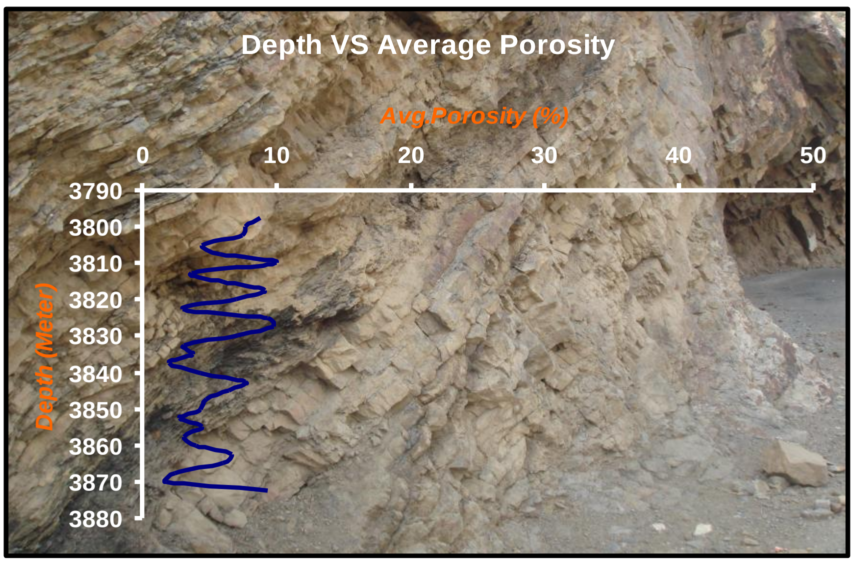

Figure 7.7 e Graph showing Porosity (avg) Vs Depth of Zone 3

The porosity (avg) of Zone 3 is from 2-10% as seen in fig. 7.7 e.

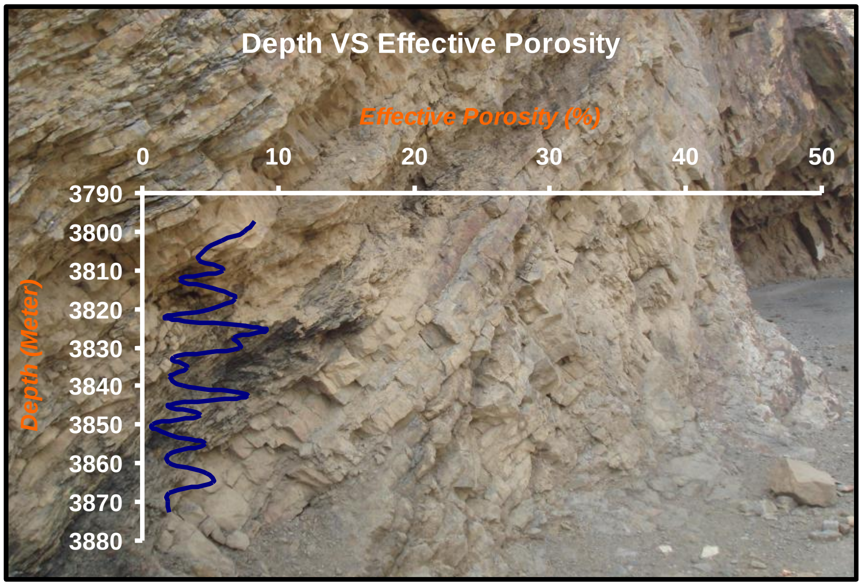

Figure 7.7 f Graph showing Effective Porosity Vs Depth of Zone 3

For the zone 3 the effective porosity lies between 1-10%.

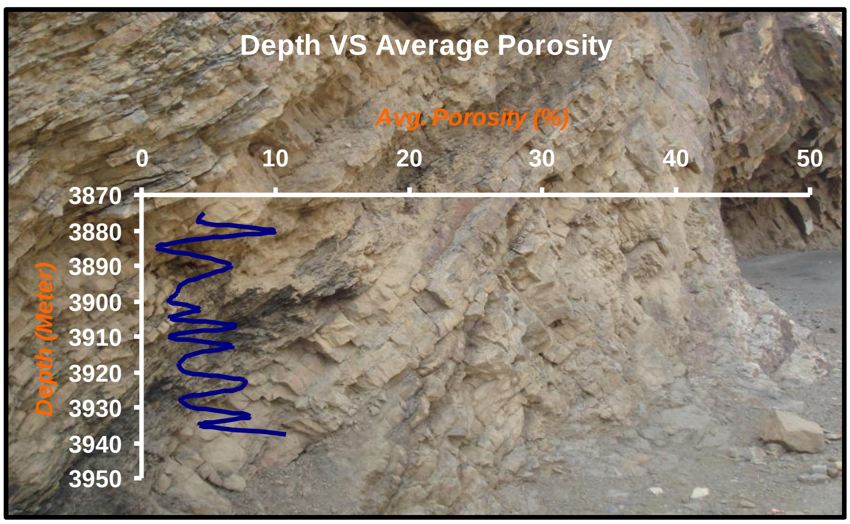

Figure 7.7g Graph showing Porosity (avg) Vs Depth of zone 4

The porosity (avg) of zone 4 has values between 2-10%.

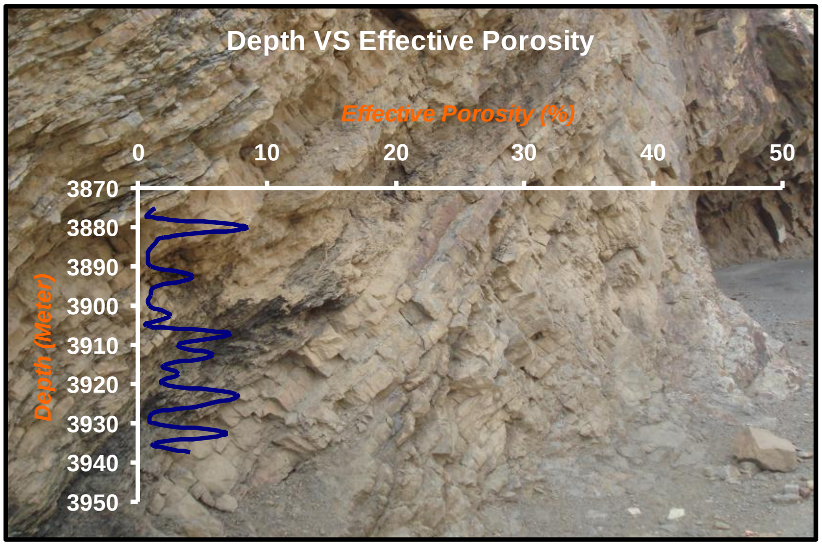

Figure 7.7h Graph showing Effective Porosity Vs Depth of Zone 4

At zone 4 the effective porosity is low as seen in figure 7.7h except for the depth of 3880m where it is almost 10%.

7.8 SATURATION OF WATER (Sw)

The fraction of pore space containing water is termed as water saturation, denoted by "Sw". The remaining fraction containing oil or gas is termed as hydrocarbon saturation denoted by Sh, which is equal to 1-Sw. There are many equations to compute water saturation but Archie Equation is the most basic and applicable. As SP log was not available so quick look method was used using Induction Logs. The equation is as follows:

$$\mathbf{S_w = \sqrt{(F*R_{w\,.a} / Rt)}}$$

Rw was calculated from Induction log while Rt values for particular Depth was derived from Lateral Log deep (LLD).

The results were plotted in Figures 7.8a, b, c and d.

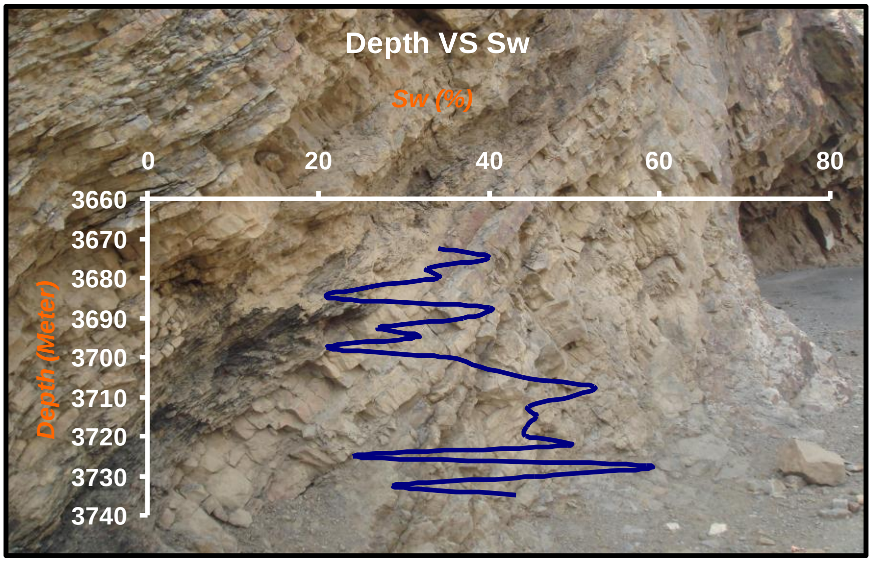

Figure 7.8a Graph showing Sw Vs Depth of Zone 1

At the zone 1 the Sw is below 40% as seen in fig 7.8 a hence it has good Hydrocarbon saturation.

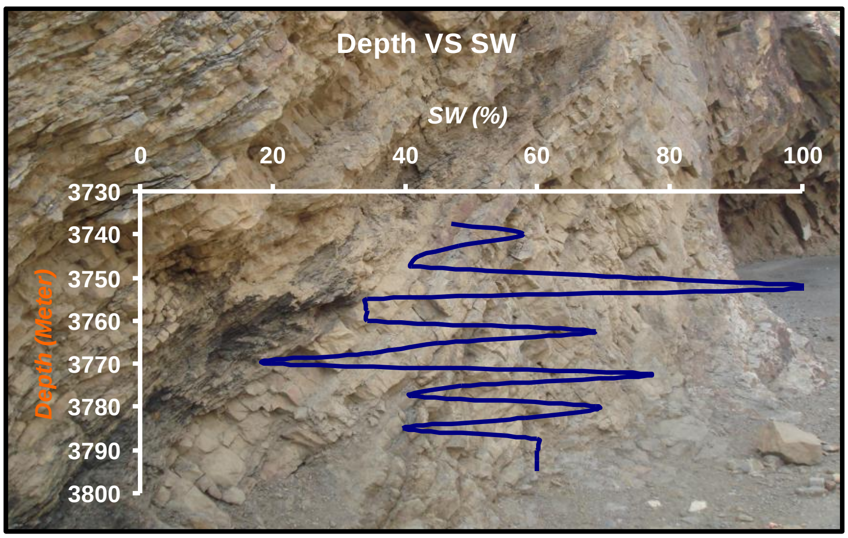

Figure 7.8b Graph showing Sw Vs Depth of zone 2

At zone 2, Sw value is between 40-60% except at depth 3750m where its touching 100%.

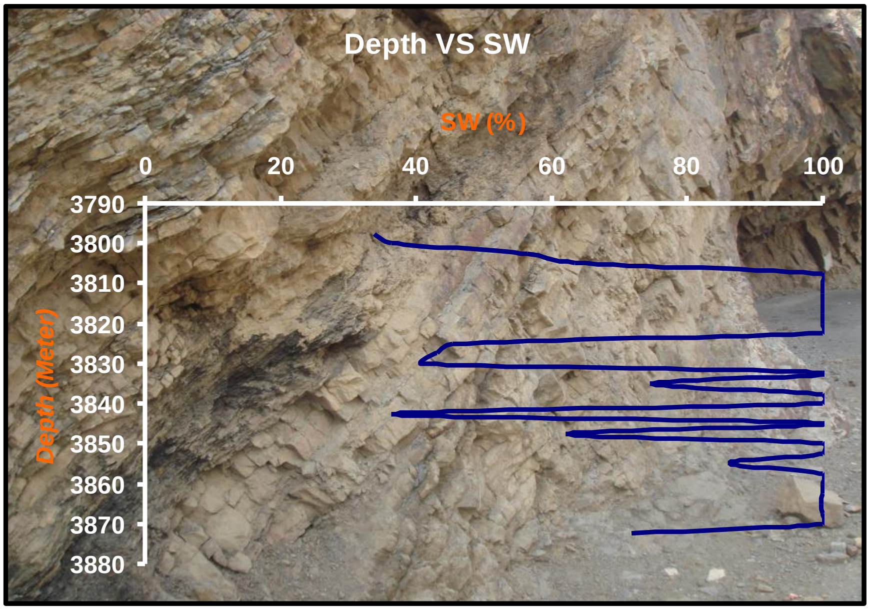

Figure 7.8c Graph showing Sw Vs Depth of Zone 3

At zone 3 at upper part i-e 3790-3800m the Sw is 30% while in the lower part high values of Sw of upto almost 100% can be seen in fig 7.8c.

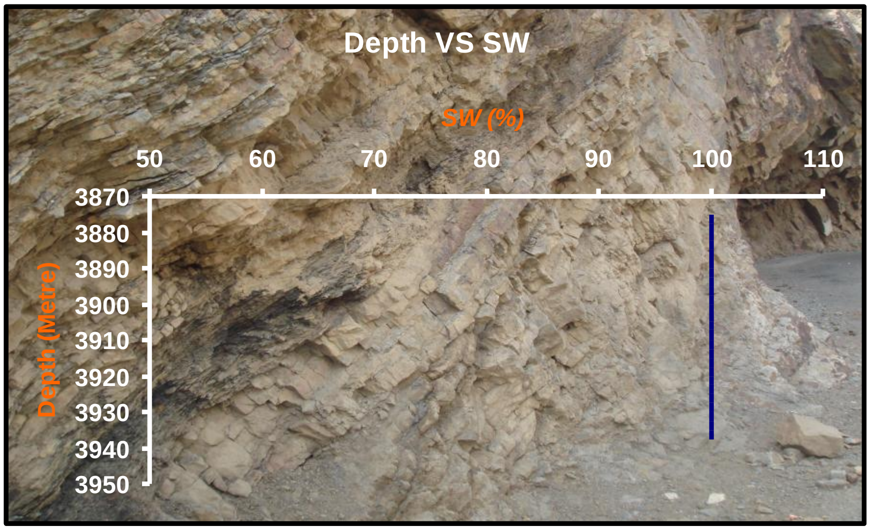

Figure 7.8d Graph showing Sw Vs Depth of Zone 4

Zone 4 is completely water wet and this can be depicted from fig 7.8d.

7.9 Permeability

Permeability is the property that permits the passage of a fluid through the interconnected pores of a rock. It is measured in millidarcies.

Permeability was calculated from the Log using Neutron porosity. The first step was to determine irreducible water followed by permeability. **Irreducible water** is the value of water saturation where no water will flow.

Sw(irreducible)= (a/(2000*Neutron Porosity^^{m}))^$^{0.5}$

Permeability= (100*Neutron Porosity^$^{2.25}$/Swirr.)^^{2}

7.10 Summation

The values of Vsh, Sw, Porosity (avg), Effective porosity and Permeability were all added together and average was calculated which are:-

Volume of Shale	54%.
Average Porosity	10%
Effective Porosity	6.5%
Saturation of Water	70%
Permeability	10mD

Table 7.9 showing results of summation.

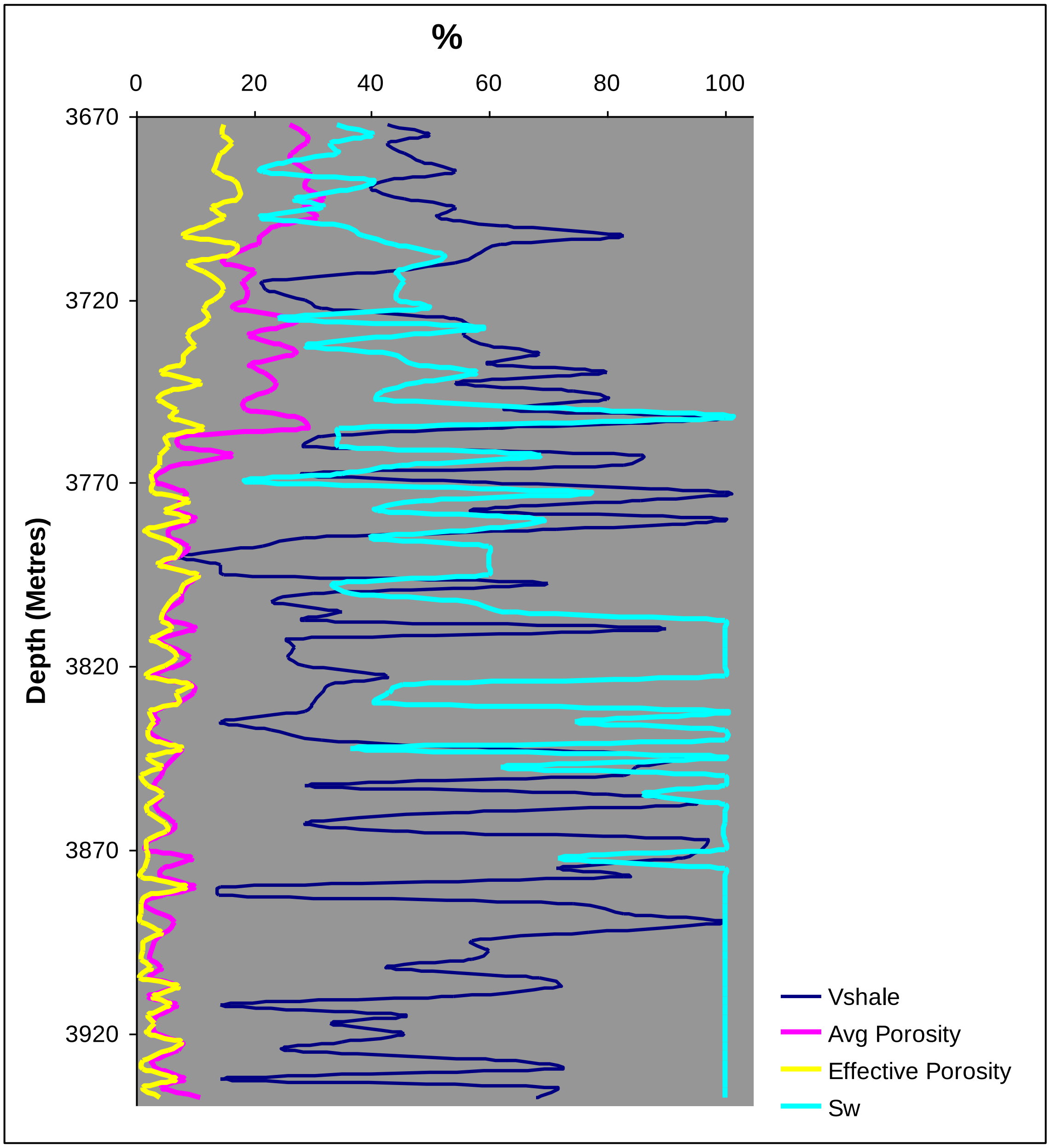

Figure 7.10 The variation between Vshale, Avg Porosity, Effective porosity and Sw Vs Depth

Conclusions

From our study, following conclusions were derived:-

- The Pab Sandstone has deltaic and shallow marine environment which can be confirmed from channelized sand and shales (deltaic part) and cross bedding as well as burrows indicate shallow marine environment.
- The Sembar Formation has good TOC as seen from its dark black color and oil seepage within it was observed confirming it a good and mature source rock.
- Isopachs at different levels shows the west ward tilting of the basin at the time of tectonic activity. They also indicate the depocentre lies in the south-west of the research area.
- Stratigraphic correlation indicates that the general dip of the formations is in the west of the study area.
- The high volume of shale i-e approximately 54% indicates that it is mud dominated facie.
- The Formation encountered has high porosity of around 10% but with low permeability of 10mD.
- The high Saturation of water i-e approximately 70% further makes it uneconomical as water saturation above 40% is often uneconomical.

Suggestions

- As Goru Formation is producing reservoir in the surrounding area, hence checking this zone is recommended.
- At upper level the well is water wet hence the well should be drilled to Goru Formation.

Appendix

The data interpreted during the interpretation is given in the tables below

ZONE 1 DEPTH 3670-3735					
Depth	**Vshale**	**Average porosity**	**Effective Porosity**	**Sw**	**Permeability**
3673	43	26	15	34	43.40
3675	50	29	15	40	35.56
3678	43	29	16	33	81.56
3680	46	26	14	34	32.40
3683	49	27	14	26	24.73
3685	54	30	13	22	22.19
3688	43	29	17	40	84.71
3690	40	29	17	37	116.32
3693	46	32	17	27	111.28
3695	54	28	13	32	17.08
3698	51	31	15	21	42.38
3700	62	24	12	35	10.34
3703	83	21	8	39	0.74
3705	62	21	17	44	99.52
3708	58	16	16	52	71.04
3710	54	15	9	50	1.59
3713	43	20	12	45	8.02
3715	21	18	14	46	30.33
3718	22	19	15	44	44.12
3720	29	19	13	44	19.50

ZONE 2 DEPTH 3737-3795m					
Depth	**Vshale**	**Average porosity**	**Effective Porosity**	**Sw**	**Permeability**
3738	60	20	8	47	0.63
3740	80	22	4	58	0.01
3743	54	24	11	48	5.30
3745	74	23	6	42	0.09
3748	80	19	4	41	0.01
3750	63	19	7	77	0.29
3753	100	28	6	100	0.11
3755	60	29	12	34	8.10
3758	31	7	5	34	0.04
3760	29	8	5	34	0.06
3763	86	16	4	69	0.01
3765	83	7	4	45	0.01
3768	29	4	3	35	0.00
3770	57	3	3	20	0.00
3773	100	8	3	77	0.00
3775	86	8	9	49	1.59
3778	57	7	5	41	0.03
3780	100	10	9	69	1.59
3783	71	6	2	58	0.00
3785	29	6	4	40	0.01
3788	21	9	7	60	0.34
3790	7	8	7	60	0.30
3793	14	4	4	60	0.01
3795	15	10	10	60	4.34

ZONE 3 Depth 3798-3872					
Depth	**V.shale**	**Average porosity**	**Effective Porosity**	**Sw**	**Permeability**
3798	70	9	8	34	0.88
3800	30	8	7	36	0.47
3803	23	8	6	57	0.09
3805	35	5	5	63	0.02
3808	29	6	4	100	0.01
3810	90	10	6	100	0.11
3813	26	4	3	100	0.00
3815	27	6	6	100	0.07
3818	26	9	7	100	0.26
3820	29	7	5	100	0.04
3823	43	3	2	100	0.00
3825	33	9	9	45	1.69
3828	31	10	7	43	0.25
3830	30	7	7	41	0.37
3833	29	3	2	100	0.00
3835	14	4	3	75	0.00
3838	23	2	2	100	0.00
3840	31	4	3	100	0.00
3843	62	8	8	36	0.62
3845	92	6	2	100	0.00
3848	85	5	4	62	0.01
3850	83	4	1	100	0.00
3853	29	3	2	100	0.00
3855	80	5	5	86	0.02
3858	95	3	2	100	0.00
3860	54	4	2	100	0.00
3863	29	7	5	100	0.03
3865	44	6	5	100	0.04
3868	97	2	2	100	0.00
3870	96	2	2	100	0.00
3873	93	9	2	72	0.00

ZONE 4 Depth 3875-3938					
Depth	**Vshale**	**Average porosity**	**Effective Porosity**	**Sw**	**Permeability**
3875	71	5	1	100	0.00
3878	83	4	1	100	0.00
3880	14	10	9	100	1.18
3883	140	5	2	100	0.00
3885	74	1	1	100	0.00
3888	83	4	1	100	0.00
3890	100	7	1	100	0.00
3893	77	5	4	100	0.01
3895	57	3	1	100	0.00
3898	60	3	1	100	0.00
3900	57	2	1	100	0.00
3903	43	4	2	100	0.00
3905	69	2	1	100	0.00
3907	72	7	7	100	0.37
3910	54	2	3	100	0.00
3913	14	7	6	100	0.10
3915	46	4	2	100	0.00
3918	33	3	3	100	0.00
3920	46	4	2	100	0.00
3923	35	8	8	100	0.57
3925	26	7	5	100	0.05
3928	63	3	1	100	0.00
3930	71	4	1	100	0.00
3933	14	8	7	100	0.32
3935	71	4	1	100	0.00
3938	68	11	4	100	0.01

Depth	Vshale	Average porosity	Effective Porosity	Sw	Permeability
3673	43	26	15	34	43.40
3675	50	29	15	40	35.56
3678	43	29	16	33	81.56
3680	46	26	14	34	32.40
3683	49	27	14	26	24.73
3685	54	30	13	22	22.19
3688	43	29	17	40	84.71
3690	40	29	17	37	116.32
3693	46	32	17	27	111.28
3695	54	28	13	32	17.08
3698	51	31	15	21	42.38
3700	62	24	12	35	10.34
3703	83	21	8	39	0.74
3705	62	21	17	44	99.52
3708	58	16	16	52	71.04
3710	54	15	9	50	1.59
3713	43	20	12	45	8.02
3715	21	18	14	46	30.33
3718	22	19	15	44	44.12
3720	29	19	13	44	19.50
3723	31	17	11	49	7.57
3725	54	27	12	24	12.98
3728	57	24	10	58	4.17
3730	56	19	9	45	1.16
3733	60	25	10	29	3.04
3735	69	27	8	43	1.05
3738	60	20	8	47	0.63
3740	80	22	4	58	0.01
3743	54	24	11	48	5.30
3745	74	23	6	42	0.09
3748	80	19	4	41	0.01
3750	63	19	7	77	0.29
3753	100	28	6	100	0.11
3755	60	29	12	34	8.10
3758	31	7	5	34	0.04
3760	29	8	5	34	0.06
3763	86	16	4	69	0.01
3765	83	7	4	45	0.01
3768	29	4	3	35	0.00
3770	57	3	3	20	0.00
3773	100	8	3	77	0.00
3775	86	8	9	49	1.59
3778	57	7	5	41	0.03
3780	100	10	9	69	1.59

3783	71	6	2	58	0.00
3785	29	6	4	40	0.01
3788	21	9	7	60	0.34
3790	7	8	7	60	0.30
3793	14	4	4	60	0.01
3795	15	10	10	60	4.34
3798	70	9	8	34	0.88
3800	30	8	7	36	0.47
3803	23	8	6	57	0.09
3805	35	5	5	63	0.02
3808	29	6	4	100	0.01
3810	90	10	6	100	0.11
3813	26	4	3	100	0.00
3815	27	6	6	100	0.07
3818	26	9	7	100	0.26
3820	29	7	5	100	0.04
3823	43	3	2	100	0.00
3825	33	9	9	45	1.69
3828	31	10	7	43	0.25
3830	30	7	7	41	0.37
3833	29	3	2	100	0.00
3835	14	4	3	75	0.00
3838	23	2	2	100	0.00
3840	31	4	3	100	0.00
3843	62	8	8	36	0.62
3845	92	6	2	100	0.00
3848	85	5	4	62	0.01
3850	83	4	1	100	0.00
3853	29	3	2	100	0.00
3855	80	5	5	86	0.02
3858	95	3	2	100	0.00
3860	54	4	2	100	0.00
3863	29	7	5	100	0.03
3865	44	6	5	100	0.04
3868	97	2	2	100	0.00
3870	96	2	2	100	0.00
3873	93	9	2	72	0.00
3875	71	5	1	100	0.00
3878	83	4	1	100	0.00
3880	14	10	9	100	1.18
3883	14	5	2	100	0.00
3885	74	1	1	100	0.00
3888	83	4	1	100	0.00
3890	100	7	1	100	0.00
3893	77	5	4	100	0.01
3895	57	3	1	100	0.00
3898	60	3	1	100	0.00
3900	57	2	1	100	0.00

3903	43	4	2	100	0.00
3905	69	2	1	100	0.00
3907	72	7	7	100	0.37
3910	54	2	3	100	0.00
3913	14	7	6	100	0.10
3915	46	4	2	100	0.00
3918	33	3	3	100	0.00
3920	46	4	2	100	0.00
3923	35	8	8	100	0.57
3925	26	7	5	100	0.05
3928	63	3	1	100	0.00
3930	71	4	1	100	0.00
3933	14	8	7	100	0.32
3935	71	4	1	100	0.00
3938	68	11	4	100	0.01

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