FACIES ANALYSIS AND RESERVOIR CHARACTERIZATION OF THE OUTCROP ANALOGUE AND WELL DATA, SHINAWARI FORMATION (MIDDLE JURASSIC) IN THE NIZAMPUR AND KOHAT BASIN (KPK), PAKISTAN

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بسم الله الرحمن الرحيم

In the name of Allah,
the Most Beneficent,
the Most Merciful

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A Thesis presented to Quaid-i-Azam University, Islamabad In the partial fulfilment of the requirement for the degree of Master of Philosophy in Geology

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APPROVAL CERTIFICATE

This is to certify that the dissertation entitled "Facies analysis and Reservoir Characterization of the out crop analogue and well data, Shinawari Formation (middle Jurassic) in the Nizampur and Kohat Basin (KPK) Pakistan" submitted by SHAHID SAEED (Registration # 02112013013) is accepted by the Department of Earth Sciences, Quaid-i-Azam University Islamabad, Pakistan as satisfying the dissertation requirement for the M. Phil degree in Geology.

Supervisor;
Professor Dr. Mumtaz Muhammad Shah ______________________

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DEDICATION

The research work has been dedicated to my creator Allah SWT

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Shahid Saeed

ABSTRACT

The present study deals with the facies analysis and reservoir characterization of the outcrop analogue and well data of Shinawari Formation (middle Jurassic) in Nizampur and Kohat Basins (KPK) Pakistan. Nizampur Basin is located in the north of Kala Chitta Range whereas Kohat Basin is located on west of Kala Chitta Range. Shinawari Formation in the study area mainly composed of limestone, marl, silt/sand and shale. Thin section petrographic and paleoenvironmental study was done and subsequently used in the microfacies analysis. Five microfacies were identified in three depositional environments, which included peritidal, restricted lagoon and high-energy shoal from inner to outer part of a homoclinal carbonate ramp. The analysis was based on (Flügel, 2004) model for ramps and facies assessments.

The wire line logs data of wells (Manzali-01, Manzali-02 and Makori-01) from Kohat Basin was used for petrophysical studies and four limestone electrofacies were identified. These facies were vacillated from clean limestone to marly/argillaceous limestone, which were sandwiched by dominant shale and traces of silt/sandstone in places. Lithological correlation showed that limestone facies were slightly pinched out from north east to south west direction, with gamma ray (GR) values between 30 to 70 API. The results of wire line logs showed no hydrocarbons presence in Shinawari Formation in Manzalai-1 and Manzalai-2 wells. However, the logs were encouraging in the Makori-1 well, clean limestone was developed in the upper most part of Shinawari Formation and having considerable porosities from 1.5% to 4.5%. The wire line logs data represented the Shinawari Formation having good reservoir qualities in the eastern side of the Kohat Basin whereas the western part of the basin is less prospective. Therefore, it is not a potential target in the wells located in the western side of the Kohat Basin. Whereas the study area of Nizampur Basin is located toward north eastern side of the Kohat Basin, thin section studies showed the presence of dolomitization and other porosity behaviours which may indicate the development of secondary porosities. Based on available data interpretation Shinawari Formation can be consider as a potential future exploration target in the Nizampur Basin.

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List of abbreviation

A	Average Porosity
ACR	Attock Cherat Range
API	Unit of radioactivity measurement for gamma ray (American Petroleum Institute) API units
E	Effective Porosity
E&P	Exploration and production
FP	Fracture Porosity
GR	Gamma ray
HTF	Hissartang Thrust Fault
KCR	Kala Chitta Range
KIA	Kohistan Island Arc
KTF	Khairabad Thrust Fault
LF	Limestone Lithofacies
MBT	Main Boundary Thrust
MF	Limestone Microfacies
MMBO	Million barrels of oil
MMT	Main Mantle Thrust
MOL	Hungarian oil and gas public limited company
MP	Moldic Porosity
N	Neutron Porosity
NDFTB	Northern Deformed Fold Thrust Belt
NMR	Non Magnetic Resonance
QC	Quality Control
RS	Resistivity
SDFTB	Southern Deformed Fold Thrust Belt
SF	Shale Lithofacies
Shc	Hydrocarbon Saturation
SP	Secondary Porosity
SP	Spontaneous Potential

SRT	Salt Range Thrust
Sw	Water Saturation
Vsh	Shale volume
Δtf	Interval transit time of fluids
Δtlog	Interval Transit Time
Δtma	Interval transit time of matrix
ρb	Density from Log
ρf	Fluid Density
ρma	Matrix Density
ϕT	Total porosity

CHAPTER-1
INTRODUCTION

1.1 Introduction

The Nizampur Basin is located in the north of Kala Chitta Range whereas Kohat Basin is located on west of Kala Chitta Range, rocks of Nizampur Basin are exposed along the Hissartang thrust fault whereas Kohat Range is exposed along the Main Boundary Thrust (MBT) (figure 1.1). The Shinawari Formation in the study area mainly composed of limestone, marl, silt/sand and shale (Saboor et al., 2022). Type locality of the Shinawari Formation is on the western edge of the Samana Range, the transition zone where the Samana Suk Formation overlying and Datta Formation is underlying the Shinawari Formation in Kohat Plateau, Pakistan (Fatmi et al., 1973). Within the Trans Indus Ranges there are many exposures of the Jurassic age rocks, which have been studied in terms of sedimentation, sequence stratigraphy, and biostratigraphy (Ali et al., 2013). The Shinawari Formation is widely exposed in the Upper Indus Basin which was our focused of study as facies analysis and reservoir characterisation. Systematic analysis of the literature reveals that the Shinawari Formation is exposed in the Chichali Nala, Baroch Nala, Gulla Khel Nala, Surghar Range and Nizampur Cement Factory section in Nizampur Basin (KPK) Pakistan. In Chichali Nala section lithology of Shinawari Formation was reported like limestone, marls, and sandstone, siltstone and shale along with a mixture of laterite, hard grounds and coal disseminations. According to a microfacies investigation, the Shinawari Formation was deposited in a variety of environments, including tidal lagoons, beaches, and shoals. Therefore, Tyson (1995) supported the hypothesis of sedimentary organic matter.

The Indus Basin of Pakistan has large deposits of the middle Jurassic shallow to marginal marine carbonate. In upper and lower Indus Basin of Pakistan various exploration and production (E&P) companies have been performed a number of surveys and research projects that were especially focused on the geological characteristics of carbonate reservoirs (Jadoon et al., 2015). It has been reported that Pakistan's carbonate rock reservoirs retained a good hydrocarbon potential (Dahraj et al., 2018). In Pakistan different Basins studies indicate that the Jurassic carbonates are assumed to be potential hydrocarbon reserves, with only a few notable discoveries in the Kohat Basin that includes Nishpa, Tolanj, Sumari, Makori and Manzali fields, which still needs to be explored and expedited. Middle Jurassic Shinawari Formation is a possible target hydrocarbon play in the upper Indus Basin as future prospects. The petrophysical properties (porosity and permeability) of carbonate rocks, which are the results of both depositional and diagenetic processes, however subject to significant geographical and temporal fluctuation. It is necessary to research the petrophysical and microstructural characteristics of carbonate rocks with the factors impacting the reservoir quality, in order to effectively explore and develop the hydrocarbon reservoirs in the region. The porosity and permeability of the reservoir are closely related to the rock fabric quality, hence it is crucial to investigate the factors that affect these characteristics of the reservoir. Most limestone have textures as a result of the interaction of three factors depositional regime, biological activity and diagenesis. The majority of limestone has a depositional texture, whereas some have textures that are entirely the result of diagenesis. Compaction may be the extent of the depositional texture's diagenetic alteration (independent of any mineralogical or chemical changes), but the neomorphic recrystallization and replacement process may completely destroy the original fabric. Although biological processes have a diverse influence on texture, they often take a major role in reefs (Wright et al., 1992). The widely used classifications of limestone was based on the idea of textural maturity (Folk, 1962 and Dunham, 1962). Although it is thought that the texture reflects the amount of energy present in the depositional environment.

In carbonate reservoirs, hydrocarbons were first discovered internationally in 1856 with the discovery of the 1MMBO Heide field in Germany (Keith & Wickstrom 1991; Garland et al., 2012). The understanding of carbonate reservoirs has advanced since the late 1800s. The world's 40% of Gas and 60% of Oil reserves are covered by carbonate reservoirs (Schlumberger, 2007; Migunova et al., 2021) Major carbonate reservoirs rocks include the world's largest gas and oil fields located in Qatar and Saudi Arabia, particularly "Ghawar field in Saudi Arabia and North/South Pars field in Qatar" (Kakemem et al., 2021). The Middle East countries (Saudi Arabia, Qatar, Bahrain, United Arab Emirates, Oman, Iraq and Iran) have 70% oil deposits and 90% gas reserves in carbonate rocks, and the best example of such shallow to marine carbonates reservoirs found in the middle Jurassic (Missagia et al., 2017). These carbonates are widely dispersed throughout nearby continents for example, Oolitic peritidal carbonates have been found in the Arab Formation in the southern United Arab Emirates (Hollis et al., 2017; Sharifi et al., 2020). In central Oman, the middle Jurassic part of the Sahtan Group also had Oolitic shoals to lagoonal carbonates (Rousseau et al., 2005). Similar reports of the deposition of marginal to shallow marine carbonates come from the Dhruma Formation in central Saudi Arabia and Morocco (Yousif et al., 2018). Such carbonates reservoirs bring up significant hydrocarbon and diagenetic alteration which can be relatively productive reservoirs (Wadood et al., 2021).

1.2 Previous work

The Upper and Lower Indus Basins of Pakistan accumulated moderate to thick sedimentary successions during the Mesozoic (10 km in Lower Indus Basin thinning up to ~ 1.5 km in Upper Indus Basin). The deposits comprise principally shallow-water carbonates and siliciclastics which are deposited on the northern margin of the Indian Plate, at a paleo latitude ~20–30° south (Shah et al., 2009). Different exposures of Jurassic sequence are studied by previous worker in the Salt Ranges and Trans Indus Ranges in the context of sedimentation, sequence stratigraphy and biostratigraphy (Nizami, 2009; Ali et al., 2013). For studying a reliable stratigraphic sequence of any rock unit, it is essential to first put the same rock unit into a reliable biostratigraphic framework. In Pakistan the proposed stratigraphic framework of different rock units is extremely diversed in different parts, raising questions about its applicability (Khan, 2013). The Shinawari Formation was named by Fatmi (1973) after the name of a village in the western side of Samana Range, Kohat area for the transition zone between Datta Formation (lower Jurassic) and overlying Samana Suk Formation (Bathonian - Collovian age) in the said area. The age of the upper part of the Shinawari Formation is based on a supposition (Shah, 2009). These ages can be determined via palynostratigraphic analysis to establish the rock unit's sequence stratigraphic framework and order of cyclicity. Additionally the establishment of paleo environments for the various facies stored within the Shinawari Formation with the aid of palynofacies and microfacies data will be helpful in building a relative sea level curve. When matching with palynostratigraphic ages, this sea level curve will aid in defining the depositional surfaces, system tracts and sequences. Due to their complexity and heterogeneity in comparison to clastic layers, the reservoir potential of these rocks is relatively difficult to predict (Nazari et al., 2019; Tavakoli, 2019). Changes in the depositional and diagenetic settings as well as their subsequent modification by tectonics are the main sources of the geographical and temporal variability in the petrophysical characteristics (porosity and permeability) of the carbonates. The packing, sorting, and size of the grains, which varies depending on the rock's depositional environment and regulate the principal porosities within carbonates (Ali et al., 2018). The basic mineralogy of the carbonates rocks is also influenced by the depositional environment, which affects diagenetic changes and secondary porosity (Worden et al., 2018). Similar to how diagenesis regulates the development of secondary porosity in carbonate rocks at several phases, including eogenetic starts at the seafloor, mesogenetic which occurs during burial, and telogenetic which is uplifting period (Choquette and Pray, 1970). The fundamental fabric, composition, rigidity, and porosity are altered during these stages by compaction, neomorphism, dissolution/precipitation, replacement, and dolomitization (Flügel, 2004). The significant changes in pore size and shape that occur during diagenesis may improve or destroy the reservoir quality (Afife et al., 2017; Amel et al., 2018). The porosity evolution in carbonate rocks is correlated with sea level changes (Flügel et al. 2004). For example, during regression large pore systems' porosity occludes due to heavy cementation, whereas during transgression the deposition of matrix-supported lithologies preserves higher primary porosities. Petrography is an important method for establishing the diagenetic links between rocks (Hiatt et al., 2014). Understanding the diagenetic relationships and other typical reactions that occur in carbonate rocks is crucial because they can alter the texture of the rock, upsetting the grains, matrix, cements, evolution of the porosity, and permeability, all of which have an impact on the quality of reservoir rocks. There are several excellent examples of carbonate rock information in the literature (Boggs et al., 2006) and more specifically these examples provide a method for visualising, considering, and understanding the permeability and porosity evolution in carbonate reservoirs.

1.3 Aims and Objectives

The aim of study was to collect the high quality data of Shinawari Formation s from Nizampur cement factory Nala section, based on thin sections petrographic study and petrophysical property measurement in order to analyse the purposed carbonate rock facies and understand the reservoir characteristics i.e. textures, porosity, permeability and to assess the diagenetic features which effects the carbonate rock quality.

- To investigate and interpret outcrop rock samples (thin sections) in terms of petrology and biostratigraphical analysis.

- To establish facies associations, depositional environment, diagenesis and structural elements.
- To establish the well logs correlation and lithofacies of Shinawari Formation.
- To correlate representative samples data set with petrophysical data and validation of the data base.
- To determine the reservoir quality, rock type and porosity distribution based on pore typing.

1.4 Location and accessibility

The study area "Nizampur cement factory Nala Section" which is located in the Nizampur area of District Nowshera, Khyber Pakhtunkhwa. It is located to the north of Indus River and south of Attock Cherat Ranges. The outcrop is accessible by black top road from Khairabad to Nizampur through Qamar Mela Village. The main accessibility of the study area through Islamabad-Peshawar GT road and (M-1) Islamabad-Peshawar Motorway.

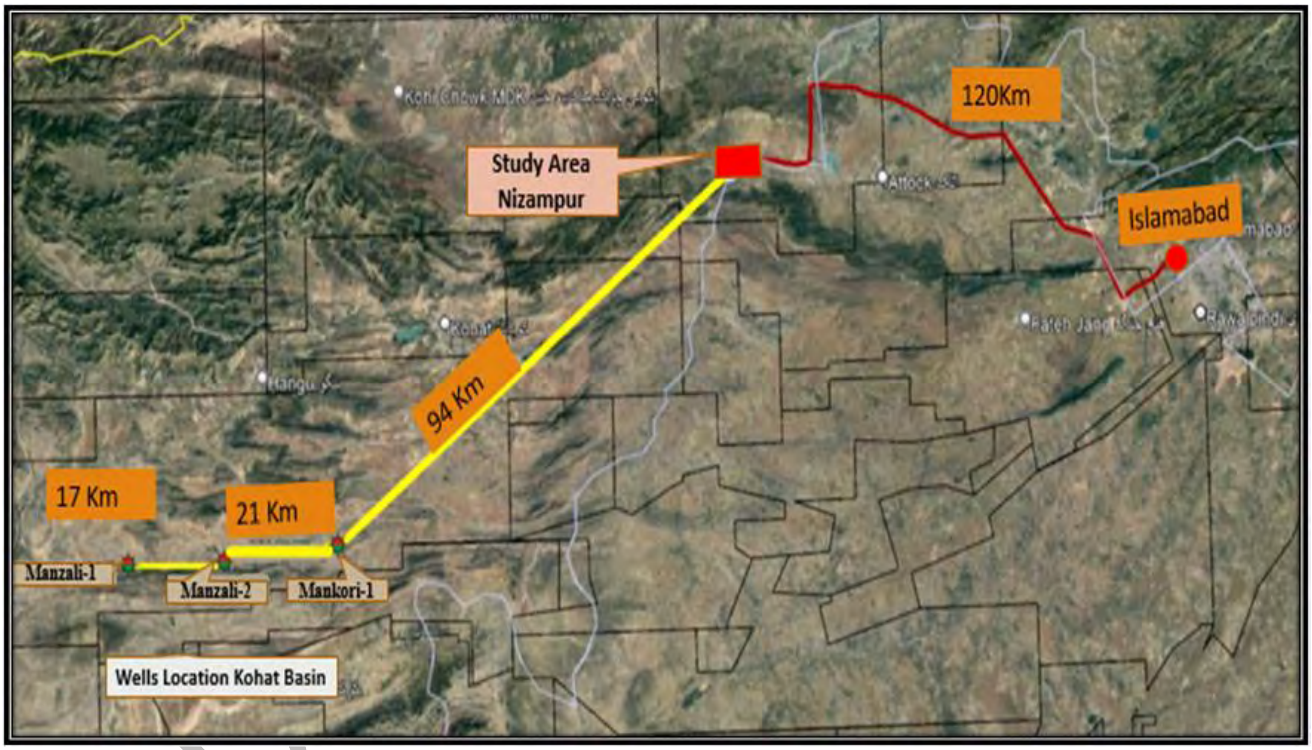

Figure 1.1 Location and access map of study area in Nizampur Basin and wells location in Kohat Basin (Compiled from Google map)

Geologically the research area is in the Nizampur-Basin of the north western Upper Indus Basin, which is linked with well data from the Kohat-Basin. Kohat Range's rocks are exposed along the Main Boundary Thrust and is situated in the western portion of the Kala Chitta Range whereas the Nizampur Basin is located in the north of Kala Chitta Range and its rocks are exposed along the thrust faults (figure 1.1 to figure 1.3). Askari cement factory in Nizampur Basin is located at Lat. 33° 81' 954"N and Long. 72° 09' 421"E,which is 120 km way from Islamabad, Pakistan.

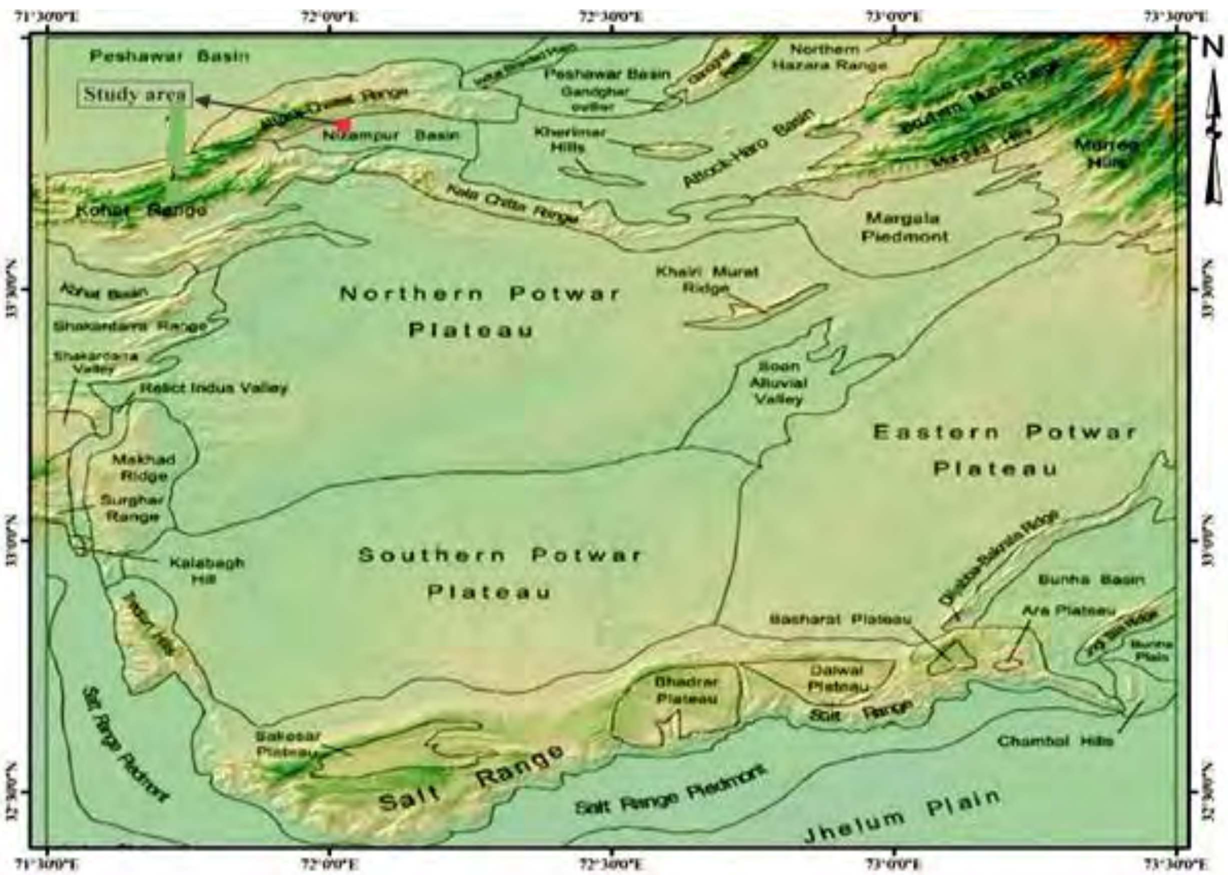

Figure 1.2 Generalized map showing the location of the study area in the Nizampur Basin (Hylland, 1990).

1.5 Methodology

Fieldwork was done in the study area, rock samples were collected as per plan (figure 1). Programs were used like Google Earth, Global Mapper, Tech log and Coral Draw for cross section and restoration of the geological data and reviewed before being arranged, examined, and presented. Total 24 rock samples were collected randomly as well as systematically wherever variations in the lithological characters were found. The rock thin sections were prepared for the detailed petrographic analysis and subsequent use in the paleo-environmental interpretation. The integration of the outcrop analogue data and petrophysical data of wells (Makori -1, Manzali-1, and Manzali-2) were used for the reservoir characterization of Shinawari Formation. The research methodology steps are shown in flowchart (figure 1.3).

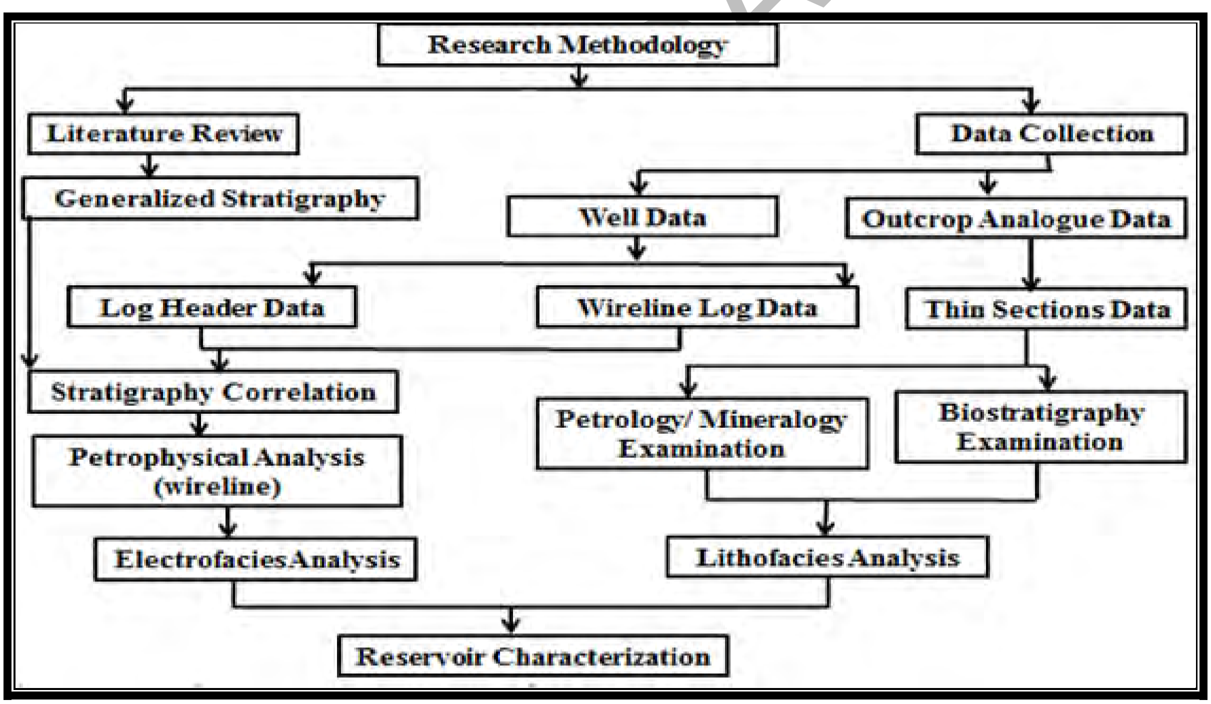

Figure 1.3 Flow Chart defines the steps followed to draw the results of the study work.

1.5.1 Field observation

The study includes section measurement, sampling and litholog preparation of the Shinawari Formation in the Nizampur cement factory Nala section. During field work data was collected at outcrops scale systematically and randomly, measured 72m thick exposed sections and samples were collected. Megascopic field features were studied and captured with precise specifications.

- Lithological description and sampling.
- Measurement of stratigraphic section of the Shinawari Formation with the help of measuring tape and sampling of key horizons at an interval of 3 meters.
- Logging of all field data, bedding, colour, lithology and texture.

1.5.2 Laboratory Study

Laboratory studies were comprised of thin sections from out crop analogue samples. The planktonic foraminifera were extracted from the soft shale/marl and limestone by using conventional paleontological procedures and Lirer's wet sieve techniques (2002). Thin sections were prepared in HDIP and detail study were performed by using a polarising microscope in the Petrographic Laboratory (University of Peshawar) and department of earth sciences Quaid-i-Azam University Islamabad.

1.5.3 Well logging data Analysis

By using the Wire line logs data of Wells (Manzali-1, Manzali-2 & Makori-1) of the Kohat Basin. Using wire line logs of the respective wells the petrophysical analyses was carried out. The following logs were used for the petrophysical investigation, Resistivity, Sonic (DT), Spontaneous potential (SP), Gamma ray (GR), Neutron (NPHI), Bulk Density (RHOB), and Calliper (CALI). Volume of the shale (Vsh), density porosity (D), neutron porosity (N), sonic porosity (S), average porosity (A), effective porosity (E), qualitative permeability, water saturation (Sw), and hydrocarbon saturation (Shc). Following formulas were used for petrophysical parameters calculation and measurement.

(1) $Vsh = GRlog - GRmin/GRmax - GRmin$

(2) $\phi D = \rho ma - \rho b/\rho ma - \rho f$

(3) $\phi A = \phi N + \phi D/2$

(4) $\phi s = \Delta tlog - \Delta tma / \Delta tf - \Delta tma$

(5) $\phi E = \phi T \times (1 - Vsh)$

GR log = GR log reading, GR max = maximum GR log GR min = minimum GR log; ρb = density from log, ρma = matrix density of = fluid density; Δtlog = interval transit time from log, Δtma = interval transit time of matrix, Δtf = interval transit time of fluids; ϕT = total porosity

Water saturation (Sw) has been calculated through Archie equation as follows

(6) $Sw=[(a/\phi m)(Rw/Rt)]1/n$

Sw = water saturation, ϕ = porosity, Rw= formation water resistivity,

Rt= true resistivity, a= tortuosity factor, m= cementation factor and n= saturation exponent. The hydrocarbon saturation (Shc) has been assessed by the following equation.

(7) $Shc=1-Sw$

CHAPTER-2
REGIONAL GEOLOGY AND STRATIGRAPHY

2.1 Regional Geology and Tectonic

The supercontinent "Pangea" split into the northern hemisphere known as Laurasia and the southern hemisphere known as Gondwanaland continent about 300–200 Ma ago. These two regions are divided by the recently formed "Tethys Ocean," which is generated due to the rifting of these continents (Smith et al., 1981). North America, Europe and Asia make up the Laurasia continent, while Gondwanaland is made up of South America, Africa, India, Antarctica, and Australia. The "Paleo Tethys," or northern ocean and the "Neo Tethys," or southern ocean were separated from the Tethys Ocean (Smith et al., 1981). The Indian plate split off from Gondwanaland, moved toward the north, collided with Eurasia, and created the Himalayas (Johnson et al., 1976). During the Eocene era when the Neo Tethys Ocean was blocked, the Indian plate collided with the Kohistan Island Arc (KIA) (Tahirkheli et al., 1979). The Indian plate is still being thrusting beneath the Eurasian plate and as a result the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT), and Salt Range Thrust (SRT) formed (Grelaud et al., 2002). A zone of highly deformed rocks known as Northern deformed fold and thrust belt (NDFTB) is located between the MMT and MBT. This region spans from Kashmir in the east to the Kurram region in the west. Southern deformed fold and thrust belt (SDFTB) is the name of the deformed sedimentary rock between MBT and SRT. The Attock-Cherat Range is located in the northern half of the axial belt and is a part of the Margalla Hill Ranges. It is divided from the Potwar Plateau in the south by the MBT and from the higher Himalayas in the north by the Khairabad fault (Yeats and Lawrence, 1982; Shah, 2009). In the village of Dag Ismail Khel, the Attock-Cherat Ranges come to an end. They then spread to the south-west and converge with the Nizampur-Kohat Mountains. The region is severely deformed with folds and faults. Three major thrust faults are the Cherat thrust, Khairabad thrust, and Hissartang thrust, as well as numerous minor faults are responsible for the Range's deformation (Hussain et al,. 1989, 1990b; Malkani et al., 2016). North Pakistan's Hill Ranges include the Kala Chitta Ranges (Yeats and Lawrence, 1984). Kala Chitta Ranges' northern most region. The extensive deformation of the Kala Chitta Ranges causes folding and thrusting on both a small- and large-scale. The Kala Chitta Range is deformed as a result of thrusting along the Hissartang fault (Ghauri et al., 1991). The Northern Deformed Fold and Thrust Belt includes the Kala Chitta Ranges (NDFTB). The southern portion of Nizampur Basin is formed by the eastern border of the Kala Chitta Range (Yeats and Hussain, 1987).

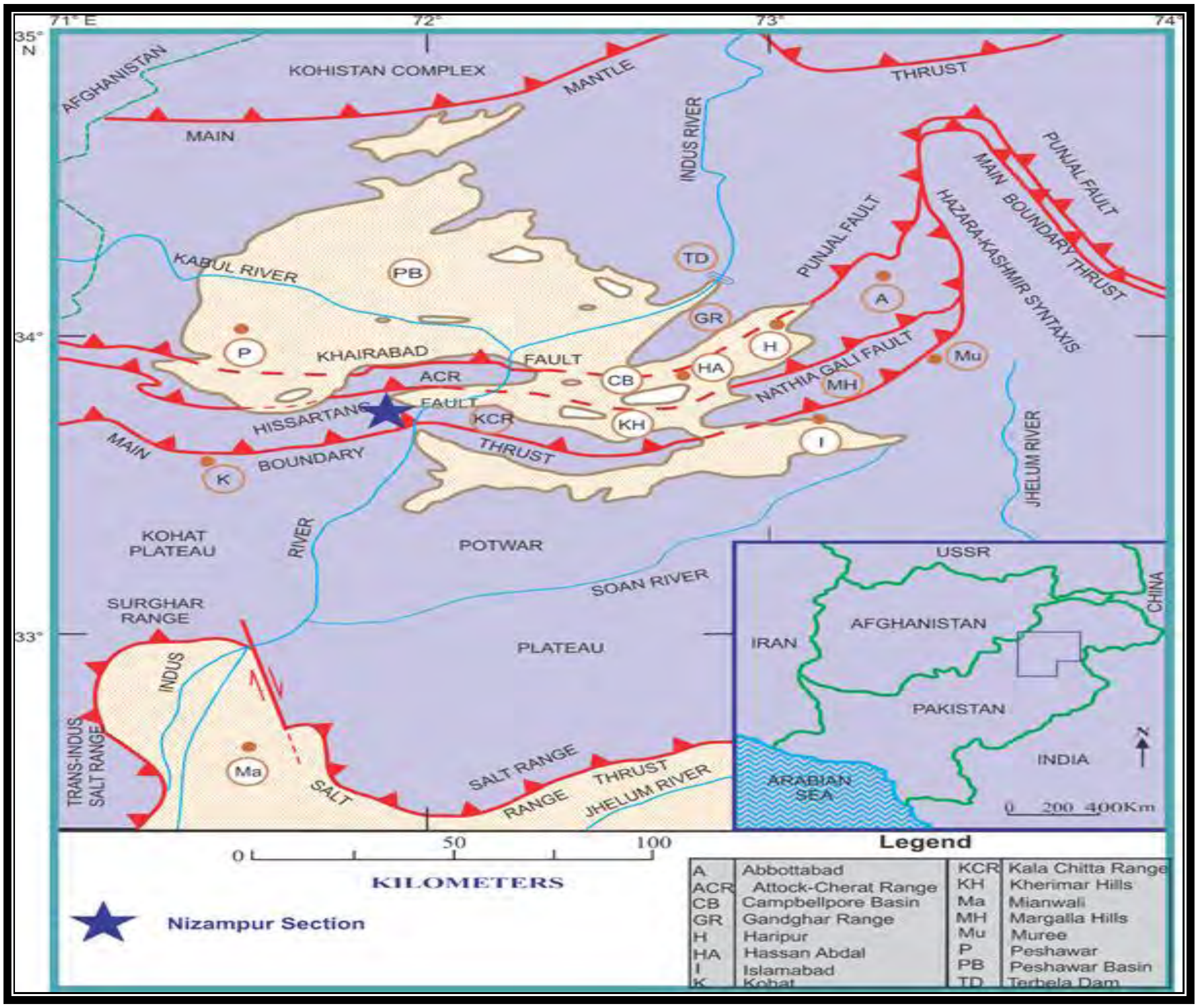

Figure 2.1 Generalized Geological and Tectonic map of the northern Pakistan (Hylland and Riaz, 1988; Hashmi et al., 2018).

Several traverses were made in the study area to prepare a digital geological map which might be the true representative of formations exposed in the area. The geological map is showing the different mapped units and displayed according to scale and legends (figure 2.2).

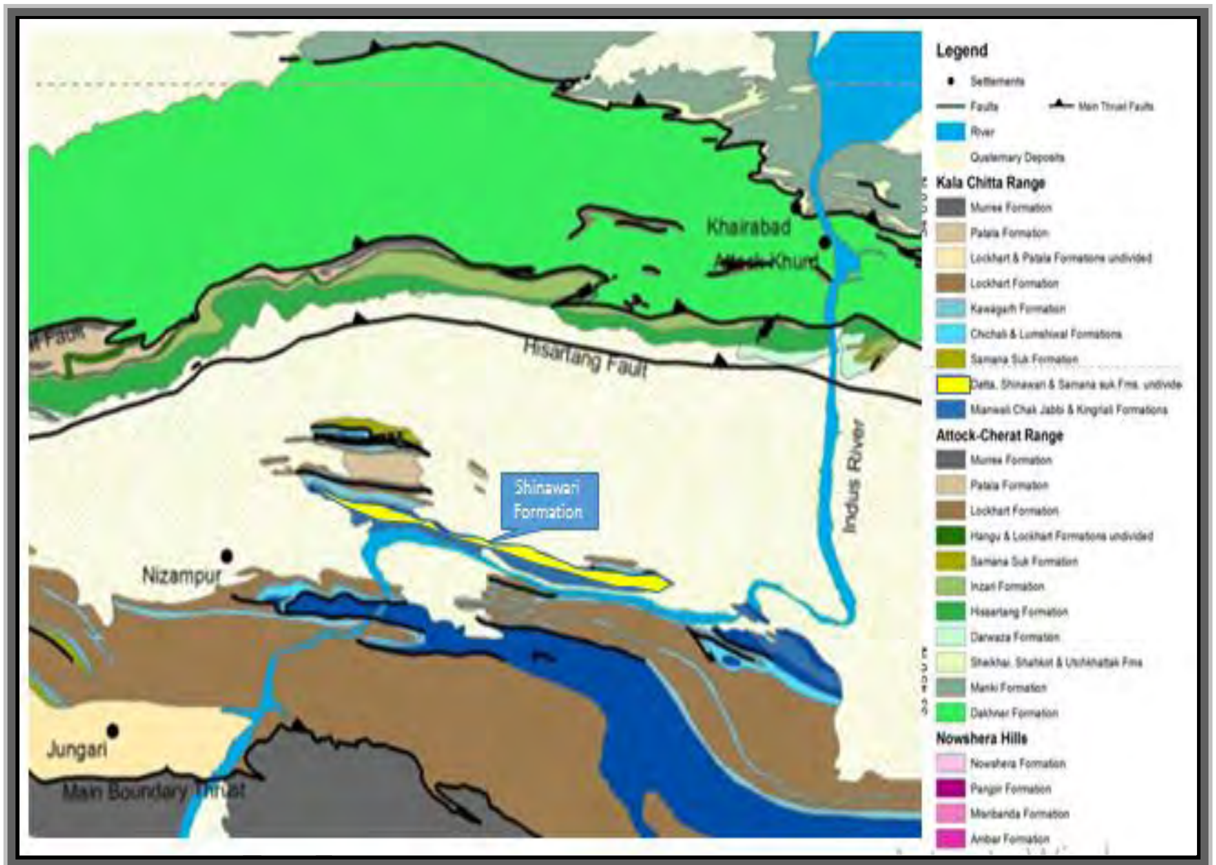

Figure 2.2 Geological Map of Study area, modified (Asif et al., 2013).

The thickness of the formations has been measured along the exposed parts during detail mapping of the area. To comprehend the area's subsurface geology and structure, geological cross sections are created along the north-south axes (figure 2.3). In the research area, the strata from the Eocene to the Triassic succession is exposed at the surface, all of the strata have a general southward dipping. The exposed lithology from the Eocene to the Jurassic was mapped in the research area. Google maps and Formation geology have been used to determine the surface area of each formation and surface calculations of dips and exposed measurement portions have been used to estimate the depth of each formation.

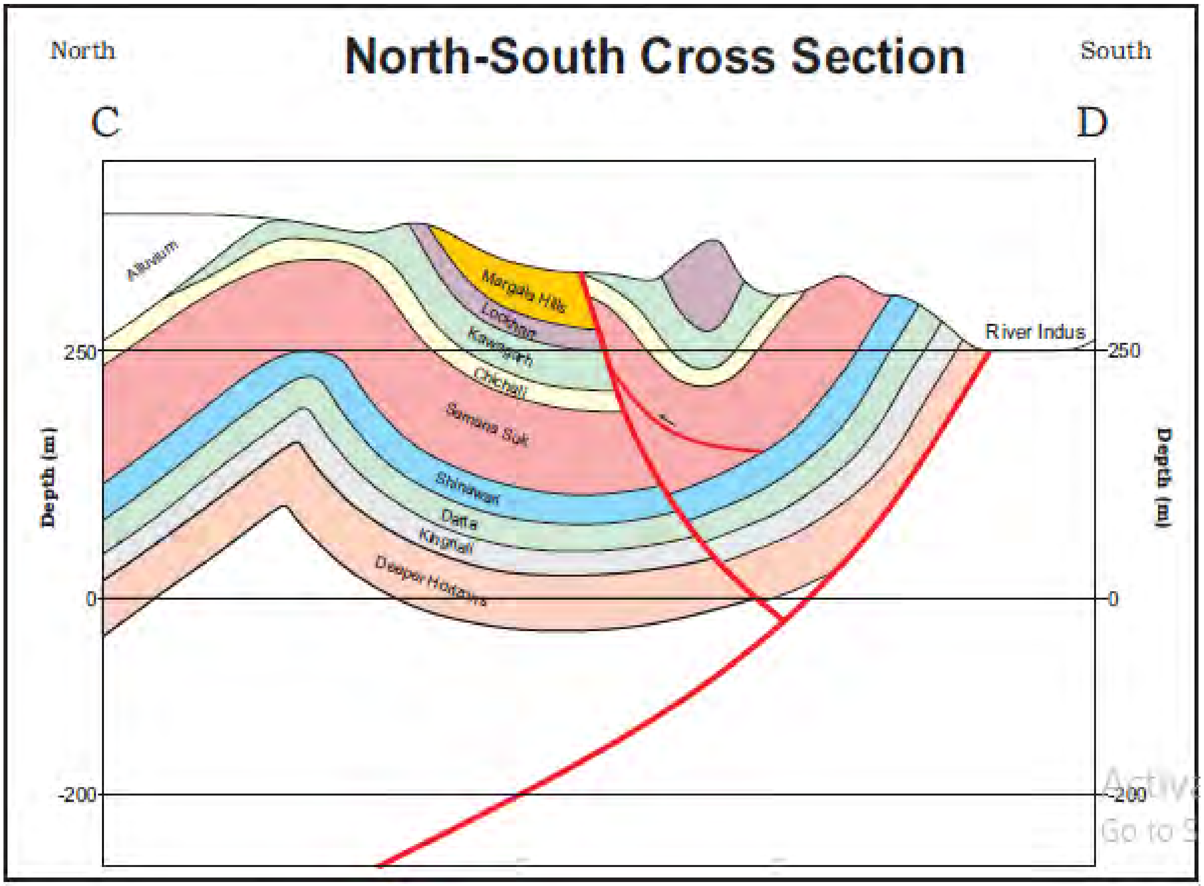

Figure 2.3 Geological model (North – south) cross-section of the Study area shows the prominent stratigraphic horizons, Nizampur sub Basin KPK.

2.2 Stratigraphy of the study area

Jurassic to Eocene age Ranges are represented by the geological succession exposed in the research area (Nizampur Basin). Formations exposed as the Datta, Shinawari, and Samana Suk in the Jurassic sequence in the area. The Cretaceous rocks, which comprise the Chichali, Lumshiwal, and Kawagarh formations, are found on top of the Jurassic rocks. Paleocene rocks, such as the Hangu, Lockhart, and Patala Formations are found above the Cretaceous strata. The research area's youngest succession of rocks include those from the Eocene, specifically the Margalla Hill Limestone, Chorgali, and Kuldana Formations. The Shinawari Formation exposed in the Nala part of the Nizampur cement factory served as the source of samples for this study.

Table 2.1: Stratigraphic chart of Study area (modified from Yeats and Hussain, 1987**).**

Era	Period	Formation Name	LITHOLOGY	DESCRIPTION
Cenozoic	Eocene	Margalla Hill Lst.		Light to medium grey, massive nodular Limestone with inter bedded Shale
	Paleocene	Patala		Grey to greenish grey Shale with inter bedded Limestone and Marl
		Lockhart		Massive noduler Limestone with inter bedded Shale
		Hangu		Sandstone with intercalaltion of Shale
Mesozoic	Cretaceous	Kawagarh		Light to dark grey Limestone and Marl
		Lumshiwal		Quarlzitic Sandstone in lower and upper part is Argillaceous Limestone and Marl
		Chichali		Dark grey to greenish grey, blackish grey shale with interbedded Sandstone
	Jurassic	Samana Suk		Medium to thick bedded oolictic, ferruginous Limestone and Dolomitic Limestone with intercalation of Shale
		Shinawari		Medium to thick bedded oolitic Limestone with interbedded Shale,in place marly, occasionally silty & salty, occasionally calcite vans and fractures observed, traces to abundent fossils fragments
		Datta		Ferruginous Sandstone, Carbonaceous Shale with intercalaltion of Siltstone and Sandstone

2.2.1 Jurassic Succession

Jurassic rocks in Pakistan primarily consist of limestone, shale, and sandstone, with trace amounts of dolomite (Shah, 2009). The Datta, Shinawari, and Samana Suk Formations make up the study area's Jurassic sequence. The Datta Formation, which is primarily of continental origin, is made up of shale and sandstone of various colours (Fatmi et al., 1990). In the study area, Shinawari Formation lies on top of the poorly exposed Datta Formation. Having lithology like limestone, marl, shale, and sandstone/siltstone with thin to well-bedded limestone. In the Kohat, Kala Chitta, Hazara, Trans Indus, and Salt Ranges, the structure is well visible (Shah, 2009). Samana Suk Formation rocks make up the upper Jurassic rocks. Major components of the Samana Suk Formation are limestone and shale, with lesser amounts of sandstone, dolomite, and calcareous marl (Fatmi, 1977). The limestone is medium to thick bedded, Oolitic, yellowish in hue, and mottled with burrows by biological activity. Between units of limestone lies a yellowish grey subordinate shale. The rocks from the Cretaceous period lie on top of the Samana Suk Formation.

2.2.2 Cretaceous Succession

The Cretaceous rocks are present almost in all the Basins of Pakistan. In Upper Indus Basin the Cretaceous succession includes Chichali Formation, Lumshiwal Formation and Kawagarh Formation (Shah et al., 2009). The lithology of Chichali Formation at its type locality i.e., Chichali Pass consists of dark green, greenish grey, weathered brown glauconitic sandstone with grey colour sandy beds and silty shale (Fatmi, 1977). In the study area it is mostly consists of sandstone and shale. The sandstone are mostly thin bedded and reddish brown in colour while the shale are black to brown in colour. The Chichali Formation is widely distributed in Trans-Indus Ranges, Western Salt Range, Northern Kohat Ranges, Nizampur Basin, Kala Chitta Ranges and Southern Hazara. The Chichali Formation is conformably overlain by Lumshiwal Formation. Lithologically Lumshiwal Formation is thick bedded to massive sandstone with silty and sandy shale in its type locality and other sections in Trans-Indus Ranges (Shah et al., 2009). In the study area, the sandstone of Lumshiwal Formation is thin bedded, channelized, reddish brown in colour with alternate minor amount of siltstone and shale. The Lumshiwal Formation is conformably overlain by the Kawagarh Formation. The Kawagarh Formation is studied in two sections in Nizampur Basin and Kohat Ranges.

2.2.3 Paleocene Succession

The paleocene rocks are well exposed in Kohat-Potwar area, except in Khisor- Marwat and Bittani Ranges where these are not found (Shah et al., 2009). The Paleocene rocks are important for coal, laterite, iron ore and bauxite. The Paleocene rocks in upper Indus Basin are represented by Hangu Formation, Lockhart Formation and Patala Formation. Kohat area the lithology of the Hangu Formation is sandstone with shale intercalation. In Nizampur Basin, Western Kala Chitta and Hazara areas, the Formation consists of oolitic sandstone, siltstone and clay (Shah et al., 2009). Its thickness is less than 15m in Nizampur- Kala Chitta Ranges. In the Nizampur Basin, the reddish beds of Hangu Formation overlies the Kawagarh Formation. While in Kohat Range, the Hangu Formation is not exposed. Hangu Formation is conformably overlain by the Lockhart Formation. The Lockhart Formation mostly consists of grey to light grey colour medium to thick bedded nodular limestone with shale intercalations (Shah et al., 2009). In the study area, it consist of mostly medium to thick bedded grey colour nodular limestone. The Lockhart Formation is conformably overlain by the Patala Formation. The lithology of the Patala Formation at the type locality is described by (Malkani et al., 2017), which consists of shale and marls with minor limestone and sandstone. Locally, in Dandot area coal seams of economic value are also present within Formation (Shah et al., 2009). The Paleocene rocks in the study area are conformably overlain by the Eocene rocks.

2.2.4 Eocene Succession

In the study area, the Eocene succession were represented by Margalla Hill Limestone, Chorgali Formation and Kuldana Formation. The Margalla Hill Limestone was named by Latif (1970) as Margalla Hill Limestone which was later formally accepted by the Stratigraphic Committee of Pakistan. The name is given after Margalla Hills in Hazara. The Formation consists of limestone with subordinate shale and marl. The limestone is grey, medium to thick bedded and sometime massive. The Formation is well developed in Hazara, Kala Chitta and some parts of the Kohat- Potwar area (Shah et al., 2009). In Nizampur Basin Margalla Hill Limestone is also present and consists mostly of medium to thick bedded grey, fossiliferous limestone. The Formation is conformably overlain by the Eocene Chorgali Formation. The Chorgali Formation is comprised of limestone and shale. The limestone is brownish grey, whitish grey and creamy in colour whilst the shale is greenish grey to brownish grey in colour, splintery and mostly present in lower part of the Formation (Shah et al., 2009). The Chorgali Formation is conformably overlain by the Kuldana Formation. The Kuldana Formation consists of variegated clays in the lower part whilst coarse grained medium bedded sandstone is present in the upper part of theFormation. The stratigraphy of the Nizampur Basin and Kala Chitta Range is similar in characteristics. Rocks from Triassic (Kingriali Formation) to Eocene (Margalla Hill Formation) are well exposed in the area.

CHAPTER -3
FIELD OBSERVATION AND PETROGRAPHIC STUDIES

3.1 Introduction and Field observation

This study includes section measurement, out crop sampling and established detail litholog of the Shinawari Formation in the Nizampur cement factory Nala section. Conducted detail fieldwork in the study area and collected rock samples as per plan. During field work data was collected at outcrops scale, section measurement of the Shinawari Formation was done and recorded expose formation thickness 72m. Collected outcrop rock samples of Shinawari Formation from every three meter's systematically as well as randomly. Samples were also collected where variation observed in the lithological characters from bed to bed study. Photographs were also taken where features were megascopically visible. Thin sections of 24 representative rock sample were prepared for the detailed petrographic analysis and subsequent use in the paleo-environmental interpretation.

3.2 Shinawari Formation

The Shinawari Formation was first named by Fatmi (1977) for its type locality, Shinawari hamlet in the western Samana Mountains, Kohat district. The Stratigraphic Committee of Pakistan later formalized the term under the same name as Shinawari Formation and its aged in the Middle Jurassic. Thick strata of limestone with oolitic ferruginous shale and marl beds can be found in this formation in the study area. The carbonate (limestone unit) is extensively fossiliferous and occasionally contains large to tiny ripples. It is grey to dark grey, dark brown to yellowish brown weathered colour. The marl present with layers of ferruginous reddish brown colour shale and sand/siltstone intercalation. The presences of ammonoids, gastropods, brachiopods and crinoids are reported in this formation which indicates that the early to middle Jurassic transgression occurred there (Kazmi and Abbasi, 2008). The fauna suggests an early to middle Jurassic age (Shah et al., 1977). In the study area, the Shinawari Formation having conformable upper contact with Samana Suk Formation whereas the bottom contact with Datta Formation is also conformable. The detailed review of the literature indicated the good exposure of Shinawari Formation in the Upper Indus Basin. It was studied in the Chichali Nala Section, Baroch Nala, Gulla Khel Nala, Surghar Range, and Askari Cement Factory Section Nizampur, Kala Chitta Range, which is dominated by limestone with thin beds of sandstone, shale, marls, and siltstone, occasionally in association with laterite, thin coal layers, and coal disseminations reported in places. Litholog of exposed Shinawari Formation in the study area was prepared as shown in table 3.1. Furthermore, representative photographs of megascopically visible features were taken from the study area as shown in figure 3.1 to figure 3.5, to illustrate the field characteristics of Shinawari Formation.

Table 3.1 Litholog of the Shinawari Formation in the study area.

AGE	FORMATION	SCALE	LITHOLOGY	SAMPLE	THIN SECTION	DESCRIPTION
MIDDLE JURASSIC	SHINAWARI FORMATION	72m 68m 64m 60m 56m 52m 48m 44m 40m 36m 32m 28m 24m 20m 16m 12m 8m 4m 0m		• SF-24 • SF-23 • SF-22 • SF-21 • SF-20 • SF-19 • SF-18 • SF-17 • SF-16 • SF-15 • SF-14 • SF-13 • SF-12 • SF-11 • SF-10 • SF-9 • SF-8 • SF-7 • SF-6 • SF-5 • SF-4 • SF-3 • SF-2 • SF-1	18653 18652A 18652 18651A 18650A 18650 18649A 18649 18648A 18648 18647A 18647 18646A 18646 18645A 18645 16844A 18644 18643A 18643 18642A 18641A 18642 18641	**Limestone:** (Mudstone-wackestone) Medium to dark grey on weathered surface, grey to greyish brown, yellowish grey on fresh surface, medium to thick bedded oolitic limestone with interbedded shale, in place marly, occasionally silty & sandy, occasionally calcite vans and fractures observed, traces to abundant fossils fragment, placypodes, brachiopords & bivalves. **Argillaceous Limestone:** Medium to dark grey, greenish grey thin to medium bedded, marly/ shaly with reddish brown ferruginous layers, in places silty, occasionally fossiliferous, oolitic. **Shale:** Grey to greenish grey, greyish brown, reddish brown, soft to moderately hard, subfissile to fissile, subblocky to blocky, fossiliferous. **Marl:** Medium to dark grey, greenish grey, soft to moderately hard, amorphous to subblocky.

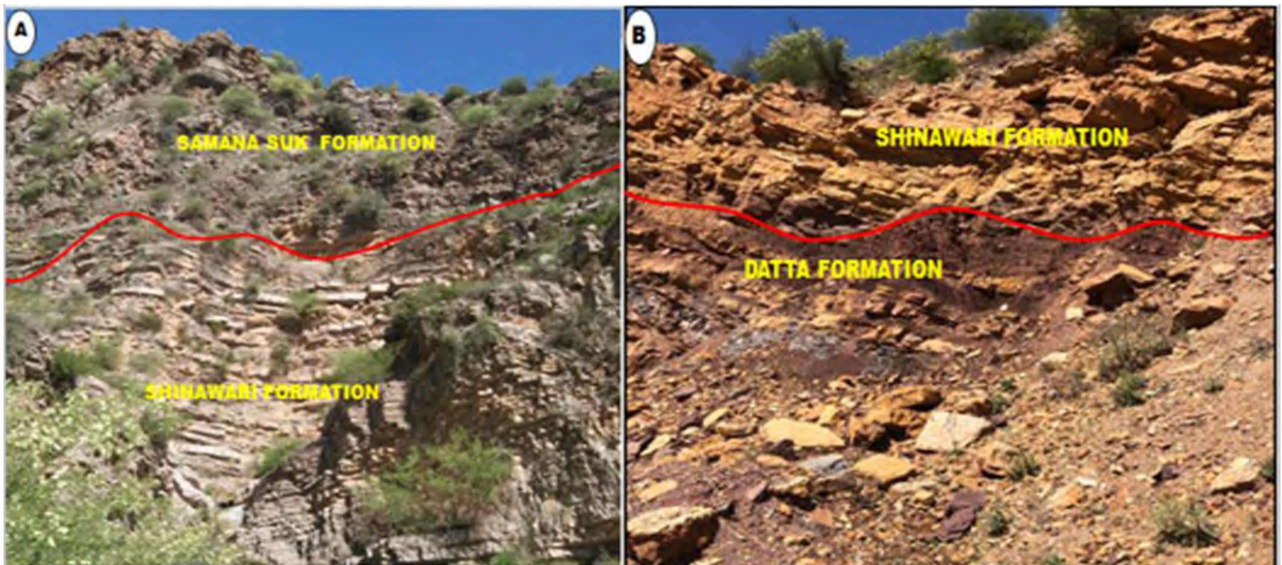

Figure 3.1 Field photograph (**A**) shows the contact view of Shinawari Formation and Samana Suk Formation, (**B**) shows the contact view of Shinawari Formation and Datta Formation in the study area.

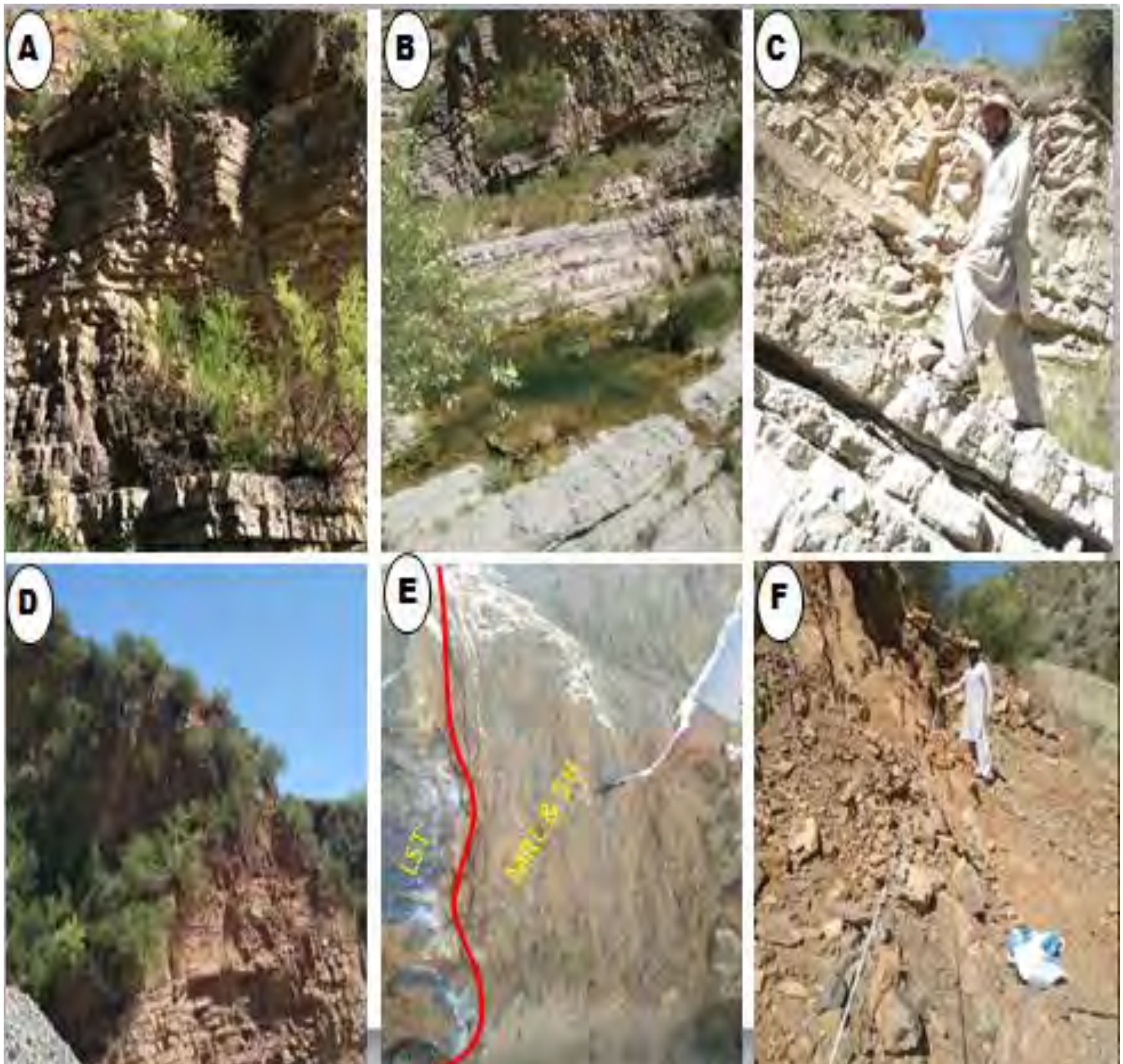

Figure 3.2 Field Photograph (**A, B**) shows fractures & solution weathering effect in limestone. (**C**) View of thick bedded limestone. (**D**) Shows interbedded shale and thin to medium bedded argillaceous limestone with vegetation cover. (**E**) Shows interbedded shale & marl with limestone. (**F**) Shows section measurement of Shinawari Formation in study area.

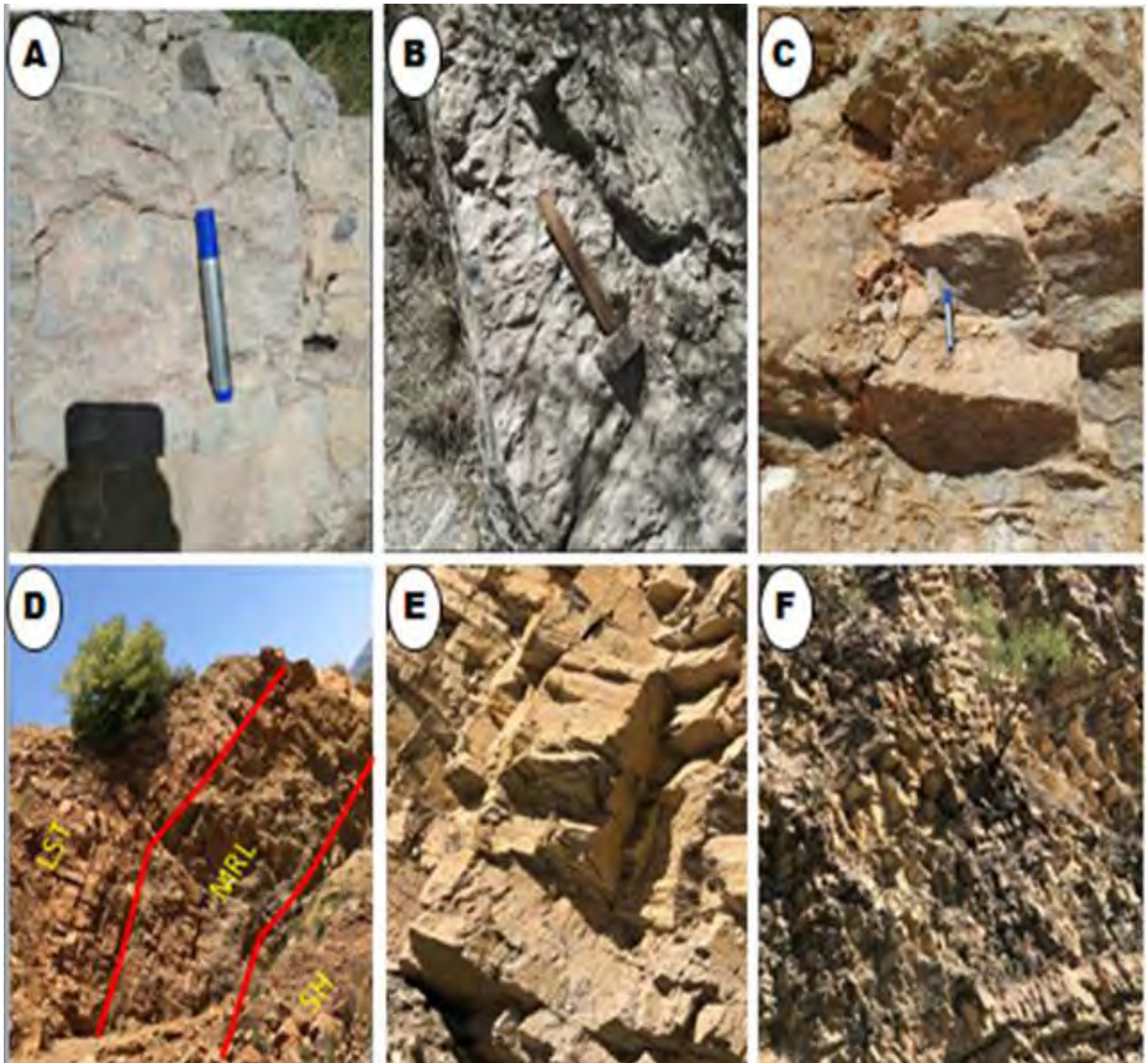

Figure 3.3 Field Photograph (**A, B**) Shows solution weathering effect in limestone. (**C**) View of thick bedded limestone with peloids and Ooids, skeletal grains. (**D**) Shows close view of interbedded shale and marl with thin bedded limestone. (**E**) Shows thick bedded yellowish grey ferogenious limestone. (**F**) View of aggressive effect due to tectonic stresses, highly fractured limestone of Shinawari Formation.

3.3 Thin section Studies and Overview of Microfacies

Paleontological and petrographic studies were done to illustrate the thin sections criteria in constitution of the microfacies. Brown first invented the term "microfacies" in 1943. A modern definition of microfacies includes all sedimentological and paleontological data which was categorised and characterised from thin sections or polished slabs of rock samples (Flügel, 2004). Numerous depositional settings are used to create carbonate rocks. Each depositional habitat has distinct physical, chemical, and biological features, which are represented by the kind of carbonate rock or by the association of its facies. Understanding of these characters is crucial for interpreting depositional history and environment. The Dunham (1962) classification scheme was used in this study, and it is based on the carbonate ingredients and the depositional fabric. In comparison to Folk's (1959) classification, which is used on genetically-bases, this classification has been frequently employed in the description of carbonate rocks. The Standard Microfacies Scheme (SMS) of Wilson (1975) is the foundation for the Microfacies study, which is based on microscopic investigation of thin sections and field criteria used to interpret paleoenvironment.

For the microfacies examination of the Shinawari Formation , 24 representative samples were selected from the Nala sections of the Nizampur cement factory for the petrographical and biostratigraphical studies of thin sections. By comparing with the standard literature of Flügel, the presence of planktonic foraminifera, plankton (Radiolarians and Calcispheres), and other fossil groups (Bivalves, Bryozoans, Gastropods, Echinoderm plate and spine, and Ostracods) and intraclasts were recorded to interpret history and environment of deposition of the Shinawari Formation.

3.4 Microfacies of the Shinawari Formation

Shinawari Formation sampling was carried out from the exposed stratigraphic sections in the Nizampur Cement Factory Nala at predetermined intervals, a total of 24 representative samples were selected. Five microfacies were identified in three facies associations and related depositional environments, which are including peritidal, restricted lagoon, and high-energy shoal on the inner part of a homoclinal carbonate ramp. Those were recognised through field analyses, grain configuration, texture, and structure studies by applying Flügel's (2010) conventional facies model for ramps and facies assessments.

The following microfacies were recognised based on a thorough petrographic analysis of the selected samples.

- Mudstones Microfacies (MF-1)
- Bioclastic mudstone Microfacies (MF-2)
- Ooidal grainstone Microfacies (MF-3)
- Peloidal Packstones Microfacies (MF-4):
- Dolomitized Ooidal Grainstone Microfacies (MF-5)

3.4.1 Mudstone Microfacies (MF-1)

Extremely fine lime mud makes up the majority of this mudstone microfacies, the fractures of this microfacies were mostly filled with calcite and tiny amplitude of stylolite that is crosscutting and postdating these fractures (figure 3.4, 3.5). Few horizons in the formation under study contain such mudstones which were partially dolomitized. The presence of pure micrite during the deposition which is homogeneous and non-fossiliferous, that indicates the lagoonal environment (Wilson, 1975; Flügel, 2010; Hussein et al., 2017).

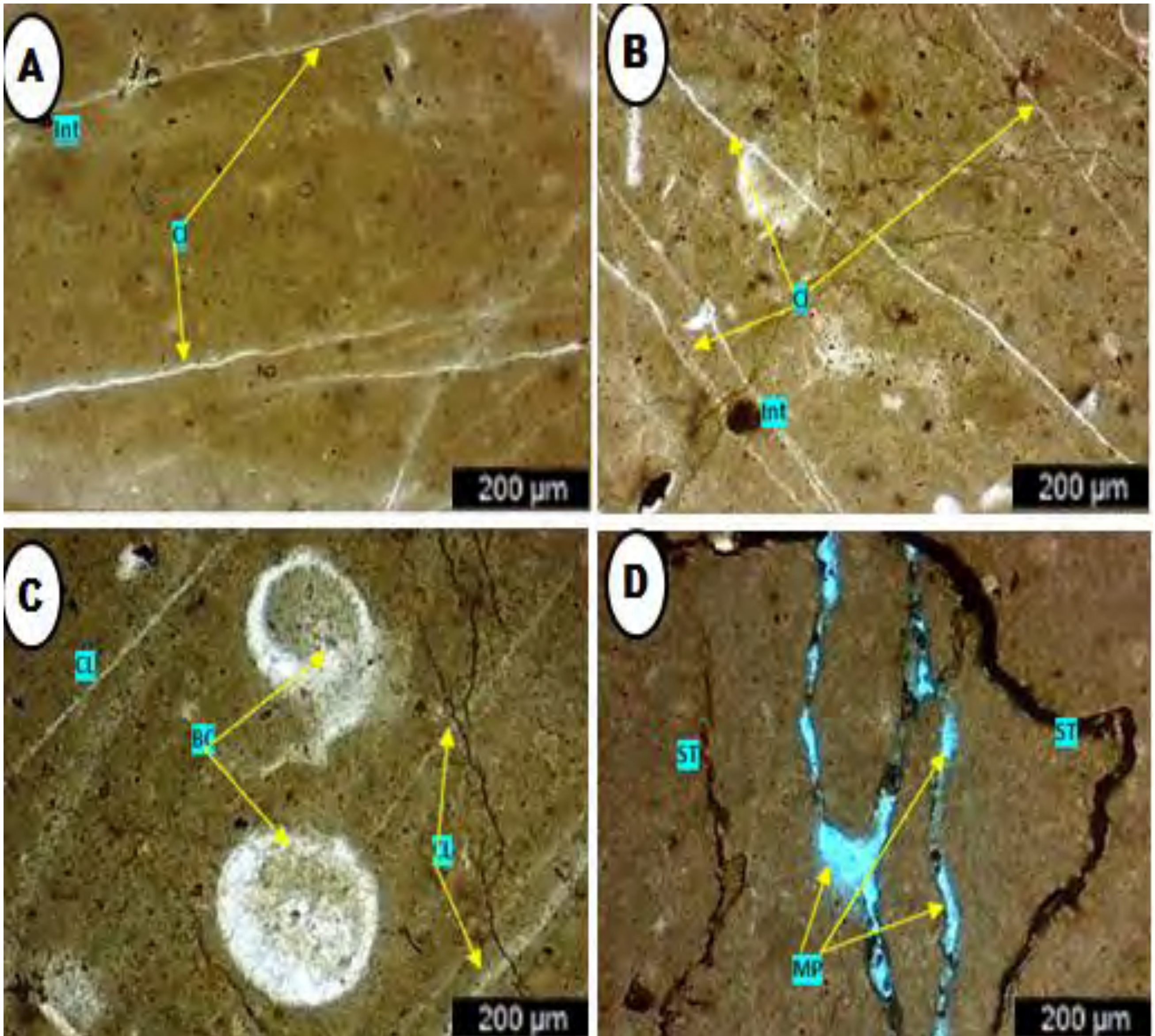

Figure 3.4 Photomicrograph (**A-B**) shows mudstone facies with multiple sets of calcite veins and few intraclast. (**C**) Shows bioclastic mudstone facies with thin calcite veins and (**D**) shows mudstone facies with moldic porosity (MP) and stylolite's (PPL. Mag. X4).

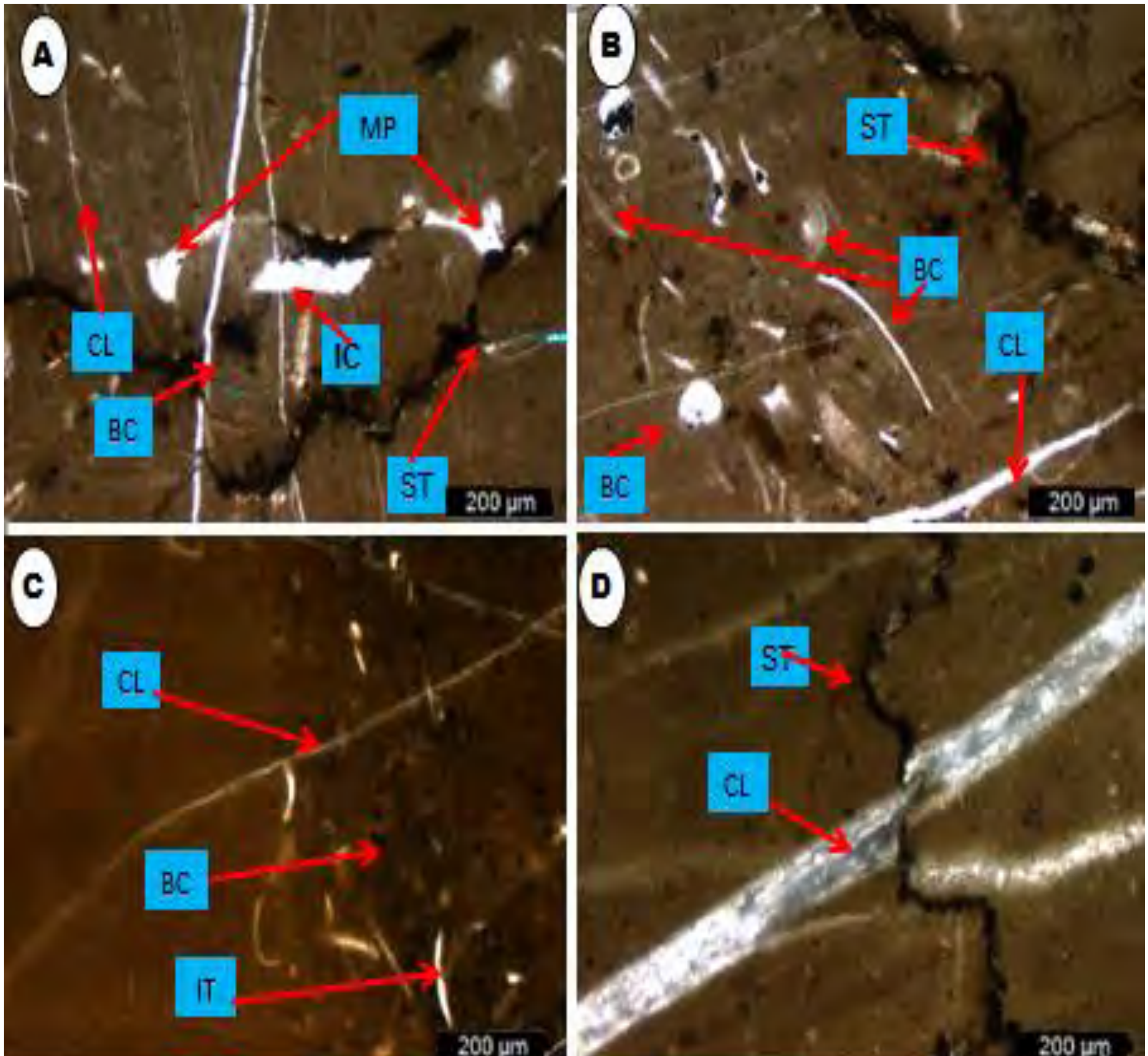

Figure 3.5 Photomicrograph (**A,B**) shows mudstone facies with multiple sets of calcite veins and few bioclast (BC) and moldic porosity (MP). (**C**) Shows bioclastic mudstone facies with thin calcite veins (CL) intraclast (IT) and bioclast (BC). (**D**) shows mudstone facies with calcite veins (CL) and stylolite's (ST) (PPL. Mag. x4).

3.4.2 Bioclastic Mudstone Microfacies (MF-2)

It has bioclasts of gastropods and bivalves that range in presence from 5 to 10% in lime-mud (locally microscopicized). Lime mud is pierced by a few calcite veins (figure 3.6 and figure 3.7). The presence of bioclast and intraclast material in mudstone implies that the deposition took place in the peritidal zone (Flügel, 2010; Ranjbaran et al., 2007). Grapestones are frequently found in the grainstone microfacies of the Shinawari Formation (figure 3.6 and figure 3.7). Although grapestones existence is not frequent in other microfacies.

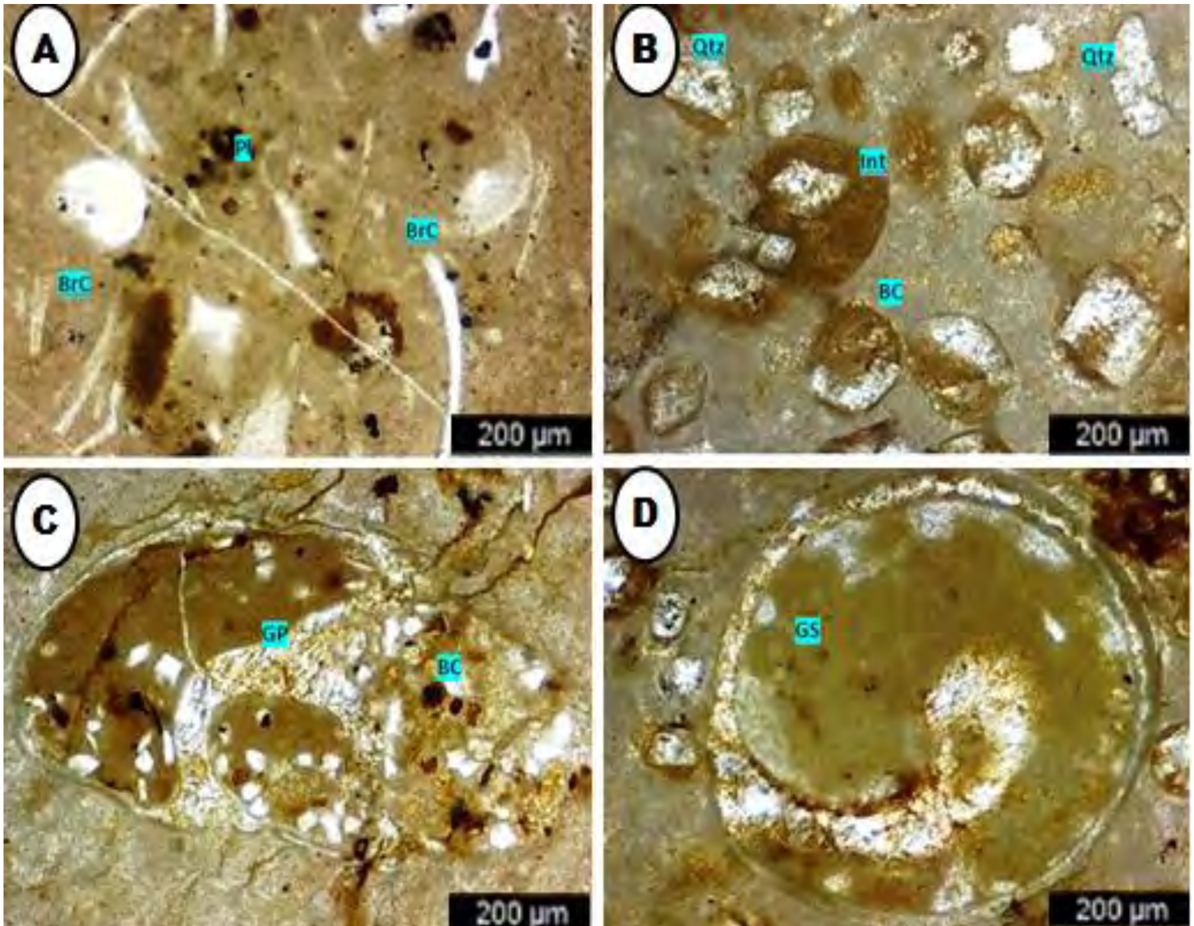

Figure 3.6 Photomicrograph (**A, B**) shows bioclastic wackstone with pellet/peloids, intraclast, quartz and thin calcite veins. (**C**) Shows bioclastic wackstone with grapestones having intergranular cement filling (GP), (D) shows repetition of aragonite in gastropod shell by spray calcite. (PPL. Mag. x4).

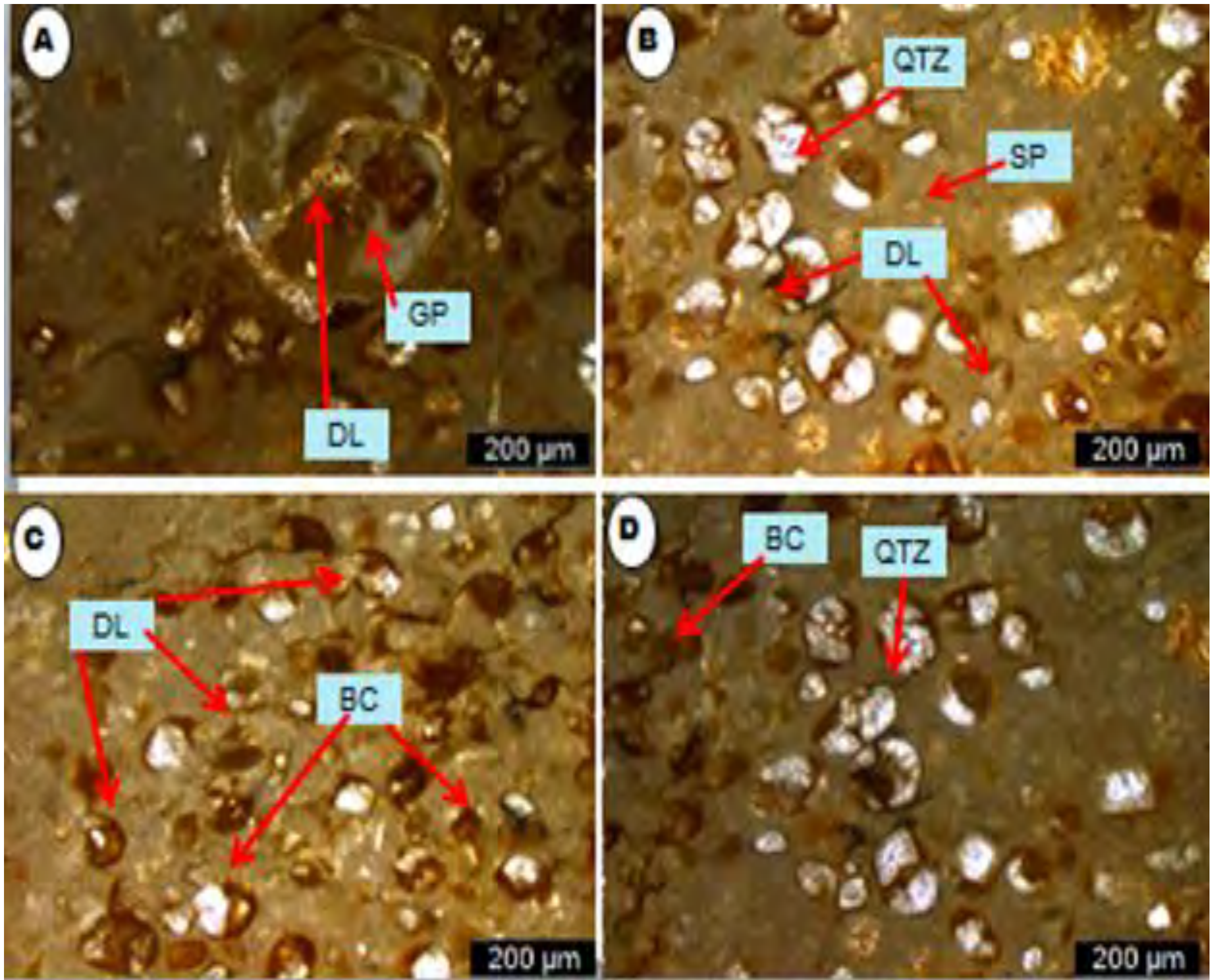

Figure 3.7 Photomicrograph (**A**) shows bioclastic wackstone with alternation of aragonite of gastropod shell (GP) by spray calcite and dolomite (DL). (**B,C,D**) Shows bioclastic wackstone with granestones having intergranular filling by spray calcite and dolomitic cement, pellet/peloids, Ooids, bioclast (BC) intraclast and quartz (QTZ). (PPL. Mag. x4).

3.4.3 Ooidal Grainstone Microfacies (MF-3)

Grainstone assemblage is up to 32% which is a higher percentage in the analysed sections. Ooids make up the majority of these microfacies and range in percentage from 75 to 85%, while bioclasts make up 5 to 10%. The Ooids are micritized between 40 and 150 m, and sparite/microspar is used to cement them. The micrite envelopes of the dissolving Ooids can still be seen. Numerous calcite veins pierce the sediments' structure (figure 3.8 and figure 3.9), this facie has moldic porosity. The presence of well-sorted, medium- to coarse-grained Ooids with occasional cross-bedding indicates that Oolitic grainstone normally form above the wave base in an agitated marine environment, such as a shoal environment (Flügel, 2010; Beigi et al., 2017).

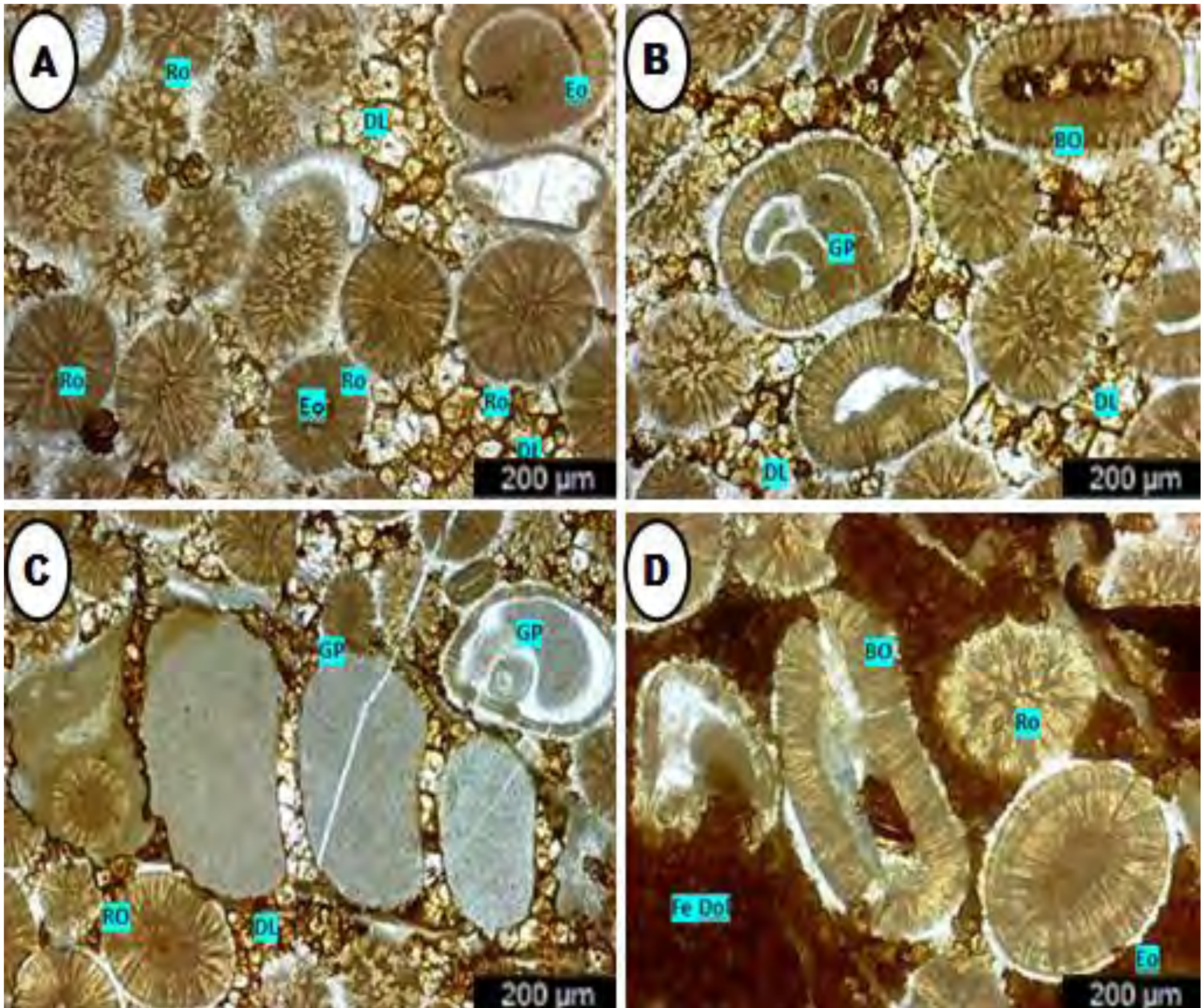

Figure 3.8 Photomicrograph (**A,B**) shows various radiated (RO), eccentric Ooids (EO), bio-Ooids (BO), surrounded by sparry calcite and iron partially intercorporated in the intergranular dolomite cement. (**C**) Shows Ooidal grainstone facies with a larger bioclast of gastropod having micritic envelops and alternation of aragonite of smaller gastropod (GP) shell by sparry calcite, and intergranular dolomite cement. (**D**) Shows various radiated (RO), eccentric Ooids (EO), mechanically compacted bio-Ooids (BO), surrounded by ferron dolomite cement. (PPL. Mag. x4).

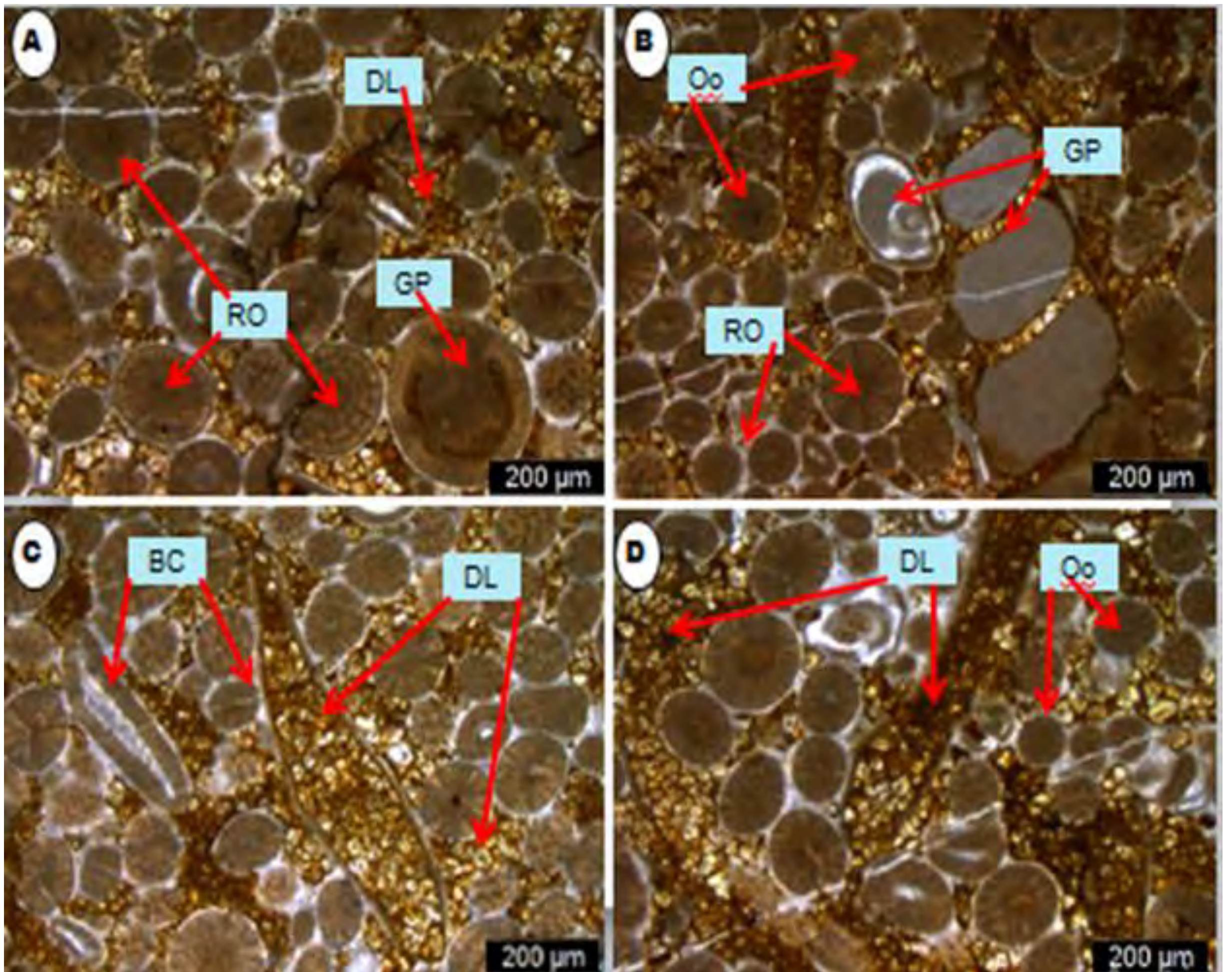

Figure 3.9 Photomicrograph **(A**) Shows various Ooidal grainstone with radiated and radial eccentric Ooids and smaller gastropod shell surrounded by sparry calcite, (B) shows larger bioclast of gastropod having micritic envelops and alternation of aragonite of by sparry calcite, and partially intercorporated in the intergranular dolomite cement and dolomitized matrix. The cortices of the Ooids are spelled off and filled by calcite. (**C, D**) Shows Ooidal grainstone with various radiated and eccentric Ooids and gastropods shells surrounded by sparry calcite, and dolomitized matrix. The cortices of the Ooids and gastropods are spelled off (OFF) and filled by calcite. (PPL. Mag. x4)

3.4.4 Peloidal Packstone Microfacies (MF-4)

The Peloids and Ooids that make up the Peloidal Packstone Microfacies are allochems. Peloids make up the majority of this microfacies and range in percentage from 85 to 95%, followed by Ooids at 20%, bioclast at 15 to 25%, and intraclast at 10%. These bioclast and some of the intraclast have undergone microscopic modification. There are between 40 and 60 percent more peloids than micrite. Some of the grains have calcite-filled cement between them (figure 3.10). The facie frequently exhibits mouldy porosity. Peloids richness combined with a limited diversity of skeletal grains and bioclast points to a sub tidal lagoon with limited water availability. Slow sedimentation is indicated by iron oxide stains along the pressure solution seams. These sorts of facies are the same as those identified for lagoon settings close to the shoals and carbonate sand's edge (Amel et al., 2015).

Mechanical compaction;

The subsequent diagenetic process is the mechanical compaction of the carbonate sediments. The inter-grain and interstitial space shrinks as a result of this diagenetic process which may reducing the rock's overall porosity. When sediments are not properly compacted by mechanical means, the component grains may break (figure 3.10). The rock becomes fractured as a result of such and few other reasons, which improves the rock's porosity and permeability.

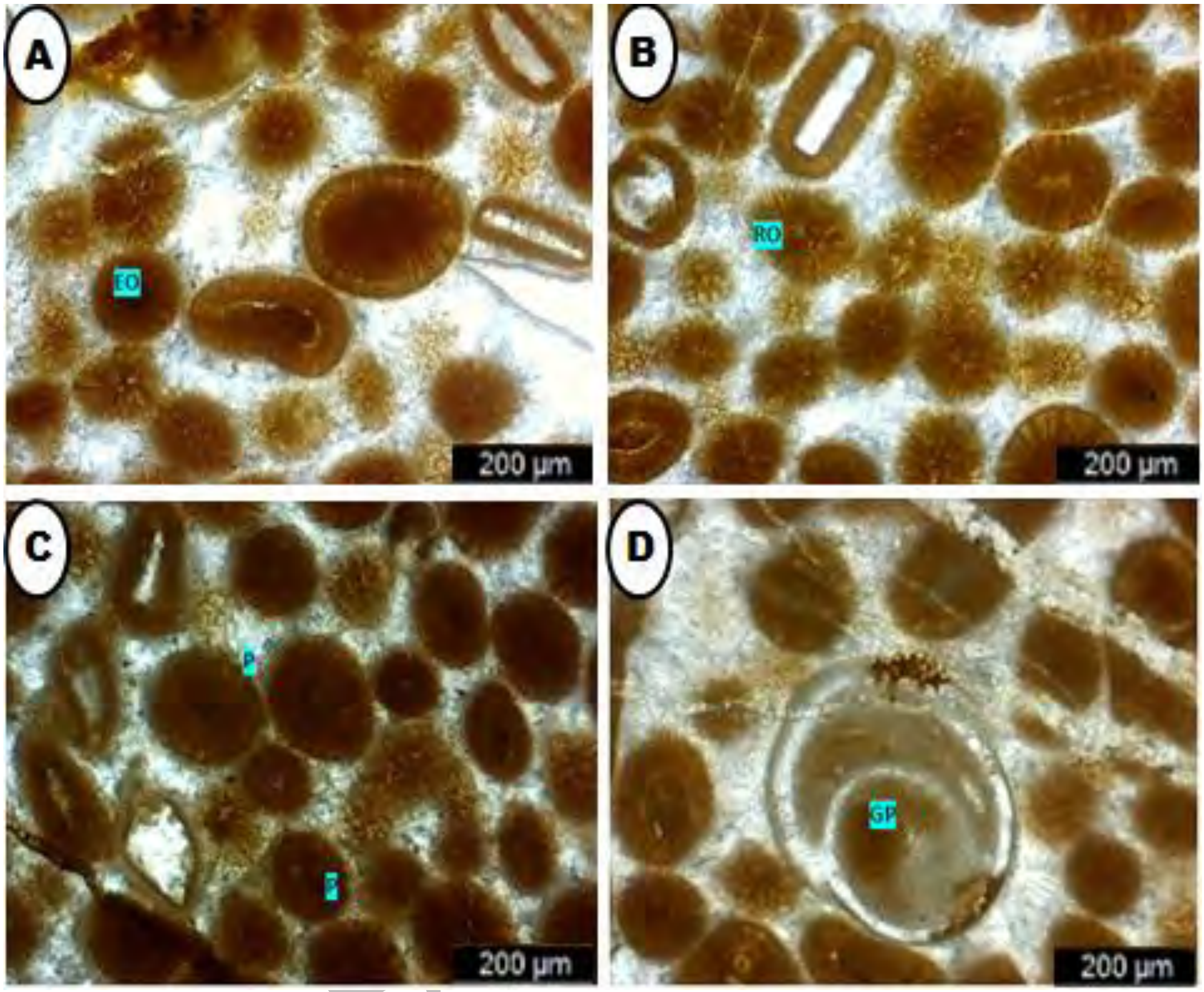

Figure 3.10 Photomicrograph (**A-D**) shows peloidal grainstone various peloids (P), radiated (RO) and eccentric Ooids (EO) surrounded by sparry calcite, . The signatures of mechanical compaction are visible in photograph A, B. The gastropods shell is surrounded by sparry calcite, matrix. (PPL. Mag. x4).

3.4.5 Dolomitized Ooidal Grainstone Microfacies (MF-5)

A diagenetic process known as "dolomitization" results in the mineral dolomite from aragonite and calcite. Dolomitization causes significant textural changes in the limestone that either entirely or partially destroy the depositional fabric. One of these modifications is increased porosity, which raises reservoir potential (Tucker et al., 2009). Shinawari Formation dolomitization is secondary in nature and characterised by the selective replacement of calcite during late diagenesis. The interbedded shale and marl were probably compacted to provide the necessary Mg source. The examined limestone showed selective dolomitization of the micritic matrix but not of the allochemical components. The types and levels of dolomite substitution range from isolated areas to a large range (10% to 80%). The dolomite is non-pervasive, subhdral to euhedral, and fine-medium crystalline. It can be found as a single rhombic crystal or a group of crystals. In addition, dolomite has been observed as stylocummulate along micro stylolite's (Figure 3.11 to figure 3.13) and it has also been discovered as cement.

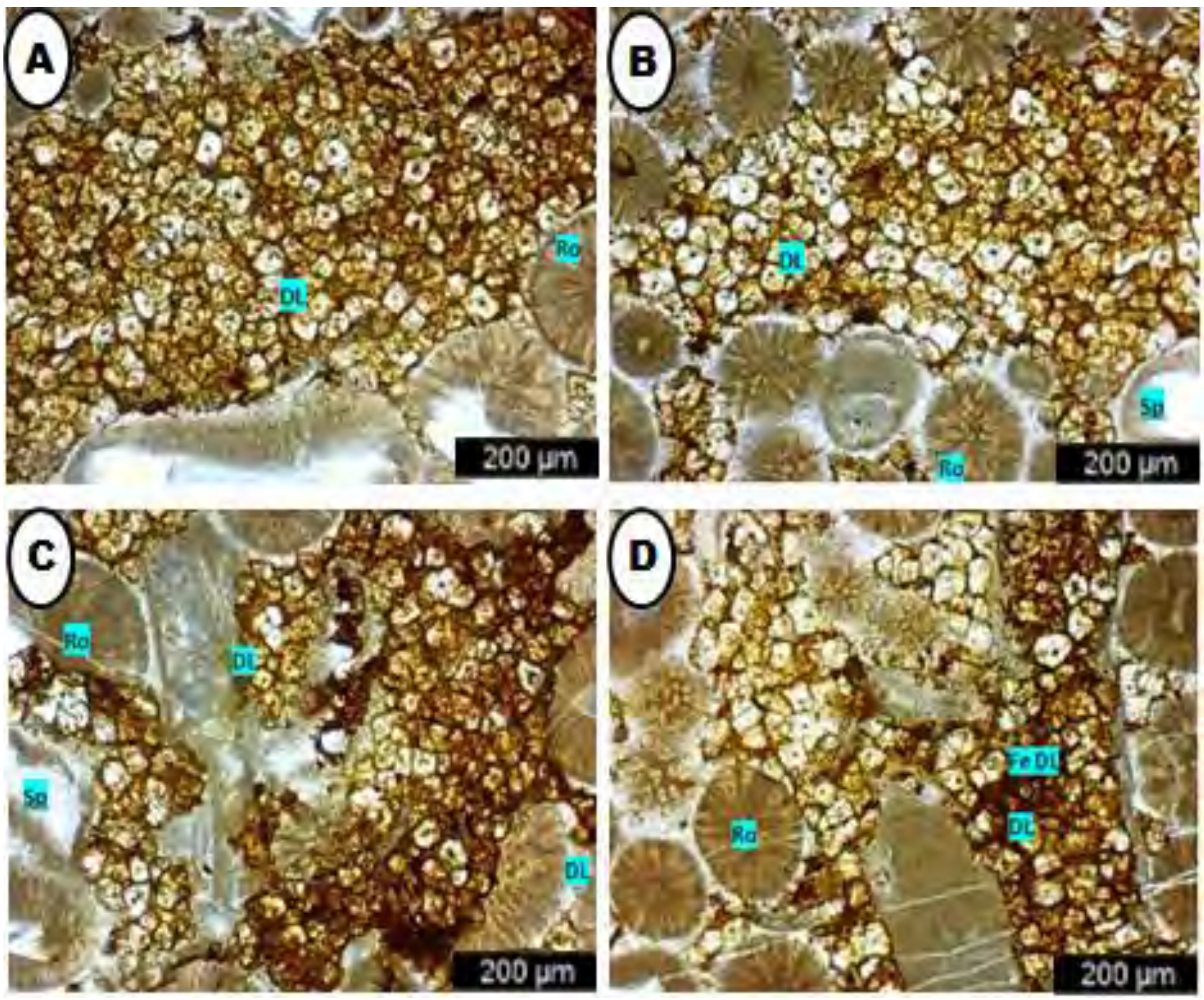

Figure 3.11 Photomicrograph (**A-D**) shows dolomitized Ooidal grainstone with various radiated (RO) and eccentric Ooids (EO) surrounded by sparry calcite, (SP) and dolomitized matrix (DL) (PPL. Mag. x4).

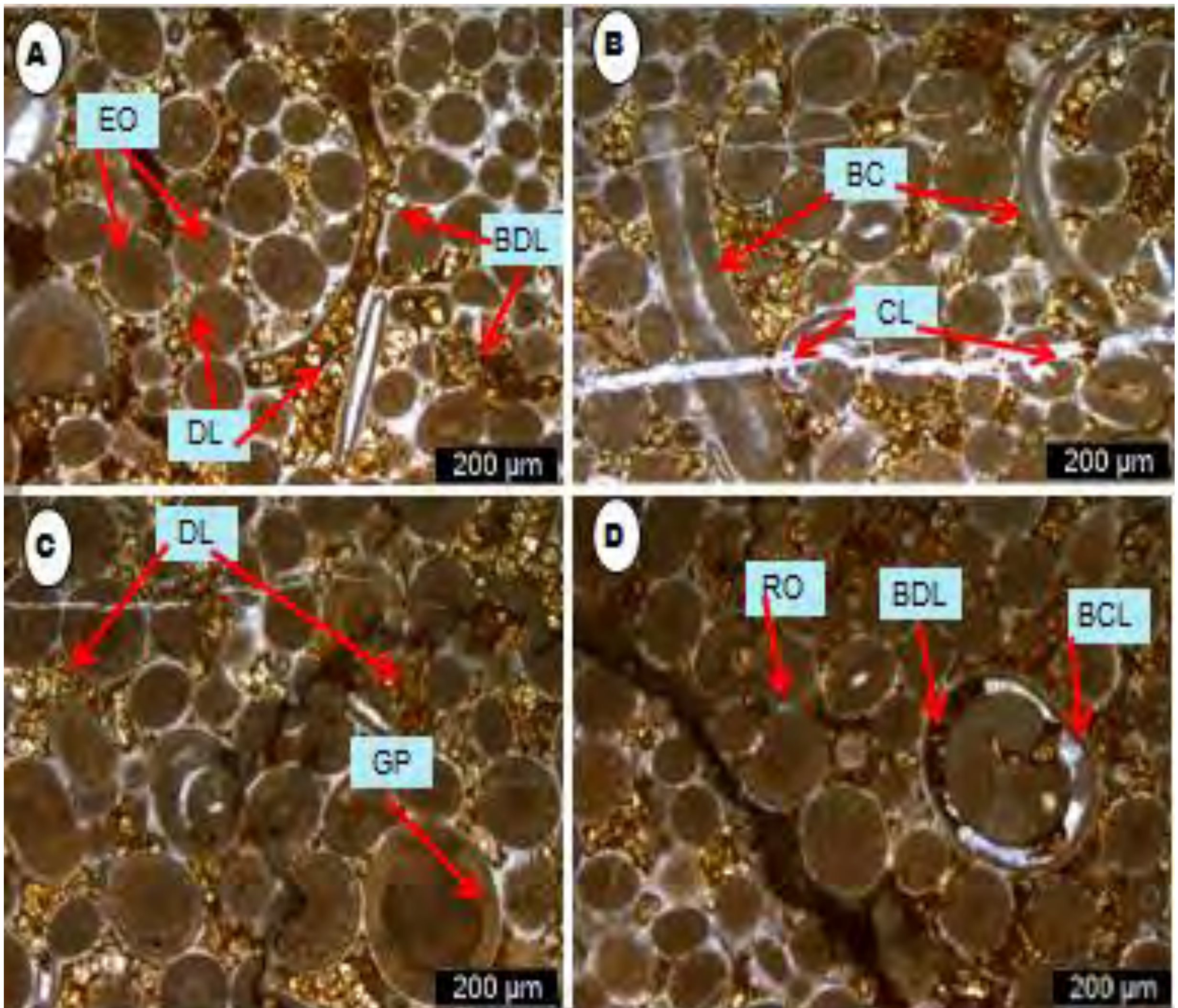

Figure 3.12 Photomicrograph (**A-D**) showing dolomitized Ooidal grainstone with various radiated (RO) and eccentric Ooids (EO) surrounded by sparry calcite, (SP) and dolomitized matrix (DL), a bioclast of gastropod having micritic envelops and alternation of aragonite of smaller gastropod shell by sparry calcite and intergranular dolomite cement. (Mag. x40.ppl).

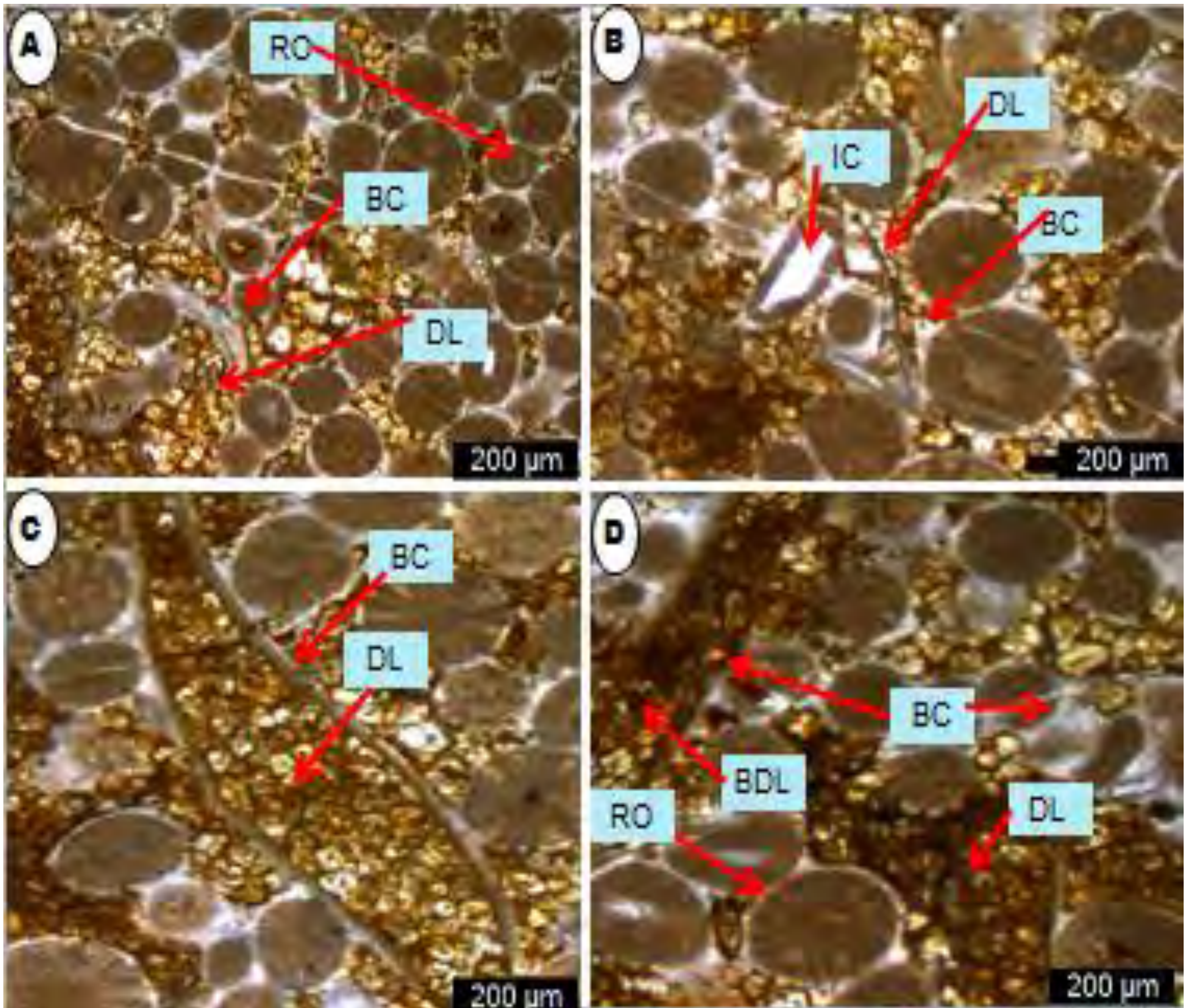

Figure 3.13 Photomicrograph (**A-D**) showing dolomitized Ooidal grainstone with various radiated (RO) and eccentric Ooids (EO) and bioclast surrounded by sparry calcite, and commonly replaced with dolomitized matrix (DL). The cortices of the Ooids and bioclast are spalled off (OFF) and filled by calcite and dolomite. (PPL. Mag. x4).

CHAPTER-4
WELL LOGS CORRELATION AND LITHOFACIES IDENTIFICATION

4.1 Introduction

The definition of well log correlation given by the Oilfield Glossary at www.Slb.com/glossary is "a point-to-point relationship from well to well in which data revealed that the points were deposited at the same time (chronostratigraphic) or having comparable and related properties. The current study was an effort to perform lithological correlation of three wells conventional petrophysical data from Kohat Basin (Manzali-01, Manzali-02, and Makori-01).

Tech Log, a leading oil and gas industry software, was utilised to correlate data and assess petrophysical job flows. Petrophysical rock parameters were record and interpreted (resistivity, self-potential, natural radioactivity, density, sonic-velocity, bedding dips, temperature, formation pressure, etc.) by using wells data (Manzali-1, Manzali-2, Makori-1) of the Shinawari Formation in order to determine the depth, lithology, thickness, orientation, and porosity of the reservoir as well as to characterise any fluid types (Gas, Oil, Brine).

The petrophysical analyses were performed to determine the volume of the shale (Vsh), the density porosity (D), the neutron porosity (N), the sonic porosity (S), the average porosity (A), the effective porosity (E), the qualitative permeability, the water saturation (Sw), and the hydrocarbon saturation (Shc). The following formulas were used to calculate the aforementioned petrophysical parameters.

(1) $Vsh = GR\ log - GR\ min\ /\ GR\ max - GR\ min$

(2) $\phi D = \rho ma - \rho b\ /\ \rho ma - \rho f$

(3) $\phi A = \phi N + \phi D\ /\ 2$

(4) $\phi s = \Delta tlog - \Delta tm\ /\ \Delta tf - \Delta tma$

(5) $\phi E = \phi T \times (1 - Vsh)$

Where, GR log = GR log reading, GR max = maximum GR log, GR min = minimum GR log; ρb = density from log, ρma = matrix density, ρf = fluid density; Δtlog = interval transit time from log, Δtma = interval transit time of matrix, Δtf = interval transit time of fluids; ϕT = total porosity

(Sw) has been calculated through Archie equation as follows

(6) $Sw=[(a/\phi m)(Rw/Rt)]1/n$

Sw = water saturation, ϕ = porosity, Rw= formation water resistivity, Rt= true resistivity,

a= tortuosity factor, m= cementation factor and n= saturation exponent. The hydrocarbon saturation (Shc) has been assessed by the following equation.

(7) $Shc=1-Sw$

4.2 Quality Control of well logs

The effectiveness of wire line service providers, tool reliability, tool calibration, and well log data quality and consistency are all essential core elements. Data quality, consistent complementary readings checks (such as density and neutron logs or porosity logs), repeatability of recorded logs as needed, and accurate tool calibrations and verifications of all equipment are all important for the collection of high-quality data. The following log curve is subject to quality control, as are all conventional log curves.

- An organised and complete logging programme considered the site's safety conditions, equipment details, acquisition criteria, borehole environmental conditions, and planned operational processes. Correct use of the logging programme shared by the operator, wire line service provider, and wire line log witness.
- All fieldwork is recorded, including field notes, data collection sheets, field logbooks, and completely documented instrument digital data, in addition to the work that is done on-site.
- Routine equipment checks were carried out on a regular basis and after every problem and resolution. An equipment operational check and test measures were completed before starting each task and each run.
- Standard adjustments and revisions to logging programmes have been documented by field engineers or data managers for operating procedures, borehole conditions, previously unknown site characteristics, and primary depth shifts. The rationale for implementing the modification, any concessions, and any potential repercussions were all documented.
- All the factors influencing the survey and measurements were recorded and documented as soon

as they were found to act as a guide for future challenges ("Lessons learned").

- All equipment problems and their solutions to correct them, the effects of the changes on the recorded data were documented.
- Confirmed that the values of the digitally or electronically recorded data were found in well logs are in accordance with the surrounding circumstances. All wire line logs comparing and matching was done on depth based (final depth control).
- Any missing or erroneous data, as well as the scale and scale compatibility of the density-neutron family curves was checked. During analysis, the software analysed and contrasted all logs curves side by side.
- Calliper log was used to evaluate the overall accuracy of bore hole data, especially for padded tools, and built-in curve for the purpose of evaluating the reliability of density data, density correction curve (DRHO) was utilised (density, neutron and micro resistivity logs). The calliper record also provides information on the location of less compacted layers.
- Accurate clay volume indicator with a computed gamma-ray (CGR) curve (Gamma-ray minus uranium curve or it is summation of potassium and thorium sources radioactivity). Data that has undergone comprehensive examination, including software checks for any depth shift of the log curves.

4.3 Correlation guidelines while working on Shinawari Formation Logs

The general standards and procedures were followed for the lithological correlation of the Shinawari Formation.

- The lithological correlation work flow started at the bottom and worked its way up, following the direction that the rocks were deposited.
- The patterns/signatures of the resistivity logs were used to correlate lithologies, but always taken into account variances caused by fluid effects.
- Correlated the top and bottom of a formation interval, for example, a shale out area or a time with little to no discernable sand body (such as the presence of water or oil on the resistivity logs).
- Correlated the formation tops and markers as the starting point, then the minor modifications and beds, before correlating the large-scale to the small-scale alterations.

- Checked twice for omissions and duplicate sections.
- Merging correlation lines showed units that pinch out between wells. Scale variations, casing shoes, and acoustic log cycle skips were non-geological phenomena that carefully observed.

4.4 Outcome of Shinawari Formation Logs Correlation

The wire line logs data of selected wells were used for correlation and their outcomes detail is as below.

- Four limestone and four shale facies were found by lithofacies analysis. The limestone facies range from argillaceous/marly limestone to planer laminated mudstone to grainstone/rudstone.
- As shown by lithological correlation, limestone facies are slightly pinching out from north east to south west direction, with gamma rays (GR) values between 50API to 120API (American Petroleum Institute). In the targeted well's, Shinawari Formation ranges from clean limestone to argillaceous limestone and is sandwiched by dominant shale and silt/sandstone in some places.
- Using the cross plot technique, the association of the Shinawari Formation lithofacies/electrofacies delivered a strong base and level of control.
- The framework for identifying and labelling electrofacies with their respective environments of deposition on composite well logs were established in the Shinawari Formation correlation (figure 4.1).
- The Shinawari Formation poor reservoir quality was further corroborated by porosity and permeability analyses based on petrophysical log interpretation, which verified very low porosities and permeabilities across the section.

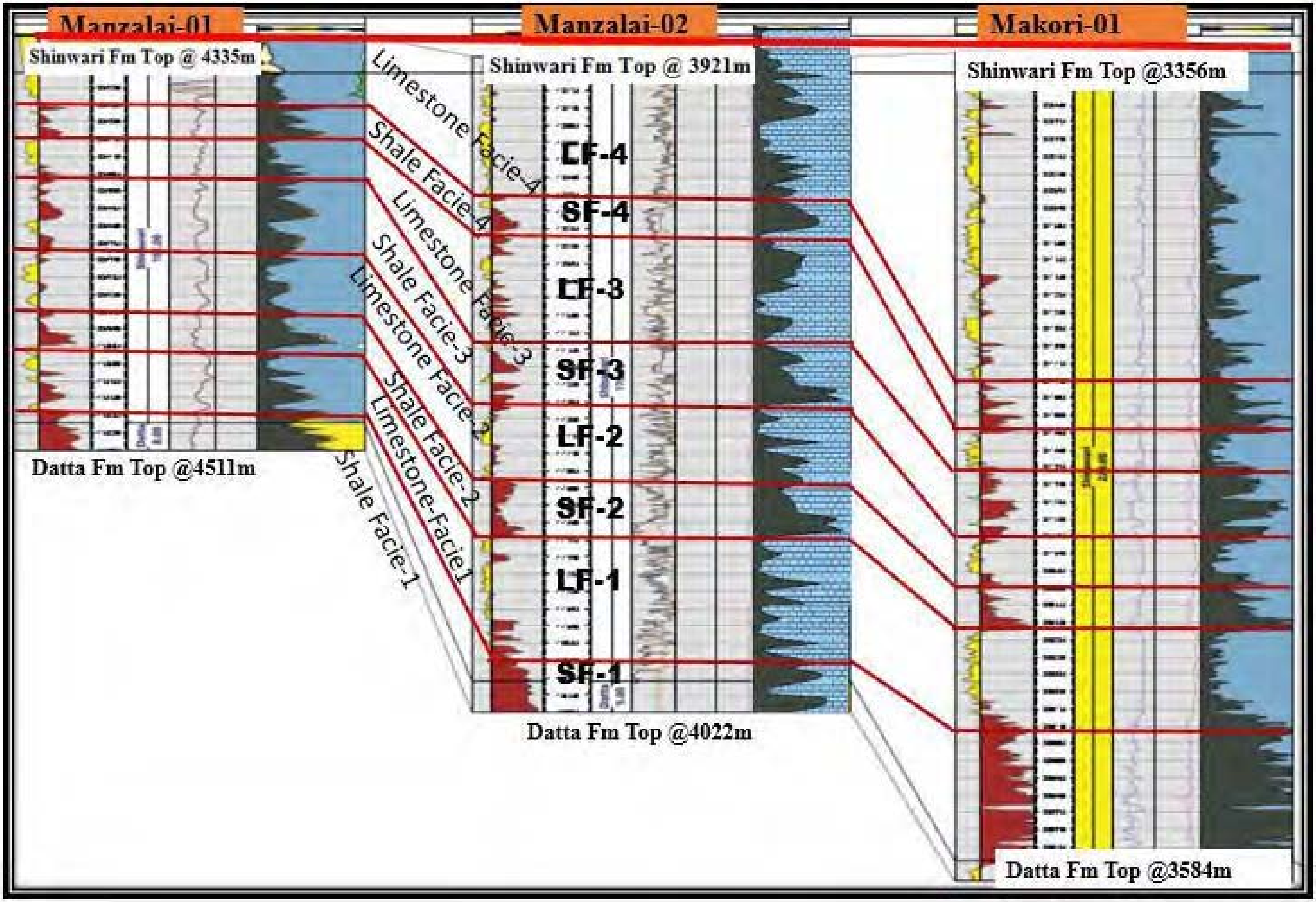

Figure 4.1 Shinawari Formation correlation of shale and limestone electrofacies of well (Makori-1, Manzali-1 & Manzali-2) in Kohat sub Basin

4.5 Delineation of Shinawari Formation Lithofacies

The term "lithofacies" is frequently used in sedimentary petrology and is defined as "lithofacies refers to the facies of sedimentary rocks. It reflects the physical, chemical and biological characteristics of a specific sedimentary environment. The presence of bioclast and intraclast material in mudstone, Oolitic grainstone, and peloidal packstone facies of marine carbonates that reflect the depositional environment (Dictionary of Earth Sciences 2006, Oxford Univ. Press). According to the oilfield glossary at www.Slb.com, lithofacies is mapable subdivision of a stratigraphic unit that may be differentiated by its facies or lithology, based on its texture, mineralogy, grain size, and the depositional environment. The best way to characterise lithofacies in the subsurface is using core data, but since it is uncommon to core the whole succession of interest, standard well log data of high-resolution used as alternative with several potential pitfalls. Gamma ray (GR), Micro Spherically Focused Resistivity (MSFL), Resistivity Latrolog Shallow and Latrolog Deep (LLS and LLD), Density (RHOB), Neutron (CNL), and Photoelectric factor (PEF) were correlated to depositional facies of the Shinawari Formation in the current study. The conventional logs dataset of three wells (Manzali-01, Manzali-02, and Makori-01) from Kohat Basin was used.

4.6 Electrofacies/ Lithofacies of Shinawari Formation

Based on interpretation of neutron porosity-shale volume cross plot and composite logs of Shinawari Formation exhibits four shale and four limestone electro facies as follow (SF1 to SF4 & LF1 to LF4).

4.6.1 Shale facies of Shinawari Formation

Based on composite logs interpretation of Shinawari Formation reveals four shale facies within Shinawari Formation from top to bottom. This shale facies were characterized based on the higher GR values, on average the values of GR in the shale was from 70 to 110 API , whereas range of neutron porosity of these shale facie is from 10-18% (Fig. 4.1). The shale's were recognized from top to bottom of Shinawari Formation as (SF4, SF3, SF2 and SF1) these facies were seemed hydrophilic and considerable water adsorption. These shale facies were developed in all of the studied wells (Makori-1, Manzalai-1 & Manzalai-2), as shown in figure 4.1.

4.6.2 Limestone Facies of Shinawari Formation

Based on the composite log of Shinawari Formation interpretation four limestone facies (LF1 to LF4) were identified based on the wire line logs data correlation of three wells. The LF1, LF2 and LF-3 facies having more or less the same thickness, whereas the LF-4 limestone facies was showing increasing trend from east to west. In the Makori-1 well the thickness of this facies is 60m whereas it is thinner in the Manzalai -2 and further the thickness decrease in Manzlai-1 well. These limestone facies were composed of clean limestone having the GR values 20-30API, whereas the argillaceous limestone having the GR values from 30 to 60API. The western most well Manzalai-1 was showing GR values up to 70 API. From top to second identified limestone facie is (LF3) which is slightly argillaceous. Its thickness varies in studied wells from 10-30m. From top to third limestone facie is identified as LF2 which is argillaceous limestone. From top to bottom fourth limestone facie was identified as LF1, which is slightly clean limestone having same GR values as LF-4 in the eastern well (Makori-1). Where as in the western wells, it is slightly argillaceous and the GR value increased up to ~60API.

4.7 Cross plots technique (Neutron Porosity and Shale Volume)

Cross plot is effective ways to display how different combinations of logs respond to the reservoir property being investigated, such as lithology and porosity. Additionally, cross plot provide a visual representation of the combinations that the log suit best disclose (Liu, 2017). The shale volume-neutron cross plot is a popular and effective method for estimating porosity and determining lithology because it has strong lithological resolution and can independently determine porosity of lithology (Ala, 2002). The point will be drawn along the intended lithology lines for a clean, gas-free, and monomineralic formation. Graduations along the lithology lines also represent the porosity of the formation. Between the lithology boundaries, a common point is a combination of any two of the common three lithologies, namely limestone, dolomite, and sandstone. The sandstone cement should be determined through petrography for reliable assessment of the sandstone matrix. Hole rugosity and the use of heavy drilling muds are limitations of the shale volume-neutron cross plot that have an impact on the accuracy of the shale volume log data.

4.8 Analysis of Shinawari Formation Based on Cross Plot

Using Tech log software, neutron porosity and shale volume data of the wells (Makori-1, Manzalai-1 & Manzalai-2) from Kohat Basin were plotted on a neutron porosity-shale volume cross plot to identify the lithofacies of the Shinawari Formation Schlumberger (CP-1a, neutron porosity vs. shale volume) has chosen the relevant and accepted industry standard for the shale volume (Vsh) and neutron porosity (NPHI) curves in figure 4.2 neutron porosity-shale volume cross plot. Neutron porosity (NPHI) data presented on the Y-axis and shale volume (Vsh) data on the X-axis, graduated lines for porosity. Tech log software, in order to clearly distinguishing between different lithofacies, cross plotting of shale and limestone facies are also highlighted the corresponding facies interval on the main composite log (Figure 4.1). Below neutron porosity verses shale volume cross plots of three wells (Makoi-1, Manzalai-1 Manzalai-2) from Kohat Basin (figure 4.2 to figure 4.4).

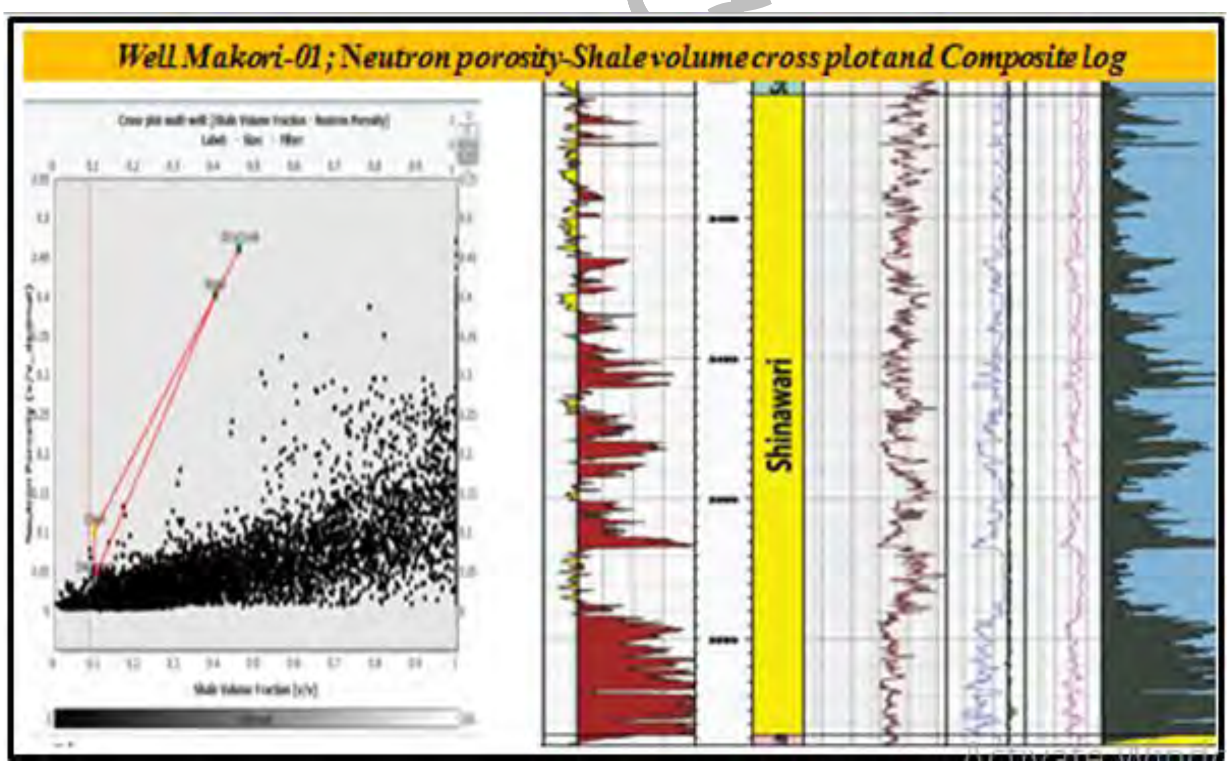

Figure 4.2 Neutron porosity & Shale volume cross plot with corresponding intervals of the composite log well Makori-01.

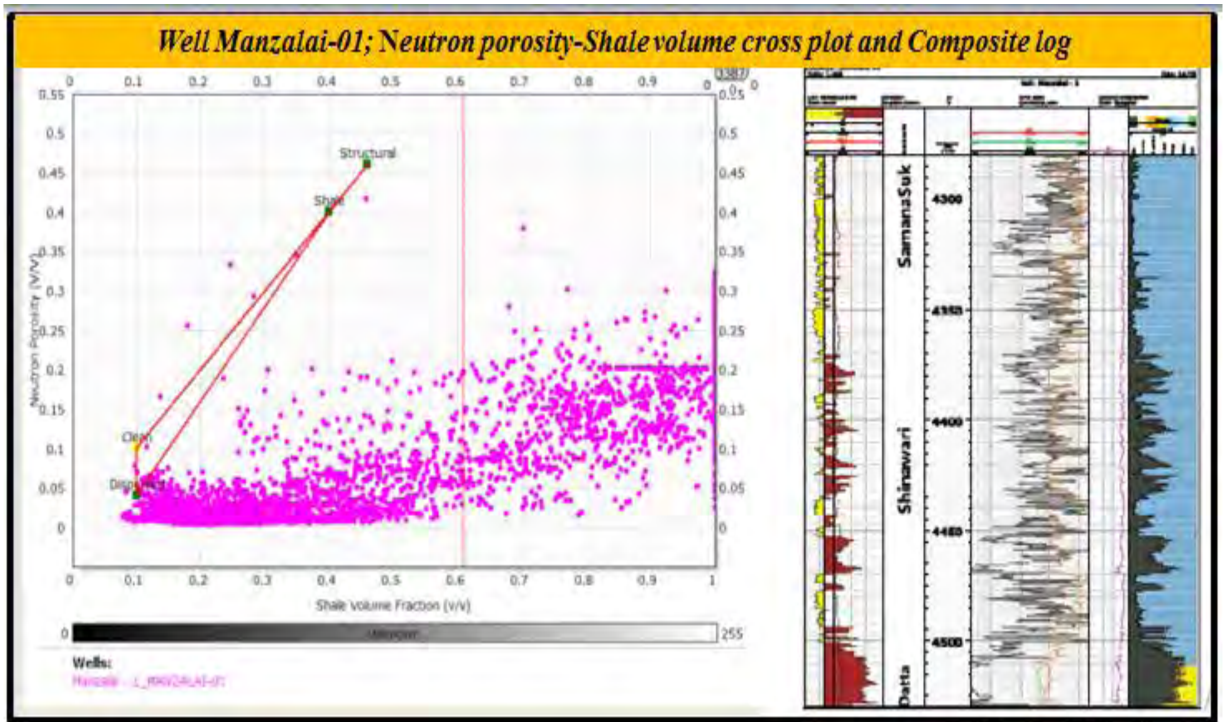

Figure 4.3 Neutron porosity & Shale volume cross plot with corresponding intervals of the composite log well Manzalai-01.

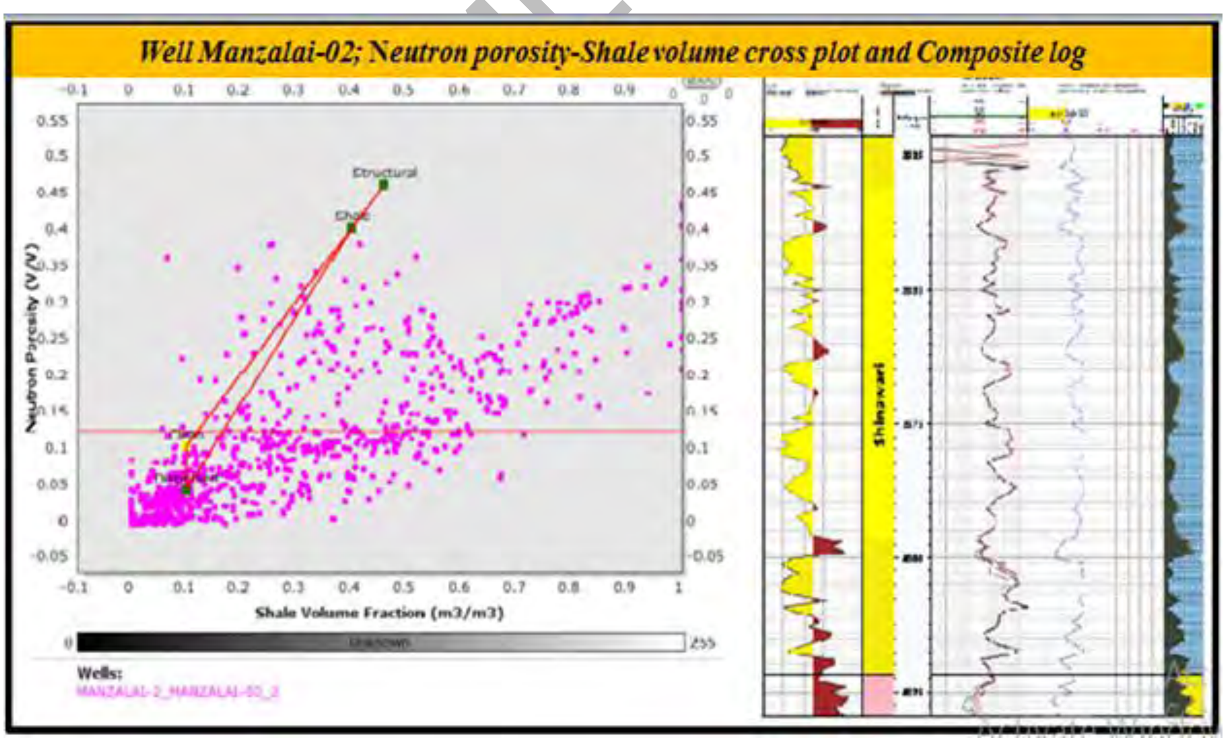

Figure 4.4 Neutron porosity & Shale volume cross plot with corresponding intervals of the composite log well Manzalai-02.

CHAPTER-5

RESERVOIR CHARACTERIZATION

5.1 Introduction

For hydrocarbon accumulation and economically production reservoir rock is required (North, 1985), which can be clastic or carbonate rock. The focus of the research study was on carbonate reservoir. Carbonate reservoir rocks are formed by depositional and diagenetic means, porosity and permeability are the two main characteristics of reservoir rocks that are produced by the texture, composition of the original sediments and modified by diagenesis processes, (Slatt, 2006). There are various processes that occur both during and after deposition that lead to develop porosity in carbonate rocks. Porosity is the proportion of a rock's total volume that is made up of interstices, whether they are related or not. While secondary porosity can generated by diagenesis at any time after deposition, such as by fracture, dissolution, or dolomitization, whereas primary porosity forms during the pre-depositional stage and depositional stage. Boring and burrowing organisms can procedure porosity which is called boring porosity. The capacity of a rock to permit fluids to move through it is known as permeability. The most significant kind of reservoirs for oil and gas are carbonate rocks. It is estimated that around 60% of the world's oil reserves are found in carbonate reservoirs, according to various data about their global occurrence (Akbar et al., 2000), it is estimated that 70% of Middle Eastern conventional oil reserves are contained in carbonate reservoirs (Aljuboori et al., 2019). If one takes into account their most significant attribute, which is dual or even multiple porosity (permeability) feature, one may say that this type of reservoir is more heterogeneous than clastic reservoirs. Fracturing and fundamental diagenetic processes result in secondary porous media (Lucia, 2007; Van Golf- Racht, 1996). The carbonate reservoirs heterogeneity presents several challenges to manage its output effectively.

Carbonate reservoirs heterogeneity demand to have a good set of well data (geological and hydrodynamic) to drain out hydrocarbon from reservoir in an efficient way. The data set using conventional and classical methods primarily characterise the matrix in the initial reservoir's medium. Technically this type of data gathered while drilling wells are logged and tested (Lucia, 2007; Mazzullo, 1996; Heinemann and Mittermeir, 2014). The geostatistical approaches available to evaluate the reservoirs by using different wells logs data (Lucia, 2007). Outcrop properties, electrical borehole scans, disconnected fracture network (FDFN), and comparison to other reservoirs are frequently used methods to determine properties of fracture system (Kim and Schechter, 2009). It is also reported that in case of absence of a secondary porosity (fracture system in any form) most of the carbonate reservoirs are non-producing or uneconomical. So it is essential to evaluate the properties of secondary porosity in a reliable way. The most reliable information can be obtained through studying a reservoir's or a well's long-term dynamic behaviour. There is a method for calculating the drainage radius of a well and the characteristics of a fracture system, such as the average length of the matrix/fracture block, the fracture porosity, and the fracture aperture, from available production data of the well which is not available in case of this study . For the reservoir characterization of Shinawari Formation following parameters were used.

- Diagenesis impact on reservoir Potential.
- Thin section visual porosity and permeability estimation
- SEM analysis
- Petro-Physical Analysis

5.2 Diagenesis Impact on Reservoir Potential

In order to control hydrocarbon reservoir quality two most important parameters are porosity and permeability, porosity and permeability regulate the ultimate pore space geometry, grain orientation and packing, degree of cementation and clay filling of pore spaces are intensely impacted by diagenetic processes (Burley and Worden, 2003; Gao et al.,2009). The reservoir characteristics of the Shinawari Formation are impacted by a variety of diagenetic events. Compaction and cementation are two processes that decreased the potential of the reservoir, compaction immediately start after the deposition process occurred. Stylolites are a type of compaction that develops when mudstone and wackstone undergo tectonic stresses which reduce their porosity and permeability. Cementation is an essential diagnostic procedure that decreases porosity. The cementing material mostly found calcite spar cement that entirely fills the cavities and thin cement coatings around the grains that partially fill the pores and change permeability patterns. Dissolution, dolomitization, and fracturing are diagenetic processes that increased the reservoir potential and developed the porosity. Secondary porosity is enhanced by fractures and large interconnected vug's as a result of dissolution whish enlarges fractures and interparticle pores. Additionally it increases porosity since dolomite is denser and takes up less space than the original calcite (Bathurst, 1971).The porosity and quality of reservoir may be decreased due to dolomitization and cementation.

5.3 Thin section porosity estimation

Characterization of conventional reservoirs is done using thin section analysis. High resolution photomicrographs were created using secondary and backscattered electron imaging. Rock's mineral morphology has been studied which also defines pore geometry and flow path (Brains, 2015). Shinawari Formation's thin-section study revealed micropores, calcitic and micritic cementation, and vuggy porosity as shown in figure 5.1 to figure 5.3. The development of vuggy porosity includes the dissolution of the grains as well as shelter porosity, shelter porosity is formed by the shelter and umbrella effect of the large grains and enhances the porosity by preventing the filling of the pore space beneath laying. Porosity decreased due to filling of calcite the intergranular pores and vugs.

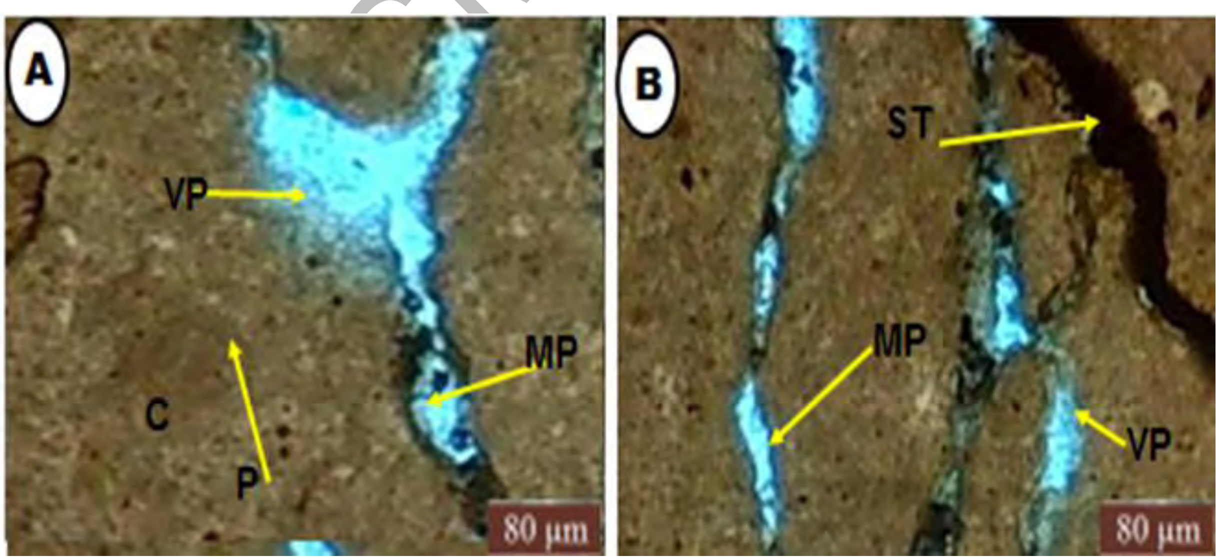

Figure 5.1 Showing images of bioclastic mudstone-wackstone microfacies. Photomicrograph (**A** and **B**) shows vuggy porosity (VP) and moldic porosity (MP), stylolite (ST), dissolution, cementation. (PPL. Mag.X10).

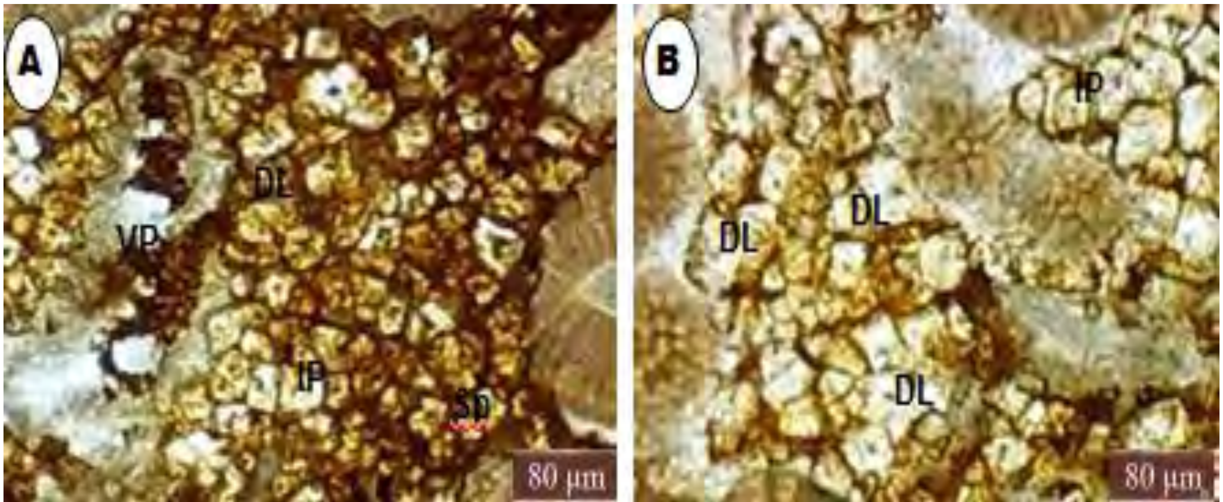

Figure 5.2 Showing wackstone microfacies, photomicrograph (**A**) shows predominantly of skeletal debris/ bioclast (BC), intraclast (IC), intercrystalline porosity (V) and zoning of quartz in vuggy porosity (black) and (**B**) Showing intercrystalline porosity (IP) with quartz (Q) and dolomite grains within micritic lime mud matrix. (PPL. Mag.X10).

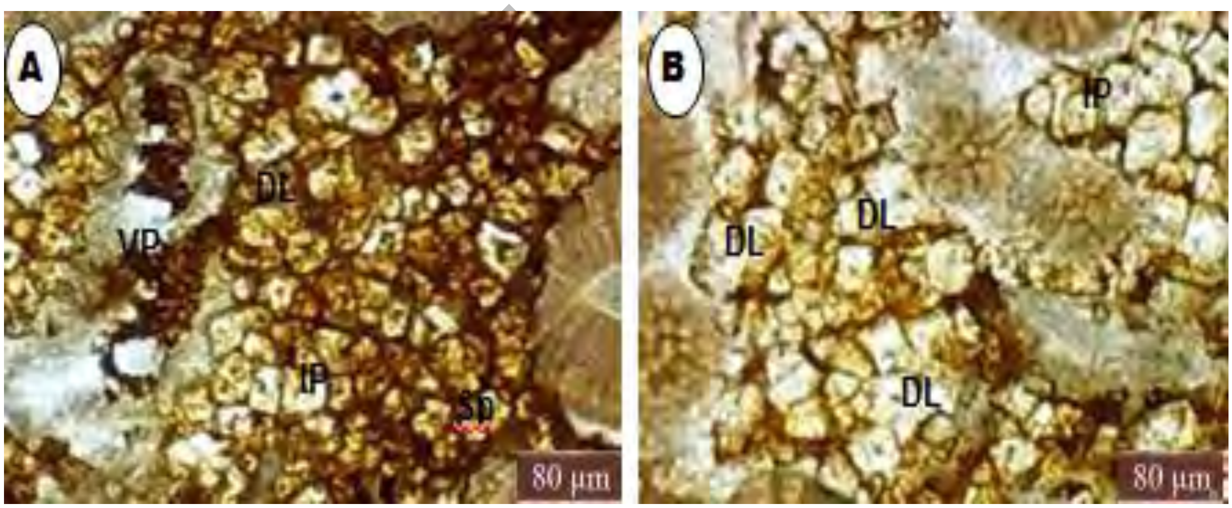

Figure 5.3 Showing Dolomitized Grainstone microfacies, photomicrograph (**A** and **B**) Showing quartz (Q), dolomite grains (DL), Inter-crystalline pores (IP) and vuggy porosity (VP), shelter pores (SP) occlude with dolomitized solution and micritic lime mud matrix. (PPL. Mag.X10)

5.4 SEM Analysis

SEM (Scanning Electron Microscope) is an advance technique for quantitative analysis of integrated petrography and textural datasets for reservoir characterisation of typical rock type. To create high resolution photomicrographs, it uses secondary and backscattered electron imaging. Rock's mineral morphology is identified by SEM analysis, which also describes the pore geometry and flow channel (Erdman et al., 2015). The SEM study of the Shinawari Formation was carried out on selected samples (thin section) to improve the interpretation of minerals components, diagenesis and porosity characteristics. The quantity and percentage are based on visual estimation of cementation, porosity, and micro-pores as shown in figure 5.4 to figure 5.7. The porosity is divided as macro porosity and micro porosity. Macropores are clearly visible in thin sections and are quantify by visual percentage estimation, whereas the micro porosity that results from grains dissolution or its directly associated with detrital mud was also visually estimated. The intergranular pores were either very small or choked by authigenic clays or occur in micro porous detrital grains. The various mineralogical and textural features combinely contribute to form the main control on reservoir quality. Primary intergranular porosity is absent in Shinawari Formation, which is due to fine lime mud that dominate in most of the samples, as it occludes intergranular pore spaces within the matrix. Secondary porosity is almost absent with exception of rare micro-fractures and vuggy porosity, which is created by the breakdown of grains and shelter porosity. It is created by the shelter and umbrella effect of the large grains witch may enhances porosity by preventing the filling of the pore space beneath laying. The porosity was reduced as a result of cementation and calcite being deposited in the vugs and intergranular pores. The partial disintegration of grains that created the microspores in the formation may increase the porosity.

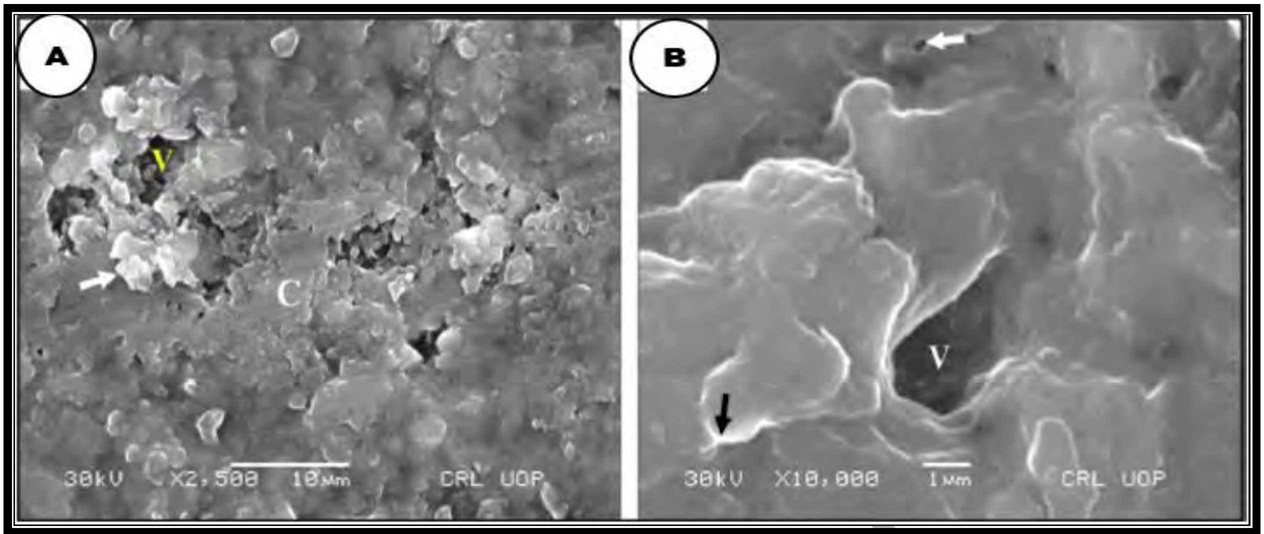

Figure 5.4 SEM images of bioclastic wackstone microfacies. Image (A) showing vugs (V), cementation (C), quartz (white arrow) and image (B) showing vugs (V), zoning of quartz (black arrow) and pores (white arrow).

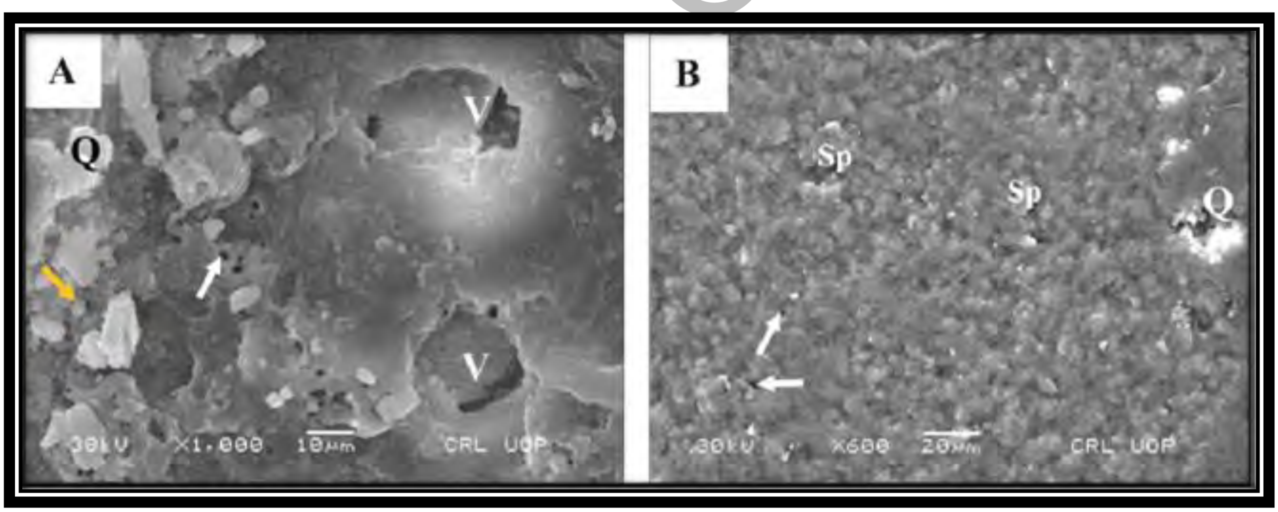

Figure 5.5 SEM images of dolomitic grainstone. Image (A) shows quartz (Q), dolomite grains (yellow arrows), pores (white arrow), vuggy porosity (V) and image (B) shows dolomite with shelter pores (SP), quartz (Q), pores (white arrows).

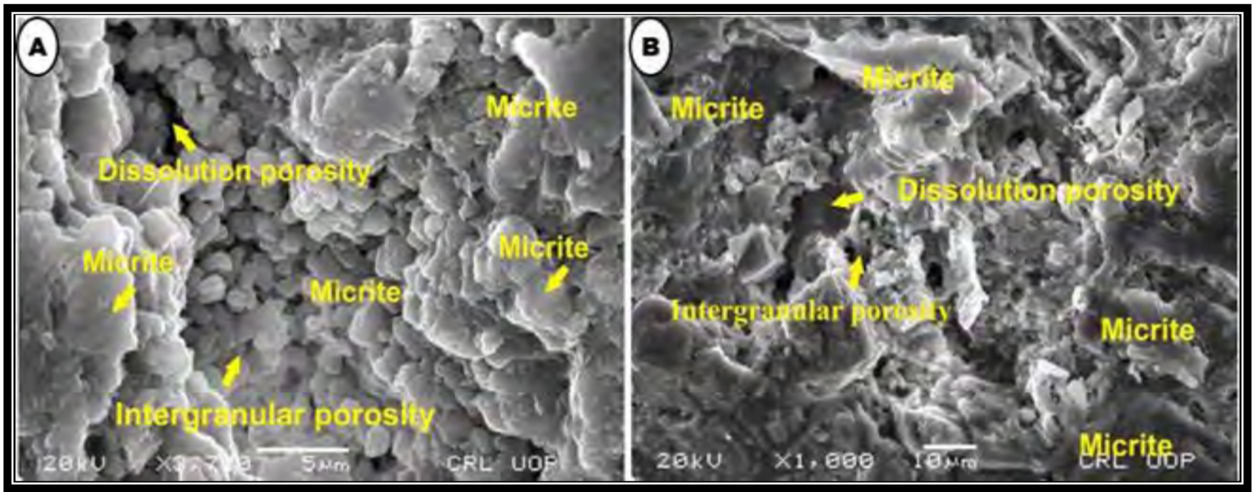

Figure 5.6 SEM Image (**A&B**) shows intergranular porosity and dissolution porosity with micritic cement in wackstone microfacies of Shinawari Formation.

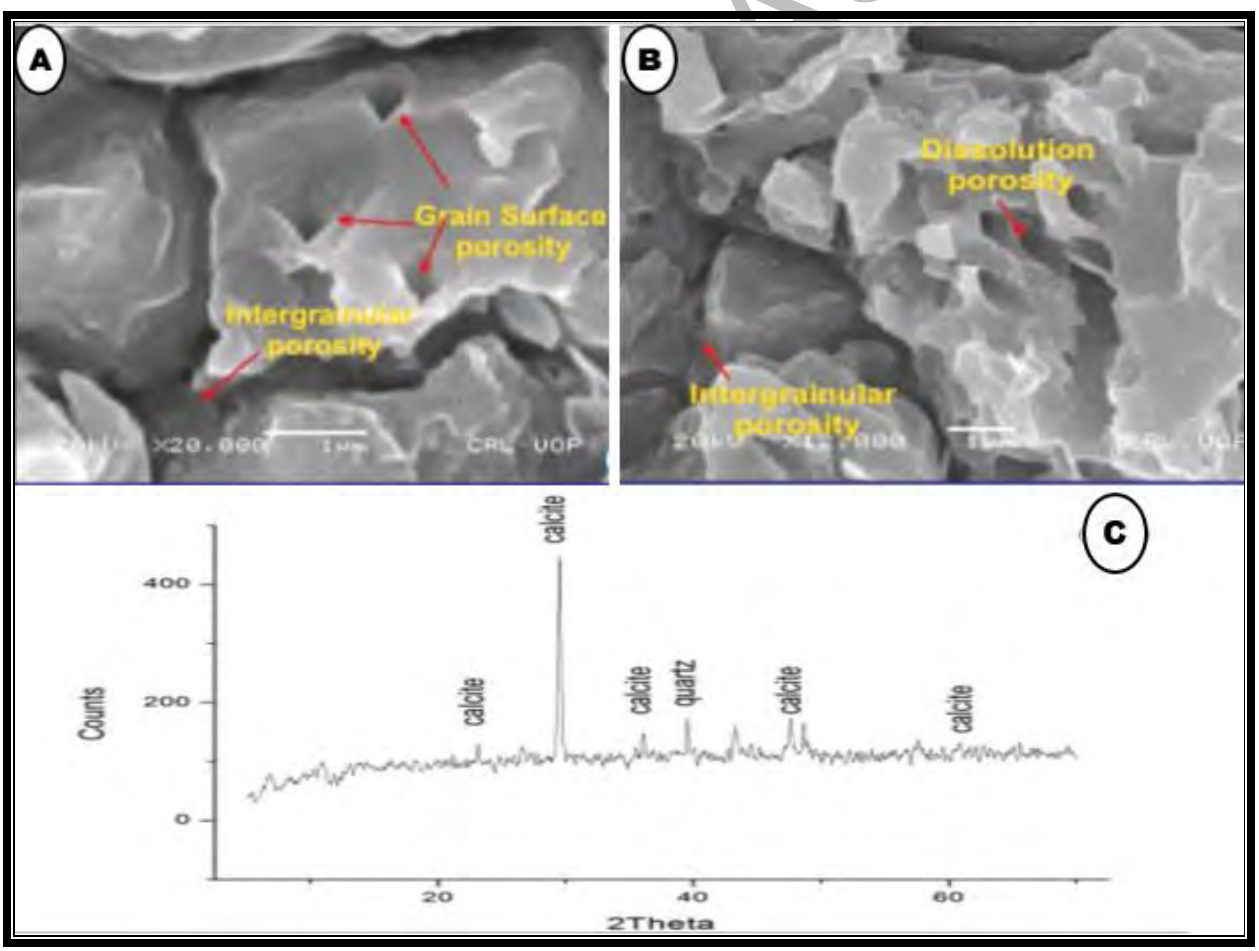

Figure 5.7 SEM Image **(A&B**) shows granular, intergranular porosity and dissolution porosity within micritic limestone and grainstone facies. Image (C): X-ray diffractogram shows peak positions of various minerals constituents within Shinawari Formation.

5.5 Petrophysical Analysis

Well log analysis provides the information on petrophysical properties of reservoir rock and its fluid content. The present study depicts interpretation of well log responses such as gamma ray, resistivity, density and neutron logs (Das et al., 2018). The Shinawari Formation reservoir intervals were analysed quantitatively and qualitatively within Kohat Basin by using three wells (Makori-1, Manzali-1, and Manzali-2) wire line logs data. The study was done by calculating the neutron porosity (NPHI), volume of shale (Vsh), water saturation and resistivity by using composite wire line logs. The Shinawari Formation thickness encountered in these wells respectively 228m in Makori-1, 176m in Manzalai-1 and 101m in Manzalai-2. The volume of shale ranging from (0 to 70) % and average (40) % which shows the formation is clean at places. Water saturation was ranging from (0 to 100) % and average values were 55%, the hydrocarbon saturation average value was 30% which was high due to low porosity, the high resistivity value with separation in the resistivity logs may indicate hydrocarbon, but very low porosity values indicated that the presence of hydrocarbon is totally depends on the development of secondary porosities.

Based on the wire line logs it is concluded that no hydrocarbons are present in the drill section of Shinawari Formation in Manzalai-1 and Manzalai-2 wells, however, the logs are encouraging in the Makori-1 well, clean limestone developed in the upper most part of formation which shown considerable porosities values (1.5% to 4.5) %. Wire line logs data showed that the Shinawari Formation having good reservoir qualities in the eastern side of the Kohat Basin, whereas the western part of the basin is less prospective and the reservoir qualities was compromised, the wells located in the western side of the Kohat Basin, Shinawari Formation was not considered as a potential target.

Whereas the study area in Nizampur Basin, exposed measured section of Shinawari Formation was located toward north eastern side of the Kohat Basin, in which the showed the presence of dolomitization which is a good indication of development of secondary porosities. Therefore Shinawari Formation can be a potential future exploration target in the Nizampur Basin based on available field evidences.

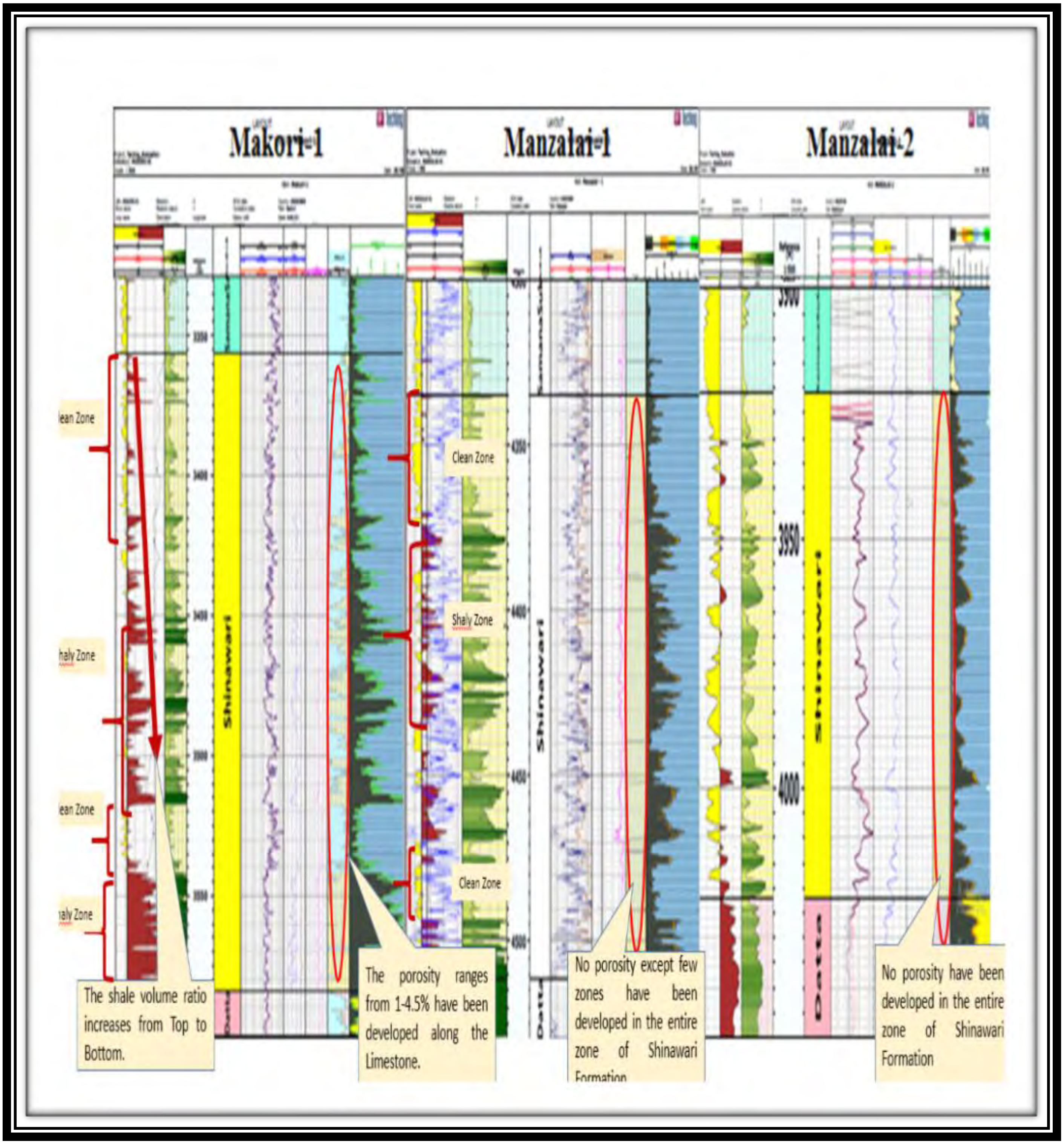

Figure 5.7 Petrophysical identification & analyses of composite log of wells (Makori-1, Manzalai-1 & Manzalai-2)

5.5.1 Cut off Factor

Cut off factor was used to differentiate reservoir and non-reservoir zones in the well. For a reservoir a cut off criteria being used, Effective porosity > 1%, volume of shale Vsh<35%, water saturation SW<50% (Schlumberger, 1991).

5.6 Petrophysical Investigation of Shinawari Formation

Petrophysics is the study of the physical characteristics of rocks and how they interact with fluids using measurements from well logs, laboratory data, and fundamental physical and mathematical laws (Djebbar and Donaldson, 2004). In this chapter the Shinawari Formation which was encountered in wells (Makori-1, Manzalai-1, and Manzalai-2) in the Kohat Basin of the upper Indus Basin KPK Pakistan was analysed by using petrophysical logs data for reservoir characterization (figure 5.7). The thickness of the Shinawari Formation varies from well to well, thickness was encountered while drilling 228 meters in Makori-1 (drilled interval from 3356m to 3584m), thickness 176 meters in Manzalai-1 (drill interval from 4335m to 4511m), and thickness 101 meters in Manzalai-2 (drill interval from 3921m to 4022m). Shinawari Formation's various petrophysical characteristics were listed in table 5.1. The overall formation is considered as a non-reservoir or tight formation because of un-conferencing the cut-off factor criterion.

Table 5.1 Petrophysical parameters of Shinawari Formation of three wells

Well	Parameters	Min	Max	Avg
Well Makori-1	DEPTH	3356	3584	228(T)
	CALI	6	10	8
	GR	25.65	122.76	75.78
	SP	-151.6	-110.31	-136.74
	LLD	5.45	1987.56	256.89
	LLS	3.57	387.89	125.76
	MSFL	0.236	98.56	10.67
	RHOB	0	0	0
	NPHI	-0.009	0.21	0.045
	DT	0	0	0
	VSH	0	1.16	0.34
	PHIE	0	0.19	0.042
	SW	0	1.2	0.61
	BVW	0	0.0345	0.0089
	PHIIT	0	0.287	0.038
	THICKNESS	228		

Well	Parameters	Min	Max	Avg
Well Manzalai-1	DEPTH	4335	4511	176(T)
	CALI	6.5	12	7.5
	GR	35.52	133.32	99.21
	SP	-151.64	-117.31	-115.74
	LLD	4.85	1985.56	236.89
	LLS	3.19	387.89	145.76
	MSFL	0.21	78.56	11.67
	RHOB	0	0	0
	NPHI	0	0	0
	DT	45.67	77.72	56.21
	VSH	0	1.21	0.34
	PHIE	0	0	0
	SW	0	1.8	0.71
	BVW	0	0.0365	0.0078
	PHIIT	0	0.207	0.031
	THICKNESS	176		

Well	Parameters	Min	Max	Avg
Well Manzalai-2	DEPTH	3921	4022	101(T)
	CALI	7	9.5	8.2
	GR	20.51	130.23	85.45
	SP	-161.64	-115.31	-126.74
	LLD	5.45	1896.56	246.39
	LLS	3.57	377.82	125.76
	MSFL	0.236	98.56	11.62
	RHOB	0	0	0
	NPHI	-0.0087	0.23	0.045
	DT	0	0	0
	VSH	0	1.16	0.3
	PHIE	0	0.23	0.042
	SW	0	1.2	0.61
	BVW	0	0.0321	0.0089
	PHIIT	0	0.287	0.045
	THICKNESS	101		

CHAPTER-6

DISCUSSION

6.1 Discussion

This study was a detail investigation of designated wells E-log and outcrop analogue data to analyse the facies and reservoir characterization of Shinawari Formation (middle Jurassic). Wire line data of wells (Makori-01, Manzali-01 and Manzali-02) from Kohat sub Basin was used for correlation with outcrop analogue data of study area from Nizampur Basin. The study puts an effort to utilize microfacies and lithofacies analysis, in order to understand the depositional history and reservoir characteristics of Shinawari Formation. This study was included analyses of porosity, permeability, biostratigraphy, paleonology, minerals and petrographical interpretations. The Shinawari Formation lithologically dominated by limestone, sandstone, shale, marls, siltstone and mudstone. Microfacies analysis suggests that deposition of the Shinawari Formation occurred in peritidal lagoon, beach shoal to distal shelf setting. This interpretation was supported by sub-types of standard in Sedimentary organic matter (Tyson, 1995; Ali et al., 2019). Following the determination of the lithofacies of the Shinawari Formation (chapter- 4) using the neutron porosity and shale volume cross plot technique on conventional well logs from the designated wells from Kohat Basin, the next step was to identify the lithofacies by gamma-ray log signatures. This procedure is known as "electrofacies interpretation." The petrophysical log responses that make up the electrofacies are numerical combinations that indicate certain physical and compositional features of a rock interval (Davis, 2018). The Society of exploratory Geophysicists (Sheriff, 2002) further defined it as "The set of well-log responses that characterise a lithological unit and permit the stratigraphic interval to be associated with or discriminated from others".

6.2 Facies Analysis and Correlation

The workflow initially included the obligatory quality control of all the relevant curves and well logs correlation (Chapter no.4) by used of the neutron porosity-shale volume cross plot approach to identify the lithofacies (figures 4.2 to 4.4). In this chapter the focus of study was on analysis and correlation of electrofacies with lithofacies and microfacies by using targeted wells wire line data from Kohat Basin with exposed section of Shinawari Formation in Nizampur cement factory Nala section (study area). By using the composite well logs four electro/lithofacies were recognized (LF1-lF4) and correlated with lithological measured section with incorporation of microfacies recognized from thin section study of representative samples of Shinawari Formation as shown in (figure 5.1), which were initially marked through gamma-ray log shapes analysis. It is a regular occurrence for rocks to emit natural gamma radiation, and lithological interpretation frequently uses this property (Rider, 1990; Hampson et al., 2005). Even in the absence of core data, trends and patterns of gamma rays were used as a crucial tool for the characterisation of the underlying sedimentary facies (Chow et al. 2005). Consequently in the investigation of the Shinawari Formation, electrofacies were first found and then in placed with lithology and microfacies correlation. Microfacies have been discussed in chapter 3 and analysis of lithofacies initiated with the recognition of analogous signatures pattern of gamma ray (GR), which were singled out to interpret each lithofacies. In general GR values range from 0 to 150 API (American Petroleum Institute) units (Rider, 2002). Limestone values are in the range of 30 to 60 API, whereas gamma-ray values in the major shale out region reached up to 150 API, in order to outline the lithofacies. Electrofacies/lithofacies analysis and the framework offered by microfacies (Chapters-3) can be used to conclude facies analysis on the basis of gamma-ray log pattern and neutron-SP trends in order to recognise and understand various settings of deposition (Selley, 2013; Posamentier, 2001; Chow et al., 2005). To illustrate the sequence relationship of various facies and GR log patterns, which was utilised to assess and construct electrofacies/lithofacies composite logs after thorough study of GR log trends of the study wells and representative analogue data of study area as shown in figure 6.1.

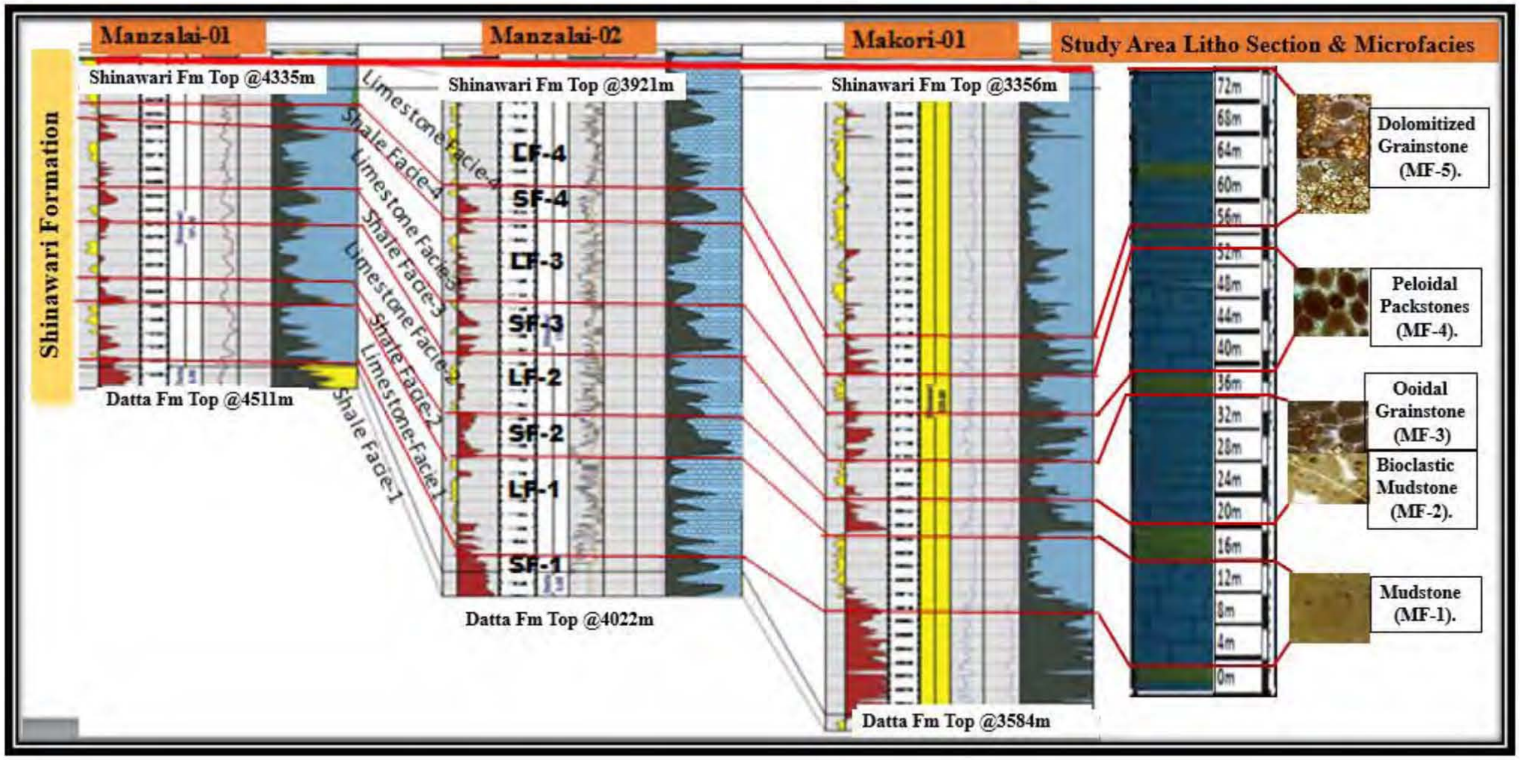

Figure 6.1 Petrophysical identification and analyses on composite log of wells (Makori-1, Manzalai-1 & Manzalai-2), incorporated Lithofacies further confirms and validatethe recognition of Electrofacies

6.3 Petrophysical investigation of Shinawari Formation

Shinawari Formation was analysed quantitatively and qualitatively by using petrophysical data of three targeted wells (Makori-1, Manzali-1, and Manzali-2) from Kohat Basin. This was done by calculating the neutron porosity (NPHI), volume of shale (Vsh), resistivity (R), and water saturation using composite wire line logs from these wells. Petrophysics is the study of the physical characteristics of rocks and how they interact with fluids using measurements from well logs, laboratory data, and fundamental physical and mathematical laws (Djebbar and Donaldson, 2004). In this chapter the Shinawari Formation which was encountered in respected wells in the Kohat Basin (upper Indus Basin KPK, Pakistan) was analysed by using petrophysical data for facies analysis (figure 4.1 and figure 6.1). The thickness of the Shinawari Formation varies from well to well, ranging from 228 meters in Makori-1, 176 meters in Manzalai-1 and 101 meters in Manzalai-2 respectively. Shinawari Formation based on various petrophysical characteristics four lithofacies were identified which were correlated and validated with microfacies. The correlation shows that lithofacies thicker to thinner trend extending from west to east direction. Based on the correlation of the wells and the exposed Shinawari Formation in study area (Nizampur Basin) it is interpreted that the dolomitized grainstone found in the representative samples (thin section) study which was the indication of secondary porosities that may developed in this area which can be potential exploratory targets.

6.4 Depositional Environment/ Paleoenvironment

The depositional model of the Shinawari Formation represents a portion of the Jurassic rock revealed in the stratigraphic section of the Nizampur Cement Factory Nala section, which corresponds to the deposition in a geological setting with a gently sloping intertidal to middle ramp. This view is based on the vertical succession of the microfacies and palynofacies in the examined region. Local differences in terrain, water depth, and salinity, temperature, and energy conditions are responsible for microfacies variations in carbonate environments (Wilson et al., 1975). The stratigraphic difference from the lime mudstone, Peloids/Ooidal wackstone, and arenacuoes packstone was good indication of shifts in energy state. Microfacies of Peloidal/Intraclastic grainstone, mixcarbonate. Siliciclastics grainstone, quartz arenite sandstone lithofacies have been documented in the literature. Facies assessments were carried out utilizing conventional facies model for ramps, homogeneous and non-fossiliferous micrite carbonate deposition presents the lagoonal environment (Wilson 1975; Flügel 2010; Hussein et al. 2017).

The analysed samples' identified microfacies and lithofacies demonstrate depositional habitats ranging from river dominated marshes to terrestrial and continental settings, beach shoals to inner ramps, intertidal to inner ramps and middle ramps (figure 6.2). When clastic rocks did not form in the Shinawari Formation as a result of the absence of carbonate rocks due to adverse geological conditions for their genesis. Therefore the shale samples were investigated thoroughly for the depositional examination of the Shinawari Formation, which is a significant stratigraphic unit. By comparing with the standard literature of Flügel, the presence of planktonic foraminifera and other fossil groups (Bivalves, Bryozoans, Gastropods, Echinoderm plate and spine, and Ostracods) and intraclast were recorded to interpret history and environment of deposition of the Shinawari Formation (Flügel et al., 2004).

The geological context of the proximal to distal shelf/ramp correlates to the depositional settings represented by the palynofacies under study. Therefore, according to carbonate and clastic analysis, the Shinawari Formation represents the geological setting from fluvial-dominated marshes and swamps to the middle ramp in the Tethys Ocean as a mixed siliclastic carbonate platform deposit in upper Indus Basin of Pakistan. The near shore, high energy, and shallow water bar, beach, and shoal habitats are represented in the study area by the grain stone microfacies of the carbonate layers. This formation's inner shelf environment below the base of fair weather waves is represented by the wackstone microfacies. This formation's highly bioclast-rich grain stone and wackstone microfacies were an indication of the influence of storms on the depositional environment. The habitat in which the Shinawari Formation was deposited is thought to have a wave-dominated shallow ramp environment based on vegetation, fauna, and physical features.

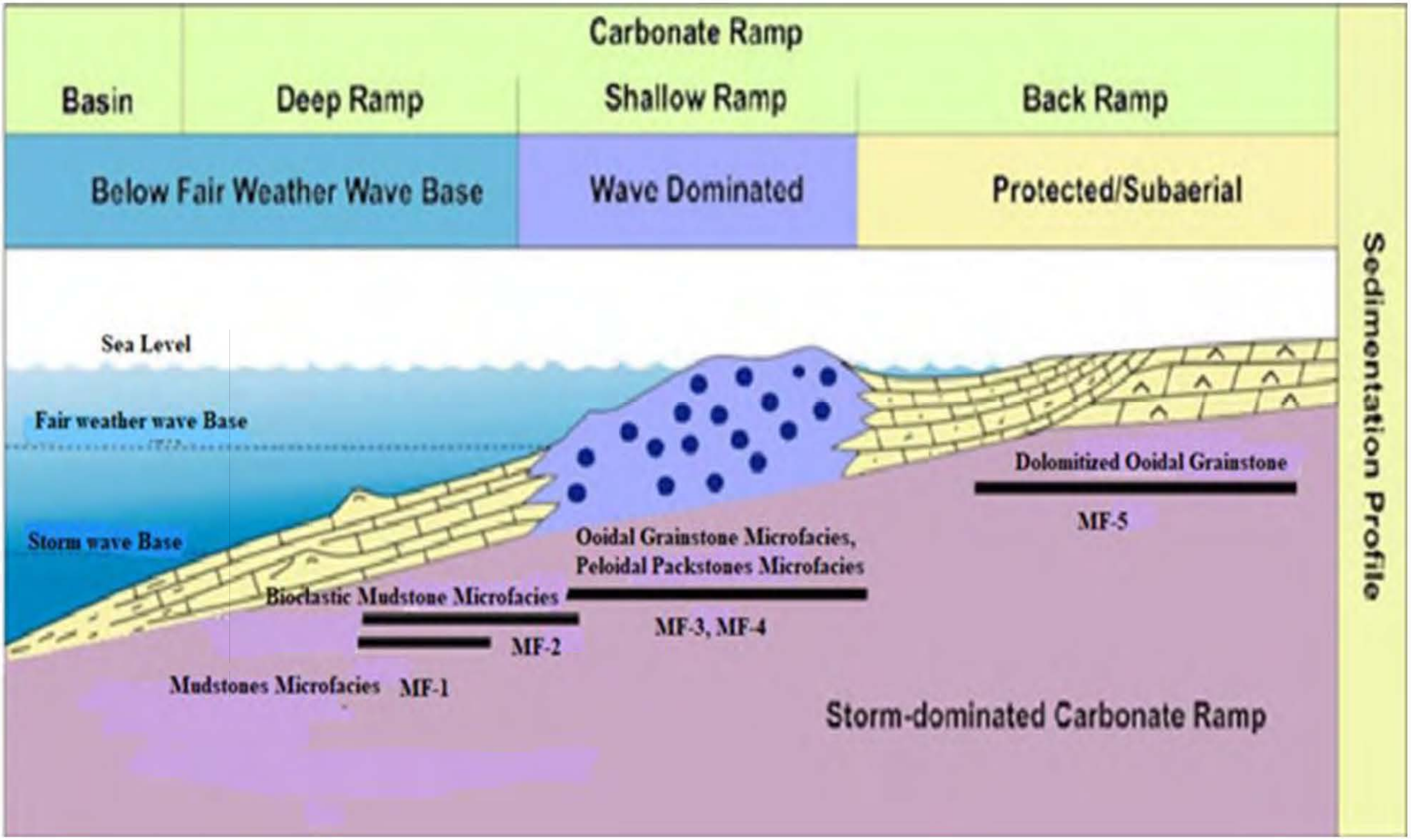

Figure 6.2 Schematic diagram of ramp-type setting (modified after Meng et al. 1997) showing the distribution of sedimentary facies.

CHAPTER-7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

All data consistently supported the observation and as a results of this research. In the Nizampur cement factory Nala section a total of five microfacies were identified in the Shinawari Formation from MF-1 to MF-5. Diversification of the facies occurred in the Shinawari Formation in the study area. It is identified within field from the lithological units of carbonate (limestone) and siliciclastics assemblages (shale, marls, siltstone and sandstone units). From previous studies in upper Indus Basin presences of laterite, hard grounds, coal layer and coal dissemination in Shinawari Formation was also reported in some places. Based on the study following conclusions were made.

- Identified microfacies and lithofacies are interpreted from the studied samples enlightening depositional environments from fluvial dominated marshes, terrestrial/continental, foreshore, lagoon, beach shoal to inner ramp, intertidal to inner ramp, inner ramp-middle ramp and outer ramp geological setting with poor reservoir potential.
- From facies variation the Shinawari Formation representing deposition under sea level fluctuation in form of different sedimentary packages. About 72m thick carbonate and clastic sediments of Shinawari Formation represented the digenesis results in the formation of calcite cement and dolomite along with the traces of authigenic clays as illite and kaolinite with poor primary intergranular porosity, likely due to the fine lime mud (60% of total rock volume) that is dominated in most samples. Well develop calcite cement further reduced the intergranular micro porosity, secondary porosity is poor to completely absent with the exception of rare micro-fractures.
- Integrated outcrop analogue and petrophysical data analysis suggested poor reservoir facies (exception of few mudstone facie zone which is also later occluded by cementation/ authigenic clays) encountered in Shinawari Formation in the study area. Interpretation from stoneley reflection analysis also suggested poor reservoir potential as there is no indication of fractures development which aid in secondary macro porosity.

- The diagenetic analysis is the fundamental requirement for the feasibility of reducing exploration risks. Hence, the study has analysed the main diagenetic processes that may have considerably effect on the original rock fabrics and its characteristics after deposition.
- Moreover, the study may supplement a new knowledge on the various essential aspects of the reservoir rock such as presence of cement types, open and cemented fractures, diagenesis, as well as the influence of diagenesis on quality of reservoir rock to evaluate the potential of carbonate reservoirs in the region. This study aims to introduce an integrated method by combining both lithofacies and microfacies and quantitatively characterize the pore structure of carbonates, insights into fluid flow and lithology of carbonate reservoir rocks.
- Additionally, the present study may offers a sound base to evaluate the parameters that impact the fluid flow within carbonate reservoirs rocks along with diagenetic controls.
- Interestingly, the study would have significant implications in investment making decisions that would reduce the risk associated in the target reservoirs exploitation.
- Furthermore, it provides a comprehensive understanding of the carbonate rock petrophysical properties and impact of diagenesis in the exploitation and development of unconventional tight carbonate resources.
- The nuclear magnetic resonance (NMR) data may require for better understanding of proposed formation petrophysical relationships to explore the feasibility and sensitivity of using T1/T2 ratio as a lithology indicator for characterizing electrofacies subclasses within these carbonates.

  NMR, T1= longitudinal relaxation time and T2= Transverse relaxation time of fluids in rock porous under certain conditions is also controlled by surface interactions. The T1/T2 ratio can be important controls on theories of the relaxation mechanism.
- By combining different geophysical techniques, this study advances understanding of the complex structure and pore networks of carbonate rocks and how these pore attributes affect the geophysical response at the outcrop analogue and well-log scales. The results also reveal the full potential of NMR logging data in characterizing petrophysical properties of reservoir rocks, aspects that have traditionally been overlooked. These results are essential for accurate interpretations of borehole geophysical measurements into carbonate reservoirs properties.

7.2 Recommendations

From the above study it is considered that the Shinawari Formation has poor reservoir properties in the study area of Nizampur Basin, although Shinawari Formation have hydrocarbon potential but due to poor quality reservoir no economical discovery found in Kohat Basin MOL (Hungarian oil and gas public limited company) drilled few wells in Tall block. Based on available data study there is possibility of Shinawari Formation as a potential reservoir, which may require to drill an exploratory well in the Nizampur Basin to confirm its reservoir potential and presence of commercial quality of hydrocarbon.

Pakistan has considerable unexplored hydrocarbon reserves which is confirmed by several research studies made by some exploration companies and individual research scholars. Country is facing the challenges of hydrocarbon insufficiency, it is estimated that hydrocarbon import is above 40% of country total imports (survey, 2014). The findings of present study may have substantial implications for further development of new discoveries of oil and gas fields to improve the Hydrocarbon production in the country and in region. Based on above facts and conclusions it is recommended to establish a possible surface and subsurface correlation and basin modeling for better understanding of reservoir behavior of Shinawari Formation in Nizampur Basin.

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