Petrophysical Analysis of Mesa Kaswal Well#1

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Certificate

This thesis is submitted by **Raja Adnan** and is accepted in the present form by Department of Earth & Environmental Sciences, Bahria University, Islamabad as the partial fulfillment of the requirement for the degree of **Bachelor of Sciences** in **Geology.**

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Abstract

The purpose of study is to find the hydrocarbon potential of well, by evaluating their well logs which include, Porosity calculation, Shale volume calculation, Water saturation calculation , Permeability and to resolve lithology.

The results showed that the chorgali limestone is main reservoir rock. The chorgali limestone contains 7% average porosity, shale volume is 8% and water saturation is 51%. The porosity was calculated from the combination of bulk density (RHOB) and neutron porosity (NPHI) logs, shale volume was calculated from GR linear equation while water saturation was calculated from Indonesia equation. Three minerals model has used for calculation of volumes of quartz, limestone and dolomite.

In this study also calculate the thickness of gross pay interval and net pay interval. The gross pay thickness is 57 meters while net pay thickness is 9 meters. The net pay thickness calculated by applying the cut off of porosity, shale volume and water saturation.

Acknowledgement

I am richly grateful to the God almighty for his beneficence and mercy which reposed the confidence in me to get through this arduous effort of compiling my age long learning into this work of thesis.

I must not forget my family and my friends who kept me in good spirits and provided and emotional equilibrium which lead me to an in fatigable discovery not only of my literary capabilities but also of my resilience and diligence.

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Chapter 1

Introduction

Petroleum is vital to many industries, and is of importance to the maintenance of industrialized civilization itself, and thus is a critical concern for many nations. Oil accounts for a large percentage of the world's energy consumption, ranging from a low of 32% for Europe and Asia, up to a high of 53% for the Middle East. In other words, the economy of the world is being controlled by the energy sector. The energy resources and reserves are being used as indicator of economy and political stability of a country. Petroleum and related energy reserves of a country constitute its most important assets. The role of hydrocarbon availability, exploration and development is directly related to the overall development and prosperity of the human being. The petroleum exploration and its exploitation have gained special importance over the past few decades to meet the increasing demand of the world energy. Due to its importance this field has developed special interests of the scientists and various hydrocarbon agencies and a number of new geophysical techniques and methods have been developed to explore and exploit the hydrocarbon buried in subsurface geological formations. Geophysical well logging is one of the strong tools which are used to evaluate the formation characteristic features having potential for hydrocarbon development. Well logging, also known as borehole logging is the practice of making a detailed record (log) of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (geological logs) or on physical measurements made by instruments lowered into the borehole (geophysical logs). Well logging is done when drilling boreholes for oil and gas, groundwater, minerals, and for environmental and geotechnical studies.

The oil and gas industry records rock and fluid properties to find hydrocarbon zones in the geological formations within the Earth's crust. A logging procedure consists of lowering a 'logging tool' on the end of a wire-line into an oil well (or hole) to measure the rock and fluid properties of the formation. An interpretation of these measurements is then made to locate and quantify potential depth zones containing oil and gas (hydrocarbons). Logging tools developed over the years measure the electrical, acoustic, radioactive, electromagnetic, and other properties of the rocks and their contained fluids. Logging is usually performed as the logging tools are pulled out of the hole. This data is recorded to a printed record called a "Well Log" and is normally transmitted digitally to office locations. Well logging usually refers to downhole measurements made via instrumentation that is lowered into the well at the end of a wire-line cable. The wire-line consists of an outer wire rope and an inner group of wires. The outer rope provides strength for lowering and lifting the heavy instruments and the inner wiring provides for transmission of power to the downhole equipment and for data telemetry uphole to the recording equipment on the surface.

Although most logs are run to evaluate oil and gas wells, increasing numbers are being run yearly for other purposes, including evaluation of the geothermal energy and ground water. Well log analysis in petroleum industry for oil and gas emphasis the evaluation of basic petrophysical properties of formations containing hydrocarbons.

1.1 Introduction of Study Area

Pakistan has high potential of hydrocarbons in its northern (like Potwar, Kohat) and southern (like Badin, Mari etc.) parts. The Indus basin, including the Kohat-Potwar (study area) depression, belongs to the category of extra-continental downward basins which account for 48% of the world's known petroleum resources (Riva, 1983). The Potwar sub basin is dominated by the structural traps and mostly seismic data is incorporated for the delineation of these structures.

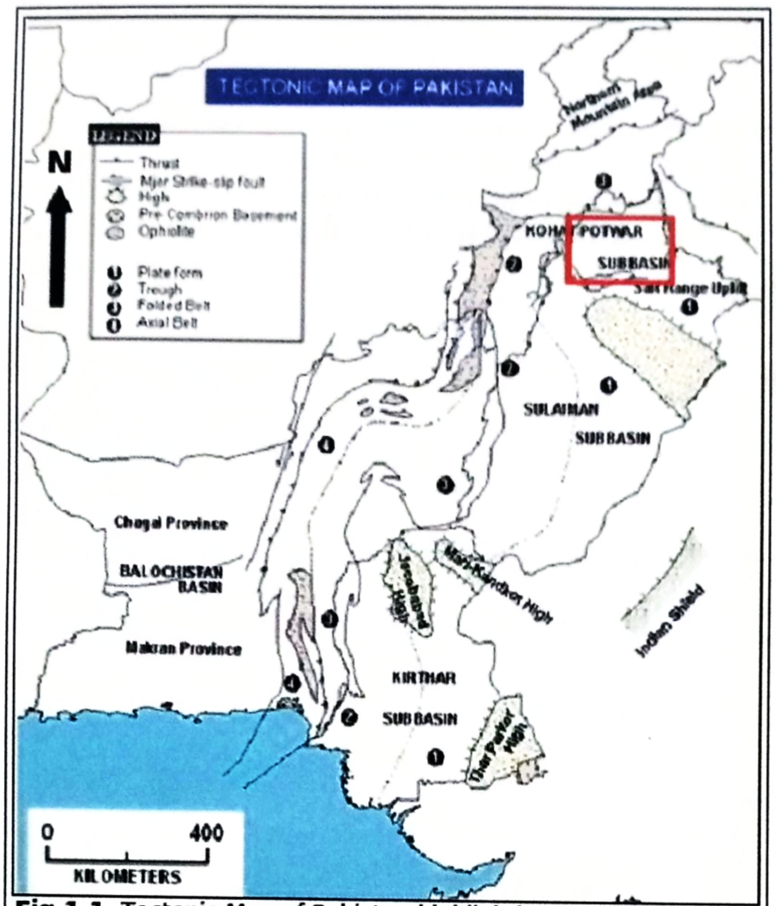

Fig 1.1 Tectonic Map of Pakistan highlighting Potwar sub Basin

1.2 Location of the Study Area

Missa Kaswal Oil Field is located at a distance of about 60 Km in the south-east of Islamabad in the eastern part of Potwar basin (fig1.3). The field was discovered in June 1991 and came on regular production from December 1992.On surface; it is a thrust bounded anticline striking in SW-NE direction. First seismic work was carried out in 1980, followed by drilling of an unsuccessful well. Another well was drilled after an improved seismic programme which resulted in discovery of oil and gas in seven different reservoir units of Cambrian, Permian, Paleocene, Eocene and Miocene age. Among these, three reservoir units namely Jutana, Baganwala and Kussak of Cambarian age had never produced in the Potwar basin earlier. The field had original, in place, proven reserves of 37.650 MMSTB of oil and 27.900 BSCF of gas. Current production from three wells is around 4500 barrels of oil and 7.3 MMSCFD of gas a day. This production comes from fractured limestone and porous sandstone rocks. It is an exploration case history, making a comparison between old and new seismic work. Low density of seismic profiles, inaccurate acquisition and processing parameters and lack of local interpretation experience contributed to earlier failures. Interpretation of new seismic data reveals that strata of platform sequence display a duplex geometry overlain by a passive roof complex of Siwaliks sequence as against earlier interpretation of a pop up structure. Closed area at Eocene level is 30 sq. kms. Structure is bounded by a main thrust fault in the strike direction. Few orthognal faults exist which may provide lateral barriers to the flow during production. Probably upward migration of oil from the underthrusted block of the duplex has contributed to the occurrence of a multi-reservoir system in the upper block. *coordinates*: 33° 12' 0" North, 73° 22' 0" East

1.3 Climate

The climate of the area is hot in summer and dry cold in winter. The average annual rainfall is 880 mm and temperature during the winter season remains between 8 degree centigrade to 20 degree centigrade which shoots up to 42 degree centigrade during summer. Its elevation varies from 1,000 to 2,000 ft (300 to 600 m) in a system of residual hills and hillocks formed from glacial debris as remnants of the Ice Age and comprises mostly on sedimentary rocks of tertiary origin.

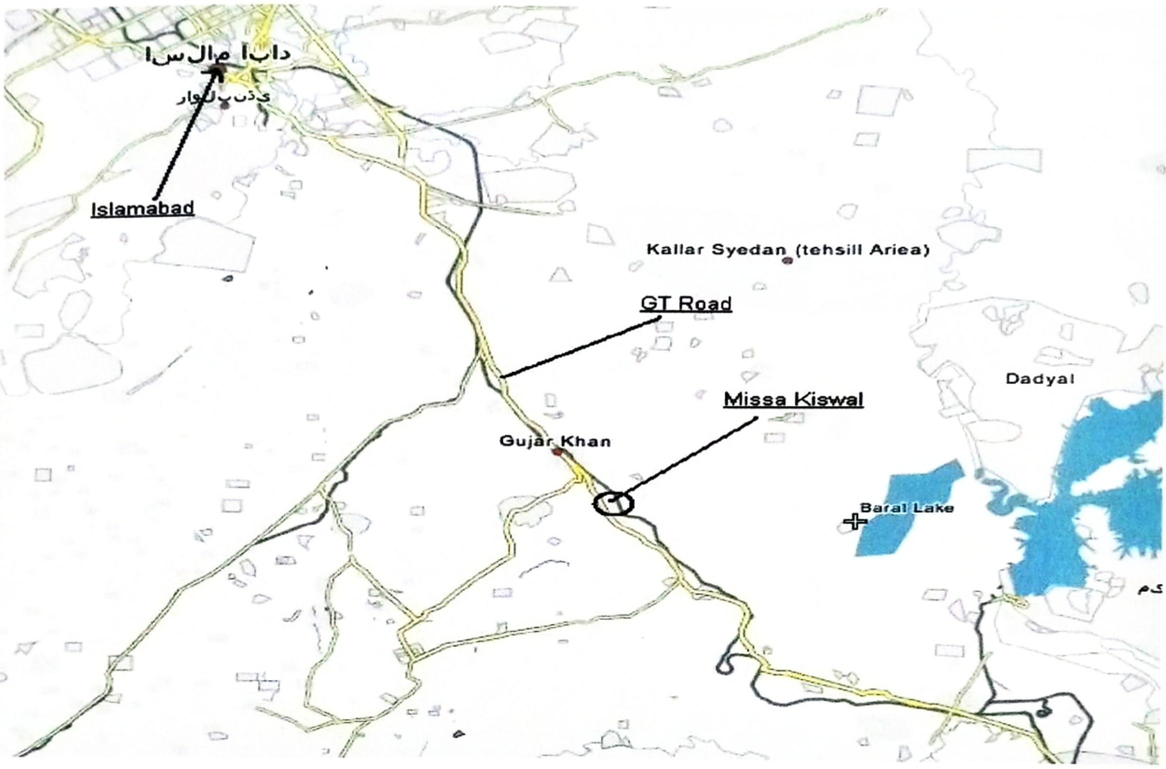

Fig.1.2 Location map of Missa Kaswal (Google Earth)

1.4 Objectives set for the thesis project

The aim of the study was to interpret the hydrocarbon potential in the deep reservoir of Missa Keswal Oil Field by evaluating their well logs which includes porosity calculation, shale volume calculation, water saturation calculation, hydrocarbon saturation calculation, permeability calculation and to resolve lithology.

Chapter 2

Geology

2.1 Regional Geology of Pakistan

Pakistan is comprised of three broad geological subdivisions that, from north to south, may be referred to as the Laurasian, Tethyan and Gondwanaland domains (Kazmi and Jan, 1997). Their origin may be traced back to Late Paleozoic. In late Paleozoic all the continents had drifted to form a continuous landmass, the super continent of Pangaea. By Late Triassic, Pangaea had split into two super continents, Laurasia to the north and Gondwanaland to the south separated by the Tethys seaway. Pakistan is located at the junction of Gondwanian and Tethyan domains.

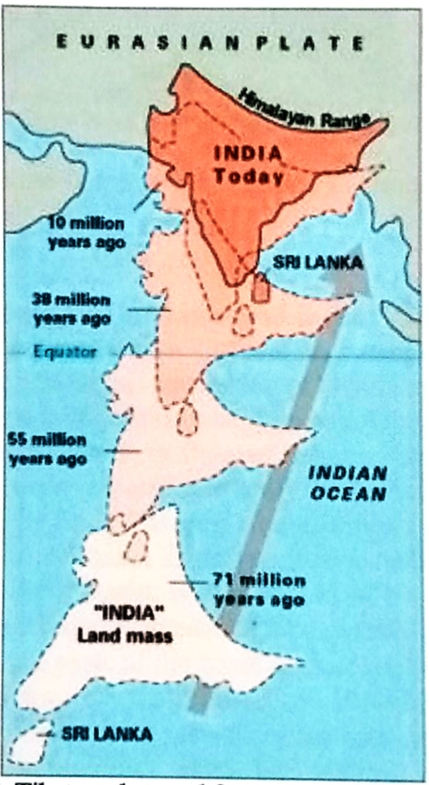

Fig2.1 Collision of Indian plate with Tibetan plate and formation of Himalaya (modified after USGS, 1999)

(Jackson and Bilhan, 1994, Pandey et al., 1995, Bilham et al., 1998, Geology of Nepal)

2.2 Tectonic Framework of Pakistan

Active plate boundaries of various types are exceptionally well exposed in Pakistan. There are two active convergent boundaries in Pakistan.

1. In the north there is an active continent-island arc-continent collision boundary, the west end of Himalayan.
2. In the southwest, there is an active boundary of oceanic lithosphere subducting beneath arc-trench gap sediments and continental sediments, the oceanic part of Arabian plate passing under the Makaran arc-trench gap and Afghan micro plate.

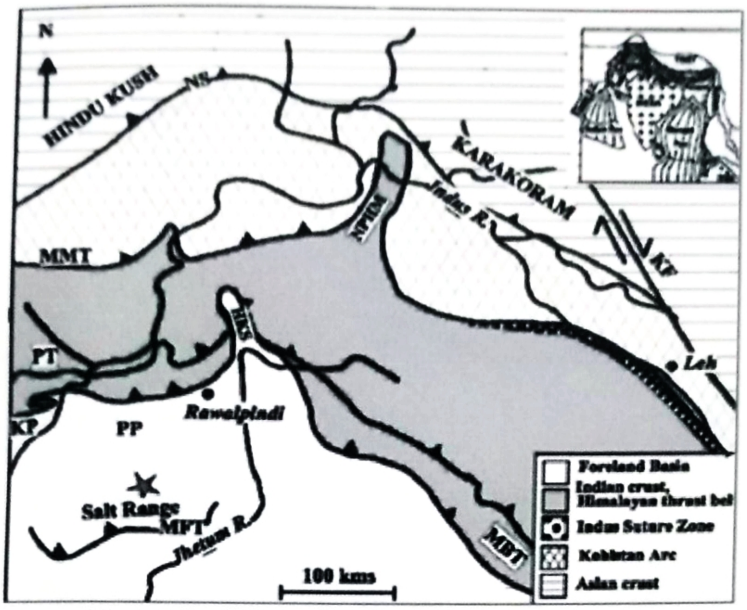

Fig 2.2 North West Himalayan Fold & Thrust Belt

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2.3 Tectonic and Depositional Setting

The Jurassic Rifting and breakage of Gondwanaland in part of the Indus basin, presently Southern Indus Basin, resulted in the submergence of platform and produced deep-water sedimentation of Shrinab and Chiltan Formation. In early Cretaceous, the actual separation of Gondwanaland (Indian-Antarctica-Australia) from the western Gondwanaland started, the time when Sembar/Goru was being deposited. The whole Cretaceous represents shallow water while northern floor of the southern arm of the Tethys was subducting beneath the Iran–Afghanistan micro-continent and northern Tethys were subducting beneath the Tibetan plateau. At the end of Cretaceous and in Early Tertiary, the northward drift of the Indian Plate accelerated (16cm/yr). The collision of Indian and Eurasian Plate resulted in submergence of numerous local areas throughout the Tertiary in the Lower Indus Basin, which is marked by various phases of transgression and regression. In early transgression phase Khadro Formation was deposited in the low areas of Central Sulaiman and the Kirthar regions while the elevated parts of the basin did not receive sediments. The transgression was followed by a short-lived regression before the main Paleocene (Ranikot) sea transgressed and covered the whole Indus Basin. In Central Indus Basin rocks of Paleocene age are almost entirely of marine origin. Dominant lithology is limestone with subordinate marls and varying proportions of shale, sandstone and conglomerate. The sandstone/shale ratio decreases away from the Indian shield and of shale increases abundantly in Ranikot Nala, Tangi Sar section and also in Sui area.

Facies changes across the Indus basin represent widespread carbonate platform and shale basins. Central Pakistan is unaffected by collisional events. However subsidence with Mesozoic rift basin is continued during the Paleocene. The Indo-Pakistani continental margin in the Lower Indus Basin was very active during the Paleocene, being affected only by subsidence and minor localized up lifts.

Paleohighs such as Kairpur-Jacobabad and Mari-Kandkot, which had formed during the Mesozoic when adjoining areas rifted apart, were subaqueous Islands in an otherwise stable carbonate platform environment. Carbonate sedimentations was essentially affected by sea level changes. Terrigeneous input in Central Pakistan was limited to marine trangressive events when the carbonate. Eocene marks the initial contact of the Indo-Pakistan subcontinent with Chitral/Ladakh island arc system or the southern continental margin of Eurasia. As the north movement of India slowed down, it begun to rotate counterclockwise. This caused the widespread and stable shallow water carbonate plateform with a few depressions in Sulaiman Basin.

2.4 Tectonic Zones of Pakistan

On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones (See Fig 2.3)

- Indus Platform and foredeep. East Baluchistan fold-and-thrust belt.
- Northwest Himalayan fold-and-thrust belt.
- Kohistan-Ladakh magmatic arc.
- Karakoram bloack
- Kakar Khoarasan flysch basin and Makran Accretionary zone.
- Chagai magmatic arc.
- Pakistan offshore.

With in these broad tectonic zones there are subtle differences in tectonic and changes in structure style to merit further subdivision into smaller subdivision. Here we are not concern about those we are going to discuss the revelent that is the Indus Plateform and foredeep which is our area of interest as from all above mentioned tectonic zones our seismic line belongs to this area (Kazmi A.H, et al. 1977).

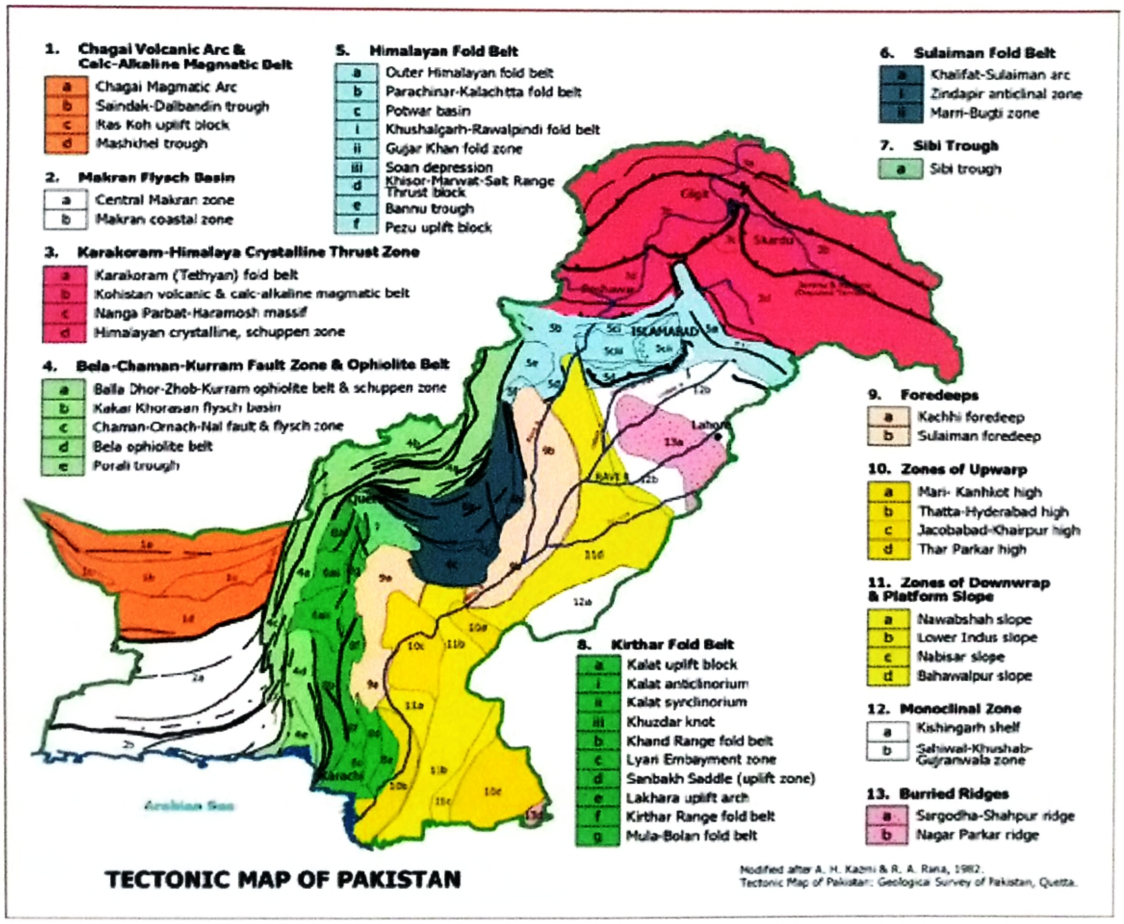


Fig 2.3 Tectonic Zones of Pakistan modified after Kazmi, A.H (1997)

2.5 Indus Platform and Foredeep

This zone extends over an area exceeding 250,000 square km, in southern Pakistan and includes the Indus plain and Thar-Cholistan Deserts. It hosts 80% of Pakistan population, extensive coal deposits, valuable oil and gas fields, potential for geothermal energy and vast groundwater reservoir.

2.5.1 Structural Zones

The Indus platform and foredeep comprise following main structural zones. (Kazmi A.H, et al. 1977)

- Buried Ridges
- Zones of Upwraps
- Zones of Down warps
- Foredeep

2.6 Sedimentary Basins

Basin is an area characterized by regional subsidence and in which sediments are preserved for the longer periods of time. In a basin a receptacle or container, which is basin's substratum is called the Basement. The container fill or content, which is the accumulation of sediments resting on the basement, is called a Sedimentary cover. The gradual settling of the basin is called Subsidence. The point of maximum sedimentary accumulation is called the Depocenter. The depocenter may not correspond to the zone of maximum subsidence.

Sediments originate at a certain place. These sediments may be deposited at the same place or may be transported to some other place by transporting agents. The sediments deposited at the same place are called molasses deposits. The transported sediments rest on the basement of a basin and form the sedimentary cover.

2.7 Basins of Pakistan

Pakistan is comprised of following Basins these includes

(1) Indus Basin
  i. Upper Indus Basin.
  ii. Lower Indus Basin.
  iii. Central Indus Basin
  iv. Southern Indus Basin.
(2) Balochistan Basin.
(3) Kakar Khorasan Basin (Kadri, 1995).

2.8 Indus Basin

The geological history of the Indus Basin goes back to Pre-Cambrian age. The depositional features mark the limit of the basin and it's divisions. Following is the classification of Indus Basin.

➢ Upper Indus Basin: Kohat sub-Basin.
Potwar sub-Basin.

➢ Lower Indus Basin: Central Indus Basin.
Southern Indus Basin (Kadri, 1995).

2.9 Upper Indus Basin

This basin is characterized by the complex structural style and stratigraphy sequence ranging from Precambrian to Recent. A number of oil fields occur in this zone e.g. Missa, Rajian, Pindori, Toot, Sadkal and Kal. Dhurnal oil field the largest one with has reserves of about 52 million barrels of oil and 0.13 TCF of gas.It is located in the northern Pakistan and is separated from the central Indus Basin by Sargodha High. Upper Indus Basin is further divided into two parts by the Indus River,

Kohat Sub Basin – West to the Indus River

Potwar Sub Basin – East to the Indus River

Potwar Sub Basin preserves the sediments from Precambrian to Quarternary in the sub surface and all are exposed in the Salt Range which is present south to the Potwar Plateau while the Trans Indus Ranges, present in the south of the Kohat Sub Basin, expose sediments from Cambrian to Pliocene age.

Mesozoic sediments are also exposed around the basin rim, however, their presence is considered to because of the Pre Paleocene erosion.

2.9.1 Potwar Sub Basin

The Potwar Basin lies at the northern extremity of the Upper Indus Basin and is the oldest producing basin in Pakistan (fig 2.4). The Basin is predominately oil-prone. Eocene and Palaeocene carbonates are the most productive reservoirs although more recent exploration targets are the deeper Permian formations.

The Kalachitta and Margala Hills bound the Potwar Basin to the north, the Indus River and Kohat Plateau to the west, and the Jhelum River and the Hazara-Kashmir syntaxis to the east. It is largely covered by the Siwalik sequence, though at places upper Eocene shales and limestones crop out locally in folded inliers. The wide and broad Soan syncline divides the Potwar Basin into Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ)

2.9.1.1 Division of Potwar Sub Basin

The potwar sub basin is divided into two zones due to the amount of deformation in both the zones. They are:

North Potawar deformed Zone

South Potwar Platform Zone

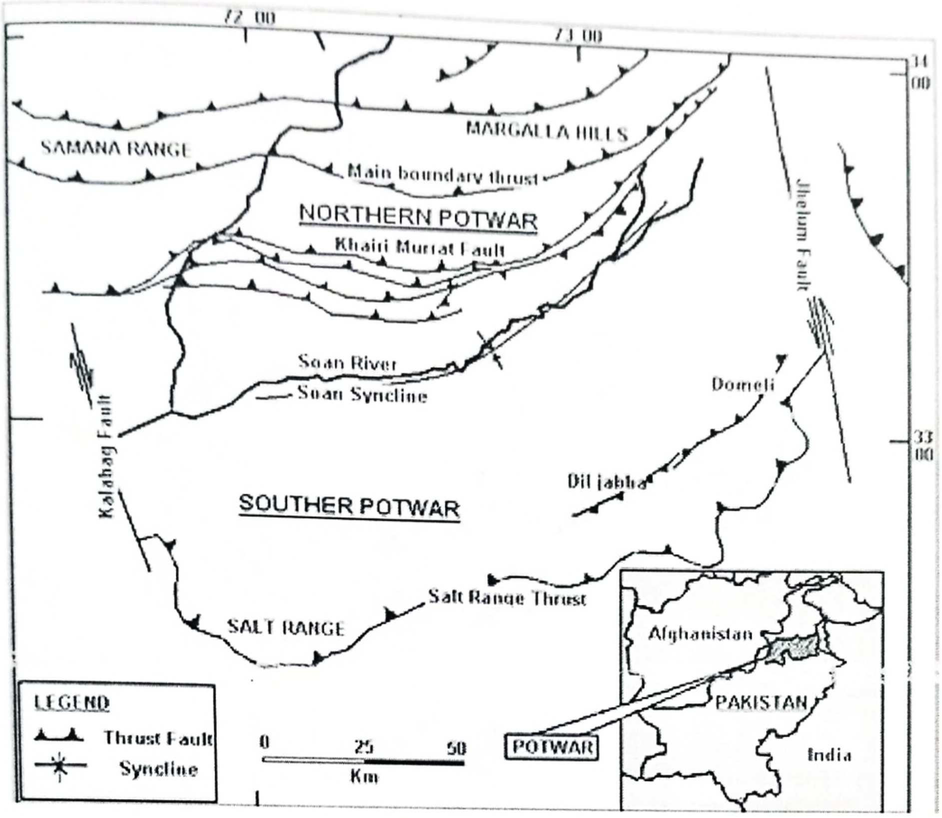


Figure 2.4 Potwar basins with sub division (Kadri, I.B. (1995)

(a) North Potwar Deformed Zone (NPDZ)

The NPDZ is more intensely deformed than the southern part. It is a belt of Neogene deformation, extending southward from the MBT to the Soan syncline. The zones are shown in fig 2.6. Formation outcrops and faults are generally east-northeast trending, approximately perpendicular to the tectonic transport direction. The highly dissected NPDZ is an area of wide synclines, compressed folds and closely spaced imbricate thrusts. The deformation style of NPDZ abruptly changes from east to west. The eastern NPDZ represents a buried thrust front with the development of foreland syncline on the back of Dhurnal Fault, passive roof duplex (triangle zone) and hinterland dipping imbricate stack farther north (Kemal, 1991). While the western NPDZ which is characterized by compressed and faulted anticlines separated by large synclines, representing the emergent thrust (Kemal, 1991). Jaswal et al (1997) calculated about 55 km of horizontal shortening for the zone between the Soan syncline and a point near MBT and the minimum rate of shortening in this zone is estimated to be 18 mm/yr.

The NPDZ is followed to the south by asymmetrical wide and broad Scan syncline, with a gently northward dipping southern flank along the salt range and a steeply dipping northern limb along NPDZ. The eastern part of the Southern Potwar Platform Zone represents strong deformation as compared to the central and western parts. The thrusts and back thrusts bounded salt cored anticlines represent both foreland and hinterland verging deformation. In the central and western parts of the Southern, Potwar only minor deformation is present within the overthrusted Phanerozoic sedimentary section, due to effective decoupling within Eocambrian evaporates above the basement.

(b) Structural Style of Potwar Sub Basin

The structural style of the central eastern and western parts of Potwar Plateau shows a marked difference. In the central western parts of Potwar Plateau, the deformation appears to have occurred by south-verging thrusting, whereas in the eastern part the deformation is mainly in northeast-southwest direction with tight and occasionally overturned anticlines separated by broad synclines. This difference may be related to

lesser amount/thickness of salt in the Infra-Cambrian in the eastern areas and very low dip of the basement (1°-1.5°) as compared to Central Potwar (2°-3°).

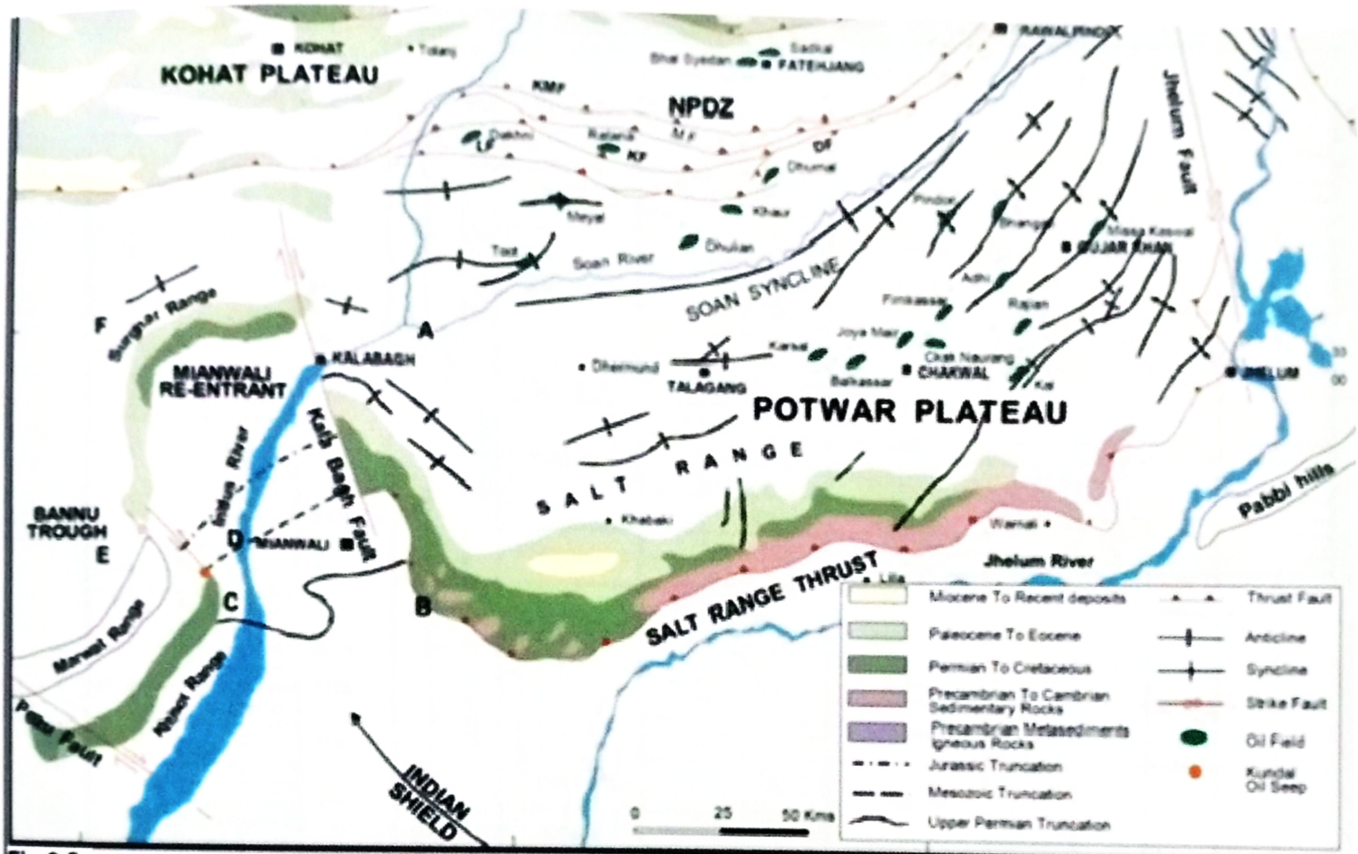


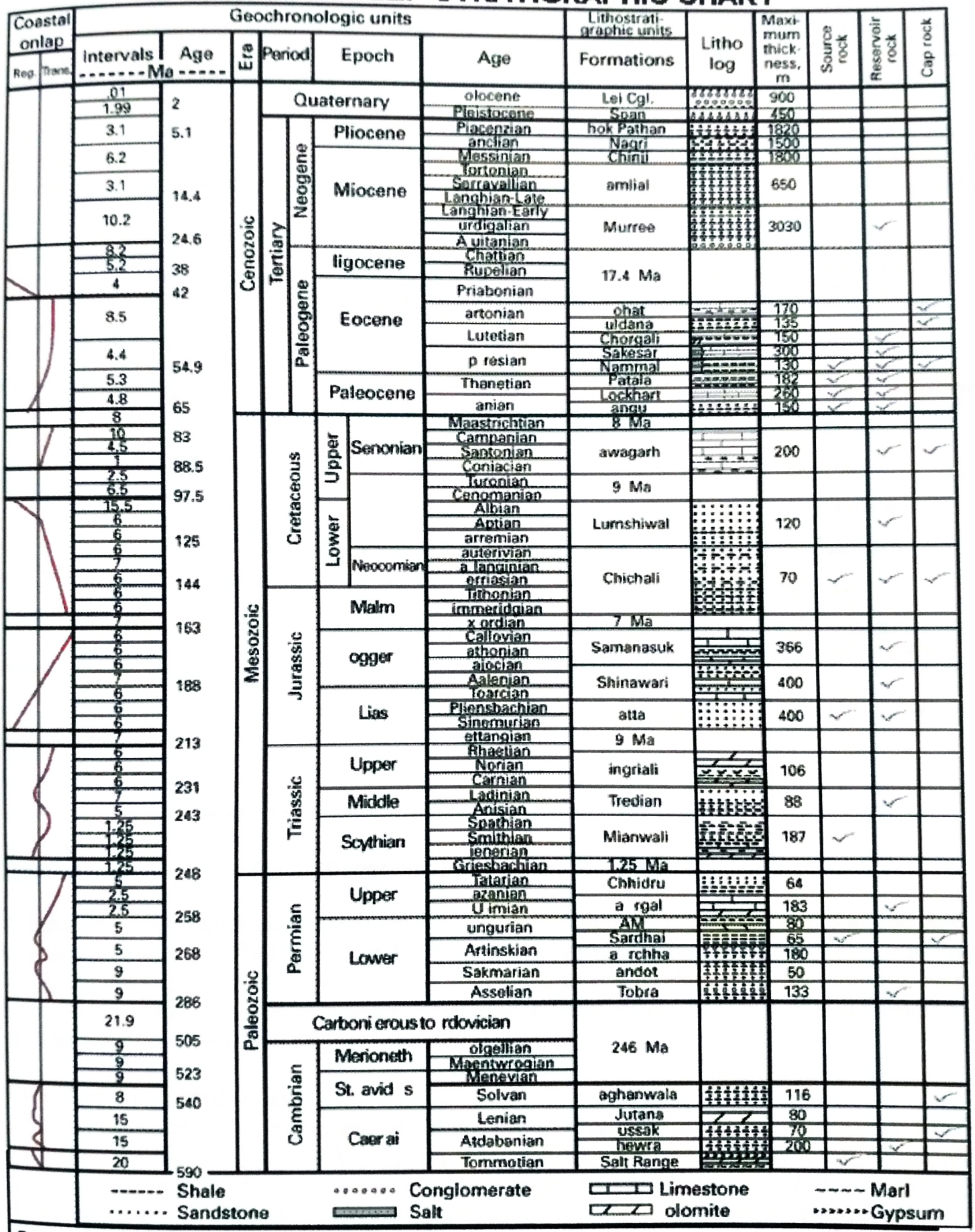
Fig 2.5 Structural, Stratigraphic and Tectonic Map of Potwar Basin **(OGDCL)**

overturned anticlines separated by broad synclines. This difference may be related to lesser amount/thickness of salt in the Infra-Cambrian in the eastern areas and very low dip of the basement (1°-1.5°) as compared to Central Potwar (2°-3°). In Central Potwar, structures are mainly fault bounded mostly by thrusts and backthrusts, while at some places, asymmetric anticlines are bound by a single fault. Based on the seismic interpretation, the structures in Potwar area may be divided into: Pop-up anticlines, Snake-head anticlines, Salt cored anticlines and Triangle zones (Moghal et al, 2OO3).

2.10 Stratigraphy

The detailed stratigraphic sequence for the Potwar basin is given below in table 2.1

POTWAR FOREDEEP STRATIGRAPHIC CHART



Coastal onlap Reg. Trans.	Geochronologic units Intervals Ma	Age Ma	Era	Period		Epoch		Age	Lithostratigraphic units Formations	Litho log	Maximum thickness, m	Source rock	Reservoir rock	Cap rock
	.01		Cenozoic	Quaternary				olocene	Lei Cgl.		900			
	1.99	2						Pleistocene	Span		450			
	3.1	5.1		Tertiary	Neogene	Pliocene		Piacenzian	hok Pathan		1820			
								anclian	Nagri		1500			
	6.2					Miocene		Messinian	Chinji		1800			
								Tortonian						
	3.1							Serravallian	amlial		650			
		14.4						Langhian-Late						
								Langhian-Early						
	10.2							urdigalian	Murree		3030		✓	
		24.6						A uitanian						
	8.2				Paleogene	ligocene		Chattian						
	5.2	38						Rupelian	17.4 Ma					
	4	42				Eocene		Priabonian						
	8.5							artonian	ohat uldana		170 135			✓ ✓
								Lutetian	Chorgali		150		✓	
	4.4	54.9						p resian	Sakesar Nammal		300 130	 ✓	✓ ✓	 ✓
	5.3					Paleocene		Thanetian	Patala Lockhart		182 260	✓ ✓	✓ ✓	
	4.8	65						anian	angu		150	✓	✓	
	8		Mesozoic	Cretaceous		Upper	Senonian	Maastrichtian	8 Ma					
	10	83						Campanian						
	4.5							Santonian	awagarh		200		✓	✓
	1	88.5						Coniacian						
	2.5							Turonian	9 Ma					
	6.5	97.5						Cenomanian						
	15.5					Lower		Albian						
	6							Aptian	Lumshiwal		120		✓	
	6	125						arremian						
	6						Neocomian	auterivian						
	7							a langinian						
	6	144						erriasian	Chichali		70	✓	✓	✓
	6			Jurassic		Malm		Tithonian						
	6							immeridgian						
	7	163						x ordian	7 Ma					
	6					ogger		Callovian						
	6							athonian	Samanasuk		366		✓	
	6							ajocian						
	7							Aalenian	Shinawari		400		✓	
	6	188				Lias		Toarcian						
	6							Pliensbachian	atta		400	✓	✓	
	6							Sinemurian						
	7	213						ettangian	9 Ma					
	6			Triassic		Upper		Rhaetian						
	6							Norian	ingriali		106			
	6	231						Carnian						
	7					Middle		Ladinian	Tredian		88		✓	
	5	243						Anisian						
	1.25					Scythian		Spathian						
	1.25							Smithian	Mianwali		187	✓		
	1.25							ienerian						
	1.25	248						Griesbachian	1.25 Ma					
	5		Paleozoic	Permian		Upper		Tatarian	Chhidru		64			
	2.5							azanian	a rgal		183		✓	
	2.5	258						U imian						
	5					Lower		ungurian	AM Sardhai		80 65	 ✓		 ✓
	5	268						Artinskian	a rchha		180			
	9							Sakmarian	andot		50			
	9	286						Asselian	Tobra		133		✓	
	21.9			Carboni erous to rdovician					246 Ma					
	9	505		Cambrian		Merioneth		olgellian						
	9							Maentwrogian						
	9	523				St. avid s		Menevian						
	8	540						Solvan	aghanwala		116			✓
	15					Caer ai		Lenian	Jutana		80			
	15							Atdabanian	ussak hewra		70 200		 ✓	✓
	20	590						Tommotian	Salt Range			✓		

------ Shale	▫▫▫▫▫▫▫ Conglomerate	▭ Limestone	~~~~ Marl
.... Sandstone	▨ Salt	▱ olomite	›››››› Gypsum

Source: After S.M. naeem, Oil & Gas Development Co., 1991

Table 2.6

2.11 Petroleum Geology

The Kohat-Potwar depression has several features that makes it a favourable site for hydrocarbon accumulations. Located on a continental margin, the depression is filled with thick deposits of sedimentary rocks, including potential source reservoir and cap rock. It contains a thick overburden (about 3000 m) of fluvial sediments, which provide the burial depth and optimum geothermal gradient for seeps found in this area (Khan et al., 1986). The sedimentary rocks are deformed during thin-skinned Himalayan tectonics, forming the structural traps for hydrocarbons. The SRPFB is structurally favorable site for hydrocarbon accumulation (Coward and Butler, 1985).

This foreland basin is filled with thick sequence of sedimentary rocks. The source, reservoir and cap rocks are present in SRPFB. It contains thick overburden of 1980 m to 3050 m of fluvial sediments, which provide burial depth and optimum geothermal gradient for the formation of oil in SRPFB (Shami and Baig, 2002).

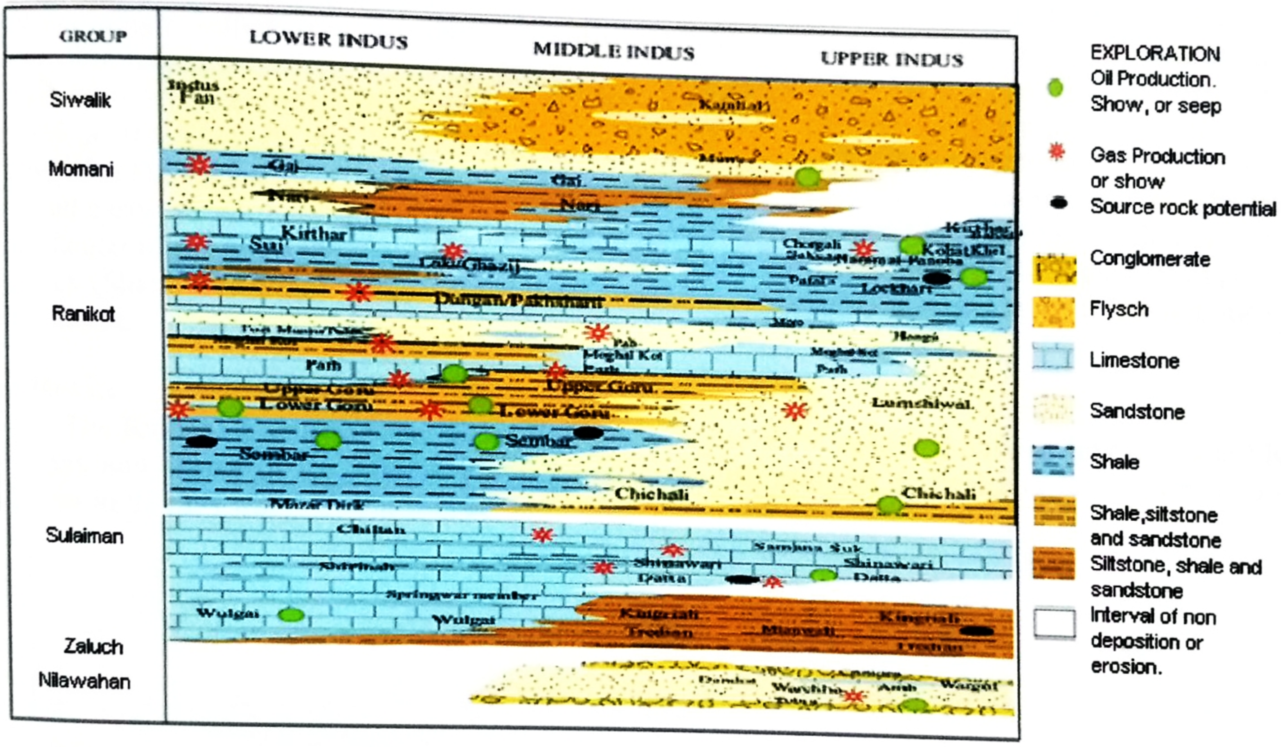


Fig 2.7 Generalise Stratigraphy of Indus Area

Simple and translated fault-propagation folds form important structural traps in fold and thrust belts. The most important traps in fault propagation folds are in the crests of major anticlines. These fault traps may be present along back limb thrusts, between the imbricates in the forelimbs and in upturned beds in the footwall. Secondary traps may also be present within major thrust sheets, particularly at the leading edge of the thrust sheet and above footwall ramps (Mitra, 1990)

2.12 Hydrocarbon Potential

The SRPFB belongs to the category of extra continental down warp basins, this accounts for 48% of the world known petroleum (Riva, 1983). It has several features suitable for hydrocarbon accumulation including continental margin, thick marine sedimentary sequence, potential source, reservoir and cap rocks. The thick overburden of 3047 m of molasse provides burial depth and optimum geothermal gradient for oil formation. The SRPFB with an average geothermal gradient of 2 °C/100 m is producing oil from the depth of 2750-5200 m (Shami and Baig, 2002). The presence of an optimal combination of source, reservoir and trap within the oil window resulted oil and gas accumulation in Joya Mair, Toot, Meyal and Dhulian oilfields (Kozary et al., 1968).

Source Rocks

The gray shales of the Mianwali, Datta and Patala Formations are potential source rocks in SRPFB (Khan et al., 1986). The oil shales of the Eocambrian Salt Range Formation include 27% to 36% total organic content (TOC) in isolated pockets of shales, and are considered as the source rock in SRPFB (Shami and Baig, 2002).

Reservoir Rocks

The Cambrian, Permian, Jurassic, Paleocene and Eocene reservoirs are producing oil in SRPFB. The fractured carbonates of the Sakesar and Chorgali Formations are the major oil producing reservoirs in the area. In Missa kaswal Chorgali and Sakesar Formations are major oil producing reservoirs. The Sakesar limestone is light yellow gray, massive and partly dolomitized and locally contains chert concretions. The Chorgali Formation is creamy yellow to yellow gray, silty, partly dolomitic and thin bedded limestone. Core analysis from Missa kaswal, Meyal, Dhulian and Balkassar oilfields shows that the primary porosity is less than 1% in the Chorgali and Sakesar limestones. The fracture porosity is relatively higher in wells of northwestern Potwar because the rocks deformed several times during the Himalayan orogeny. The fracture sets trend eastwest, northeast-southwest and northwest-southeast. The fractures develop parallel, oblique and perpendicular to the fold axes of anticlines. The fractures are usually concentrated along the crestal part of the anticlines (Shami and Baig, 2002). Murre Formation here is acting as a reservoir rock but not for oil for ground water.

Cap Rocks

The Kuldana Formation acts as cap for the reservoirs of Chorgali and Sakesar limestones in SRPFB. The clays and shales of the Murree Formation also provide efficient vertical and lateral seal to Eocene reservoirs in SRPFB where ever it is in contact.

Chapter 3

Introduction to Petrophysics

3.1 Introduction

Petrophysics (petro is Latin for "rock" and physics is the study of nature) is the study of the physical and chemical properties that describe the occurrence and behavior of rocks, soils and fluids. Petrophysics mainly studies reservoirs of resources, including ore deposits and oil or natural gas reservoirs. Petrophysicists in the oil and gas industry typically are employed in helping the engineers and other geoscientists understand the rock properties of the reservoir.

Petrophysicists evaluate the reservoir rock properties by employing well log measurements, in which a string of measurement tools are inserted in the borehole, core measurements, in which rock samples are retrieved from subsurface, and sometimes seismic measurements, and combining them with geology and geophysics.

Petrophysical studies are utilized by petroleum engineering, geology, mineralogy, exploration geophysics and other related studies. Some of the key properties studied in petrophysics are lithology, porosity, water saturation, permeability, density, solid mechanics, magnetization, electrical conductivity, thermal conductivity and radioactivity.

3.2 Conventional Petrophysical properties

Most petrophysicists are employed to compute what are commonly called conventional (or reservoir) petrophysical properties. These are:

3.2.1 Lithology

Lithology gives us the answer of the question that what type of rock is it? When combined with local geology and core study, geoscientists can use log measurements such as natural gamma, neutron, density, Photoelectric, resistivity or their combination to determine the lithology downhole.

3.2.2 Porosity

The porosity of the rock is the number of the pore (void) space in a rock, as shown in figure 3.1. It is measured as a fraction, between 0 – 1, or as a percentage between 0 – 100 % and is φ. The porosity depends on the shape, represented by the symbol φ surface, texture, angularity, orientation, and degree of cementation and size distribution of the grains, which make up the rock. Porosity can be divided into three categories primary porosity, secondary porosity and effective porosity.

a. Primary porosity

The pore spaces left between the fragments of the rock forming material during the time of deposition is known as the primary porosity.

b. Secondary porosity

Secondary porosity is the porosity which develops after the process of deposition. It develops due to dissolution, fractures, pits and other discontinuities in the bulk volumes of matrix. The contribution of the secondary to the overall bulk porosity is generally small yet it can lead to dramatic increases in bulk permeability.

c. **Effective porosity**

The degree to which pores within the material are interconnected is known as effective porosity. Effective porosity is the only capacity, which can make contribution to the flow. Pores initially present but subsequently seals off by cementation or ecrystallization effects are of no interest.

Porosity is typically measured using an instrument that measures the reaction of the rock to bombardment by neutrons or by gamma rays. Sonic wave speed and NMR logs are also measured to derive rock porosity.

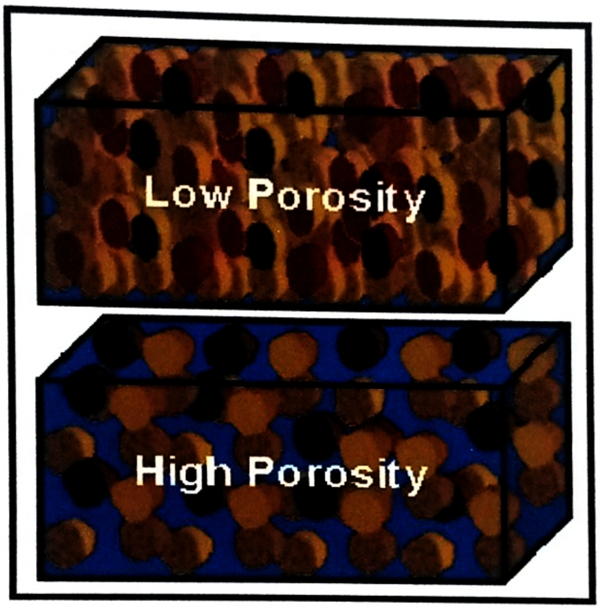


Figure 3.1: Diagram showing porosity in a rock unit.

3.2.3 Saturation

The saturation of a formation is the fraction of its pore volume occupied by the fluid considered. Water saturation, then, is the fraction (or percentage) of the pore volume that contains formation water. If nothing but water exists in the pores, a formation has a water saturation of 100%. The symbol for saturation is S, various subscripts are used to denote saturation of a particular fluid (S, for water saturation, S, for oil saturation, S, for hydrocarbon saturation, etc.).

Oil, or gas, saturation is the fraction of the pore volume that contains oil, or gas. The pores must be saturated with some fluid. Thus, the summation of all saturations in a given formation rock must total to 100%. Although there are some rare instances 'of saturating fluids other than water, oil, and gas (such as carbon dioxide or simply air), the existence of a water saturation less than 100% generally implies a hydrocarbon saturation equal to 100% less the water saturation (or 1 - Sw).

The water saturation of a formation can vary from 100% to a quite small value, but it is seldom, if ever, zero. No matter how "rich" the oil or gas reservoir rock may be, there is always a small amount of capillary water that cannot be displaced by the oil. Similarly, for an oil- or gas-bearing reservoir rock, it is impossible to remove all the hydrocarbons by ordinary fluid drives or recovery techniques. Some hydrocarbons remain trapped in parts of the pore volume.

3.2.4 Permeability

Permeability is the property of a rock which allows the liquid to pass through or in other words it is simply the measure to the ease with which a fluid can pass through a rock (figure 2.2). Just aswith porosity, the packing, shape, and sorting of granular materials control their permeability.Although a rock may be highly porous, if the voids are not interconnected, then fluids within the closed, isolated pores cannot move hence making the rock impermeable. The symbol most commonly used for permeability is K. Permeability is measured in Darcy, but the permeability in petroleum-producing rocks is usually expressed in units called milliDarcys (one milliDarcy is 1/1000 of a Darcy).

Permeability is also divided into three sub categories namely absolute permeability, effective permeability, and relative permeability.

a. Absolute permeability

The measurement of the permeability, or ability to flow or transmit fluids through a rock, conducted when a single fluid, or phase, is present in the rock. This is the property of the rock and not of the fluid flowing through it. Absolute permeability is measured with the fluid which saturates 100% of the pore space.

b. Effective permeability

The ability to preferentially flow or transmit a particular fluid when other immiscible fluids are present in the reservoir (e.g. effective permeability of gas in a gas-water reservoir). The relative saturations of the fluids as well as the nature of the reservoir affect the effective permeability. The effective permeability is always less than the absolute permeability for the rock.

c. Relative permeability

It is the ratio of the effective permeability to the absolute permeability. If a single fluid is present in a rock, its relative permeability is 1.0. Calculation of relative permeability allows comparison of the different abilities of fluids to flow in the presence of each other, since the presence of more than one fluid generally inhibits flow.

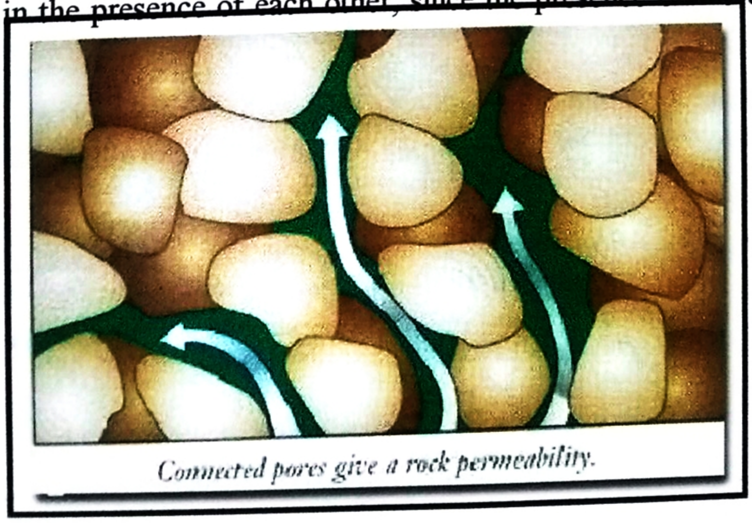


Figure 3.2: Diagram showing permeability in a rock

3.2.5 Thickness of the Reservoir

Thickness of rock with enough permeability to deliver fluids to a well bore. This property is often called "Net reservoir rock." In the oil and gas industry, another quantity "Net Pay" is computed which is the thickness of rock that can deliver hydrocarbons to the well bore at a profitable rate.

Reservoir models are built upon their measured and derived properties to estimate the amount of hydrocarbon present in the reservoir, the rate at which that hydrocarbon can be produced to the Earth's surface through wellbores and the fluid flow in rocks. In the water resource industry, similar models are used to compute how much water can be produced to the surface over long periods of time, without depleting the aquifer.

3.3 Methods of formation evaluation

In petroleum exploration and development, formation evaluation is used to determine whether a potential oil or gas field is commercially viable. Essentially, it is the process of "recognizing a commercial well when we drill one". Only in rare cases do oil and gas wells come in with a fountain of gushing oil. In real life, that is a blowout and usually also a financial and environmental disaster. Modern rotary drilling uses a heavy mud as a lubricant and as a means of producing a confining pressure against the formation face in the borehole, preventing blowouts. This is a double edged sword mud filtrate soaks into the formation around the borehole and a mud cake plasters the sides of the hole. These factors obscure the possible presence of oil or gas in even very porous formations. Further complicating the problem is the widespread occurrence of small amounts of petroleum in the rocks of many sedimentary provinces. In fact, if a sedimentary province is absolutely barren of traces of petroleum, one is probably foolish to continue drilling there.

The formation evaluation problem is a matter of answering two questions:

1. What are the lower limits for porosity, permeability and upper limits for water saturation that permit profitable production from a particular formation or pay zone; in a particular geographic area; in a particular economic climate?

2. Do any of the formations in the well under consideration exceed these lower limits? It is complicated by the impossibility of directly examining the formation. It is, in short, the problem of looking at the formation indirectly.

Formation Evaluation Techniques are:

1. Coring

2. Mud logging

3. Wire-line logging

3.3.1 Coring

One way to get more accurate samples of the formation at a certain depth in the well is coring.

There are two techniques commonly used at present. The first is the "whole core", a cylinder of rock, usually about 3" to 4" in diameter and, with good luck, up to 50 feet to 60 feet long. It is cut with a "core barrel", a hollow pipe tipped with a ring shaped, diamond chip studded bit that can cut a plug and retain it in a trip to the surface. If no shale or fractures are encountered, the full 60 foot length of the core barrel can be filled. More often the plug breaks while drilling, usually at the aforementioned shale or fractures and the core barrel jams, very slowly grinding the rocks in front of it to powder. This signals the driller to give up on getting a full length core and to pull up the pipe.

Taking a full core is an expensive operation that usually stops or slows drilling for at least the better part of a day. A full core can be invaluable for later reservoir evaluation. One of the tragedies of the oil business is the huge amount of money that has been spent for cores that have been lost because of the high cost of storage. Once a section of well has been drilled, there is, of course, no way to core it without drilling another well.

The other, cheaper, technique for obtaining samples of the formation is "Sidewall Coring". In this method, a steel cylinder a coring gun has hollow-point steel bullets mounted along its sides. These bullets are moored to the gun by short steel cables. The coring gun is lowered to the bottom of the well and the bullets are fired individually as the gun is pulled up the hole. The mooring cables ideally pull the hollow bullets and the enclosed plug of formation loose and the gun carries them to the surface. Advantages of this technique are low cost and the ability to sample the formation after it has been drilled. Disadvantages are possible non recovery because of lost or misfired bullets and a slight uncertainty about the sample depth. Sidewall cores are often shot "on the run without stopping at each core point because of the danger of differential sticking. Most service company personnel are skilled enough to minimize this problem, but it can be significant if depth accuracy is important.

3.3.2 Mud logging

The simplest and most direct tool is well cuttings examination. Some older oilmen ground the cuttings between their teeth and tasted to see if crude oil was present. Today, a well-site geologist or mud-logger uses a low powered stereoscopic microscope to determine the lithology of the formation being drilled and to estimate porosity and possible oil staining. A portable ultraviolet light chamber or "Spook Box" is used to examine the cuttings for fluorescence. Fluorescence can be an indication of crude oil staining, or of the presence of fluorescent minerals. They can be differentiated by placing the cuttings in a solvent filled watch glass or dimple dish. The solvent is usually carbon tetrachlorethane. Crude oil dissolves and then redeposit as a fluorescent ring when the solvent evaporates. The written strip chart recording of these examinations is called a sample log or mud-log.

Mud logging (or Well-site Geology) is a well logging process in which drilling mud and drill bit cuttings from the formation are evaluated during drilling and their properties recorded on a strip chart as a visual analytical tool and stratigraphic cross sectional representation of the well. The drilling mud which is analyzed for hydrocarbon gases, by use of a gas chromatograph, contains drill bit cuttings which are visually evaluated by a mud-logger and then described in the mud log. The total gas, chromatograph record, lithological sample, pore pressure, shale density, etc (all lagged parameters because they are circulated up to the surface from the bit) are plotted along with surface parameters such as Rate Of Penetration (ROP), Weight On Bit (WOB), etc. on the mud-log which serve as a tool for the mud-logger, drilling engineers, mud engineers, and other service personnel charged with drilling and producing the well.

3.3.3 Wire-line logging

In 1928, the Schlumberger brothers in France developed the workhorse of all formation evaluation tools: the electric log. Electric logs have been improved to a high degree of precision and sophistication since that time, but the basic principle has not changed. The detail description is big topic so concentrated in another chapter.

Chapter 4

Petrophysical Analysis

4.1 Introduction

Petrophysical analysis is the study and interpretation of the wire-line logs, generated by the down hole logging. In this, petrophysist generally follow the sequence of task in order to evaluate the hydrocarbon potential of the formation. In order to do so, they calculate different parameters to find out the saturation of hydrocarbons in the reservoir. The complete interpretation workflow is shown in figure 4.1.

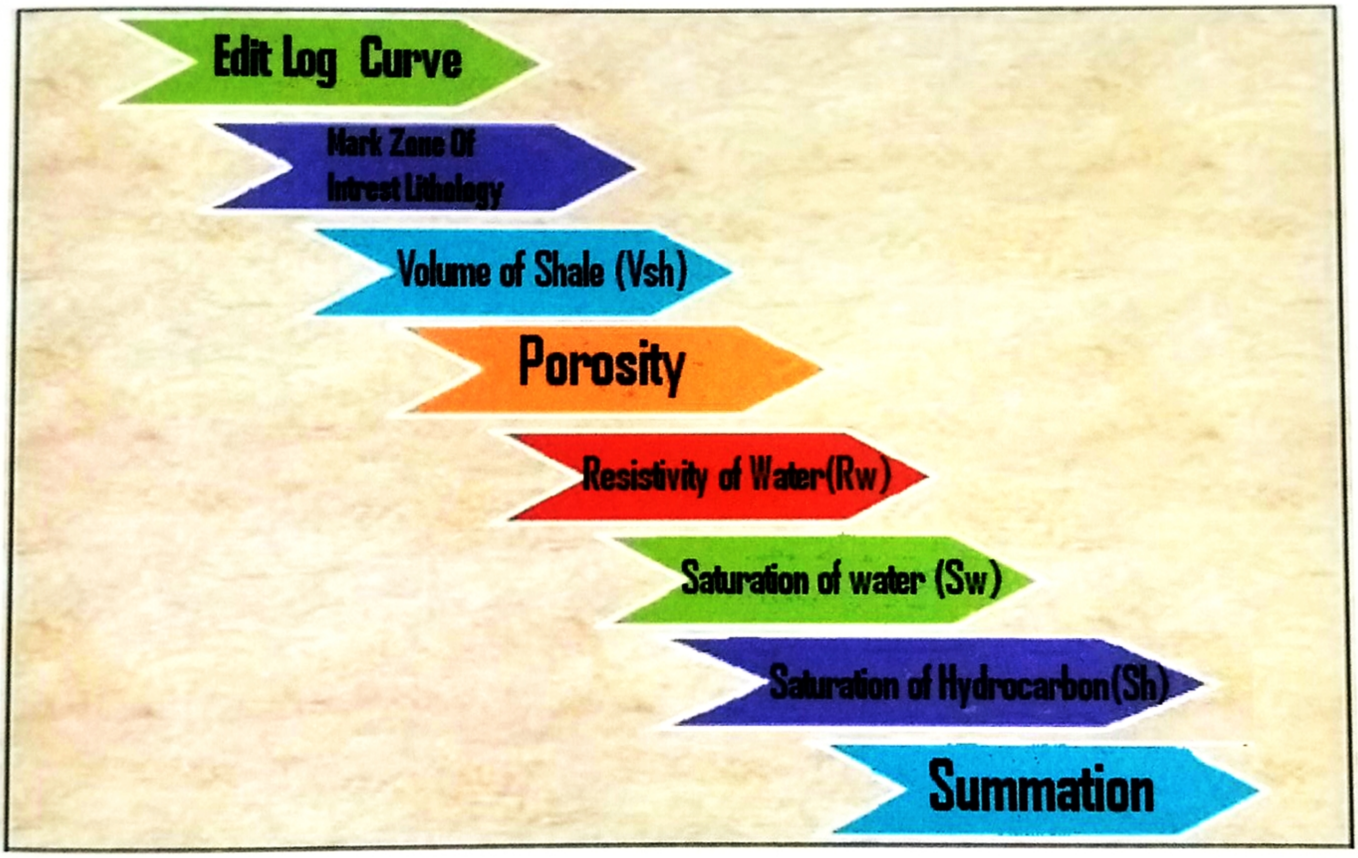


Figure 4.1: Diagram showing Interpretation work Flow

The interpretation involves, first of all the editing of the newly generated raw log curve. After the log has been edited, zones of interest are marked. Now we are ready to calculate different parameters from the different log curves like volume of shale (Vsh), porosity (φ), Saturation of Water (Sw), Saturation of Hydrocarbon (Shc) and Lithology. During the calculation of these parameters, one thing should be kept in mind that all the relevant logs are being studied side by side rather separately in order to get the accurate measurement. In addition to this, make sure that the scale of all the logs is the same.

4.2 Methodology adopted

In evaluating of well, namely Missa Keswal !, the method for the formation evaluation adopted was that first we marked the zones of interest in the logs, where we observed gas effect, after that we calculated volume of shale with the help of GR log. Porosity was calculated with the help of Neutron log, Bulk Density log and Dual Lateral Log. And finally, saturation of water, saturation of hydrocarbon and lithology were calculated by using different techniques. The methodology adopted for the determination of these petrophysical parameters is discussed in detail below:

4.2.1 Determination of volume of shale (V_{sh})

Volume of Shale was calculated with the help of GR log. In this, we first note down the maximum and the minimum values of the GR curve in that particular zone and then we note down the GR readings at different intervals in each zone marked. Then we apply all these data gathered into the following formula in order to get the volume of shale or gamma ray "shale index" IGR at different depths.

$$\mathbf{IGR} = \frac{GR_{Log}-GR_{Min}}{GR_{Max.}-GR_{Min}}$$

Where,

GR log = log response in the zone of interest, API units

GR min = log response in the clean beds, API units

GR max = log response in the shale beds, API units

4.2.2 Determination of Lithology

The lithology was determined with the help of "M-N Plot for mineral identification" (i.e "ρma and ΔTma Plot for mineral identification") cross plot shown in figure 2.2 below. This cross plot is used to identify mineral mixtures from density and sonic logs.

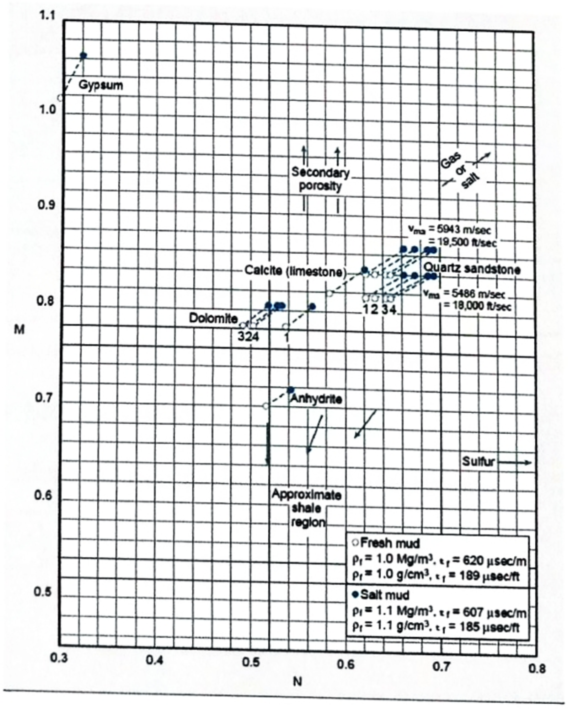


Figure 4.2: M-N Plot for mineral identification

4.2.3 Calculation of Porosity

Porosity was calculated by using cross plot between bulk density (ρB) and Neutron porosity Hydrogen Index (Nφ) shown in figure 7.3 below. Both of these were noted down from the log at different depth intervals and then plotted in the cross plot with bulk density on the Y – axis and the neutron porosity index on the X – axis. We plot these values and eventually get to a point where these two lines meet then we drop this point vertically to the lithology at that particular depth where we get the porosity of the rocks at that depth. Following is the cross plot used for calculating the porosity of the formation.

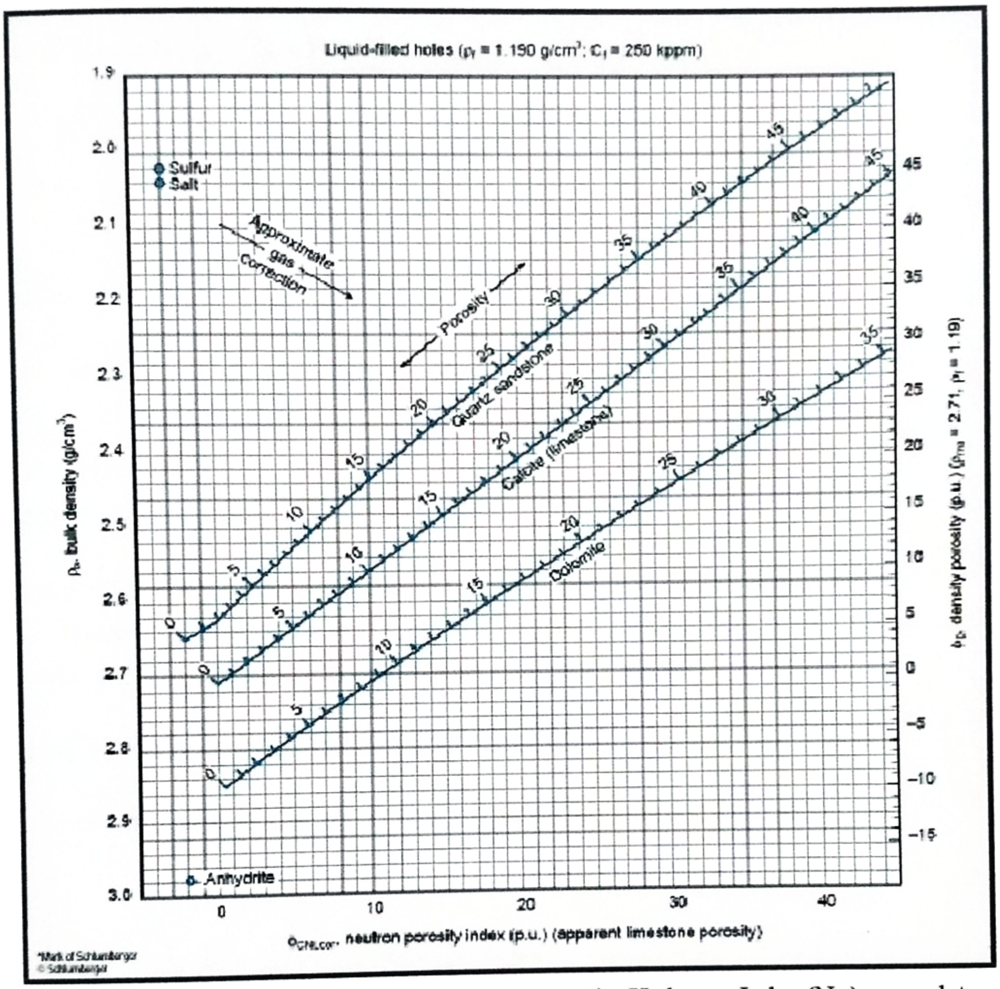


Figure 4.3: Bulk density (ρB) and Neutron porosity Hydrogen Index (Nφ) cross plot.

4.2.4 Calculation of Water Saturation (S w)

Water saturation was calculated with the help of Archie's equation:

$$S_w = \sqrt{\left(\frac{a}{\varphi^m}\right) \times \left(\frac{R_w}{R_t}\right)}$$

Where,

S w = Water Saturation

φ = Porosity

R w = Formation water resistivity

R t = Observed LLD curve

a = A constant (often taken to be 1)

m = Cementation factor (varies around 2)

In calculating porosity, we first calculated the formation water resistivity Rw from the water zone in that formation, by using following formula:

4.2.5 Calculation of Resistivity (R_w)

$$R_w = \frac{\varphi^m \times R_t}{a}$$

Where,

R w = Formation water resistivity

R t = Observed LLD curve

φ = Porosity

m = Cementation factor (varies around 2)

Above calculated Rw is kept constant throughout the formation along with the values of other two constants a and m. These are put into the Archie's equation, along with the value of Rt , which is the resistivity of the formation at different depth intervals.

4.2.6 Calculation of Hydrocarbon Saturation (S_{hc})

Hydrocarbon saturation was calculated by a simple formula given below:

$$S_{hc} = 1 - S_w$$

Where,

Shc = Saturation of hydrocarbon

Sw = Saturation of water

Chapter 5

Interpretation of Missa Keswal Well # 1

5.1 Interpretation of Missa Keswal1

Missa Keswal 1 encountered one zone in chorgali limestone.In order to evaluate the hydrocarbon potential of this well. Different parameters calculated, which were discussed in previous chapter, are given below:

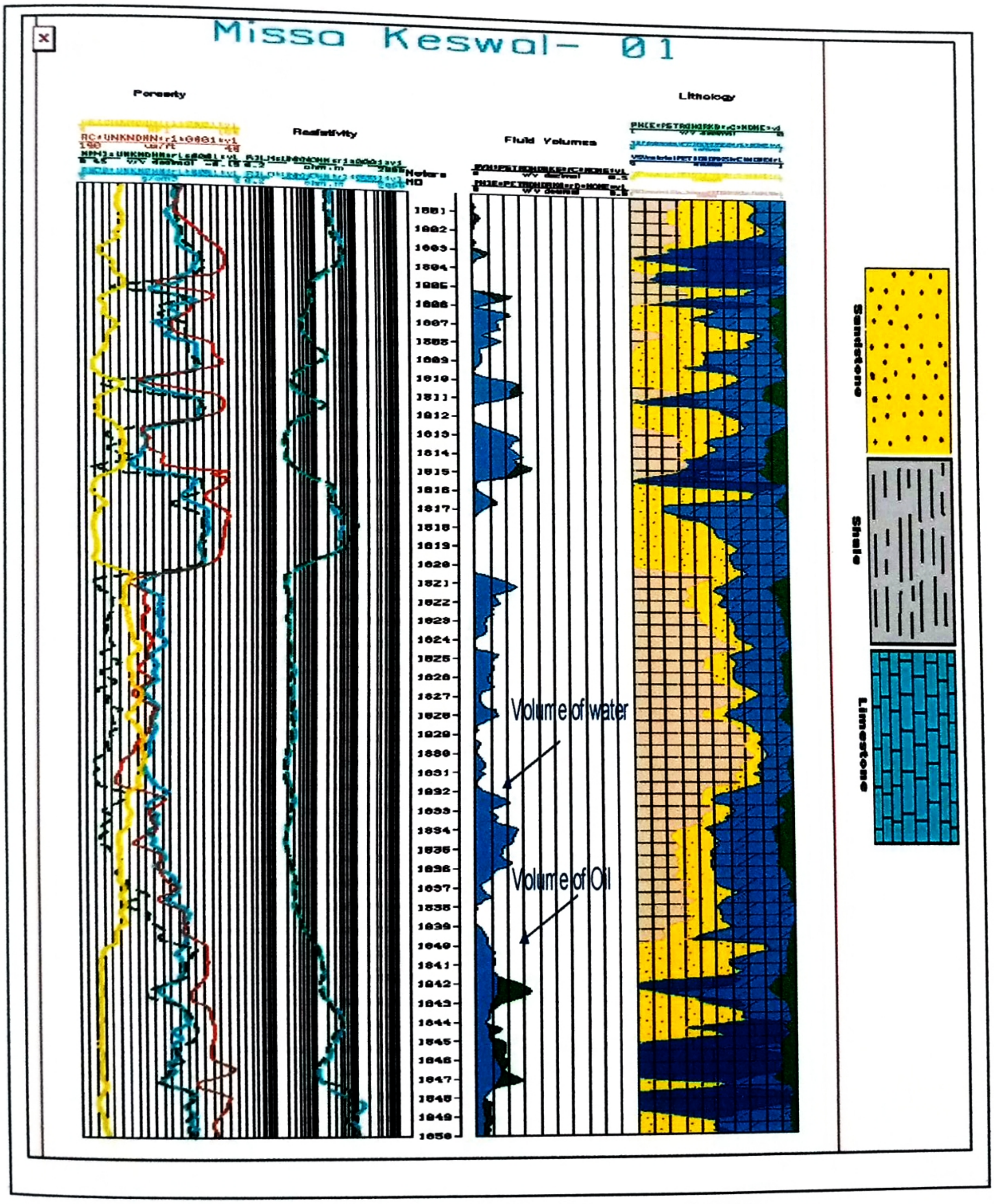
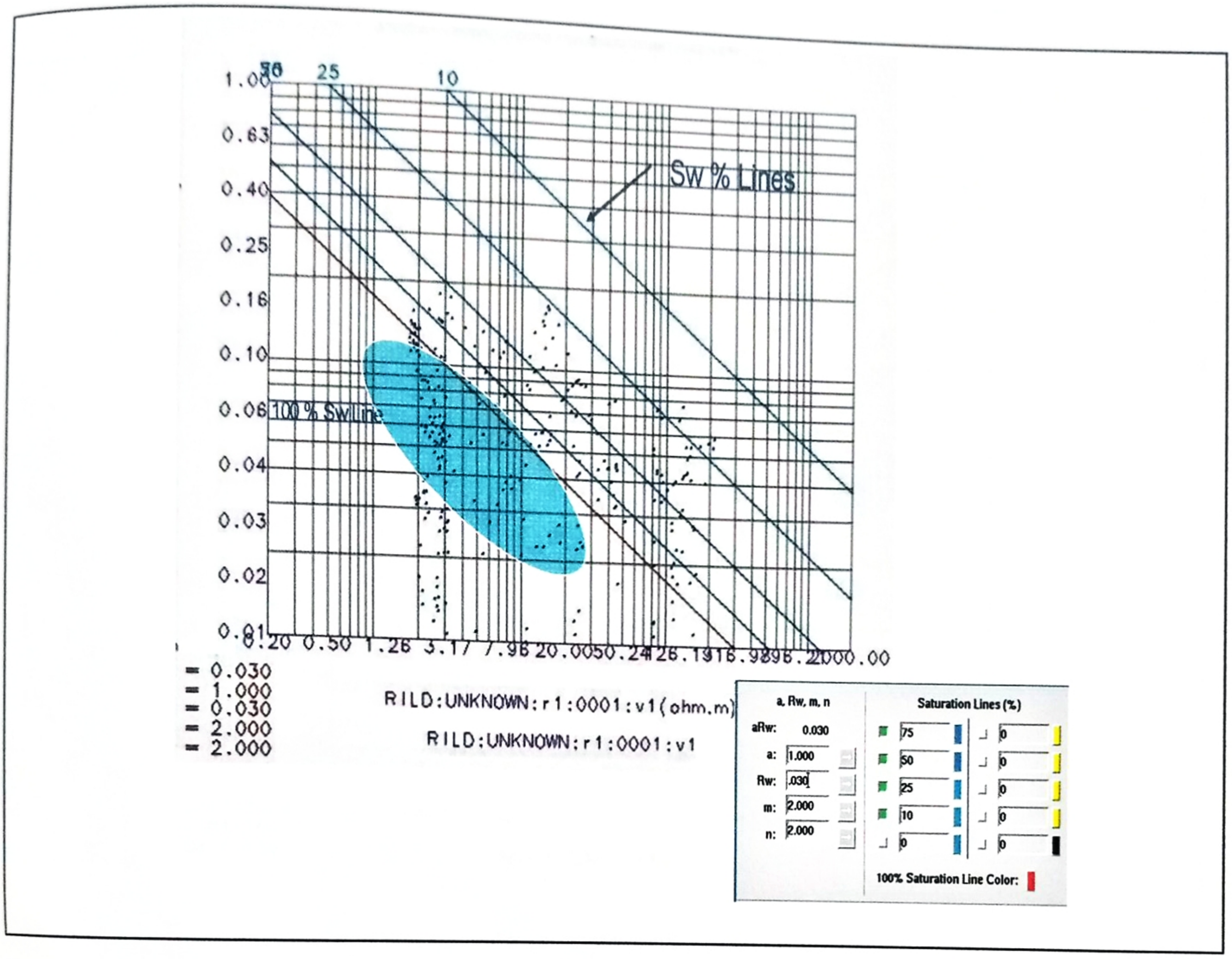


Figure 5.1 Interpretation of Mesa Kaswal well#1

5.2 Well Zonation of Mesa Keswal # 1

Well Zones	Depth (m)	Description
Zone A	1800 – 1805	Sandy Limestone with low porosity
Zone B	1805 - 1820	Sandy Limestone with high porosity, high water saturation
Zone C	1820 -1840	Shale with minor portion of Limestone with high water saturation.
Zone D	1840 - 1845	Sandy Limestone with good porosity and high water saturation
Zone E	1845 - 1850	Clean Limestone, with good porosity and low water saturation, having good reservoir quality.



a, Rw, m, n

aRw: 0.030

a: 1.000

Rw: .030

m: 2.000

n: 2.000

Saturation Lines (%)

75	0
50	0
25	0
10	0
0	0

100% Saturation Line Color: 🟥

Figure 5.2 Porosity Resistivity Cross plot

This cross plot is between porosity (Y Axis) and Resistivity (X Axis). The lines are showing the water saturation in the zone. The red line shows the 100 % water saturation then blue lines show 75, 50, 25 and 10 % respectively.

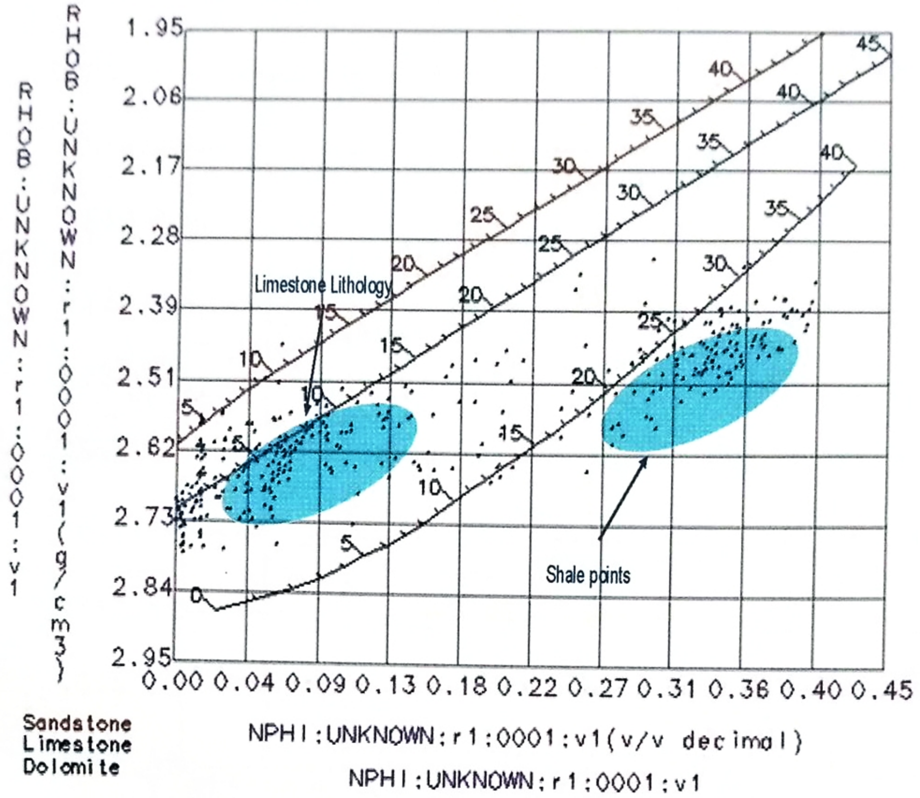


Figure 5.3 **ρB** and **Nφ** Cross plot

The cross plot shows the main reservoir zone exists in between (1800 M – 1850 M) This cross plot is between the **ρB** and **Nφ** with matrix lines. The matrix lines show the lithology and porosity of the zone. The matrix lines are Sandstone, Limestone, and Dolomite.

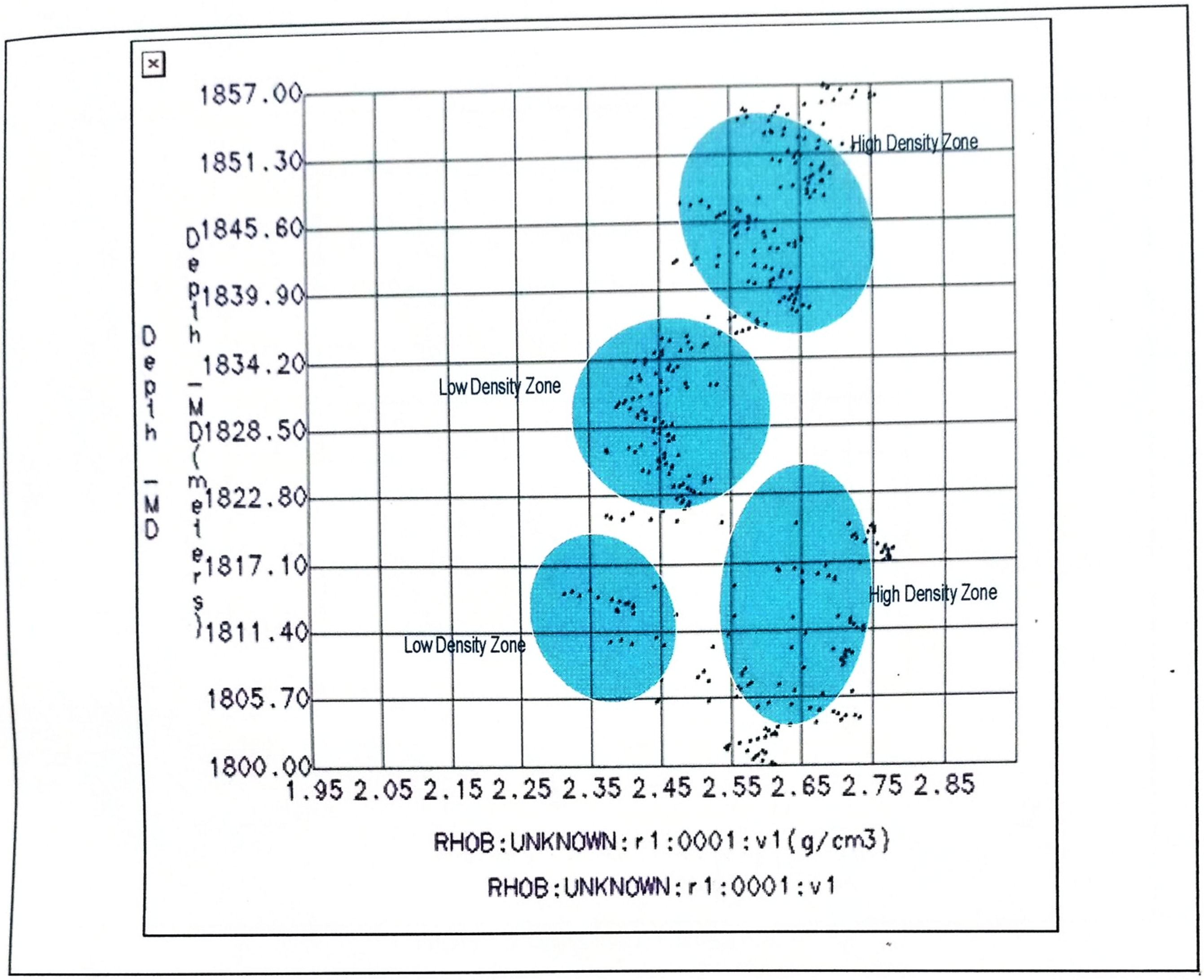


Figure 5.4 Depth and **ρB** Cross plot

In this cross plot the Depth plotted on Y Axis and **ρB** plotted on X Axis. The cross plot shows the trend of density with relation to depth.

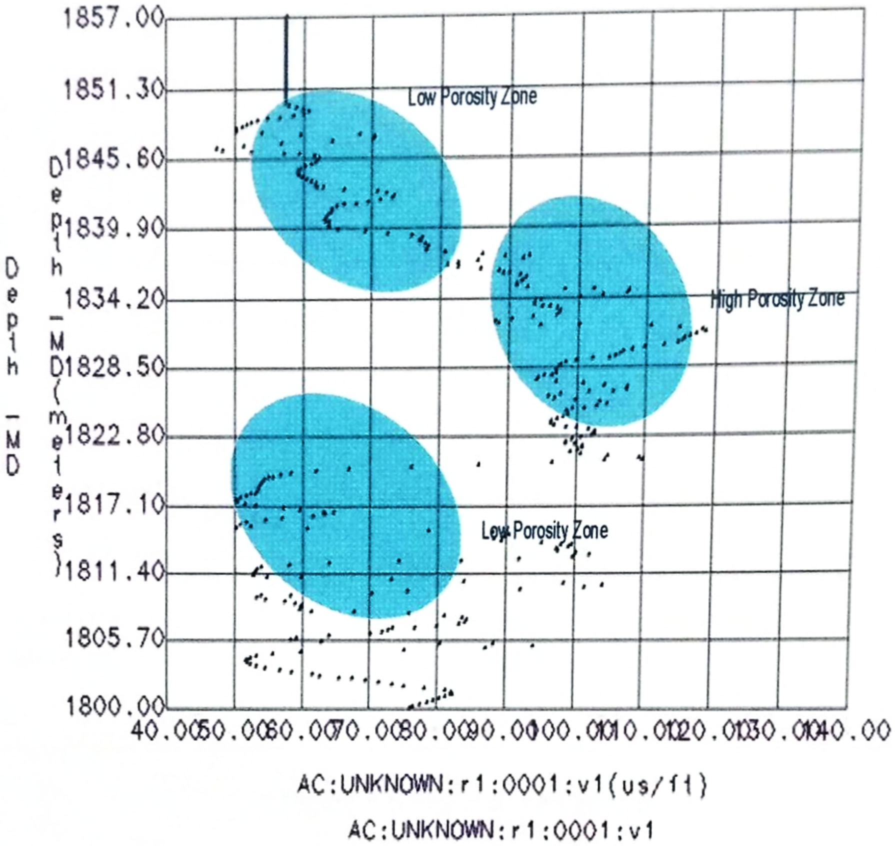


Figure 5.5 Depth and ΔT Cross plot

In this cross plot the Depth plotted on Y Axis and ΔT plotted on X Axis. The cross plot shows the trend of ΔT with relation to depth.

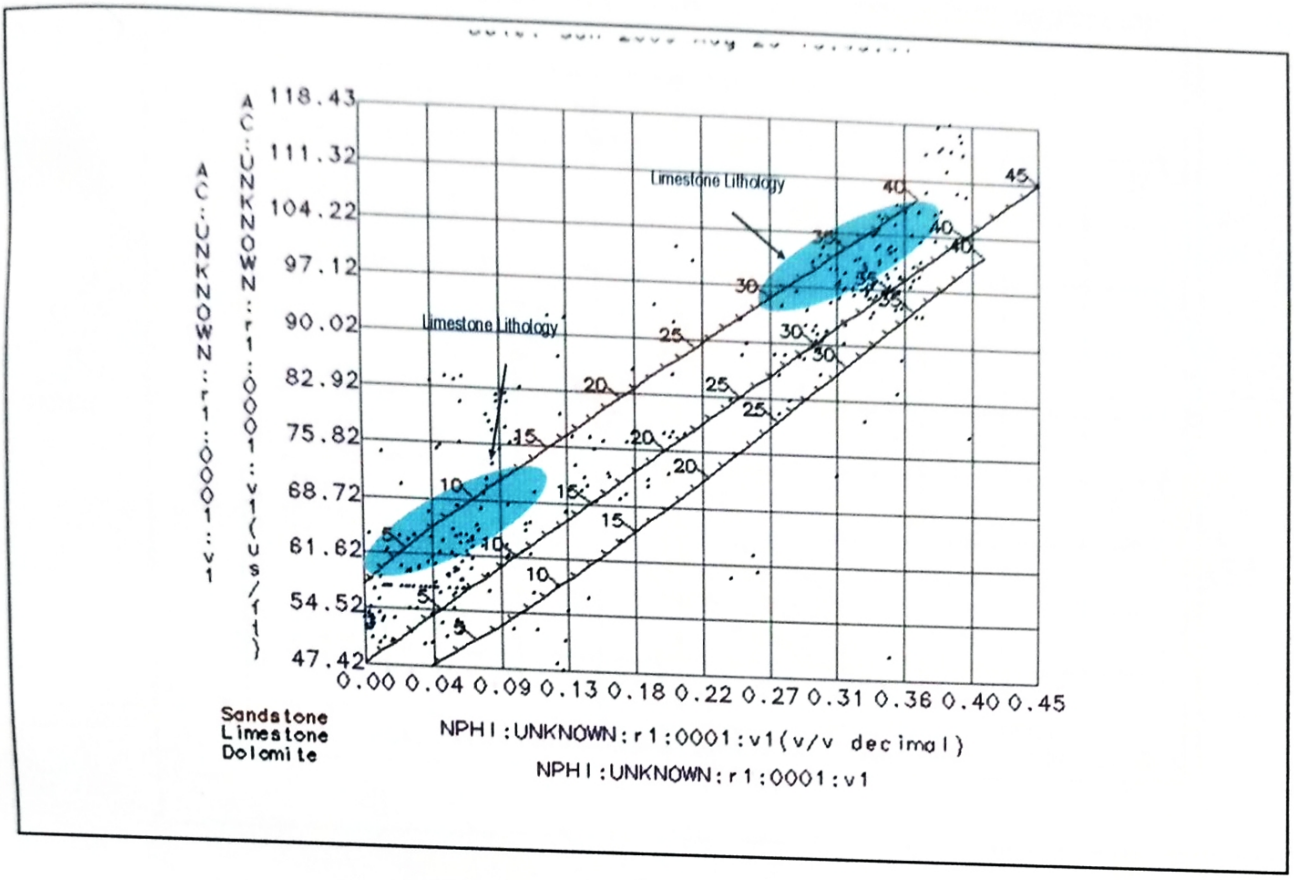


Figure 5.6 Nφ and ΔT Cross plot

The cross plot shows the main reservoir zone exists in between (1800 M – 1850 M). This cross plot is between the ΔT and Nφ with matrix lines. The matrix lines show the lithology and porosity of the zone. The matrix lines are Sandstone, Limestone, and Dolomite.

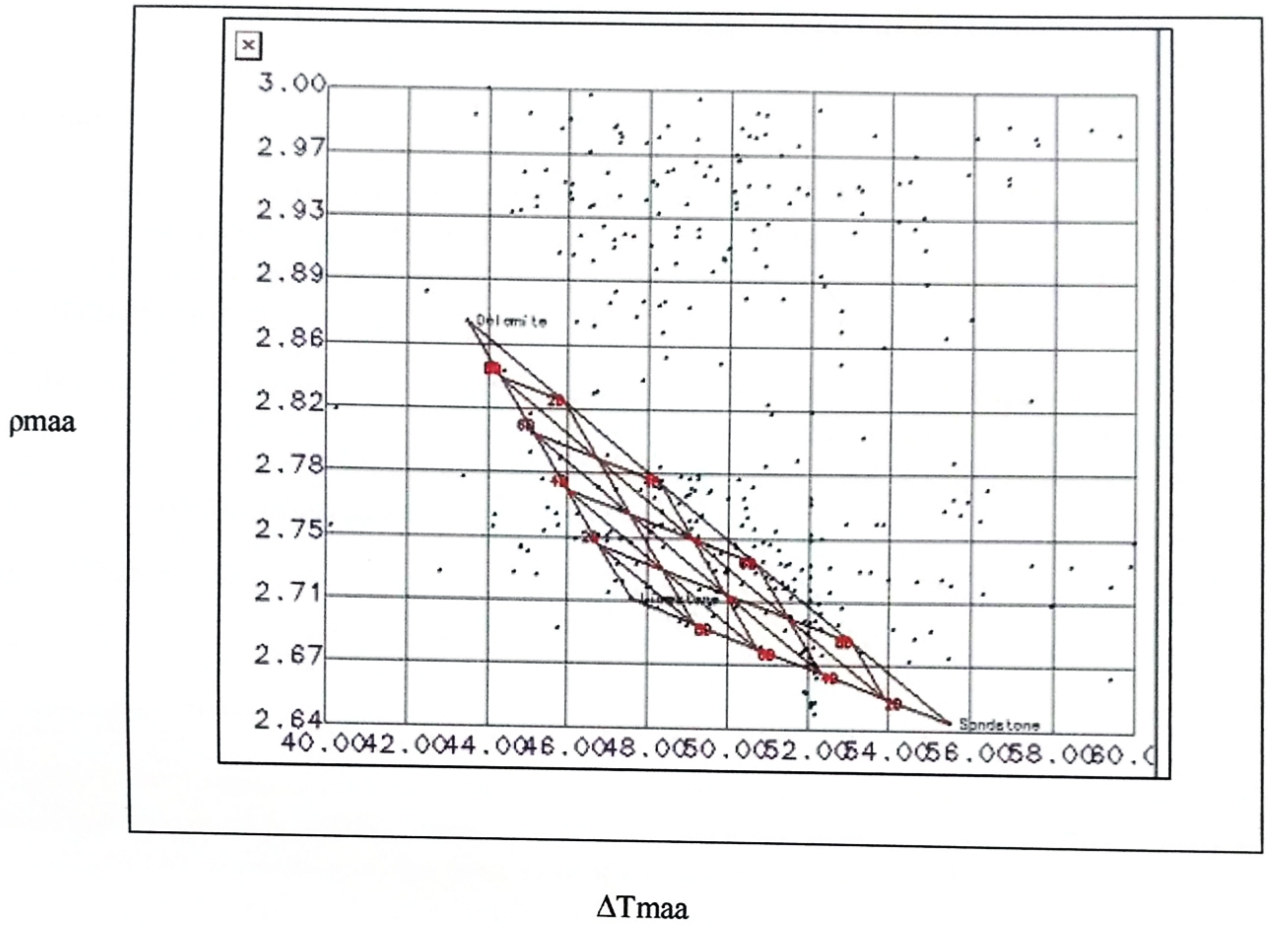


Figure 5.7 Mineral identification plot between ΔTMaa and ρMaa.

This cross plot shows the lithology of the zones. The minerals triangle is between Sandstone, Limestone and Dolomite.

Conclusion and Recommendations

Conclusion

Petrophysical interpretations were carried out successfully for Missa Keswal Well # 1 Upper Indus Basin of Pakistan. Different petrophysical parameters were calculated i.e. shale volume, Porosity, water saturation, hydrocarbon saturation, and lithology using different logs. Three potential reservoirs found, namely Chorgali limestone.

During the interpretation of Missa Keswal Well # 1, chorgali limestone found, containing hydrocarbons. The gross interval of reservoir zone is 57 meters. After applying the cut off parameters of Shale Volume, Porosity and Water Saturation the Net Pay is 9 meters and Net Reservoir rock's thickness is 31.66 meters. The details of cut off parameters are as under:

Volume of Shale = 30%

Porosity = 7%

Water Saturation = 50 %

The Gross Interval of reservoir zone is 56.9 m, Net Pay zone is 8.9 m, average shale volume in this formation was calculated to be 08%, average porosity was calculated to be 7%, average water saturation was calculated to be 51% and average hydrocarbon saturation was calculated to be 49%.

Recommendations

1. Special core analysis should be done on reservoir rocks for better control on petrophysical interpretations.
2. FMI should be run in future wells.
3. TDT, RST should be run in production wells to measure the water level in reservoir.
4. Best drilling and mud parameters should be used in future wells to minimize the well damage.

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