RESERVOIR EVALUATION OF QADIRPUR FIELD, CENTRAL INDUS BASIN, PAKISTAN

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01-262181-013

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ABSTRACT

The purpose of this study is to apply reservoir rock physics fundamentals for understanding the reservoir architecture for hydrocarbon potential. Sui Main Limestone is the main producer of gas in Qadirpur Gas-field area; hence most of the wells were bottomed up to this Formation. The research area lies administratively in Ghotki and Jacobabad districts of Sindh Province. This block is situated in the Central Indus Basin, bounded by the Indian Plate marginal zone in the west, Sargodha high in the north, Sukkar Rift in the south, and Indian Shield in the east. The basin is isolated by the Sargodha High and Pezu Uplift in the north from the Upper Indus Basin. Qadirpur field is comprised of three reservoirs, Sui Main Limestone (SML) and Sui Upper Limestone (SUL) of lower Eocene age and the Habib Rahi Limestone of Middle Eocene age. In the Lower Indus Basin, Paleocene and Eocene sediments record a period of sustained and widespread carbonate deposition of shallow water surfaces. Eocene period carbonates Habib Rahi, Sui Main Limestone and Cretaceous period clastics lower Goru Sandstone are the primary reservoir forming in the study region. The effective porosity for both wells (Qadipur-03 & 14) ranged from 13.4% and to about 21.7% with a water saturation ranging from 32.7% to 31%. Cross plots generated from petrophysical parameters confirms that's majority of values fall adjacent to the limestone and dolomite boundary which confirms the abundance of carbonates. Petrophysical analysis concluded that Sui main Limestone is acting as reservoir rock in both wells. Correlation of Sui main limestone shows the lateral width of Qadirpur 14 is more as compare to Qadirpur-03 well.

ACKNOWLEGDEMENTS

In the name of Allah, the most gracious, beneficent and most merciful. I am thankful to Allah Almighty for blessing me to complete my degree and accomplish my thesis. I am thankful and obliged to my supervisor Professor Dr. Muhammad Zafar for his guidance and encouragement to complete my thesis work. I am thankful to Dr. Said Akbar Khan, HOD E&ES department for facilitating this research. I am also thankful to Mr. Saqib Mehmood, Senior Assistant Professor, Department of Earth and Environmental Sciences, School of Engineering and Applied Sciences, Bahria University Islamabad for technical support and guidance.

I am also thankful to DGPC & LMKR for providing me data for my research work and software for petrophysical interpretations respectively.

Last but not the least, I am thankful to my parents and friends for their support during my entire endeavor for the completion of my MS program.

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SML	Sui Main Limestone
SUL	Sui Upper Limestone
I_{GR}	Index of Gamma ray
R_W	Resistivity of Water
SP	Spontaneous potential
LLD	laterolog deep
LLS	Laterolog shallow
MSFL	Micro-spherical focused log
R_{mf}	Resistivity of mud filtrate
Φm	Average effective porosity
Φs	Sonic porosity (μs/ft)
ΔT	Log's response
Δt_{mat}	Wave's travel time in matrix
ΔTf	Wave's time transit time in fluid

CHAPTER 1

INTRODUCTION

1.1. General Statement

The highlighting events that occurred in term of rock's chemical and physical properties and also conduct of rock is termed as Petrophysics. It has access the rock through the use of log estimation which contain a string series of estimation held by an equipment that is implanted within (Serra, 1984). Dispense of knowledge about the rock composition and components occurring beneath the surface environment. Gamma ray log, Self-Potential log helps in the interpretation of lithological information whilst study also involve determination of porosity if any knowing present. Permeability of rock is directly linked to effective porosity which is an essential feature of the reservoir rock. Petrophysical properties help in the calculation of Saturation of hydrocarbon for the reservoir rock.

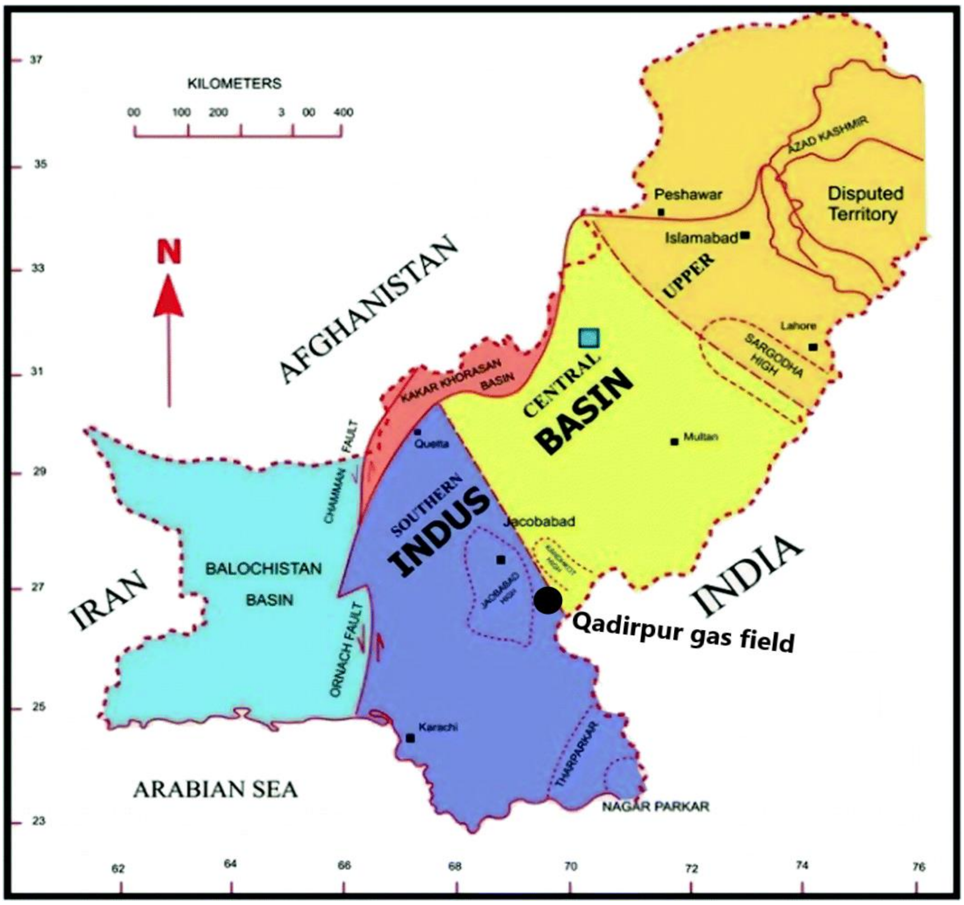

Figure 1.1. Map showing location of the study area (Wadood at el., 2020)

1.2. Introduction to The Study Area

The area of Qadirpur falls administratively in districts of Gotki and Jaccobabad of Sind Province. Within the 27° 55’ to 28° 09’ N and 69° 11’ to 69° 31’ E are the lattitude and longitude where the research region lies. Area of Qadirpur Block (Sind Province) is operated by OGDCL operates the area of Qadipur block (Sind Province) which is under their concession. Geologically, block is sited in the Central Indus Basin, bounded by the Indian Plate marginal zone in the west, in the northward lies Sargodha highs, to the southward located Sukkar Rift, and eastward falls Indian shields. The basin is isolated by the Sargodha High and Pezu Uplift in the north from the Upper Indus Basin (Kazmi and Jan, 1997). Middle Indus Basin is termed as big petroleum product bearing Pakistani Province, possible shale of Sembar formation behaving as source rocks, but shale’s of the Mughal-kot formation, Ranikot, Ghazij group and Sirki formations shales behaving as productive rocks contributing to potential source. Limestone of Sui Main and Sui Upper acting as reservoir as considered as main producers, while secondary reservoir source is Habib Rahi's limestone (Akhtar and Aamir, 2005). Shales of Ghazij group behave as capping rock for limestone of Sui main and Sui upper formations., whilst Sirki behave as capping rock over limestone of Habib Rahi as Sirki containing shales (Kadri, 1995). Statistical information relevant to reservoir of central Indus Basin is less published and often frequent. The wireline logging helps to predict reservoir capacity of the rocks drilled in hydrocarbon wells. A comprehensive detail is obtained to find the reservoir properties of the rock drilled using particularly representative number of wells which are selected to test drilled unit of rocks in these wells in the reservoirs in general and also in Qadirpur Block. Figure 1.1 shows the location of the study area.

1.3. Qadirpur field

On Jacobabad high’s northern flank, which to the south separates the sub-basin of Kirthar from the Sulaiman’s sub-basin to the north side, the Qadirpur area lies within the Central Indus basin. It lies on the western margin of the Indian Plate, flanking the Indian Shield in westward dipping position. Three reservoir comprises in the region of Qadirpur, containing limestone of Sui upper and limestone of Sui main formations of lower Eocene whereas Middle Eocene age of Habib Rahi Limestone. In the Lower Indus Basin, Paleocene and Eocene age and the Middle Eocene age of Habib Rahi Limestone. Carbonates of shallow water surface sediments records sustained and widespread deposition in the Lower Indus Basin, having Paleocene and Eocene age sediments. Foraminiferal limestone often and quite muddy sediments are mostly deposited. The Sui Main Limestone(SML) and sui upper limestone(SUL) reservoirs containing limestone of muddy nature, siltstone and having shale units which is splitted by the Sui Shale interval, having grown to a thickness of roughly 46 metres, interbedded to approximately decimeter to metre scale. Habib Rahi limestone acting as reservoir rock present above Ghazij shale, an argillaceous pattern of limestone sealed by the overlying Sirki shale. Central Indus Basin contain commonly widespread potentially source rocks and the possible source intervals for the gas at Qadirpur and local intra-formational sourcing may also be relevant which are included in lower cretaceous Sembar (Kadri, 1995).

1.4. Exploration history of Qadirpur field

Exploration related to petroleum in the Central Basin dates all the way back to 1983. Seismic 2-D survey carrying about 420 lines was performed in the 1990, 1992 and 1998 were carried out by OGDCL. Gas was discovered in year 1990, in Qadirpur region of Eocene limestones in Qadirpur area. To date today 57 wells in the Qadirpur regime have been drilled out of which about 25 wells have been drilled for extensive development of the field. Most of the wells bottomed up to the Sui main limestone formation as it is acting as reservoir rock, main gas producer in the area. Qadirpur-01 and Qadirpur X-02 drilled down to Pab, Ranikot formation of Cretaceous to Paleocene age (Ali et al., 2005). (Ali et al., 2005) from two wells which include Qadirpur-01 and 05 worked out the reservoir characterization. Qadirpur Gas field has no further published work to the reservoirs area, so a thorough study of the reservoir zones in the region of Qadirpur will be conducted to resolve this absence and to better assess formation’s drilled reservoir capacity of wells of this main sector.

1.5. Topography and Accessibility

Gas Field of Qadirpur is situated to an extent of about 08 km from region of Ghotki, from Sukkur to distance of about 70km in the direction of north-east and from east of Jacobabad is at distance of approx.. 100km in province of Sindh. N-5 Highway which is Pakistan's largest highway lead to easy access to this area, which connects directly to the Ghotki district, eventually leading to the Qadirpur field area. Sukkur airport by air is the closest airport with a range of about 65 kilometres north-eastward of the Qadirpur field. Indus Alluvial plains forms a uniform and predominantly flat topography having thick and sufficient amount of vegetation.

1.6. Objectives

Objectives of research are following which includes:

i. Petrophysical analysis of reservoir rocks of selected wells.
ii. Determination of environment of deposition.
iii. Lithological identification.
iv. Correlation of petrophysical properties of reservoir rocks between selected wells.

CHAPTER 2

GEOLOGY AND STRATIGRAPHY

2.1 General Geology of Central Indus Basin

Three major basins of Pakistan which are major classified as Upper, Middle and Southern Indus Basin of Pakistan. Central Basin is our main study field area. Dividing border between the Central and Upper Indus Basin is marked as Sargodha highs, whilst the Sukkur rift marks the divisional line between the Southern and Central Indus Basin.

2.2 Previous Work

Oblique Collision of Indian plate with Afghan plate result in formation of Central Sulaiman range where portion of Qadirpur block lies. It is claimed to be the widespread foreland fold-thrust belt greater than about 300km of the Himalayan Mountain system therefore, in the south connects with the Makran accretionary prism and main Himalayan continent-continent plate boundary occurring in the northern direction (Alleman, 1979; Bannert and Raza, 1992).

Ophiolites and flysch belt bordered the ranges of Sulaiman in the west part. During late Eocene, Oligocene continued to Miocene, Pliocene and early Quaternary is the period where Himalayan orogeny continually boosted relevant to Tectonic activity. (Naseem et al., 2003). From the Previous research history, the data showed that the strata of Paleozoic and roof thrusting occurred in Cretaceous period of Sembar Formation cause separation of sedimentary strata from the basement except which was present in the front facing portion of the Sulaiman Fold-belt occurred during Eocene sequences. Bannert et al. (1989, 1995); Bender & Raza (1995) concluded that collision between Indian and Eurasian plate causing of the regional level, North-South spreading, basement left-lateral strike-slip faults which is directly behind formation of segmentation of the Indo - Pakistan Plate. Because of broad scale distributive wrench faulting, probably narrow straight anticlines mostly regarded as flower structures present in East Sulaiman range (Kemal et al.., 1991).

2.3 General Tectonics

Pakistan is majorly divided into two sedimentary basins on the basis of genesis and having several geological history and events, and these basins are classified as Indus Basin containing Upper, Central and lower Indus basin and the other is Baluchistan Basin (Kadri, 1995). During the period of Cretaceous and Paleocene age alongside the strike-slip fault tectonic evolution of the Central Indus basin started to take place in (Kadri, 1995). Punjab Platform, secondly Suleiman depression and thirdly Suleiman Foldbelt are the three units which result in the formation of Central Indus Basin. During the time of collision between Indian and Eurasian plate which happened in post Eocene period result in formation of Suleiman Depression which is composed of longitudinally having alligned area of subsidence and also result in origination of large numbers of carved appealing tectonic structures. Ususally large Asymmetrical anticlines mostly steep in eastern direction and gently dipping from western flanks is constituent of westward flank of the Suleiman depression formed by North-South directed Zindapir fault region. Southern rim in the portion of Suleiman depression containing folded geometry which are oriented in the transversely direction constitutes the Mari-Bughti folded zone. Low level of relief containing anticlinal structures are present in the southern structure in this zone and are gently dipping whereas the Orogenically uplifted area which is attached to the folded section of the Sibi depression forms the Northern fold of the zone. Eastern Flank part of depression merges into Punjab platform whereas this eastern flank contains fluviatial and Alluvium clasts which are of Oligocene and of Pliestocene age. Mountain ranges of Suleiman lies in the western side of the Suleiman foldbelt as large anticlinal structures are present in these foldbelts mostly of them are well distributed and many act as reservoir rock which are exposed to the surface. Salt related dynamics during the Paleozoic strata cause Punjab Platform to appear in Monoclinal structure (Kemal, 1992) which can be prominently observable on Geological Map of Central Indus basin having stable geology, as it is Pakistan's most easternward feature of Pakistan and containing basement rocks (Ahmad et al., 1991). Direction of dipping is towards west and is located almost in the centre of the Indus Basin, Sargodha High bordering it in the northern direction whilst Rifts of Sukkur is bordered by Suleiman Depression in the direction directly to south and west. To south, the Punjab Platform lies on the top of Sukkur-rifting zone (Kandkot-Mari high) and is covered by Pre-cambrian age Sargodha Highs from the Northern side. As Punjab platform elongates toward Bikaner-Nagaur Basin of India in eastern side. During the Paleozoic era, gigantic sedimentary basin which lies within salt range and Aravalli ranges in the margin of south-western direction formed due to this platform (Aadil and Sohail, 2014). Non-orogenic movements result in restart of collision between Indian and Eurasian plate in the period of Pre-Cretaceous from east direction during the Paleozoic times and later on from westward side since the time of Mesozoic era. Since it is tectonically stable causes less folding and faulting and paleo-tenorrhaphy, salt tectonics causes different features related to structure (Raza et al., 1989). Monoclinal rock layer is what Punjab platform is composed of which are overlain by Indian shield rocks. Monoclinal strata is composed mainly of Cambrain to Siwaliks rocks and seismic strata shows the due to carving of basement rocks occurred in early Cambrian unconformity graben type structures are formed. The Cambrian and Permo-Carboniferous layers appear to onlap on Sargodha highs, according to recent significant stratigraphic variation (Kadri, 1995) (Figure 2.1).

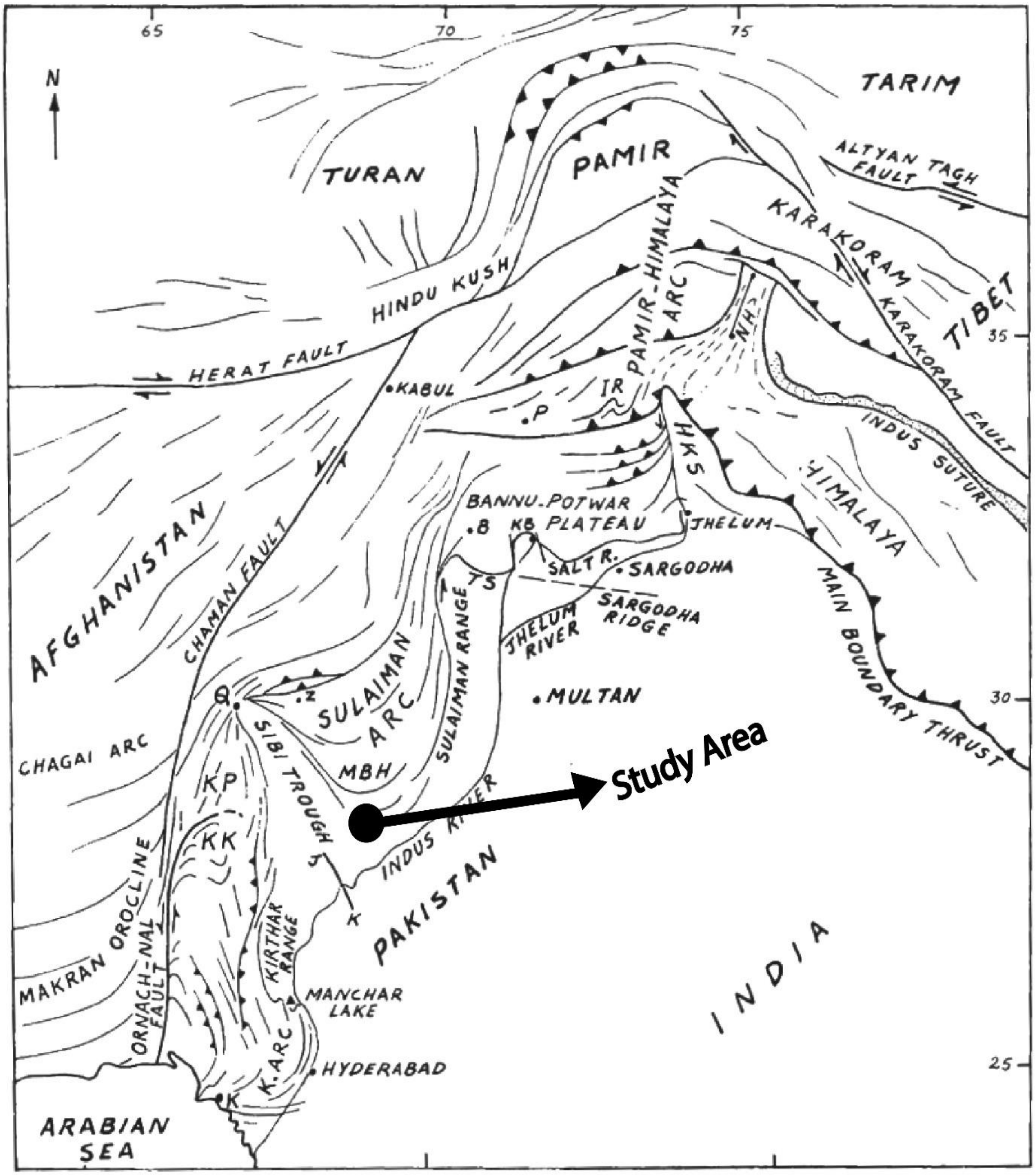

Figure 2.1. Tectonic map of Pakistan (Sarwar and Dejong., 1979).

2.4 Petroleum System

a. Source Rocks

Sembar acting as source rock Formation which lies in the anticipated region. In the Middle Indus Basin, Early Crecateous age Sembar Formation constituent of ` marine shales having detrital influx is widespread and majorly, known to be significant source of hydrocarbons production in the Middle and Lower Indus Basin. The root capacity of the shales of Goru, Mughalkot, Ranikot, Sirki and Pab formations is taken into account also.

b. Reservoir Rocks

Primary reservoir acting formations present in the study region constitute Eocene period carbonates of Habib Rahi, Sui Main Limestone and lower Goru sandstone which are of Cretaceous period clastic's (Kadri, 1995). Qadirpur and Badin gas fields are producing gas of which Sui main limestone is main source lies in the east direction. Uch and Sui fields are also in gas production from this horizon. Sands of Lower Goru and Sembar in Qadirpur Deep-01 shows good reservoir potential and in well Qadirpur Deep-01 one of the zone flowed gas from Sembar formation. Pab sandstone, Chiltan limestone and Sembar having sands are expected to be acting as secondary reservoir in the horizon. Hydrocarbon producing Formation in this horizon is evaluated to be Sui Upper Limestone.

c. Cap Rocks

Shales of Sirki Formation acting as cap rock for the Habib Rahi Limestone, (Kadri, 1995) and Ghazij perform as fuction of cap rock for Sui Main Limestone and Sui Upper Limestone.

2.5. Stratigraphy of Central Indus Basin

Central Basin do not contain the sediments of Ordovican, Silurian. Devonian and also of Carboniferous period; whereas sandstone mostly interbedded with dolomites and shales marks angular unconformity comprising rocks in this area is of Permian age and also mark boundary between Permian and Jurassic. The generalised stratigraphy of the study region varies from Jurassic to recent (Figure 2.2) at different stratigraphic stages, with non-deposition and erosion and there present about 8500 metres of thick sedimentary fill in the field. By drilling in study region Qadirpuur deep-01 well was drilled to Midddle

Jurassic, the Chiltan Limestone Formation known to be oldest stratigraphic unit reached. Sequence following from Sembar Formation to, Pab Sandstone includes sediments of Cretaceous origin. The Paleocene period Ranikot Formation and Dunghan Limestone is followed by the cretaceous phase. The Eocene sequential series contain Sui Group, shales of Ghazij, Limestone from Habib Rahi, Sirki, Pirkoh, and Drazinda, Gaj-Nari from Oligocene till the Miocene, Siwalik Group from Miocene to Pleistocene and newly to recently deposited Alluviam follow the Eocene succession. At base Permian, regional Unconformities are present, the middle Jurassic to Eocene strata present in the Punjab platform truncates below the root of Miocene and Pliocene unconformities eastward. In the basin, the sediment width rises westwards. Figure 2.2. Central Indus Basin's generalized stratigraphy.

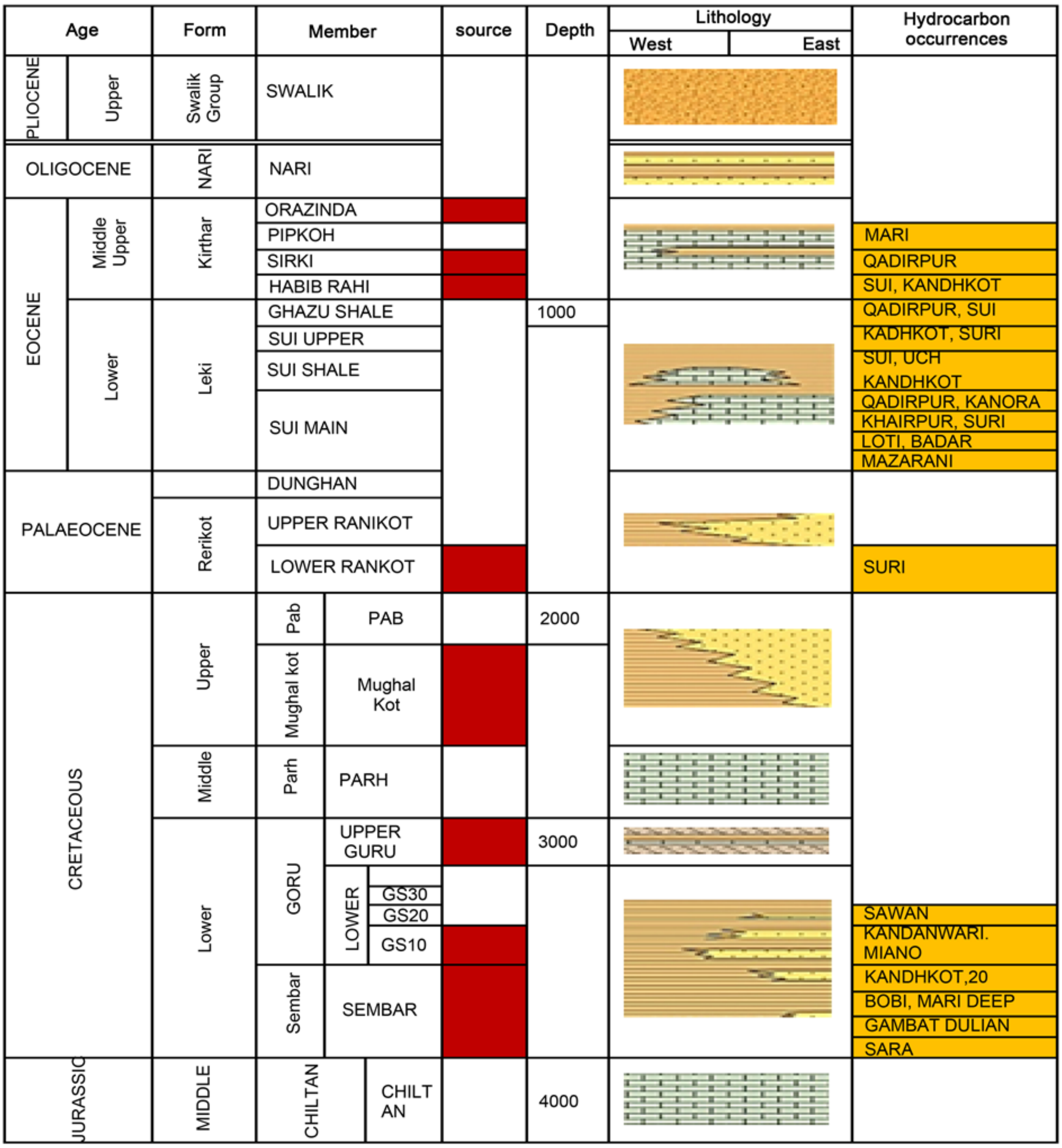

Figure 2.2 Generalized Stratigraphic column of Central Indus Basin (ENI, Pakistan).

2.5.1. Generalized Stratigraphy of study area

Generalized Stratigraphy of the area includes formations which are:

2.5.2. Alluvium

Alluvium is recorded 90m thickness with recent age. Unconformable lower contain of alluvium with Siwalik group. Depositional Environment of alluvium is the environment fluviatile. Alluvium is considered to be early material deposited which is obtained through sandstone of sand particles having sub-sequential claystone or clay particles. Sandstone is greyish-light, containing loosely medium to fine grains of sugar, somewhat chalky and rather micaceous, multi-color translucent in nature. Clay/claystone is typically light brownish having soft, sticky, water bearing and mildly calcareous nature.

2.5.3. Siwalik Group

The Siwalik Group was formed by the Stratigraphic Committee of Pakistan following Danilchik and Shah (1967), comprises formations which are Soan, Dhok Pathan, Nagri and Chinji Formation. So far, no kind of locality been identified following the group. However, Component formations and their localities are described. Siwalik group is also associated with portions of the Baluchistan Basin's Hinglaj and Gwadar formations (Cheema et al., 1977). However, thickness recorded of Siwaliks is about 390 meters This group set is predominantly composed of argillaceous clay content and sandstone of alternating beds, according to Denilchik and Shah (1967). The belt between the hills of the Sub-Himalayan and the Arabian Sea where these were placed, where after the Miocene period (Pascoe, 1963) a massive pile of freshwater sediments had begun to accumulate. This group, as a whole, consisted of molasses-type sediments of classical genesis. Typically, the lithology consists of red clay at the foot with subordinating sandstone (Chinji Formation), which overlies with minor clay of Nagri Formation by thick sandstone sequence. This is accomplished by a cyclical clay type particles and sandstone alternation (Dhok Pathan Formation), overlying conglomerate sand-clay series (Soan Formation) present on the top. Parts of the Northern Axial Belt Calcareous Plain, and in Parachinar area this group spread out in the Indus basin which is uniformly dispersed and thousands of metres high. In most localities, the Siwalik group's lower contact is conformable. Uncorformable communication with the Laki or Kirthar formations in few of the west sections of the Kirthar Province and Quetta region. Upper discontinued contact with that of Lei-conglomerate. Presence of vertebrate fauna suggests the Early Pleistocene Period of the Middle Miocene.

2.5.4. Gaj-Nari Formation

For the sequence of shale and sandstone with minor limestone Blandford in 1876 first used the term “Gaj series”. Formation is referred as Gaj because of river Gaj having shale with minor amount of sandstone and limestone (Williams, 1959). Variegated greenish grey shale is present which is mostly gypsiferous. Calcareous ferruginous brownish to greenish grey sandstone is present which is cross-bedded. Argillaceous and fossiliferous kind of limestone is present which is white yellowish to brown in colour. Nari Formation, is present at several locations containing minor conglomeratic beds having pebbles which is separately originating (Shah,2009). Sandstone with layer of clay is what Nari formation is composed of where sandstone of intermediate to coarse grain is creamy white to off-whitish in colour. Mostly, non-calcareous, unattached and some extent to temperately attached having sub-angular to sub-rounded form. Nari formation contain brownish colour clay (Shah, 1977). Gorag is conformable with its lower contact while Gaj Formation is conformable and transitional with upper contact of Nari Formation. Stratigraphic position and fauna mentioned above suggested Oligocene age for the Nari Formation.

2.5.5. Drazinda Formation

Kidwai and Hemphill in 1973 firs used the word "Drazinda Shale member" and upper clays which are chocolatey (Eames, 1952) were formulated as the Drazinda Formation by the Stratigraphic Committee of Pakistan after village named Drazinda, designated by Hemphill and Kidwai (1973) near Drazinda, the type locality. The formation is chocolaty, khaki and calcareous having minor marl which is fossiliferous interbedding in some parts, according to (Shah, 1999). Intercalation of Marl increases in upward section and containing gypsiferous in the upper portion. Brown interbeds of limestone which are fossiliferous present in middle section at some stages. In the Gomal Pass area, in the middle section, a dark green-grey calcareous sandstone unit about 10 m thick occurs. In the northern part of the Sulaiman foothills, Celestite nodules and gypsum stringers are popular. Spin Ghora Range in the south of Waziristan, alongside with Pirkoh and Domanda formation is region where Formation wedges out and terminates. In the Drazinda section, the approximate maximum thickness is 500 m, in the Domanda Post, around 400 m, and about 15meters only in Jandola region of South Waziristan.

Conformable below contact with Pirkoh Formation and Disconformable upper side with Chitarwata formation. Formation age is about middle Eocene.

2.5.6. Pirkoh Formation

Pirkoh Formation type locality designation is considered to be Pirkoh anticline. At Dhurwali Chur, a reference portion was suggested by N. K. Siddiqui PPL (1990). According to Shah (1999), fined grain lithology having thin and periodically bedded almost argillaceous nature is composed mostly of limestone, lightish grey to chalky white somewhere, buff to brownish, comprising the Pirkoh Formation. Minor beds of soft, limestone shallow in nature and Calcareous clsystone of dark greyish colour are typically found in the Formation. Pirkoh Formation forms regular continuous ridges and their thickness ranges from about 10 to 175 meters lies in the foothills of Suleiman ranges and in Bugti hill area. In the Pirkoh region, this Formation is 135 m deep, in the Zin region approximately 40 meters, in South Waziristan about 35 meters and near the Shinki Post in North Waziristan. Lower conformable contact with Domanda Formation and with Drazinda Formation upper contact is also conformable. Transitional both of contacts in nature. Creation age is reported to be the Middle Eocene.

2.5.7. Sirki Formation

Sirki Formation is made up of claystone particles with subordinating thin limestone existing at the top. Claystone is dark brown to light greenish grey in colour. It is mildly hard to be firm, fragile, sub-blocked to amorphous, often splintered, to somewhat non-calcareous in nature. Free calcite and traces of pyrite and are present. Creamy limestone, smooth to solid, amorphous to sub-blocky, rarely blocky, off-white to white in texture, sometimes blocky, microcrystalline to crystalline, chalky with plentiful fossils, off-white to white in texture. Conformable contact with both Habib Rahi and Pairkoh Formation at lower and upper part correspondingly. For this Formation, the Middle Eocene period is proposed.

2.5.8. Habib Rahi Formation

Stratigraphic committee of Pakistan formalised “Habib Rahi Member" of Meissner et al. (1968) and "Habib Rahi Limestone" of Tainshet al. (1959) to the Habib Rahi formation. Fomation consist of predominantly of dark grey brownish and cream, resistant limestone with weathering of white coat. Fine-grained limestone has thin bedded, mainly clay particles, grading into marl in certain areas. Thin beds of cherty present in the formation containing Assilina with ample marl present in the Formation upper portion (Shah, 1999). Formation width ranges from around 15 to 60 m. The Habib Rahi Formation in the Sulaiman Province contain Domanda Formation which overlies above it conformable and Baska underlies beneath it. The Habib Rahi Formation Age is from the early to middle Eocene.

2.5.9. Ghazij Group

Southeast of Harnai about 8km lies Spintangi Gorge is the region where Ghazij Group is located designated after Williams (1959). The Ghazij Group was defined by Shah (1999) as consisting mainly of shale with minor amount of conglomerate, limestone, with claystone and sandstone, as well as alabaster and coal that are locally of abundant economic interest. Limestone having pale green greyish or of light grey colour is present. In some places, highly calcareous sandstone is present as a subordinate component and sandy limestone grades. Area of Suleiman ranges and in the vicinity of Axial belt where shales of Ghazij group consists of dark maroon to olive, purple and yellow colour, and sandstone of brownish grey with arenaceous limestone interbedding and comglomerate is present. Shelly coarse grained sandstone which is carbonaceous. Thin conglomeratic beds are aligned with shale and sandstone. In the conglomerate, limestone and chert is existing as pebbles attained through primordial Axial Belt Formations. This group reported to exceeds to about 3300 meter of thickness at Mughal Kot. Maximum thickness to about 1220 meters at Zindapir, Bar Nai exceeds to about 160meter thickness, and in this located section, it is 590 m thick. Ghazij Group is consistent with very sharp contact with Dunghan Formation lies at the upper most contact. Kirthar Formation conformably overlying in Kirthar, Suleiman province and in the Axial Belt. Group upgraded by Shah, (2002). Shaheed Ghat, Baska, Kingri and Toi Formations are what Chamalang (Ghazij) group is composed of and proposed age appointed to this group is Early Eocene. which iclude Shaheed Ghatt, Baska, Toi and Kingrii formations. Proposed age of Ghazij group is early Eocene.

2.5.10. Sui Upper Limestone

Total thickness recorded in Sui Upper part limestone is about 107 meters. Limestone and claystone mainly comprise the formation. Fine greenish grey, medium to light greyish color claystone, slight-calcareous, moderately to firm which is soluble, claystone amorphous grading locally to marl, containing minor range of microfossils, often carbonaceus, also having disseminated traces of pyrite. Sub-blocky to blocky, microcrystalline, soft to solid in nature, limestone is normally off-white to light red brownish in colour lime mudstone, contain clay particles partially graded to moderately calcareous claystone with calcareous nature having abundance of fossils present.

2.5.11. Sui Shale Unit

Primarily consisting of shale with bands of limestone. The shale is calcareous in nature which is green to greyish, pyritic and sometimes fossiliferous. Off-white to white colour of limestone which is sub-blocky to amorphous texture smooth in nature. Sui main limestone underlies conformable. Thickness encountered in Sui Shale unit is about 88 meters approximately.

2.5.12. Sui Main Limestone

Recorded thickness encountered in Sui main limestone is about 110 meters. Tainsh et al. (1959) after the Village Sui gave the name of Sui Main Limestone and Stratigraphic Committee of Pakistan subsequently quoted it (Shah, 1977), but formal acceptation of this name is not announced yet. As it is not exposed to the atmosphere, Formation Subsurface section is named by Siddique (2004). PPL (Sui-36) is thus designated as the Sui Main Limestone type portion. The name of the productive formation was mentioned once in a text of Geological survey of Pakistan, Stratigraphy of Pakistan (Shah., 1997). Between shales of Shaheed Ghat and lying beneath Dunghan Formation do not contain any intervals of Eocene limestone surface section accessed of geological survey. The analysis of Sui Main Limestone lithology is focused on the examination of core evidence. Shallow-water shelf carbonates, precipitated on a depositional platform presents Sui main limestone except Suleiman range to North of Zin-Loti pattern. Shale broadly dispersed with thin carbonate intervals mostly of Habib Rahi and Pirkoh formations of middle to late Eocene deposition lies in the region north of the Zin-Loti trend and all over Sulaiman, where rapid drowning and transgression occurred at the beginning of the Eocene. The thin sequence of shale directly overlaps the Dunghan limestone of Paleocene age and claimed that due to its variable conduct, Sui main calcareous is an upper part of Dungan calcareous. South of Sui, shallow-marine conditions existed towards the Kandhkot and Qadirpur regions, increased clastic influx as carbonates continued and accumulated as Sui Main Limestone. Basin structure like that the base portion of the Sui Main was deposited in the Sui area in shallow and more limited (lagoonal) environments and constituted a low-stand system tract. In shallow marine shoal carbonate depositional settings, the upper portion was deposited, reflecting a high-stand system tract. Conformable and transitional upper contact with Shaheed Ghat whilst lower contact conformably lies with Dunghan Formation. Early Eocene is age propose to Sui Main Limestone.

2.6. Borehole stratigraphy of Study Area

Qadirpur 03 well is situated at latitude 28° 05’ 15.10” N and longitude 69° 20’ 40.38” E direction. Total depth encountered in this well is about 1405 meters which is ending in Sui main limestone (SML) potentially acting as reservoir, whereas Qadirpur 14 is located at latitude 28° 4’ 12.37” N and longitude 69° 23’ 32.59” E direction. Total depth encountered in this well is about 1866 meters which is ending in Sui Main limestone and also acting as potential reservoir zone. Table 2.1 is displaying the borehole stratigraphy of Qadirpur 03 and Qadirpur 14.

Table 2.1 Formation tops and thickness in Qadirpur wells

Formation	Age	Qadirpur 03 Tops (m)	Qadirpur 03 Thickness (m)	Qadirpur 14 Tops (m)	Qadirpur 14 Thickness (m)
Alluvium	Recent	0	96	0	90
Siwaliks	Middle Miocene	96	404	90	390
Nari	Oligocene	500	204	480	250
Drazinda	Middle Eocene	704	69	730	60
Pirkoh		773	107	790	155
Sirki		880	50	945	66
Habib Rahi		930	84	1011	168
Ghazij	Early Eocene	1014	206	1179	382
Sui Upper Limestone		1220	60	1561	107
Shale Unit		1280	53	1668	88
Sui Main Limestone		1333	72	1756	110
Total depth(TD)		1405		1866	

CHAPTER 3

MATERIAL AND METHODOLOGY

3.1. Employed Methodology

Methodology adapted for the purpose of research include following steps which are:

1) Well selected for determination of Petrophysical analysis.
2) Collection of data from wells.
3) Well logs for the purpose of Petrophysical analysis.
4) Determination of depositional environment using Gamma ray log.
5) Lithologies will be identified using cross plots.
6) Correlation of well logs.

Figure 3.1 displaying the detailed adapted methodology for research purpose.

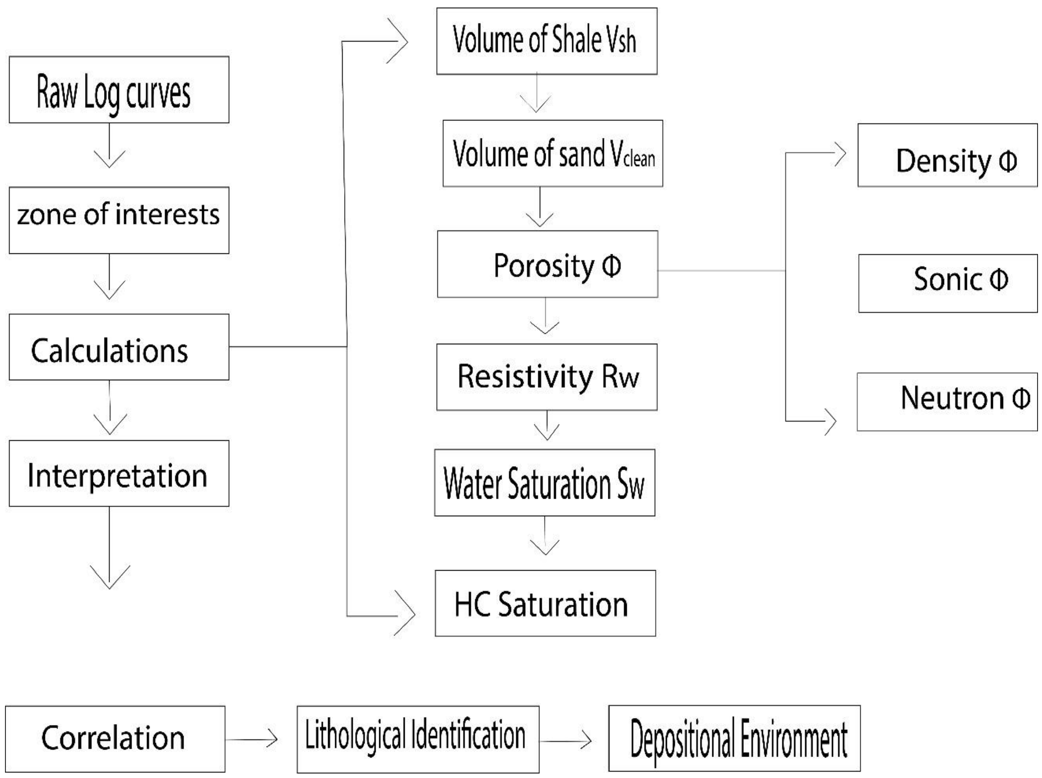

Figure 3.1. Employed methodology for research.

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3.2. Petrophysical Study

Reservoir study and properties related to cap rock including interaction of fluids with them whether gases, Hydrocarbons, or aqueous solutions form based on fundamental and applied sciences is termed as petrophysics. Properties in term of chemical and physical including fluids interactions in subsurface is studied by petrophysics (Rider, 1986). Identifying and calculation of reservoir's fluid quantity in rock is called petro-physics. By mean of wireline logging and laboratory testing of reservoir and cap rock is also termed as Petrophysical studies (Buryakovskyet al., 2012).

Table 3.1 Well Logs and their applications.

Fluid Dynamics log	**Lithology logs**	**Porosity Logs**
Resistivity	Gamma Ray	Sonic
	Spontaneous Potential(SP)	Density
		Neutron

Petrophysical parameters were determined using various log curves as these variables help in reservoir and source rock characterization.

1. Saturation of Hydrocarbons

2. Shale volume.

3. Saturation in term of water.

4. Porosity.

Table 1.2 Logs and their Functions.

Logs	**Function**
Gamma-Ray	Lithological identification and correlation
Sonic	For porosity and lithology
Caliper	For measuring borehole diameter
Neuron-Density	For porosity estimation
Self-Potential	For measuring resistivity of Water
Resistivity	Correlation and resistivity
Density	For lithology, porosity and correlation purpose

3.3.Petrophysical properties

3.3.1. Determination of Volume of Shale (V_{sh})

Using a Gamma Ray (GR) log, the shale volume is measured. The Gamma Ray log estimates the natural radiation generated by the formation of the radioactive minerals present. The shale volume will help in studying sands occurring at shallow depth. GR log values between an API of 0-150. Through gamma ray log accessing volume of shale is primary approach (Schlumberger following equation, 1974) is computing the Index of gamma ray.

$$I_{GR} = V_{sh} = (GR_{log} - GR_{min}) \ / \ (GR_{max} - GR_{min})$$

Where,

I_{GR} = Index of Gamma ray

GR_{log} = Value of Gamma Ray at required interval

GR_{max} = Maximum Gamma ray

GR_{min} = Minimum Gamma ray

Following equation will be applied during calculating volume of clean lithology (Schlumberger, 1974).

$$1 - V_{sh} = V_{clean}$$

3.3.2. Density porosity (D_{PHI})

Density log helps to calculate the density porosity of formation. Bulk density of formation is determined by density log based on gamma ray counts sent through the source and received back on the detector. Density log scale ranges from 1.95 – 2.95 gm/cm^3. Following will be applied equation for the calculation of formation porosity (Schlumberger, 1989).

$$\Phi = (\rho_{mat} - \rho_{b}) \div (\rho_{mat} - \rho_{fld})$$

Whereas,

Φ = Density porosity

ρ_{fld}= 1.0 gm/cm^3

ρ_{mat} = 2.710 gm/cm^3

ρ_{b}= Log's response of particular interval

3.3.3. Average Porosity (P_{hiA}):

Average of Density and neutron position is termed average Porosity. Estimation of average porosity is calculated through equation(Serra, 1984). The following formula will measure the average porosity of the formation.

$$A_{PHI} = \{(N_{PHI}) + (D_{PHI})\} / 2$$

3.3.4. Effective porosity (E_{PHI}):

Total amount of interconnected pore spaces in the rock is labelled as formation's effective. Effective porosity in case of no caving will be,

$$E_{PHI} = (V_{clean}) \times (A_{PHI})$$

Effective porosity in case of caving is calculated through formula shown below

$$E(_{PHI}) = (S_{PHI})(V_{clean})$$

3.3.5. Sonic porosity:

Sonic log helps us to determine sonic. Total time taken by wave from source to reaching the detector is measured by sonic log. 0-150 µs/ft is the scale of sonic log. Equation described below help in estimation of Sonic porosity (Wyllie et al, 1958).

$$\Phi S = \Delta T - \Delta t_{matrix} / \Delta T_f - \Delta t_{matrix}$$

Where

Φs = Sonic porosity (µs/ft)

ΔT = Log's response

Δt_{matrix} = Wave's travel time in matrix

ΔT_f = Wave's time transit time in fluid

3.3.6. Neutron Porosity (P_{hiN}):

Neutron porosity derived through neutron log. The hydrogen concentration in the formation is a direct reaction, since it estimates formation's sum of nuclei after bombardment. Since oil has large amount hydrogen atoms and gas concentration is limited, low porosity in case of gas and N_{PHI} values. Neutron porosity in case of oil would be high that are calculated directly from the log. Typically, gas is evaluated through this log.

3.3.7. Water saturation (S_w) and hydrocarbon saturation (S_h):

Water saturation of rock is termed as water occupying the rock's pore spaces whilst of same rock the remaining amount of hydrocarbons present within pore spaces is termes as hydrocarbon saturation. Water saturation is calculated through Archie's equation. (Archie, 1942).

$$S_w = [(a/\Phi^m)\ (R_w/R_t)]1/n$$

Where

S_w= Water's saturation

R_w= Formation's water resistivity

Φ_m= Average effective porosity

m = cementation factor: (taken as 2)

a = constant (accounted as 1)

n: Exponent of saturation

R_t= LLD response

Saturation of hydrocarbons is calculated through equation given below.

$$(1-S_w) = S_h$$

3.3.8. Resistivity of water

Resistivity of water estimated with help of the SP method.

$$G.G= B.H.T – S.T/\ Total\ depth$$

Where

B.H. T=Borehole temperature

S. T= Surface temperature

Steps include for determination of water resistivity are:

1. First of all, calculate formation temperature.

Formation temperature= (Formation tops x G.G) + Surface temperature

2. Convert Resistivity of mud filtrate measured at surface temperature to Resistivity of mud filtrate at formation temperature using Gen-9 chart (figure 3.2).

3. Convert R_{mf} to R_{mfeq} with the help of SP-2 chart (figure 3.4).

4. With the help of SP-1 chart R_{weq} would be determined (figure 3.3).

5. At last, conversion of R_{weq} to R_w using SP-2 chart.

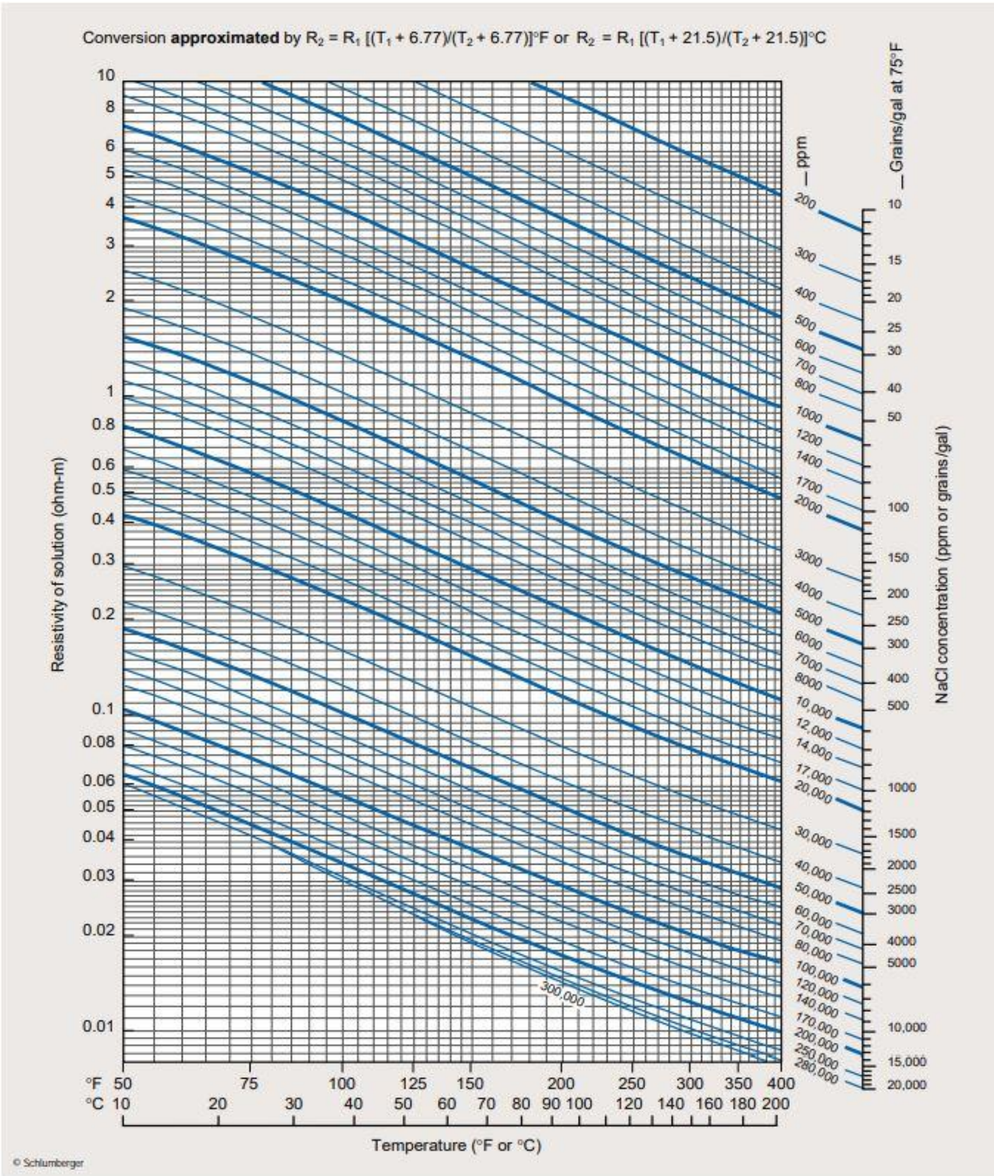

Figure 3.2. Schlumberger Gen-9 chart

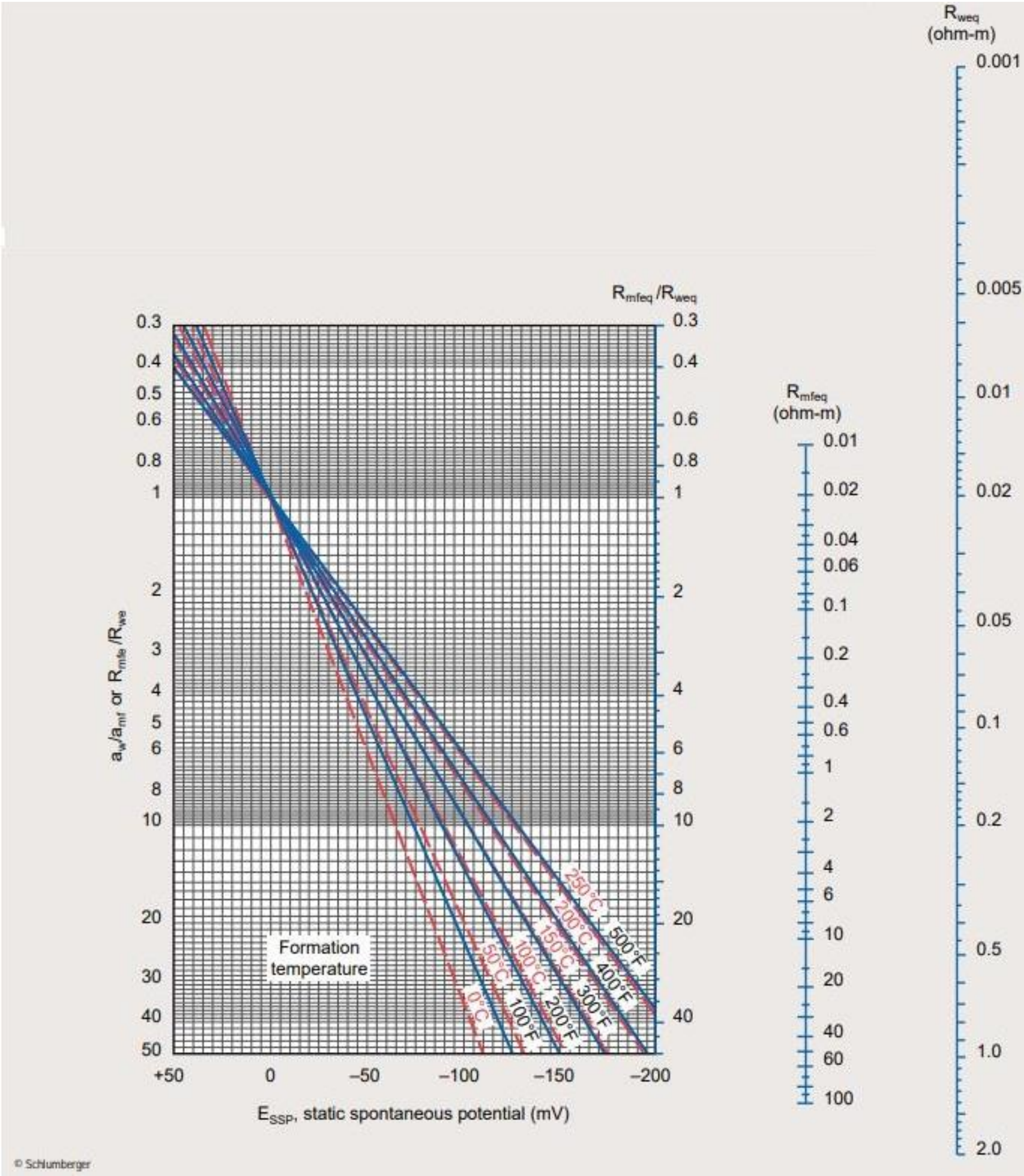

Figure 3.3. Schlumberger SP-1 chart

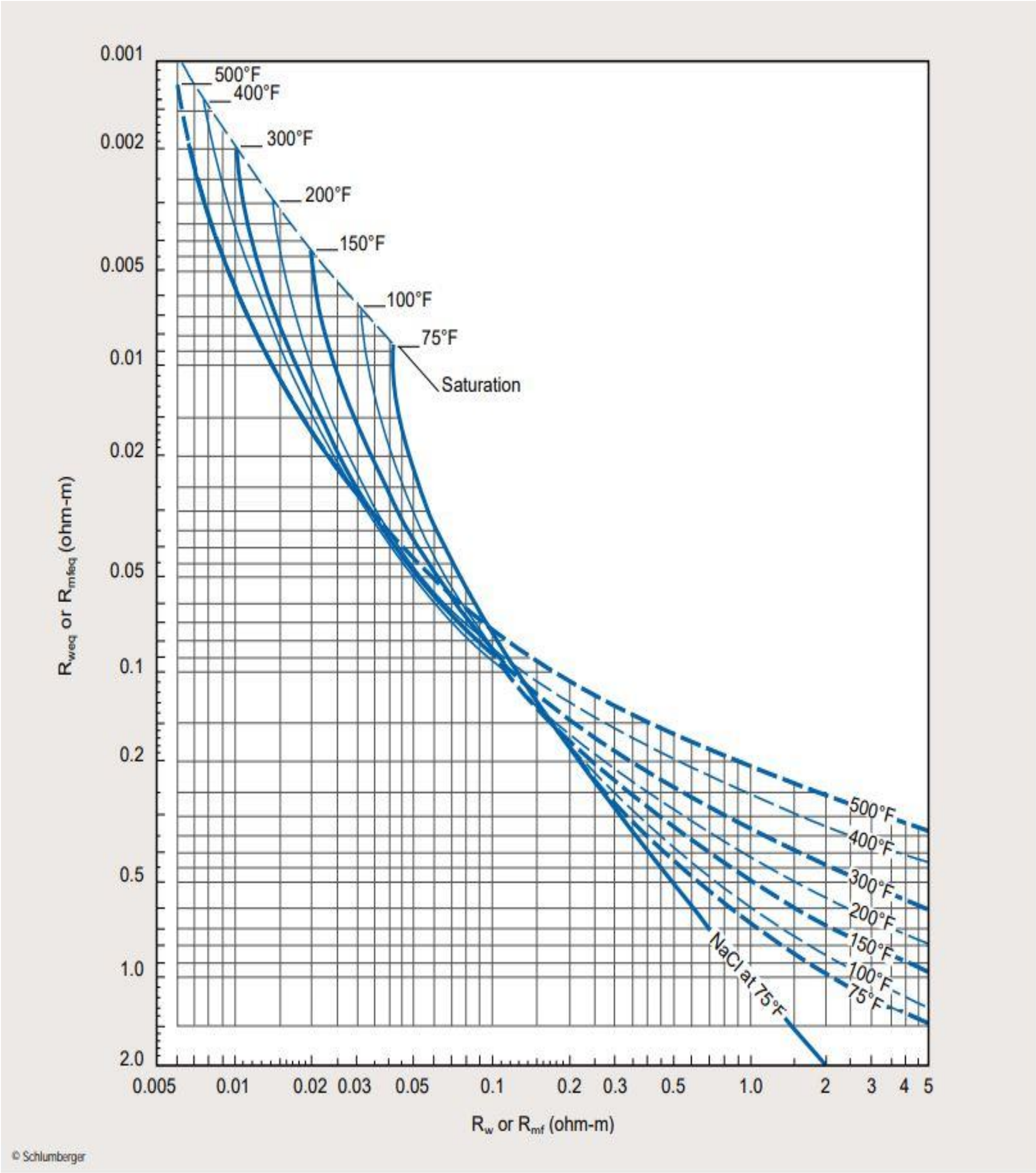

Figure 3.4. Schlumberger SP-2 chart

3.3.9. Net Pay and Pay:

Economically producible hydrocarbons present in portion of reservoir is called pay. Pay sand or pay zone is also known as pay which the term shows the capability of paying an income. Gross pay is overall interval in which pay sections occurs. Gross pay meeting local criteria in term of smaller portion of pay such as minimum amount of porosity, permeability and saturations of hydrocarbons is called net pay.

CHAPTER 4

PETROPHYSICAL INTERPRETATION

4.1.Interpretation and Results:

Techlog software used to carried out the Petrophysical analysis of selected wells. Estimation of parameters based upon equation and interpretation of log curves use for data analysis. During acquisition of data in term of (. las file) extension it was observed that the following logs were involved (Table 4.1).

Table 4.1. Data acquisition gained through logs run in selected wells.

Well Logs	Qadirpur-03	Qadirpur-14
Gamma Ray	✓	✓
Spontaneous Potential	✓	✓
Resistivity	✓	✓
Neutron log	✓	✓
Density log	✓	✓
Sonic log	✓	✓
Caliper	✓	✓

4.2.Petrophysical Analysis of Qadirpur-14 well

4.2.1. Sui Main Limestone of Qadirpur 14

Two zones of interest were marked in the reservoir rock of Qadirpur 14 well containing hydrocarbon potential. Zone 1 ranges from 1810-1825 meters interval and zone 2 interval ranges from 1832-1848 meters in Sui main limestone. Petrophysical logs helps in reservoir evaluation of well. From the response of gamma ray log both zone of interest shows that Formation is mostly containing limestone as gamma ray readings are less which indicate that Formation is clean. Resistivity log interpreted shows that in the interval between 1810-1825 meters, resistivity values are increasing, whereas in the zone 2 resistivity values are almost uniform and also in both zone of interests there is separation between LLS and LLD log indicating sweet spots.

Resistivity of water is approached for measuring saturation of water. If high resistivity indicates more saturation of water so less hydrocarbon saturation.so the most reliable method in calculating water resistivity is through SP method. As Formation temperature is about 134.9^0 F. Resistivity of mud filtrate at Formation temperature is o.65ohm-m where Rmf_{eq} is about 0. 45ohmm.Lastly, Rw_{eq} is converted to Rw using SP-2 schlumberger chart which calculated resistivity of water of 0.043 ohm-meter which is quite less.

Since sonic and neutron density log used to determine Formation porosity as Formation contain washouts which were determined with the help of caliper log. Average effective porosity calculated through sonic log ranges to about 9.5% in zone-01 and in zone-02 effective porosity is about 10.5%. Zone-01 average gamma ray clean value ranges to about 91.2% and average volume of shale calculated was about 8.8% approximately. Saturation of water calculated through petrophysical analysis is about 44 % as water saturation is defined, and calculated hydrocarbon saturation estimated to about 69% approximately.

Zone-02 contains average gamma ray values ranges to about 81.8% and average shale volume of about 18.2 percentage. Saturation of water in zone-02 is calculated about 44% and hydrocarbon saturation ranges to about 56%. Lower density values are due to presence of heavy minerals in it which require mud log for complete interpretation so, neutron and density cross-plots was unable to identify lithology in cross plots. So petrophysical analysis shows that Sui main limestone Formation is capable of producing hydrocarbons. Pay zone's petrophysical interpretation of Qadirpur-14 well showing in table 4.2 and petrophysical logs in figure 4.1.

Table 4.2 Petrophysical interpretation of Pay zone in Qadirpur 14.

Formation (SML)	**Zone-01**	**Zone-02**
Depth Interval (m)	1810-1825	1832-1848
Thickness (m)	15	16
Net Pay (m)	14.2	15.5
Avg. V_{sh} (%)	8.8	18.2
Avg. V_{clean} (%)	91.2	81.8
$R_{w\ (ohm\text{-}m)}$	0.043	0.043
Effective Porosity (%)	9.5	10.5
Avg. S_w (%)	44	34
Avg. S_h (%)	56	66

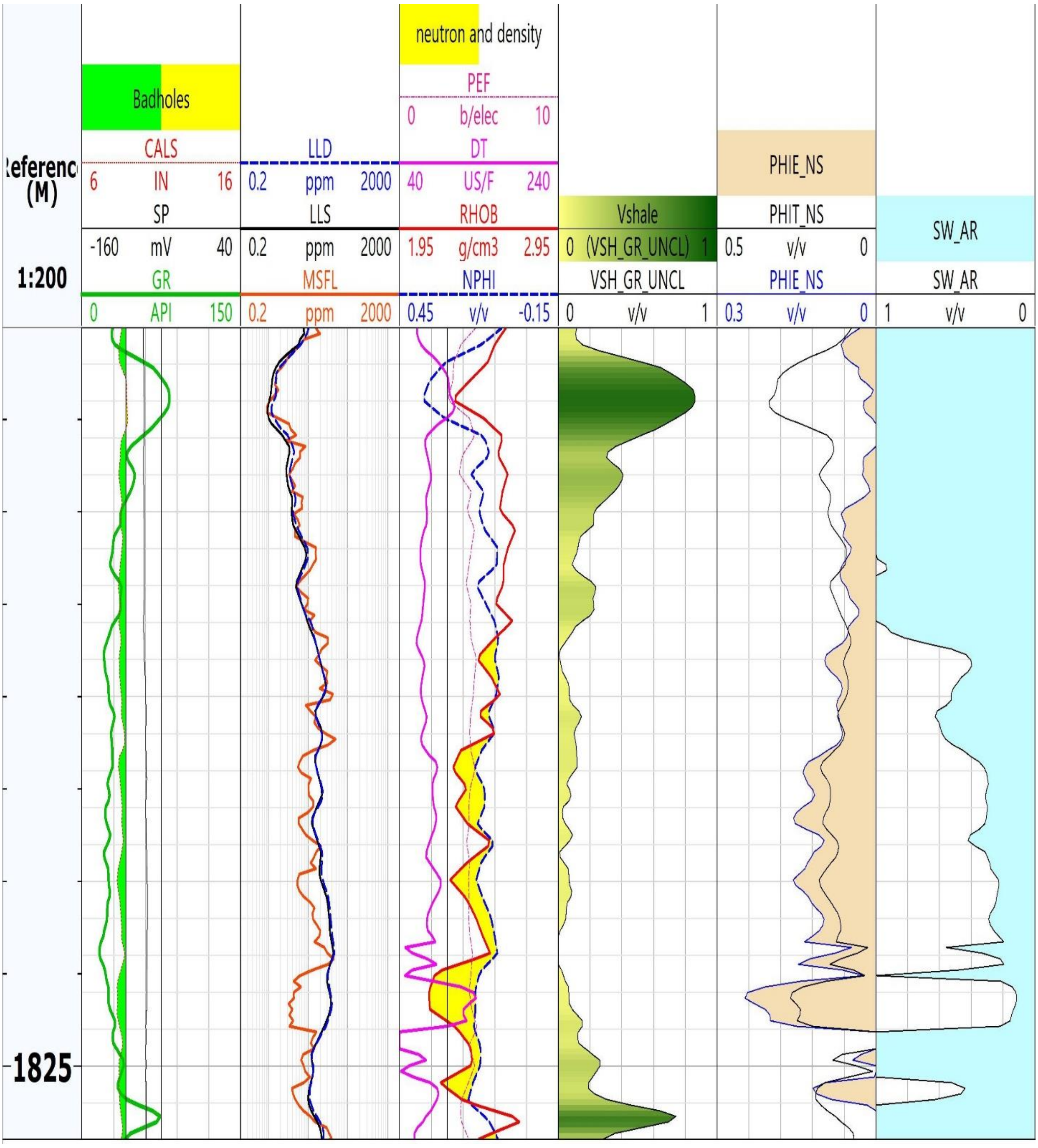

Figure 4.1. Sui main Limestone zone-01 of Qadirpur 14.

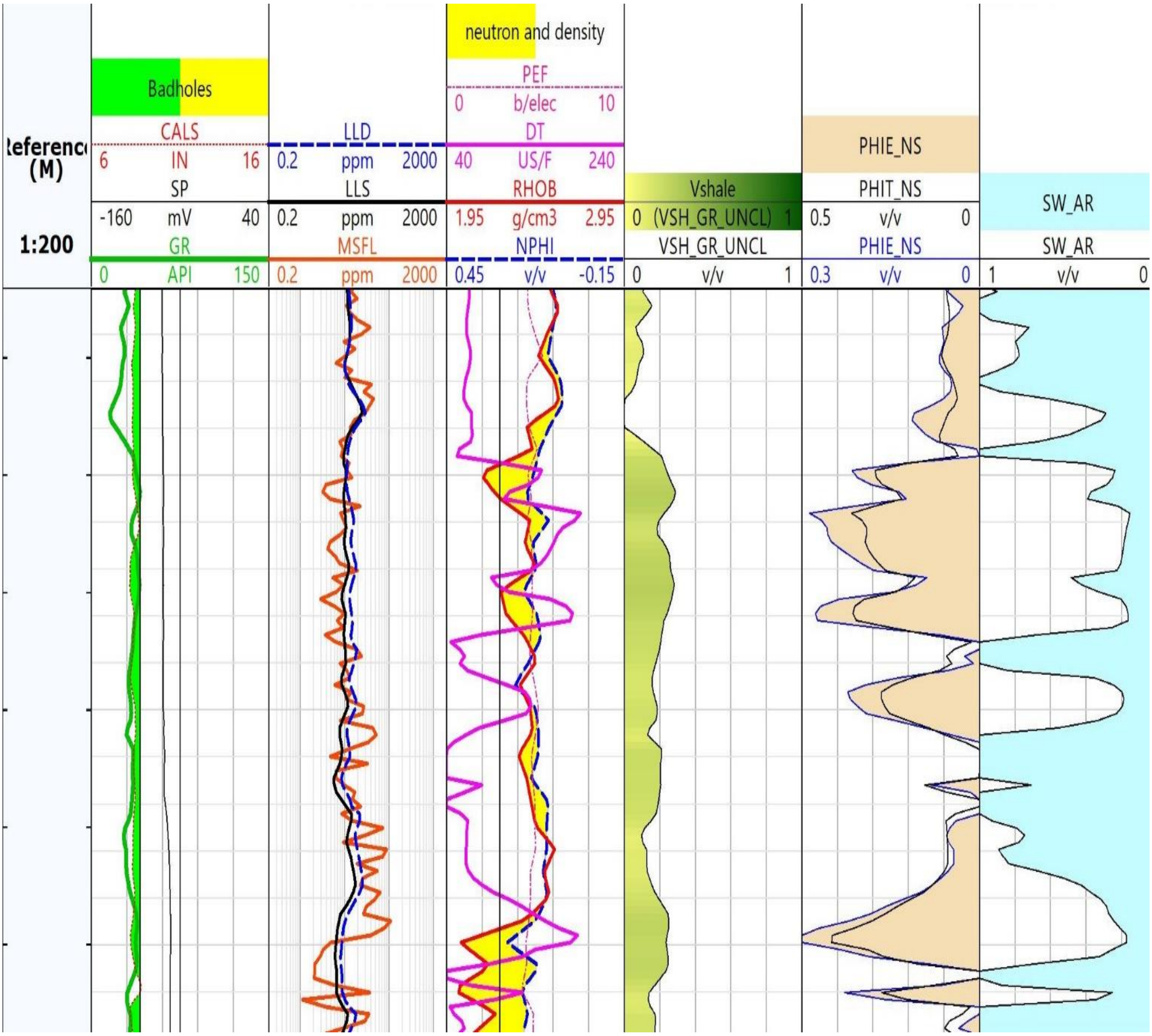

Figure 4.2 Sui main Limestone zone-02 of Qadirpur 14.

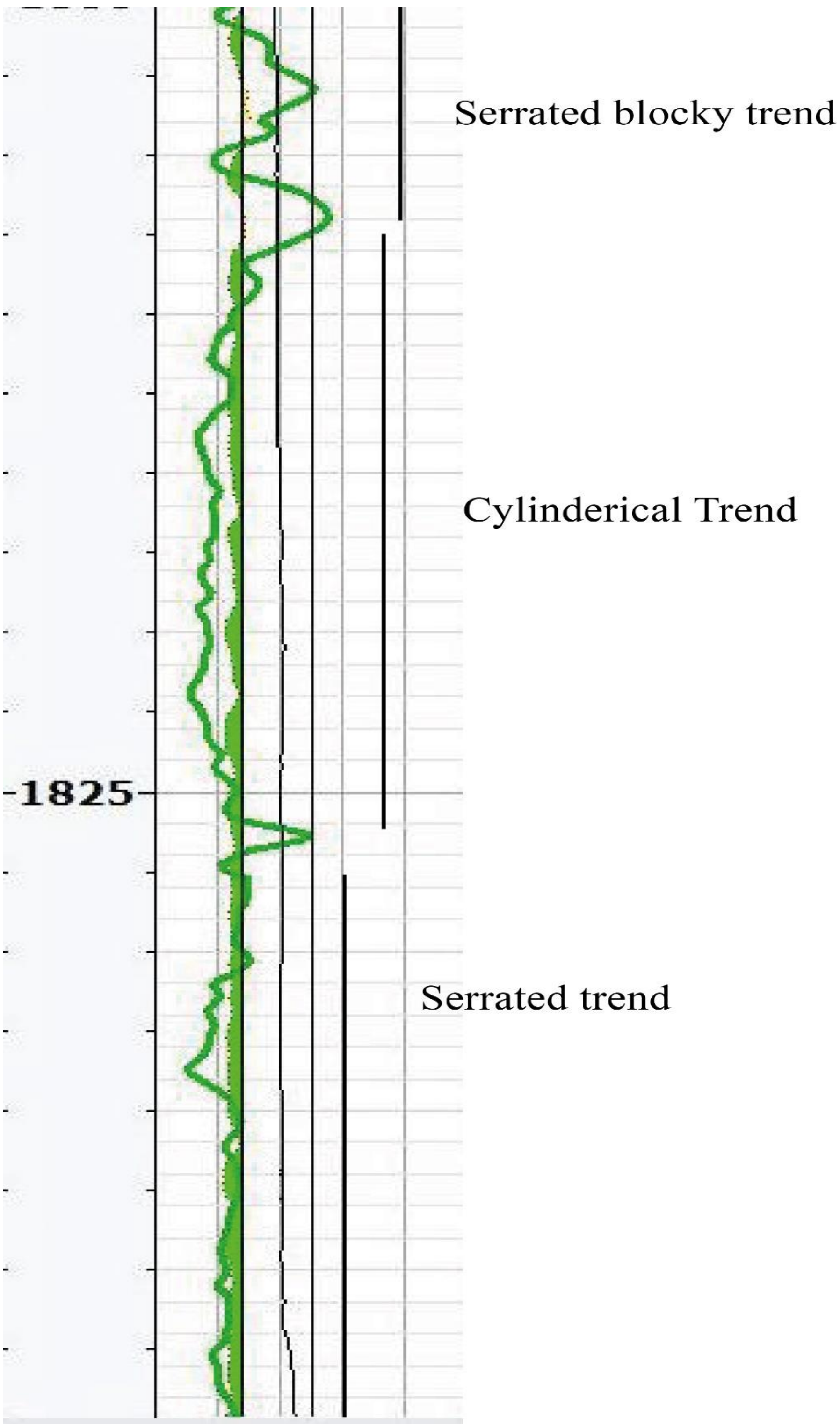

Figure 4.3 Trend line for the Depositional Environment determination of Sui main limestone Qadirpur 14 well.

From GR curves, interval between 1858-1830 meter represents their present Serrated trend in the form of saw teeth pattern. Going upward from 1825-1810m their present cylindrical trend. At the top of Formation from 1810 meters to upward shows serrated blocky trend having massive blocky limestone. From the log trend it is interpreted that Sui main limestone formation in Qadirpur 14 well represent shallow marine environment of deposition.

4.3. Petrophysical Analysis of Qadirpur-03 well

4.3.1. Sui Main Limestone of Qadirpur-03

Zone of interest marked in the reservoir rock of Qadirpur-03 well containing hydrocarbon potential. Zone interval ranges from 1362-1400 meters interval in Sui main limestone. Petrophysical logs helps in reservoir evaluation of well. From the response of gamma ray log both zone of interest shows that Formation is mostly containing limestone and shale as gamma ray values shown in figure 4.3. High resistivity values observed through resistivity log shows that in the interval between 1370-1400 meters, and also in there is separation between LLS and LLD log, also neutron and density porosity values are overlapping and marking a separation between them indicate the presence of hydrocarbons. As you can see in figure 4.3.

Resistivity of water is approached for measuring saturation of water. If high resistivity indicates more saturation of water so less hydrocarbon saturation.so the most reliable method in calculating water resistivity is through SP method. As Formation temperature is about 127.5 F. Resistivity of mud filtrate at Formation temperature is 0.69 ohm-m where Rmf_{eq} is about 0. 42 ohmm. Lastly, Rw_{eq} is converted to Rw using SP-2 schlumberger chart which calculated resistivity of water of 0.0310 ohm-meter.

With the help of sonic log porosity of Formation is calculated and hole diameter is almost uniform which is measured through caliper log. Average effective porosity calculated through sonic log ranges to about 17.6%. The average gamma ray clean value ranges to about 76.2% and average volume of shale calculated of pay zone was about 23.8% approximately. From 1373-1400meters interval is marked with net pay of 20.9 meters precisely. Saturation of water calculated through petrophysical analysis is about

29.1 % as water saturation is defined, we can calculate hydrocarbon saturated through simple equation.

$$1\text{-}S_w = S_h$$

So, the hydrocarbon saturation estimated to about 70.9% approximately. Lower density values are due to presence of heavy minerals in it which require mud log for complete interpretation. So petrophysical analysis shows that Sui main limestone Formation is capable of producing hydrocarbons. Figure 4.3. showing zone of interests and well logs run in Sui main limestone of Qadirpur-03 well. Pay zone's petrophysical interpretation of Qadirpur-03 well showing in table 4.3.

Table 4.3 Petrophysical interpretation of Pay zone in Qadirpur-03 well.

Formation	**Sui Main Limestone**
Depth Interval (m)	1373-1400
Thickness(m)	27
Net Pay(m)	20.91
Avg. V_{sh} (%)	23.8
Avg. V_{clean} (%)	76.2
R_w	0.0310
Effective. Porosity	17.6
Avg. S_w (%)	29.1
Avg. S_h (%)	70.9

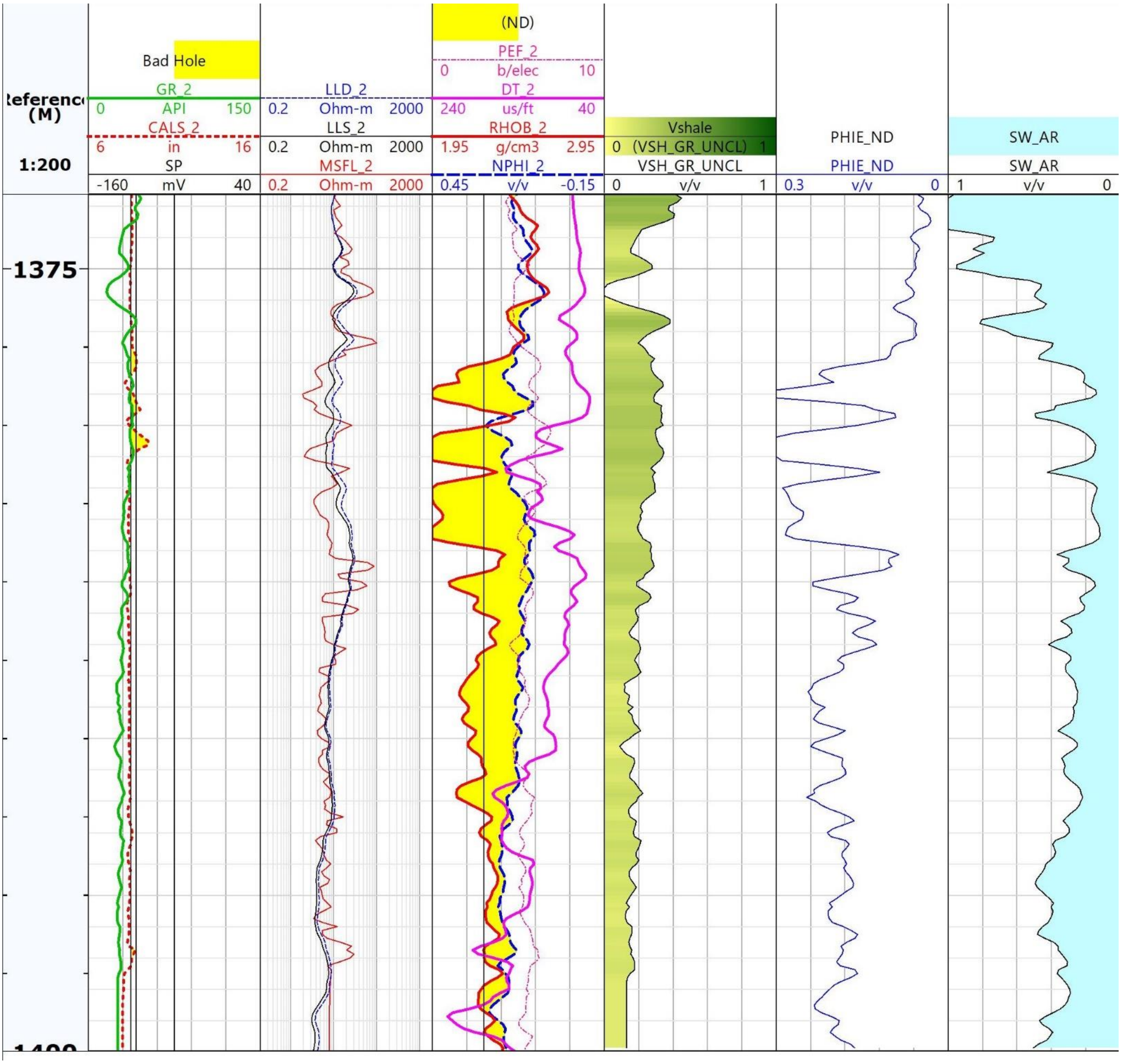

Figure 4.4 Log’s response and marked zones of interest of Sui main Limestone in Qadirpur-03.

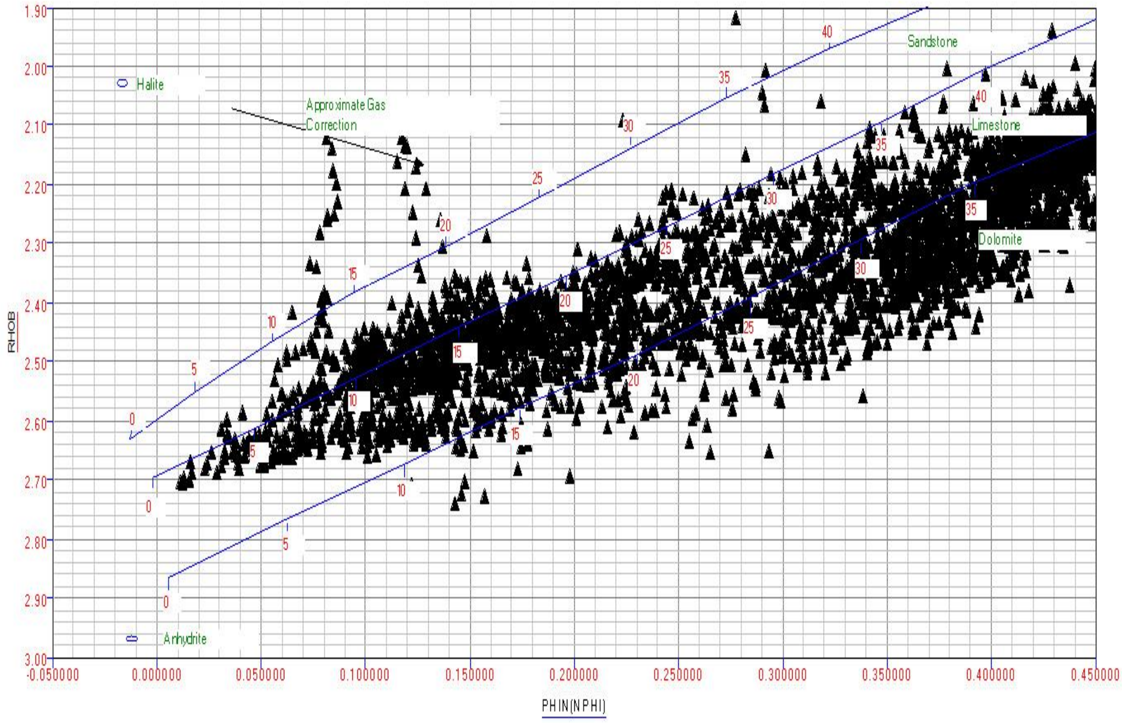

Figure 4.5 Cross plot between neutron and density for lithological identification in Qadirpur-03.

Neutron and density log calculations were used to develop a cross plot for Qadirpur-03. Schlumberger CP-1C and CP-1D, neutron vs bulk density chart was used to generate the cross plot. It was observed from the results that majority of values fall adjacent to the limestone and dolomite boundary which confirms the abundance of carbonates in the interpreted zone. In addition to this GR values also confirm the abundance of limestone present in the Sui main limestone formation. Figure 4.4 explaining cross plot between neutron and density for lithology identification in Qadirpur-03 well.

From GR log, 1400-1378 shows serrated trend present in the form of saw-tooth shape. Going upwards from 1377-1371 meters' gamma ray curve shows cylindrical trend representing fluvial channel. From 1369-1345 meters GR curve showing serrated blocky trend having massive limestone representing shallow marine environment of deposition of Sui main limestone interpreted in Qadirpur 03 well. Figure 4.5 showing Trend line for the Depositional Environment determination of Sui main limestone Qadirpur 03 well.

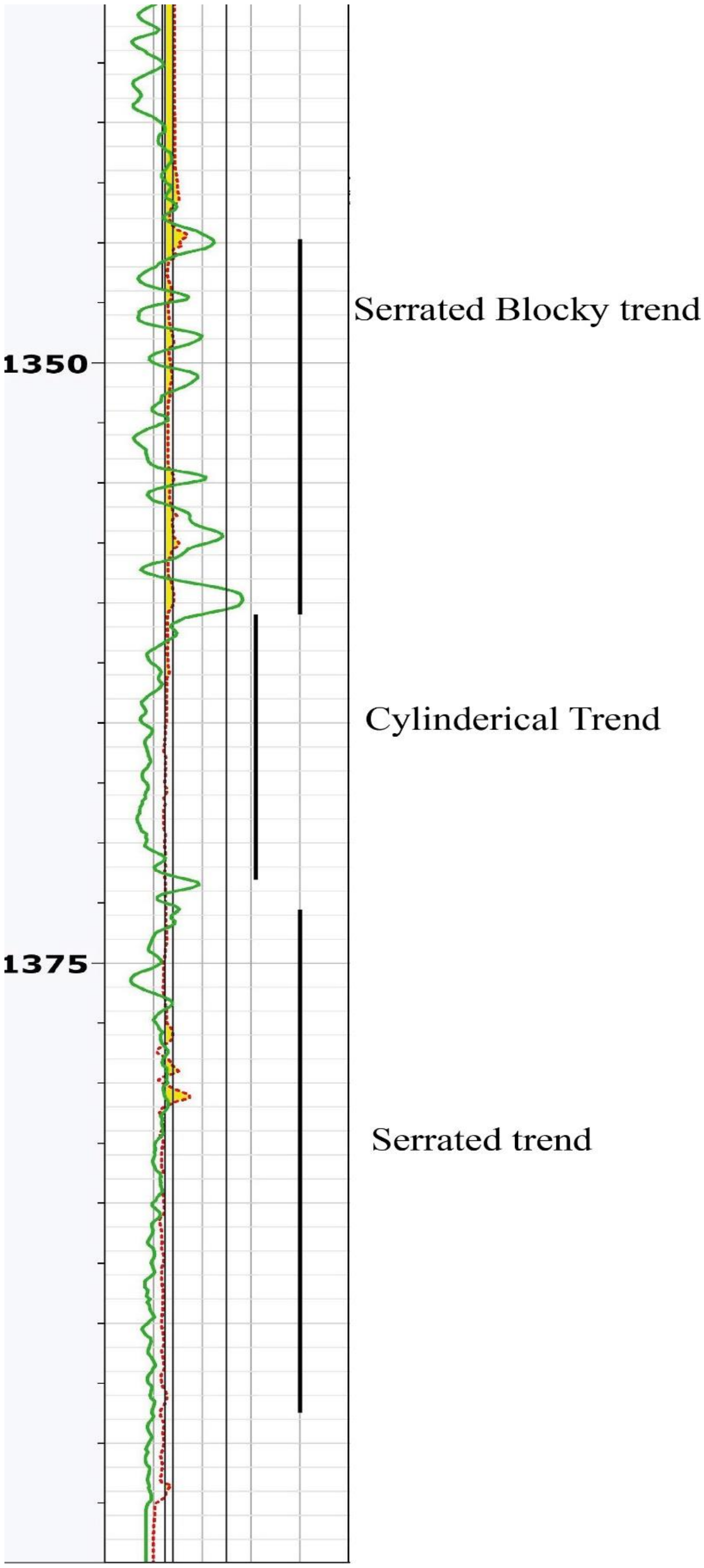

Figure 4.6 Trend line for the Depositional Environment determination of Sui main limestone Qadirpur 03 well.

4.4.Correlation of wells:

To better understand the distribution including nature of reservoir facies present in the field between Qadirpur-03 and Qadirpur-14 well stratigraphic correlation was established. Shale unit is acting as barrier between Sui Main Limestone and Sui Upper Limestone which are uniformly thick in both wells. In both wells, no major lateral variation is exhibited in log pattern by Sui main limestone.

Top of Sui main limestone in Qadirpur-03 well is at 1333meters and has been drilled to about 1405 meters' depth constituting total thickness of about 72 meters in this well. Limestone is present in the upper portion of the formation whilst regional shale unit lies below it marking regional characteristic for comprising top Sui main limestone. Formation containing inter-bedding of limestone and shale present below the regional unit of shale. Approx. 30 meter's thick limestone bed present at the depth from 1375 to 1395 meters which is considered as most productive zone lying in Qadirpur-03 well.

The thickness of 33 meter considered productive zone in Qadirpur-14, Sui main limestone top is 1756 m and drilled down to bottom of 1866. Blocky limestone below shale unit is shown at the top of the Sui main limestone. It is the regional characteristic of having the shale unit of 8.2 m top sui main limestone below blocky limestone, indicating a shallow deposition environment. The interbeds of limestone and shale are below the shale. There are massive to blocky limestone beds at 1810-1850 m, which are described as the most productive horizon of Qadirpur 14 well having suitable value of porosity and low water resistivity of about 0.043 ohm-m.

Formations occurring in both wells containing little bit of variance in lateral variation. Limestone is source of reservoir rock in the Formation as this Formation Sui Main limestone of Qadirpur field is potentially reservoir rock. Both of the wells in Qadirpur field are featuring massive beds of limestone containing good fracture porosity indicating existence of gas in the field. Table 4.4 showing the Petrophysical properties of reservoir rock in both wells.

Table 4.4 Correlation of Petrophysical properties of Reservoir zone of Qadirpur wells.

Petrophysical Parameters	**Qadirpur-03**	**Qadirpur-14**
Gross Interval (m)	72	110
Net Pay (m)	22.90	32.3
Average V_{sh} (%)	24.3	13.2
Average V_{clean} (%)	67.3	69
R_w (ohm-m)	0.031	0.043
Average S_w (%)	32.7	31
Average S_h (%)	67.3	69
Avg. effective Porosity(%)	17.6	10.5
Avg. Formation Temp	41.1	54.7
Avg. Formation pressure	14749	19703

Table 4.5. Showing wells location

Wells	**Latitude**	**Longitude**
Qadirpur-03	28° 05' 15.10" N	69° 20' 40.38" E
Qadirpur-14	28° 4' 12.37" N	69° 23' 32.59" E

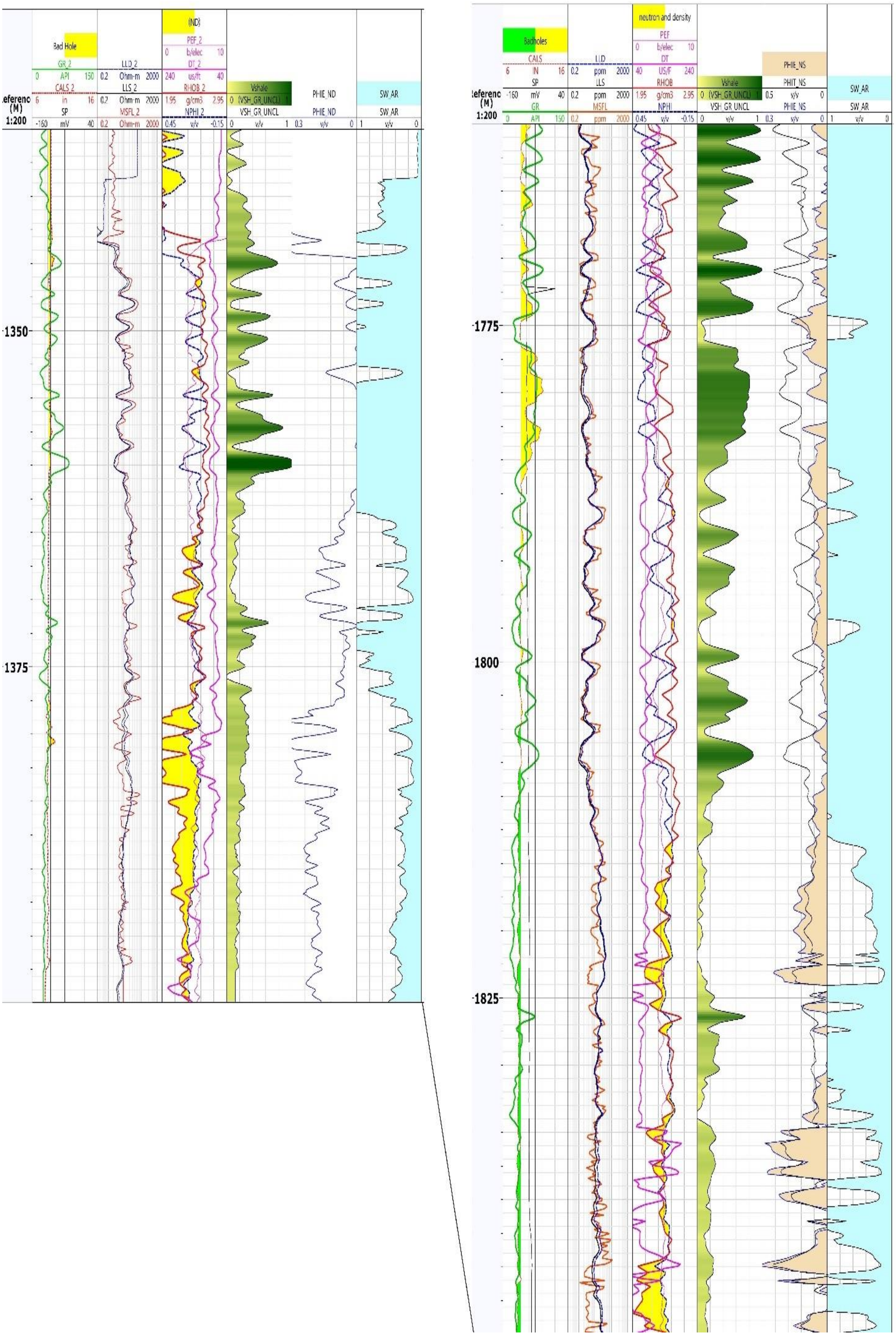

Figure 4.7 Correlation of Qadipur-03 and 14 wells

CONCLUSION

Based on the response of log, Sui main limestone in both wells (Qadipur-03 and Qadipur-14) is behaving as reservoir rock. Only one zone of interests was marked within Sui main limestone Formation in Qadipur-03 well. Total thickness is 27m and net pay of about 20.91 meters. In Qadirpur-03 well, the average amount of Gamma ray clean is about 76.2%, the average of shale volume from log response calculated to be 22.8% approximately and average effective porosity in both zone of interest within Qadirpur-03 is calculated to about 17.6%. Saturation of hydrocarbons is 70.9% and water saturation is 29.1% within Sui main limestone. Two zones of interest were marked in Qadirpur-14. Log response in Qadipur-14 well elaborates that gross thickness is 15 meters in zone-01 and 16m in zone-02 whereas net pay is about 14.2 and 15.5 meters. It is concluded that average gamma ray clean volume in zone-01 is about 91.2% and volume of shale is calculated to be 8.8% whereas average gamma ray clean volume in zone-02 is about 81.8% and volume of shale is calculated to be 18.2%. Average effective porosity is about 9.5% in zone-01 and zone-02 having effective porosity ranges to about 10.5%. Resistivity of water is calculated to be 0.043 ohm-meters. Water saturation in zone-01 of Qadirpur-14 is 44% and saturation of hydrocarbon is about 56% within Sui main limestone. LLS and LLD logs showing visible separation between them within zone of interest in both logs which is indicating presence of Formation fluid. Zone-02 containing 34% water saturation and hydrocarbon saturation ranges to about 66%. Correlation in both wells suggest that thickness of Qadipur-14 increase laterally as compare to Qadirpur-03 well. From gamma ray log response, we can have predicted depositional environment of the Formation and it is concluded shallow marine environment of deposition in both wells.

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