FACIES ANALYSIS AND RESERVOIR CHARACTERIZATION OF THE KAWAGARH FORMATION (LATE CRETACEOUS) BASED ON OUTCROP ANALOGUE AND PETROPHYSICAL DATA, IN THE NIZAMPUR AND KOHAT BASIN (KPK), PAKISTAN

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(2020-2022)

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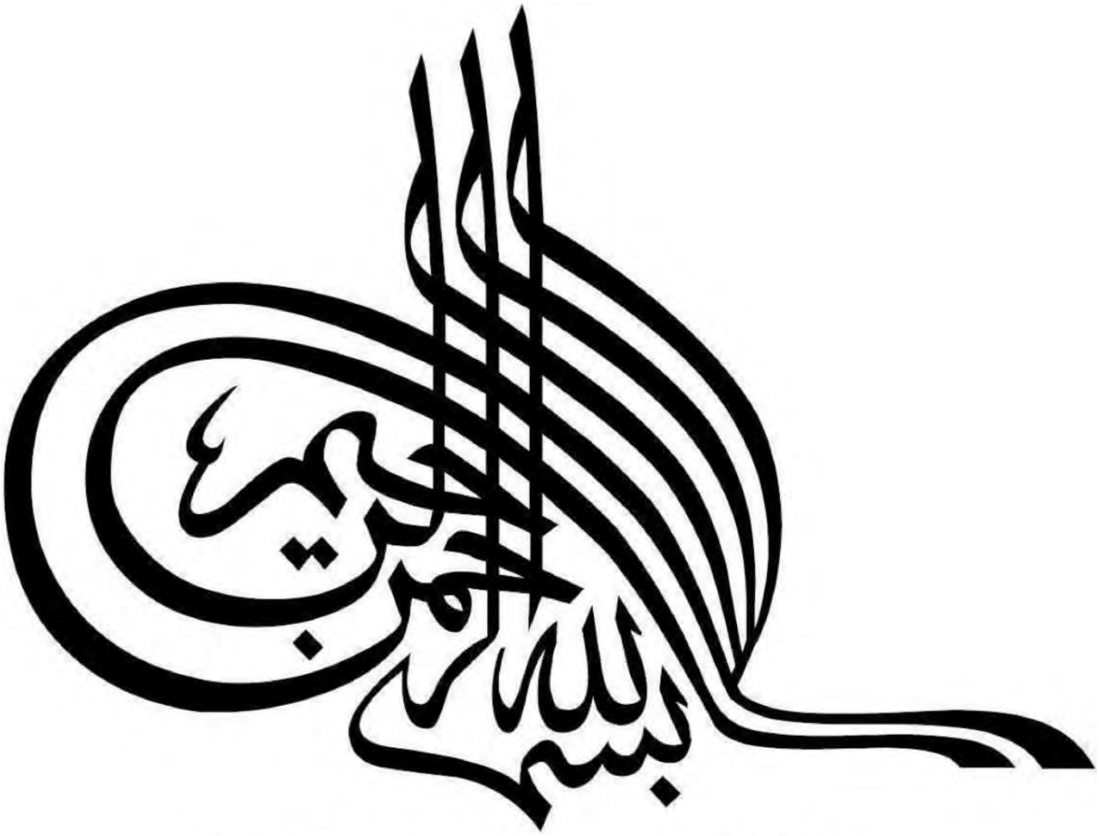

In the name of Allah,
the Most Beneficent,
the Most Merciful

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ومن يؤت الحكمة فقد اوتى خيرا كثيرا

QUAID-I-AZAM UNIVERSITY

ISLAMABAD

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

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APPROVAL CERTIFICATE

1.

This is to certify that the dissertation entitled “Facies analysis and Reservoir Characterization of the out crop analogue and well data, The Kawagarh Formation (Late Cretaceous) in the Nizampur and Kohat Basin (KPK) Pakistan” submitted by SOHAIL KHALID (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;

Prof. Dr. Mumtaz Muhammad Shah ________________________

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1.

DEDICATION

The research work has been dedicated to my creator Allah SWT

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First of all, I would like to thank "Almighty ALLAH" the spring of all the wisdom and utmost power, the most sympathetic for granting me capabilities to complete this enormous task. There are no adequate words to express my gratitude to my dignified supervisor, Prof. Dr. Mumtaz Muhammad Shah, Chairman Department of Earth Sciences, Quaid-I-Azam University, Islamabad, for his excellent and dynamic supervision of my MPhil research work. His valuable suggestions, consistent encouragement, and friendly behaviour helped me to successfully complete this task. I sincerely appreciate all of your support and guidance during this period and expecting to have the same in the future.

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Last but not least, I am thank full to my parents and all my family especially my wife and kid's who suffered a lot during my study period, their unconditional and constant support made easy this task to accomplish.

Many persons and experts whose names I did not mention contributed to this research work which is the end result of a protracted journey. May Allah bless each and every one of you who assisted me in completing this project.

Sohail Khalid

1.

ABSTRACT

The present study deals with the facies analysis and reservoir characterization of the outcrop analogue and well data of the Kawagarh Formation (middle Jurassic) in Nizampur and **Kohat Basin** (KPK) Pakistan. Nizampur Basin is situated in the north direction of Kala Chitta Range whereas Kohat Basin is located on north-west of Kala Chitta Range. The Kawagarh Formation in the study area is composed of limestone, Silt, Sandstone and Shale. A petrographic and paleo-environmental study basses on thin section was done and subsequently used in the microfacies analysis. Three microfacies were identified in three depositional environments, including peritidal, restricted lagoon, and high-energy shoal present on the inner to outer part of a homoclinal carbonate ramp utilizing conventional facies model for ramps and facies assessments. The wire line logs data of wells (Manzali-01, Manzali-02, Makori-01) from Kohat Basin was used for petro physical studies and four limestone electrofacies were identified. These facies are vacillated from clean limestone to marly/argillaceous limestone, which is sandwiched by dominant shale and traces of silt/sandstone in some places. Lithological correlation showed that limestone facies were slightly pinched out from north east to south west direction, with GR values between 30 and 70 API. The results of wire line logs showed no hydrocarbons presence in the Kawagarh Formation in Manzalai -1 and Manzalai-2 wells. However, the logs were encouraging in the Sumari Deep-01 well; clean limestone is developed in the upper most part of the Kawagarh Formation and having considerable porosities (1.5-4.5) %. The wire line logs data represented the Kawagarh Formation having good reservoir qualities in the eastern side of the Kohat Basin whereas the western part of the basin is less prospective. 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 The Kawagarh Formation can be a potential future exploration target in the Nizampur Basin.

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CHAPTER-1

INTRODUCTION

1.1 Introduction

The study area (Nizampur Basin) is situated in the north of Kala Chitta Range whereas Kohat Basin is located on north-west of Kala Chitta Range, rocks of Nizampur Basin are evident along the thrust fault whereas Kohat Range is along the MBT (Figure.2.1). The Kawagarh Formation in this area mainly composed of limestone, marl, silt/sand and shale (Saboor et al., 2022). Type locality of the Kawagarh Formation is on the western edge of the Samana Range, the transition zone where the Samana Suk Formation overlying and the Datta Formation is underlying the Kawagarh Formation in the Kohat Plateau, Pakistan (Fatmi et al,. 1973). Within the Trans Indus Ranges there are many exposures of the Jurassic formations which have been studied in terms of sedimentation, sequence stratigraphy, and biostratigraphy (Ali et al., 2013). The Kawagarh Formation is exposed in the Upper Indus Basin which was our focused of study as facies analysis and reservoir characterisation. The thorough analysis of the literature reveals that the Kawagarh Formation is exposed in the Chichali Nala Section, Baroch Nala, Gulla Khel Nala, Surghar Range and Nizampur Cement Factory Section in the Nizampur Basin (KPK) Pakistan. In Chichali Nala Section, lithology of the Kawagarh Formation was reported like limestone, marls, and sandstone, siltstone and shale units along with a mixture of laterite, hard grounds and coal disseminations. According to a microfacies investigation, the Kawagarh Formation was deposited in a variety of environments, including tidal lagoons, beaches, and shoals. Tyson support this hypothesis in Sedimentary organic matter (Tyson, 1995).

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 is including the Nashpa, Tolanj, Sumari, Makori & Manzali fields, which still need to be explored and expedited. The Middle Jurassic the Kawagarh Formation is a possible target hydrocarbon play in the upper Indus Basin as future prospects. Petrophysical properties e.g. porosity and permeability of carbonate rocks 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 1959, 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). Some of the Arabian countries especially Middle East countries like Saudi Arabia, Qatar, Bahrain, United Arab Emirates, Oman, Iraq and Iran) have 70% oil deposits and 90% of gas reserves are 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 part of Oman the middle Jurassic

Sahtan Group also had Oolitic shoals to lagoonal carbonates rocks (Rousseau et al., 2005). Similar reports of the deposition of the shallow marine to marginal carbonates rocks of the Dhruma Formation in Saudi Arabia and Morocco (Yousif et al., 2018). These carbonates reservoirs rocks carry 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 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 Range and Trans Indus Ranges in the context of sedimentation, sequence stratigraphy and biostratigraphy (Nizami and Sheikh 2009ab; 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, 2012). The Kawagarh Formation was named by Davies (1930) in the Samana Range, "Darsamand limestone" of Fatmi and Khan (1966) in western Kohat. The age of the upper part of the Kawagarh Formation was 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 Kawagarh Formation with the aid of palynofacies and microfacies data was 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). 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. 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 this study was to collect the high quality data of the Kawagarh Formation from Nizampur Cement Factory Nala Section, based on thin sections petrographic study and petrophysical property measurement in order to analyse the 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 detail as bellow,

- 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 the Kawagarh Formation.
- To correlate representative samples dataset with petrophysical data and validation of the data base.

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- To determine the reservoir quality, rock type and porosity distribution based on pore typing.

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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 in the north of Indus River and south of Attock-Cherat Range. 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.

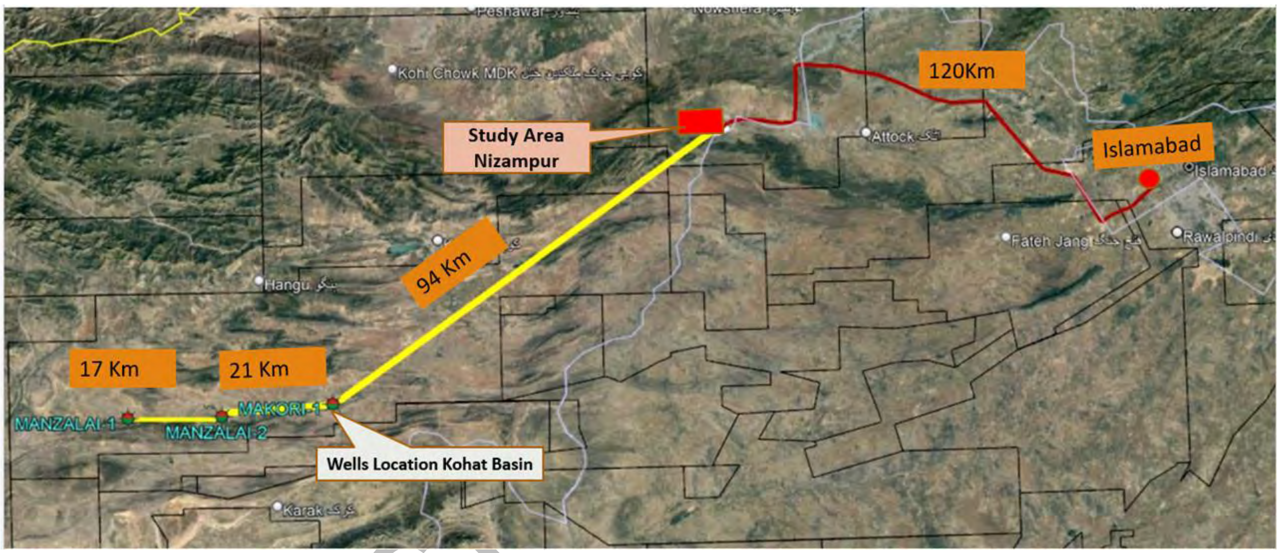

Figure 1.1 Location and access map of study area and wells location. (Compiled from Google map)

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 rocks are exposed along the Main Boundary Thrust (MBT) and is situated in the south-west of the Kala Chitta Range, whereas the Nizampur Basin is located in the north-west of Kala Chitta Range and its rocks are exposed along the Hissartang Thrust Faults (HTF) (Fig.2.3). 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.

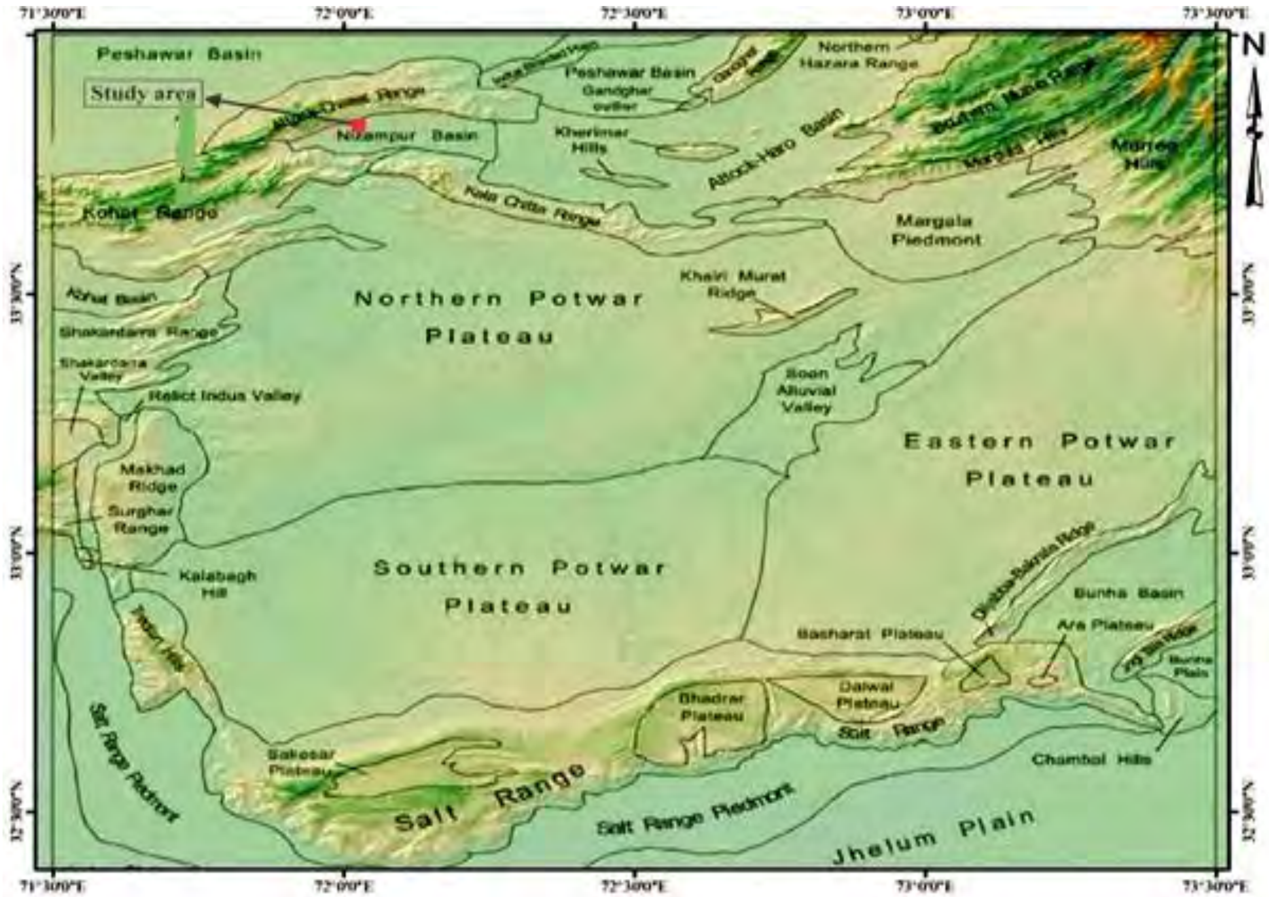

Figure 1.2 Generalized Geological map showing the location of the study area in the Nizampur Basin (after Hylland, 1990)

1.5 Methodology

Fieldwork was done in the study area, rock samples were collected as per plan. Google Earth, Global Mapper, Tech log and Coral Draw were used for cross section and restoration of the geological data and reviewed before being arranged, examined, and presented. Total 15 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 subsequently use in the paleo-environmental interpretation. The integration of the outcrop analogue data and petrophysical data of wells (Makori Deep-1, Manzali-1, and Manzali-2) were used for the reservoir characterization of the Kawagarh Formation. The research methodology steps are shown in flowchart (Figure 1.3) as bellow.

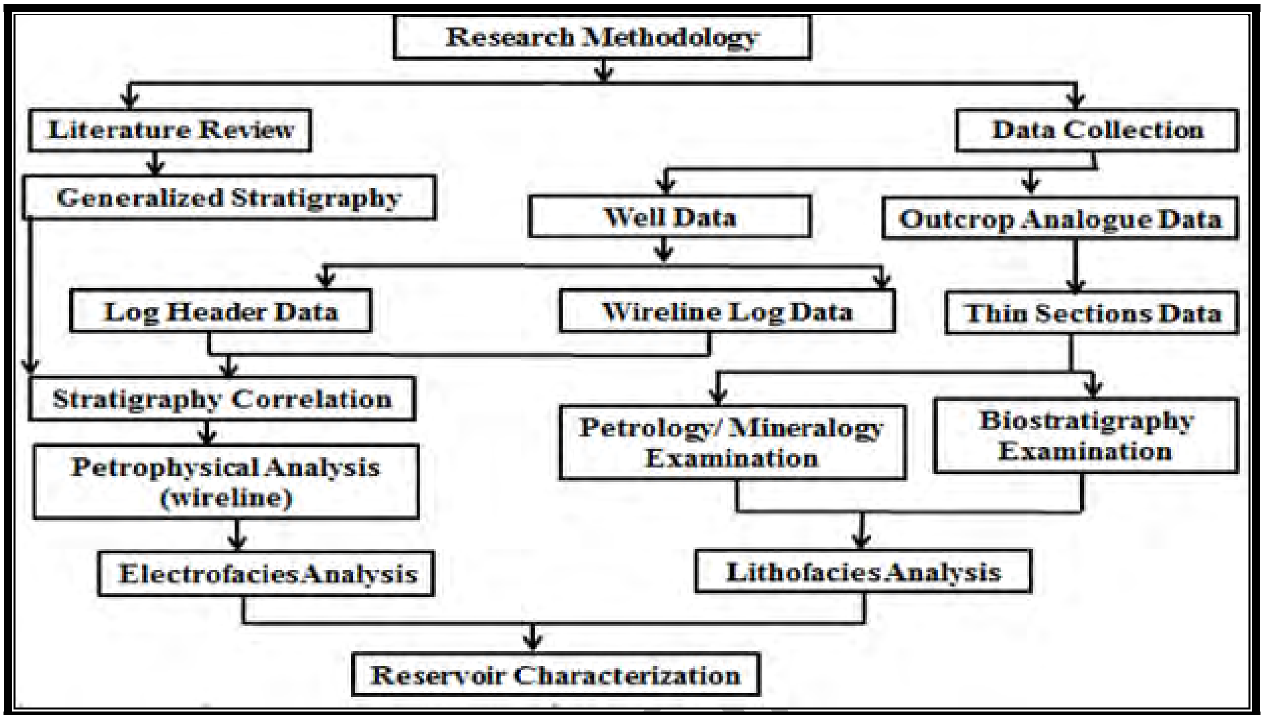

Figure 1.3 Flow Chart defines the steps followed to draw the results of the study work.

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1.5.1 Field observation and Study

This study includes section measurement, out crop sampling and established detail litholog of the Kawagarh Formation in the Nizampur Cement Factory Nala Section. During field work data was gathered at outcrops scale systematically and randomly, measure 32m thick exposed sections and 15 samples were collected from formation mostly and on observing variation during bed to bed outcrops study. Photographs were also taken where features were megascopically visible, this study work included details as bellow.

- Lithological description and sampling.
- Measurement of stratigraphic thickness of the Kawagarh Formation with the help of measuring tape and sampling of key horizons.
- Logging of all field data, bedding, colour, lithology and texture.

1.5.2 Laboratory Study

Laboratory studies were encompassed of thin sections preparation of all the collected out-crop analogue samples whereas the planktonic foraminifera were extracted from the soft shale/marl and limestone using conventional paleontological procedures and Lirer's wet sieve techniques (2002) from selected samples. Thin sections were prepared in HDIP and detail study of the petrography, biostratigraphy, palaeontology, and microfacies were performed by using a polarising microscope in the Petrographic Laboratory of the centre of Excellence in Geology University of Peshawar and in the Deportment 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 & Sumari Deep-01) of the Kohat Basin petrophysical analyses were 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 (Schlumberger, 1991).

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

Where, 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 (Serra, O., 1985).

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

Where, 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.

(2) $Shc = 1 - Sw$

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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 (Coward et al., 1986; 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). According to (Seebar et al. 1981), the Indian plate is still being thrusted 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 formed (SRT). A zone of highly deformed rocks known as (NDFTB) Northern deformed fold and thrust belt 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, 1984; Formation, 1987; 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 Hisarthang thrust, as well as numerous minor faults are responsible for the Range's deformation (Hussain et al,. 1989, 1990b). North Pakistan's Hill Ranges include the Kala Chitta Ranges (Yeats and Lawrence, 1984). Kala Chitta Range northern most region. The extensive deformation of the Kala Chitta Range causes folding and thrusting on both a small- and large-scale. The Kala Chitta Range is deformed as a result of thrusting along the Hisartang 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).

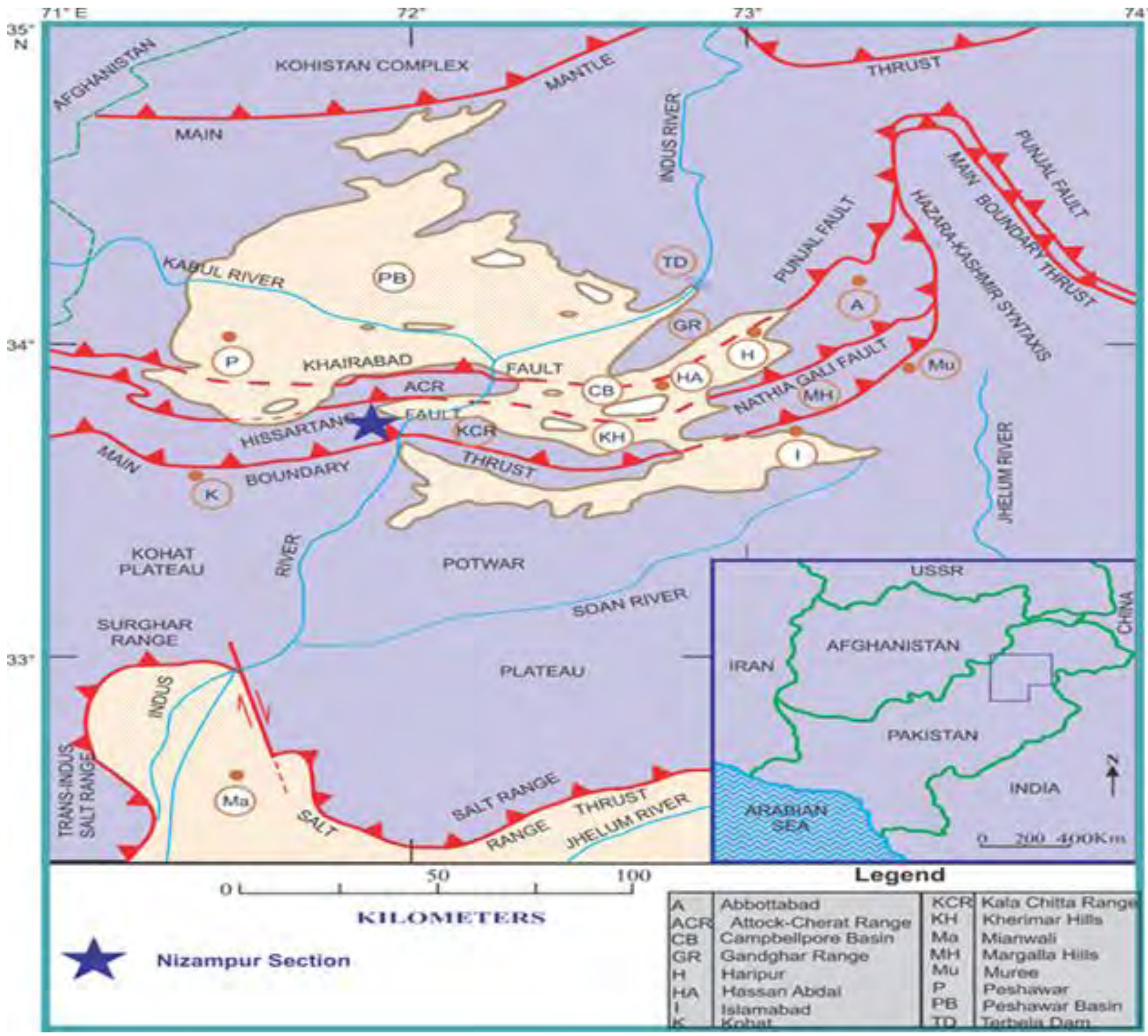

Figure 2.1 Generalized Geological and Tectonic map of the northern Pakistan that show major thrusts and structural sub-division of the upper Indus Basin. The blue star show locations of the study area. Abbreviations Salt Range Thrust (SRT), MBT-Main Boundary Thrust, Hisarthang Fault, Cherat Thrust, Khairabad Fault and Main Mantle Thrust(redrawn after Hylland and Riaz, 1988, Hashmi et al. 2018).

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

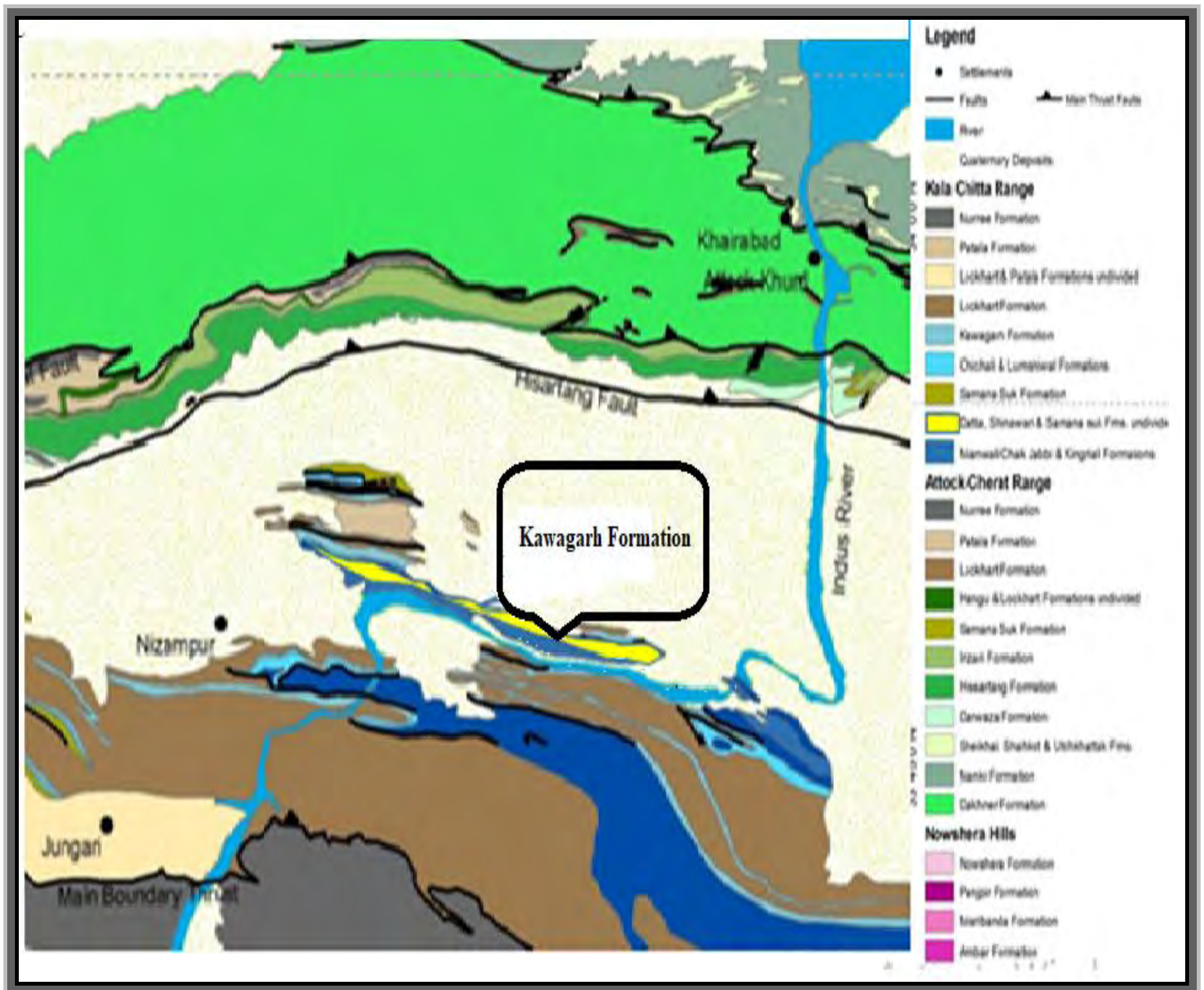

Figure 2.2 Geological map of study area, modified from Asif et al. 2013

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.

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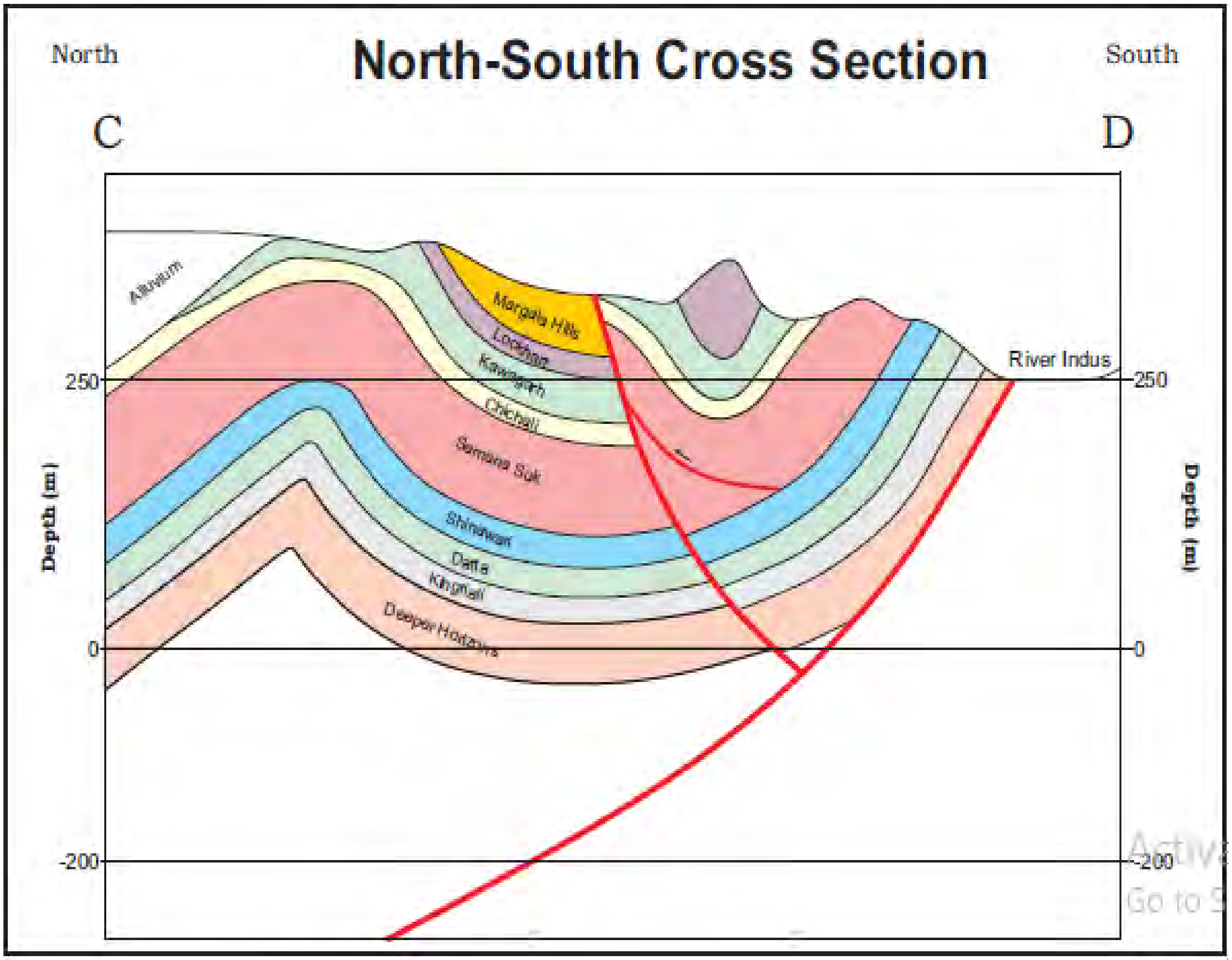

Figure 2.3 Geological model (North – south) crossection of the Study area shows the prominent stratigraphic horizons, Nizampur Sub basin KPK.

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, Kawagarh, and Samana Suk in the Jurassic sequence in the area. The Cretaceous rocks, which comprise the Chichali, Lumshiwal, and The Kawagarh Formation s, 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 Kawagarh Formation exposed in the Nala of the Nizampur Cement Factory served as the source of samples for this study.

Table 2.1: Stratigraphic chart of Study area (compiled and 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, shales, and sandstone, with trace amounts of dolomite (Shah, 2009). The Datta, Kawagarh, 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 limestone, coal, shale, and sandstone of various colours (Fatmi, 1977). In the research area, the Kawagarh Formation lies on top of the poorly exposed Datta Formation. According to Fatmi (1977), the type site of the Kawagarh Formation contains argillaceous limestone, calcareous marl, shale, and sandstone/siltstone together with thin to well-bedded limestone. In the Kohat, Kala Chitta, Hazara, Trans Indus, and Salt Ranges, the structure is well visible (Shah, 2009). The Samana Suk Formation (Upper Jurassic) composed of 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 the Chichali Formation, the Lumshiwal Formation and the Kawagarh Formation (Shah et al,. 2009). According to Fatmi (1977) lithology of the 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 shales. In the study area it is mostly consists of sandstone and shales. The sandstone are mostly thin bedded and reddish brown in colour while the shales are black to brown in colour. The Chichali Formation is widely distributed in Trans-Indus Range, Western Salt Range, Northern Kohat Range, Nizampur Basin, Kala Chitta Range and Southern Hazara (Shah et al,. 2009). The Chichali Formation is conformably overlain by the Lumshiwal Formation. Lithologically the Lumshiwal Formation is thick bedded to massive sandstone with silty and sandy shale in its type locality and other sections in Trans Indus Range (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 which will be discussed in details.

2.2.3 Paleocene Succession

The Paleocene rocks are well exposed in the Kohat-Potwar area, except in Khisor- Marwat and Bittani Ranges where they are missing (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 the Hangu Formation, the Lockhart Formation and the Patala Formation. According to (Cheema et al,. 1977) in the Kohat area, lithology of the Hangu Formation is sandstone with shales 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 the Hangu Formation overlies the Kawagarh Formation (Figure.3.3) while in Kohat Range the Hangu Formation is not exposed. 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 ismostly consists of medium to thick bedded grey colour nodular limestone. Lockhart Formation is conformably overlain by the Patala Formation. The lithology of the Patala Formation at the type locality is described by (Cheema et al,. 1977), which consists of shales and marls with minor limestone and sandstone. Locally, in the 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 the Margalla Hill Limestone, the Chorgali Formation and the 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 the 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 the Nizampur Basin the 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 the Formation. The stratigraphy of the Nizampur Basin and Kala Chitta Range is similar in characteristics. Rocks from Triassic (Kingriali Formation) to Eocene (Margalla Hill Limestone) 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 Kawagarh 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 Kawagarh Formation was done and recorded expose formation thickness 32m. Outcrop rock sampling of The Kawagarh Formation was done 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 15 representative rock sample were prepared for the detailed petrographic analysis and subsequent use in the paleo-environmental interpretation.

3.2 The Kawagarh Formation Field Analysis

The type locality of the Kawagarh Formation lies in the Kawagarh Hills, north of Kala Chitta Ranges in District Attock (Lat. 33° 45' 30"N: Long. 70° 28' 30"E). It is given the name The Kawagarh Formation after Kawagarh Hills. The lithology of the Kawagarh Formation in its type locality, Northern Kala Chitta Ranges, Nizampur Basin and Eastern Kohat consists of Marls and calcareous Shales (Fatmi, 1977). However, it is missing in the southern Kala Chitta and Trans-Indus Ranges, where the Lumshiwal Formation is directly overlain by Tertiary rocks (Shah, 2009). In this research work the Kawagarh Formation was studied in two sections. One is located in Nizampur Basin and the other is located in Kohat Range. The Kawagarh Formation encompasses of thin to medium bedded light grey to medium grey limestone, sandy limestone and few small to minor dolomitic layers (Figure. 3.2).

Table 3.1 Litholog of the Kawagarh Formation in (Study area).

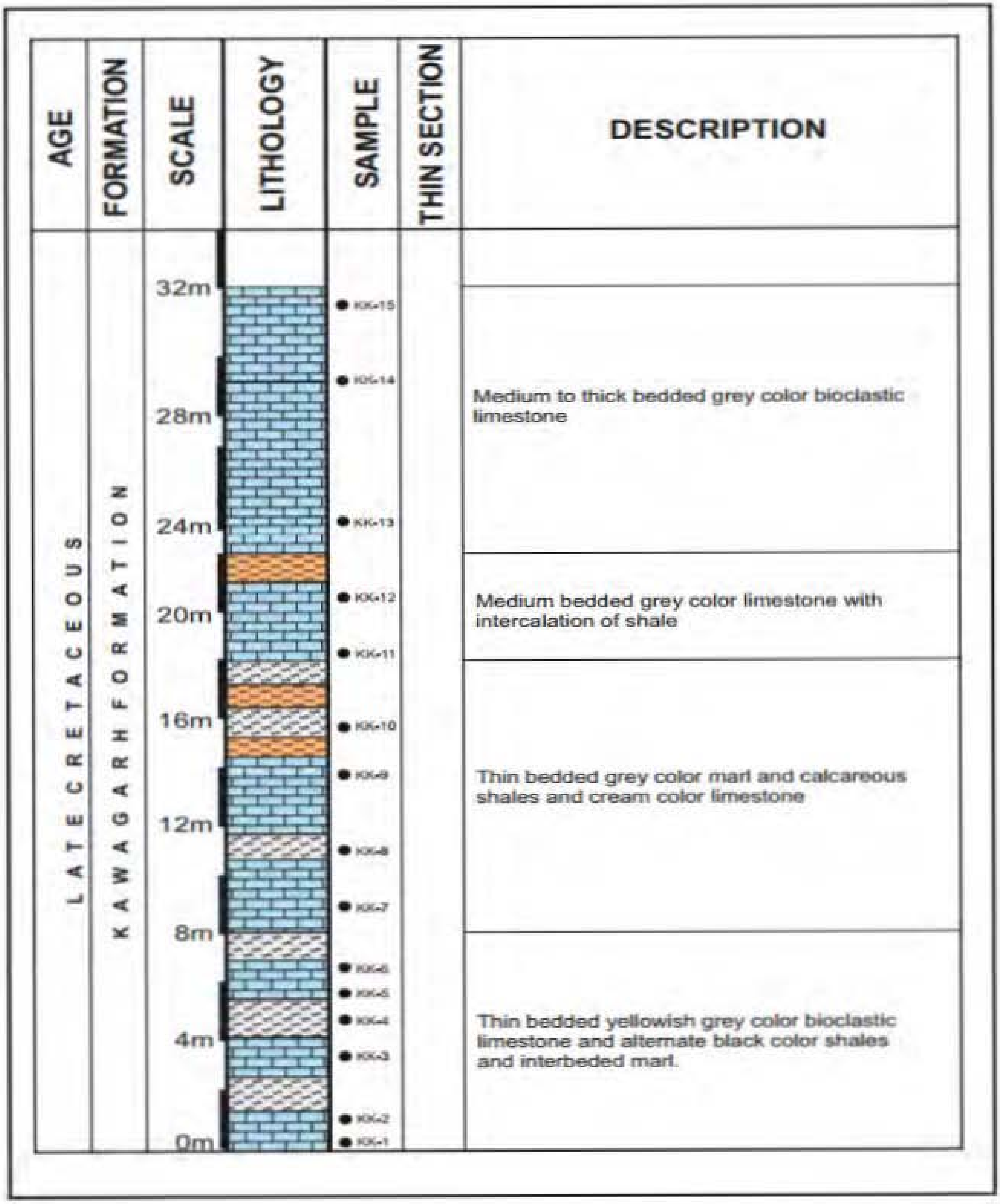

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Figure 3.1 Field photograph (A)) showing the contact view of the Kawagarh Formation and the Lockhart Formation whereas (B) showing the contact view of the Kawagarh Formation and the Lumshiwal Formation in the study area.

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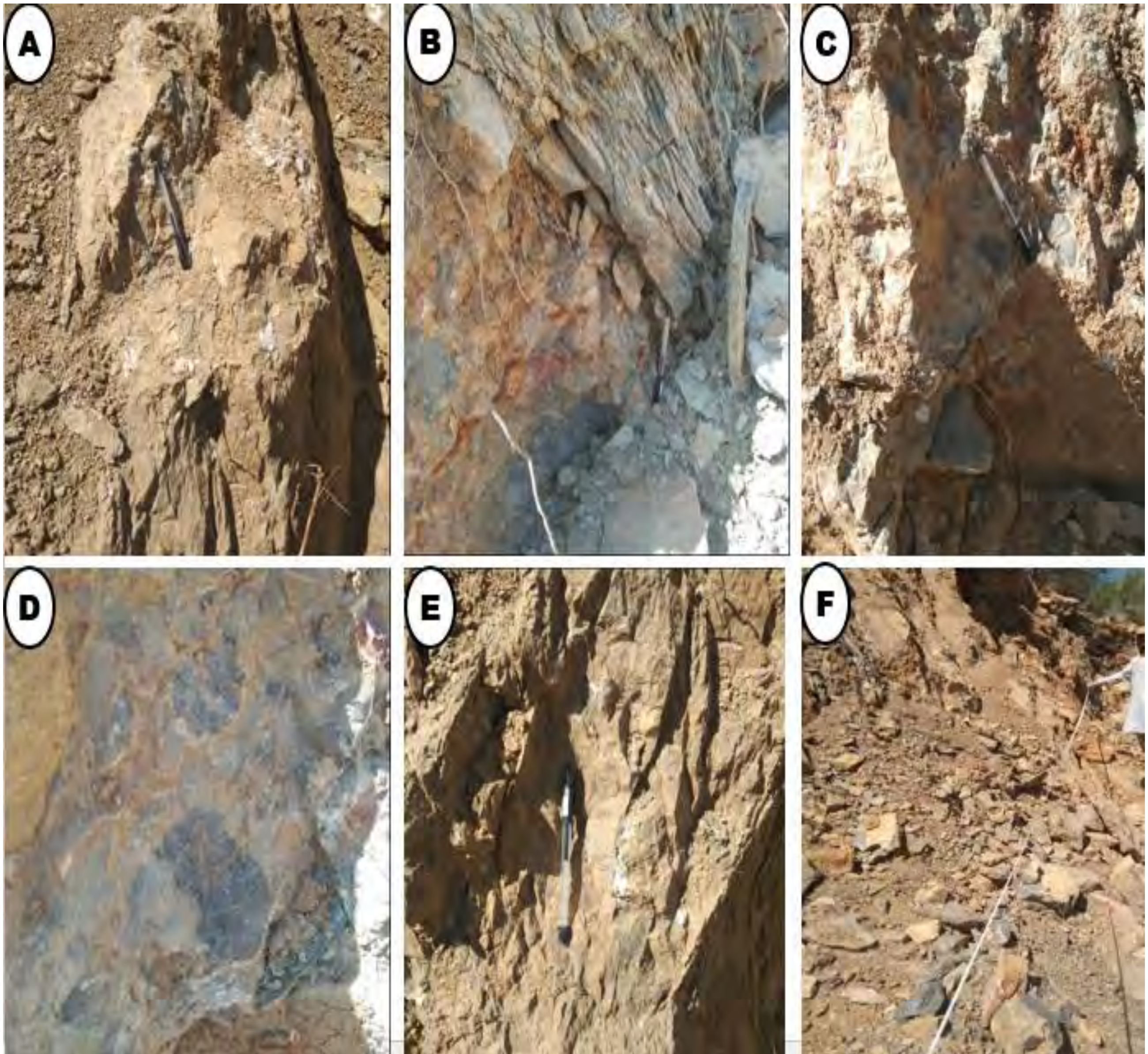

Figure 3.2 Field photograph (A,B,C,D,E) showing view of thin to medium and thick bedded limestone and (F) showing section measurement of the Kawagarh Formation.

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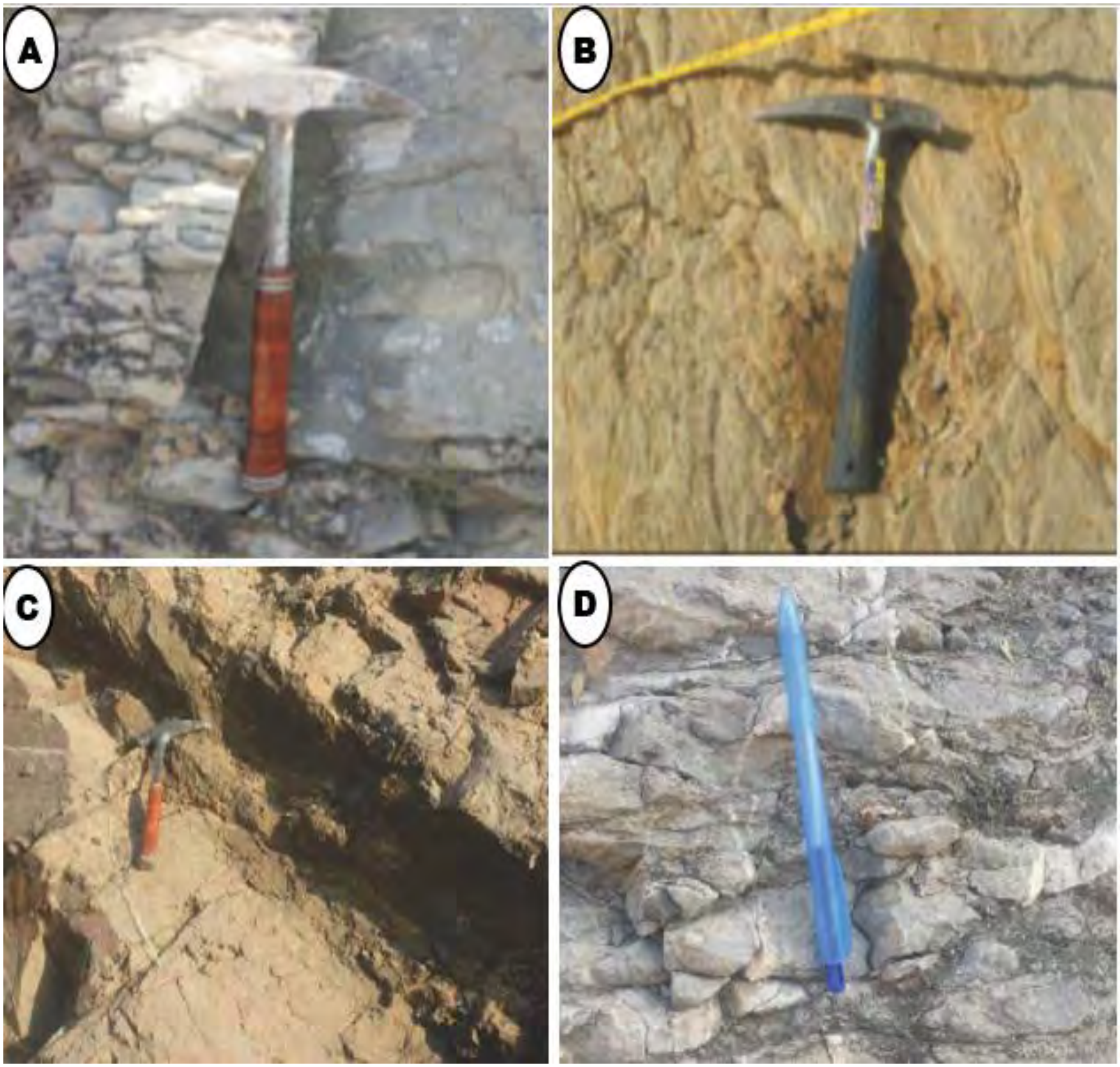

Figure 3.3 Field Photograph (A-D) showing different views of the Kawagarh Formation.

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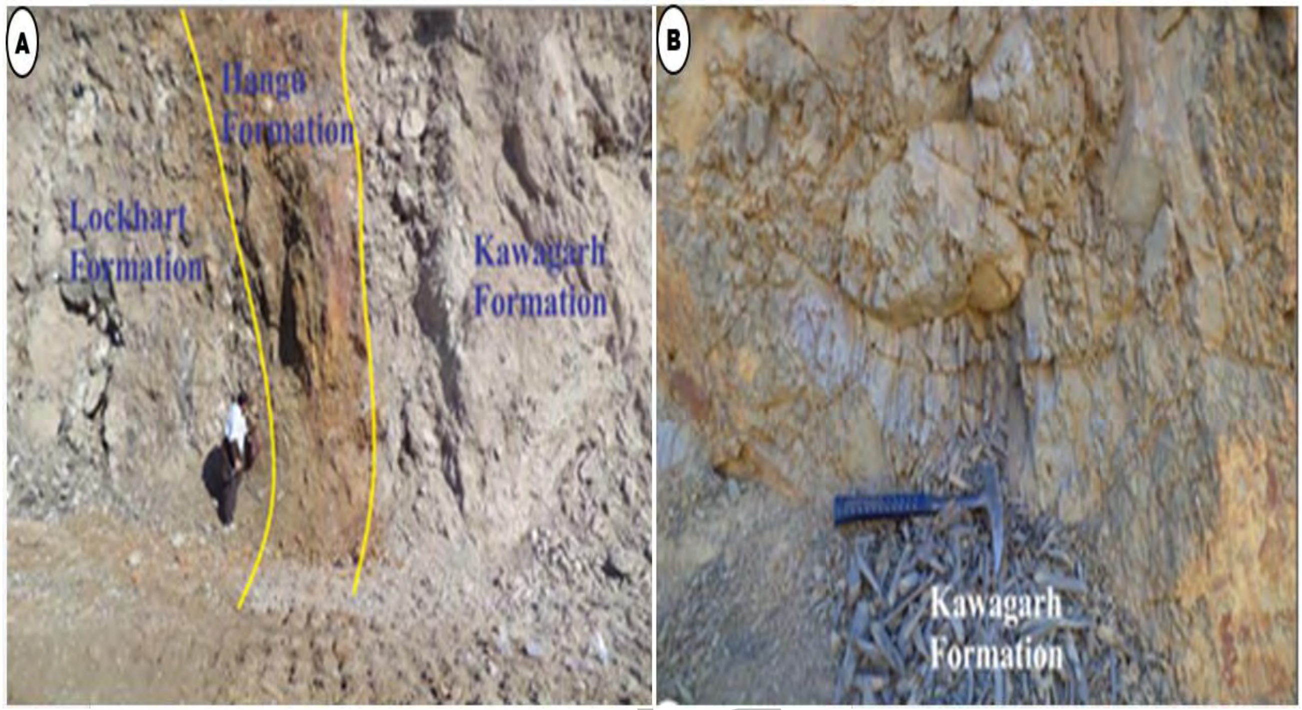

Figure.3.4 Field photograph (A) showing contact view of the Kawagarh Formation with Hangu and Lockhart Formation and (B) showing weathered limestone of the Kawagarh Formation.

3.3 Thin Section Studies and Overview of Microfacies

In thin section paleontological and petrographic studies were done to illustrate the thin sections criteria in constitution of the microfacies, the term first microfacies was invented (Brown, 1943). A modern definition of microfacies includes all sedimentological and paleontological data that is 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 has a more genetically-based use, 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 in-depth microscopic investigation of thin sections and field criteria used to interpret paleoenvironment.

For the microfacies examination of the Kawagarh Formation , 15 representative samples were selected from the Nala sections of the Nizampur cement factory for thin sections studies of the petrography and biostratigraphy. 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 Kawagarh Formation.

3.4 Microfacies of the Kawagarh Formation

To evaluate the depositional conditions of ancient limestone, microfacies analysis is thought to be the most accurate method. (Reading 1996a, b; Flügal 2004) In the current investigation, microfacies were identified using the Dunham (1962) classification with modified Flügal-developed parameters (2004). The following three microfacies are identified based on a thorough investigation of the stratigraphic section's measured samples using petrography.

- Planktonic foraminifera Wackstone Microfacies (MF1)
- Siliciclastics-bioclastic Wackstone Microfacies(MF2)
- Dolomitized Limestone Microfacies (MF3)

3.4.1 Planktonic Foraminiferal Wackstone Microfacies

The wackestone-like texture of the rock in this microfacies is evident. Between 25% and the total virtual fraction of allochems(grains) of this microfacies ranges from 20-30%, with average of 25%, while the lime mud content ranged from 70-80%, with an average of 75 %. Amongst the grains, Globotruncana Sp and Heterohelix Sp ranged from 5-7%, with an average of 6%, while rest of the planktonic foraminifera and broken biolcasts accounted from 15-20%, with an average of ~18% of the total microfacies (Figure.3.4).

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Paleoenvironment interpretation

Mudstone (micrite) with pelagic fana signifies its deposition in the outer-ramp depositional setting (Flügel, 2004). This microfacies also attests to the deposited in the outer-ramp (Flügel, 2004).

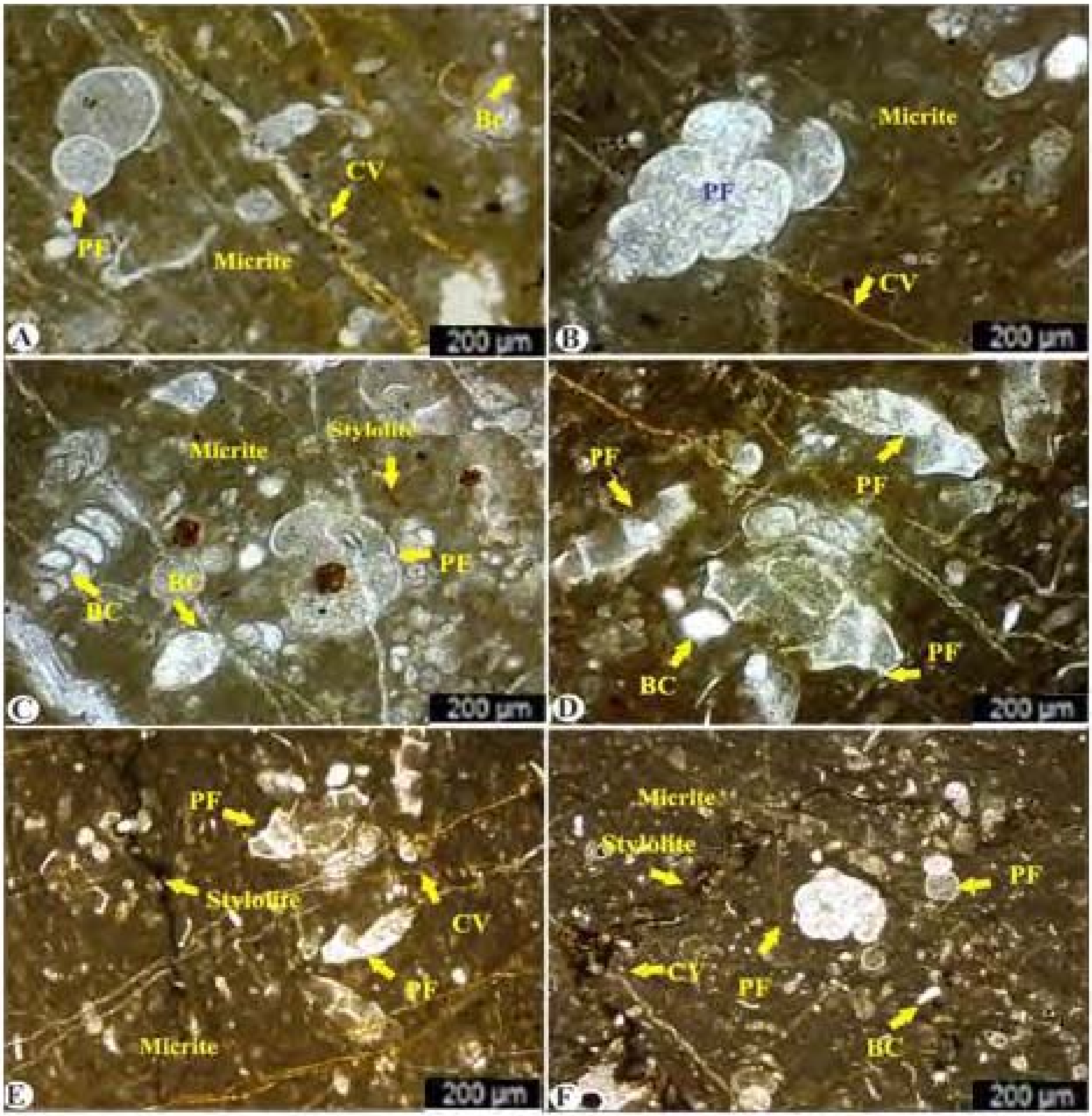

Figure 3.5: Planktonic foraminifer wackestone microfacies, Photograph. (A-F) showing planktonic foraminifera (Pf), bioclasts (BC) and stylolite within matrix of the Kawagarh Formation under plan polarized light, (PPL. Mag. X4).

3.4.2 Siliciclastics-Bioclastic Wackstone Microfacies

Siliciclastics planktonic foraminifer bioclastic wackstone Microfacies is found at both upper and lower parts of the Kawagarh Formation. During petrographic investigations, the microfacies showed wackstone-texture. The relative proportion of grains ranged from 32-38%, average of 34%, while the micrite content ranged from 62-68%, with an average of 65%. Planktonic forams represented 8% of the microfacies, while angular quartz grains are represented by 3%, glauconitic by 1% , Echinoderms are present up to 1% and broken bioclasts represent 12%. The calcispheres, radiolarian spong spicules and molluscs are below 1% each

Paleoenvironment

Bioclastic wackstone with minimal foraminifera and ostracods demonstrates deposition in an outer ramp environment (Flügel, 2004). Therefore, this microfacies was also deposited in the outer ramp setting.

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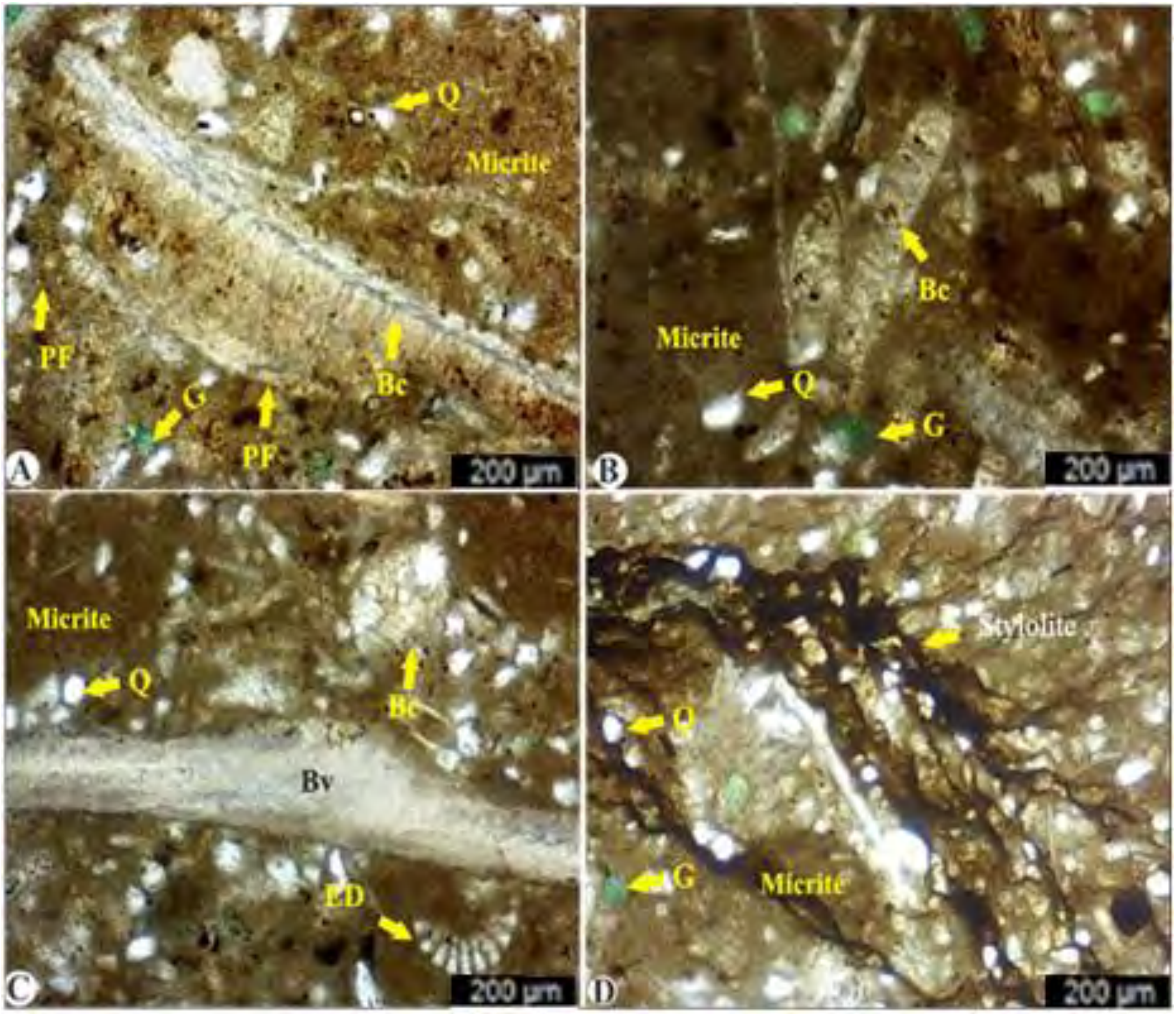

Figure 3.6 Siliciclastics-Bioclastic wackestone (MF-2). Major component in this microfacies are siliciclastics. Bioclasts, Bivalve, (Q, BC, BV), shown in Photomicrograph (A, B and C), Glauconite, Echinoderm spines, horse tail pattern Stylolite shown in (D), (PPL. Mag. X4).

3.4.3 Sandy Bivalve Wackstone Microfacies

The facies is found within the upper most interval of the Kawagarh Formation in the studies sections .These rocks are burrowed and are fractured filled grey colour Limestone. The microfacies is rich in bivalve (i.e., 14 %), the fine-grained angular quartz accounted for 2%, glauconite 1%, Sponge spicules, and smaller benthic foraminifera accounted for 1 % and red algae as 1 %. The algae represented a tiny fraction of this rock, i.e., below 1%.

Paleoenvironment Interpretation

Sandy bivalve wackestone related with glauconite and the presence of abundant mud, rare planktonic foraminifera and sponge spicules suggested the deposition of this microfacies took place in the intertidal setting (Flügel, 2004).

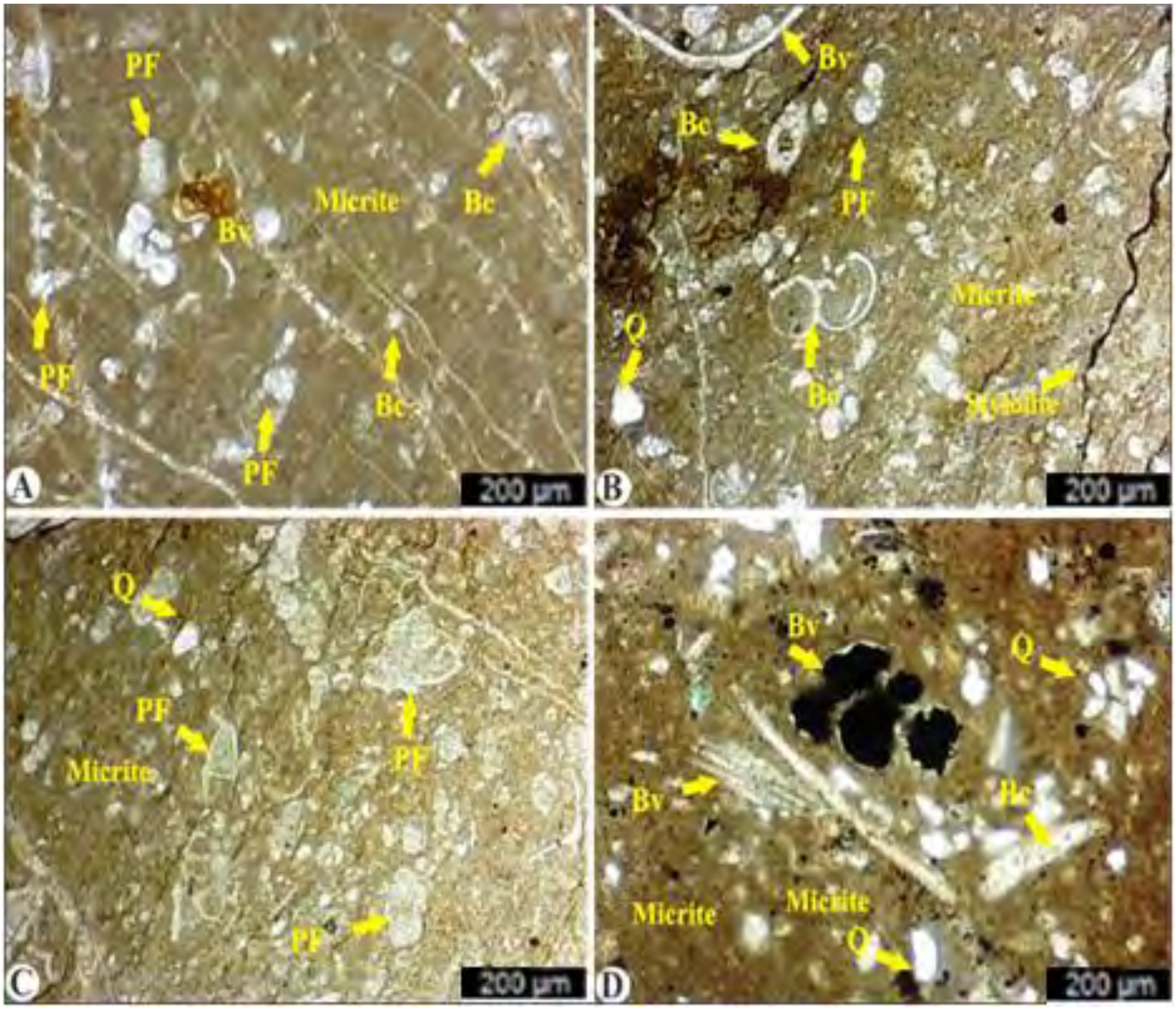

Figure 3.7 Sandy Bivalve Wackestone Microfacies Wackestone Microfacies, Photomicrograph (A-D) showing Bioclasts (Bc), Bivalve (BV), Echinoderm (ED), Quartz (Q), Glauconitic (G) and Stylolite within matrix of the Kawagarh Formation under plan polarized light, (PPL. Mag. X4).

3.4.4 Sandy Dolomitized Bioclastic Wackestone Microfacies

The texture of this microfacies is wackestone. The percent presence of the grains are 40%. Among the grains Brachiopods, bryozoans and echinoderm plates are present with percent presence of 5%, 5% and 5% respectively. Micrite is present up to 80%, in which almost 70% of the mud has been dolomitized.

Paleoenvironment

Bioclastic wackestone characterized by Bivalves, Gastropods and echinoderms are deposited in outer and mid ramp setting (Flügel, 2004); hence Dolomitized Limestone microfacies containing bivalves, gastropods, bryozoans and echinoderm spines was also deposited in middle and outer ramp setting.

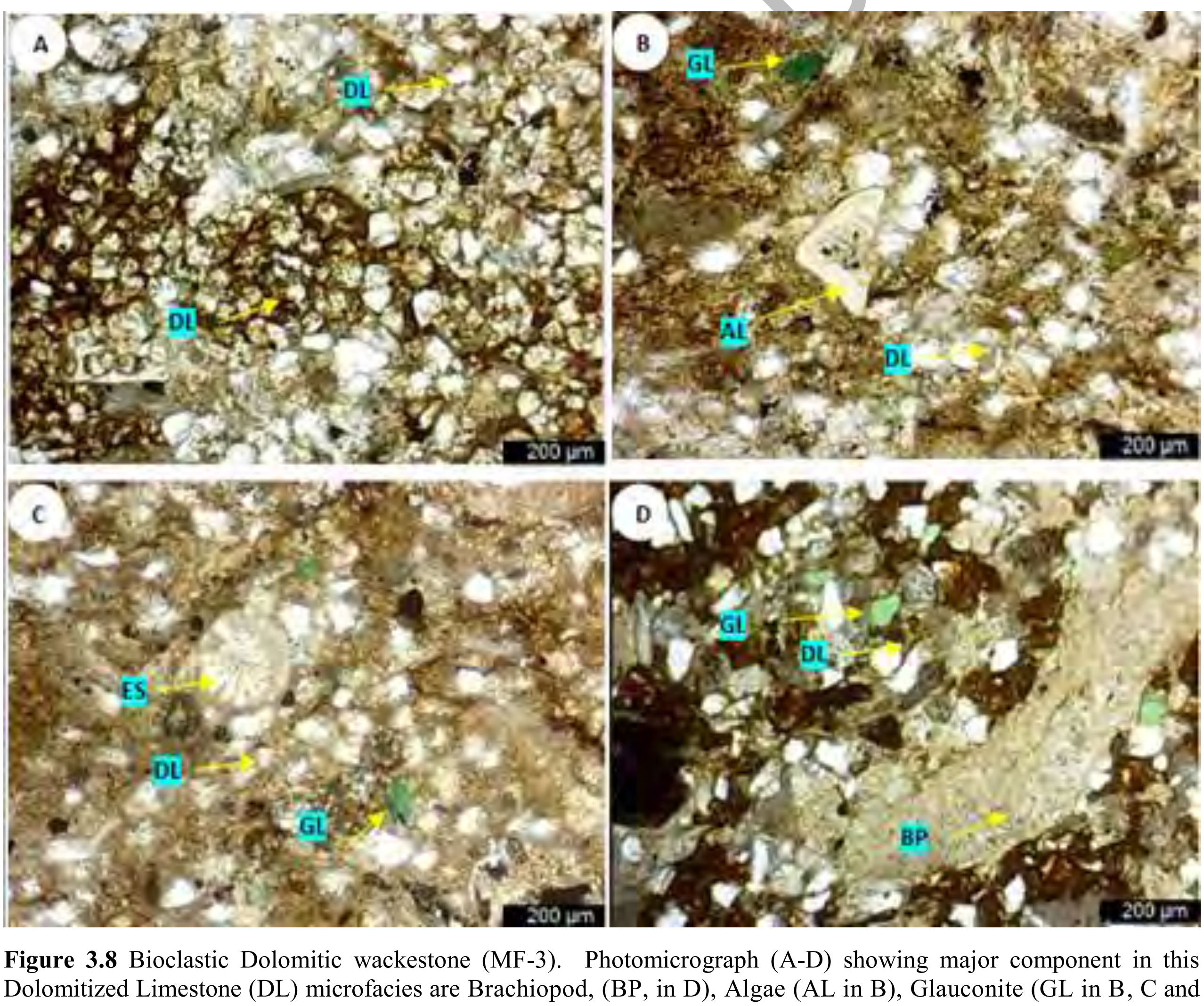

Figure 3.8 Bioclastic Dolomitic wackestone (MF-3). Photomicrograph (A-D) showing major component in this Dolomitized Limestone (DL) microfacies are Brachiopod, (BP, in D), Algae (AL in B), Glauconite (GL in B, C and D), Echinoderm spines (ES in C), (PPL. Mag. X4).

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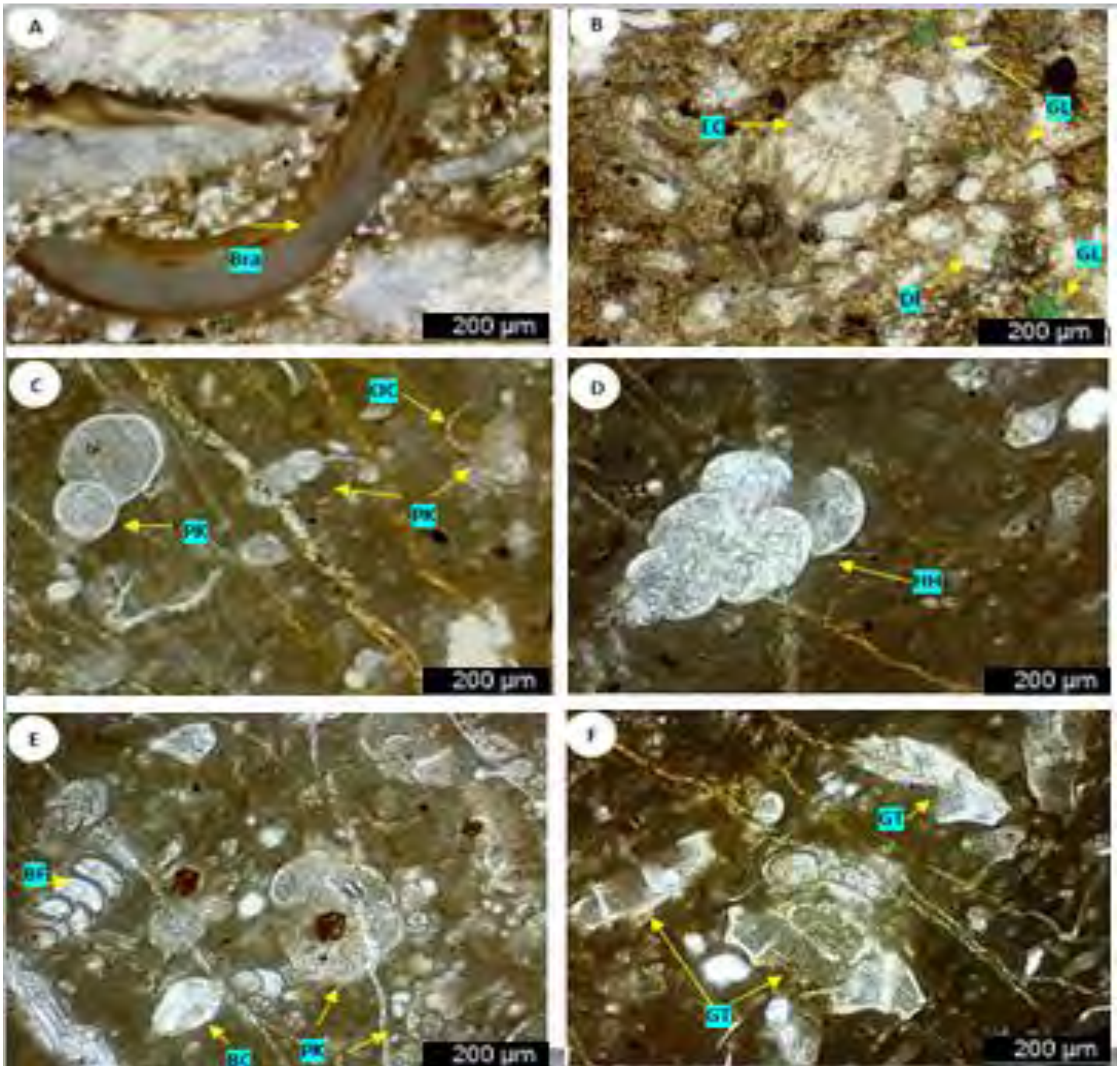

Figure 3.9 Photomicrograph (A) of The Kawagarh Formation showing brachiopod fragment and planktonic. Photomicrograph (B) of The Kawagarh Formation showing Echinoderm in dolomitized Limestone. Photomicrograph (C) of The Kawagarh Formation showing Planktonic forms. Photomicrograph (D) of The Kawagarh Formation showing Planktonic forms (Heterohelix dentata). Photomicrograph (E) of The Kawagarh Formation showing planktonics forms (Whiteinella paradubia (Sigal, 1952). Photomicrograph (F) of The Kawagarh Formation showing Globotruncanids, (PPL. Mag. X4).

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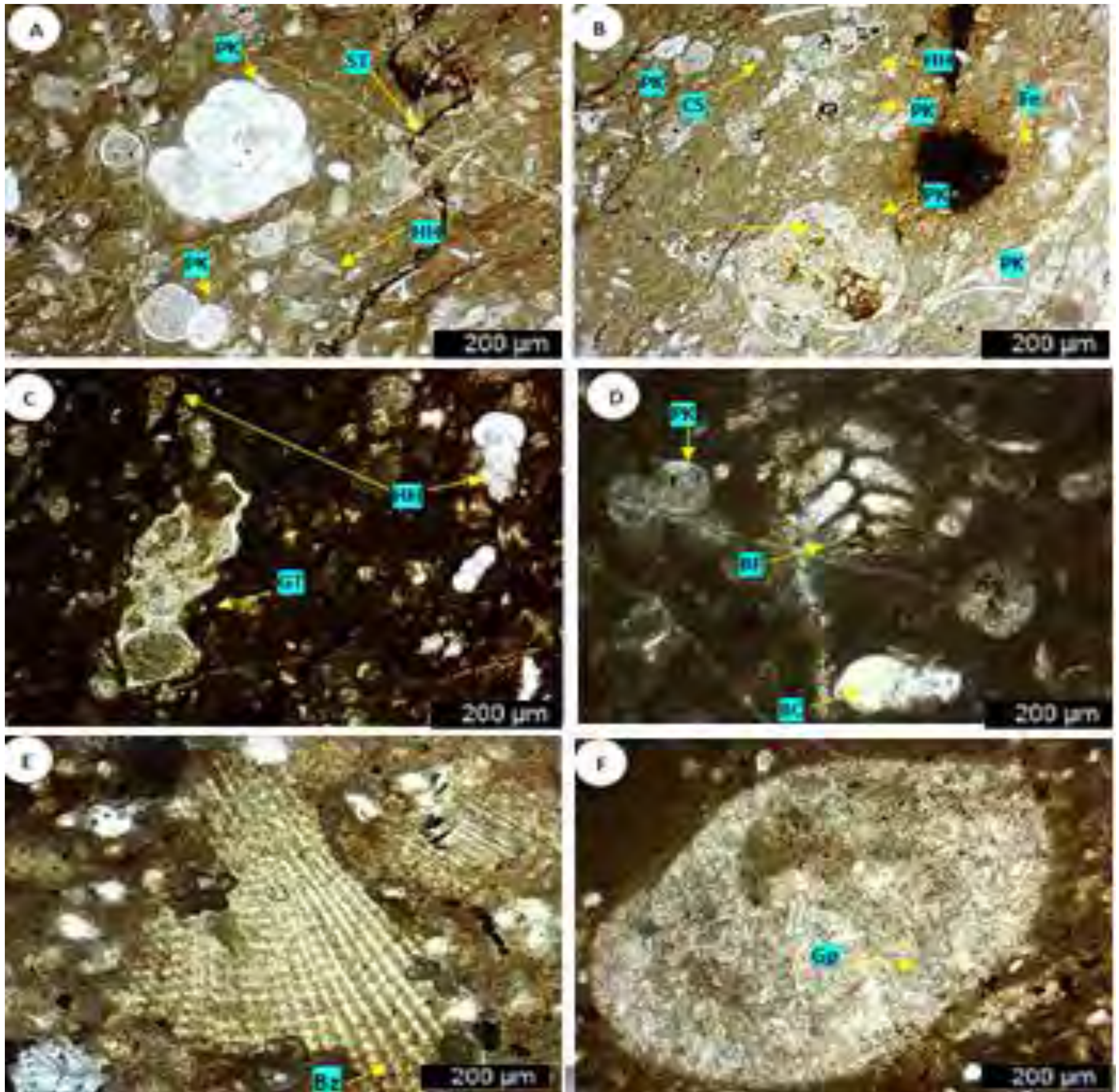

Figure 3.10 Photomicrograph (A,B) of The Kawagarh Formation showing Globotruncana linneiana. Photomicrograph (C) of The Kawagarh Formation showing Heterohelix reussi. Photomicrograph (D) of The Kawagarh Formation showing planktics,benthic foram and bioclasts. Photomicrograph (E) showing bryozoan's colony. Photomicrograph (F) of The Kawagarh Formation showing replacement of originally aragonitic shell of gastropod into coarse sparry calcite (PPL. Mag. X4).

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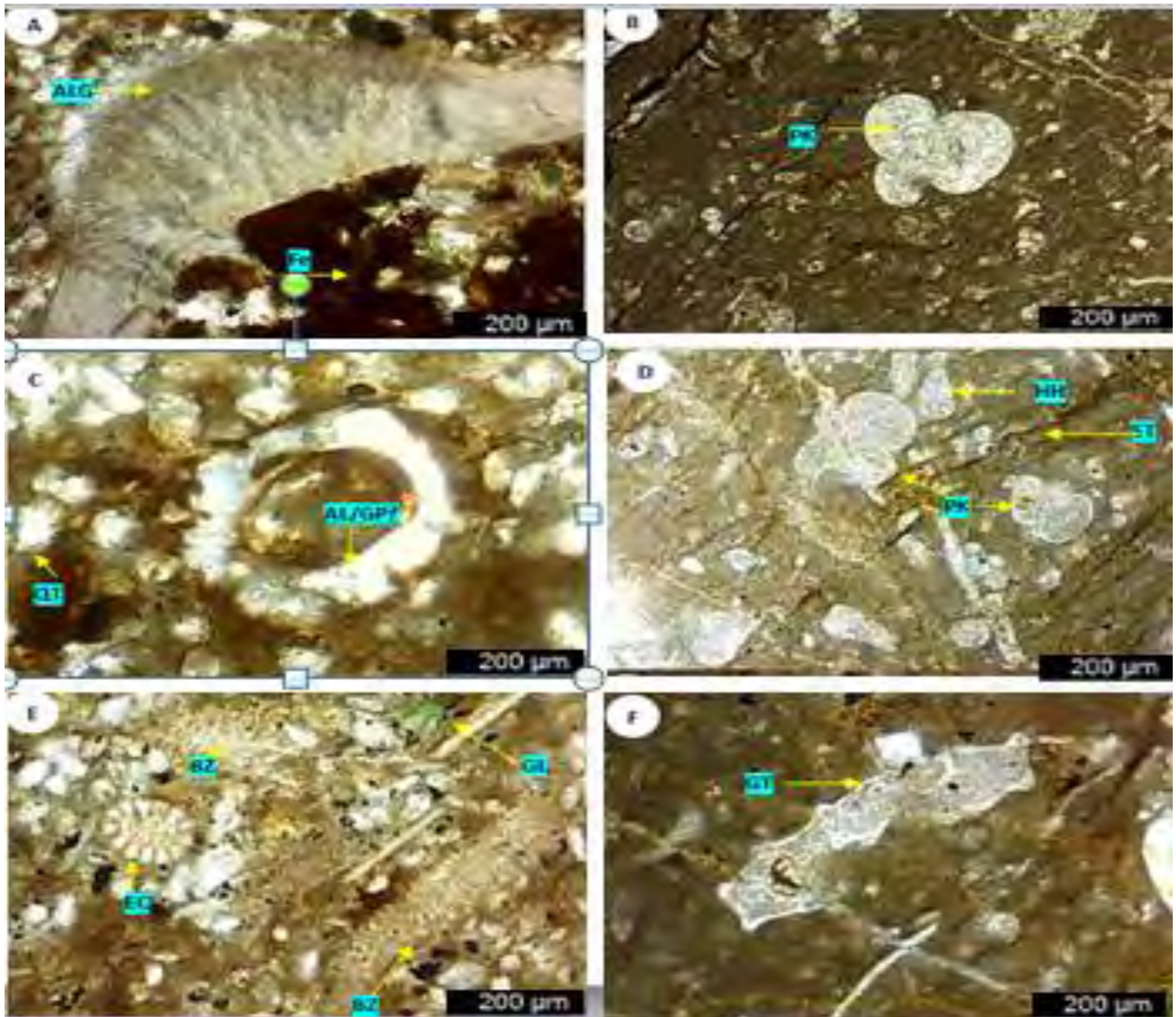

Figure 3.11 Photomicrograph (A) of The Kawagarh Formation showing Red algae with partial replacement of micrite into ferron oxide. Photomicrograph (B) of The Kawagarh Formation showing Planktonic wackstone. Photomicrograph (C) of The Kawagarh Formation showing replacement of originally aragonite shell wall to coarse sparry calcite within Algae/Gastropod and quartz (QT). Photomicrograph (D) of The Kawagarh Formation showing abundance of planktonic and stylolite Photomicrograph (E) of The Kawagarh Formation showing Echinoderm (EC), bryozoans (BZ) and glauconite (GL) Photomicrograph (F) showing Globotruncana,i.e Marginotruncana pseudolinneiana, (PPL. Mag. X4).

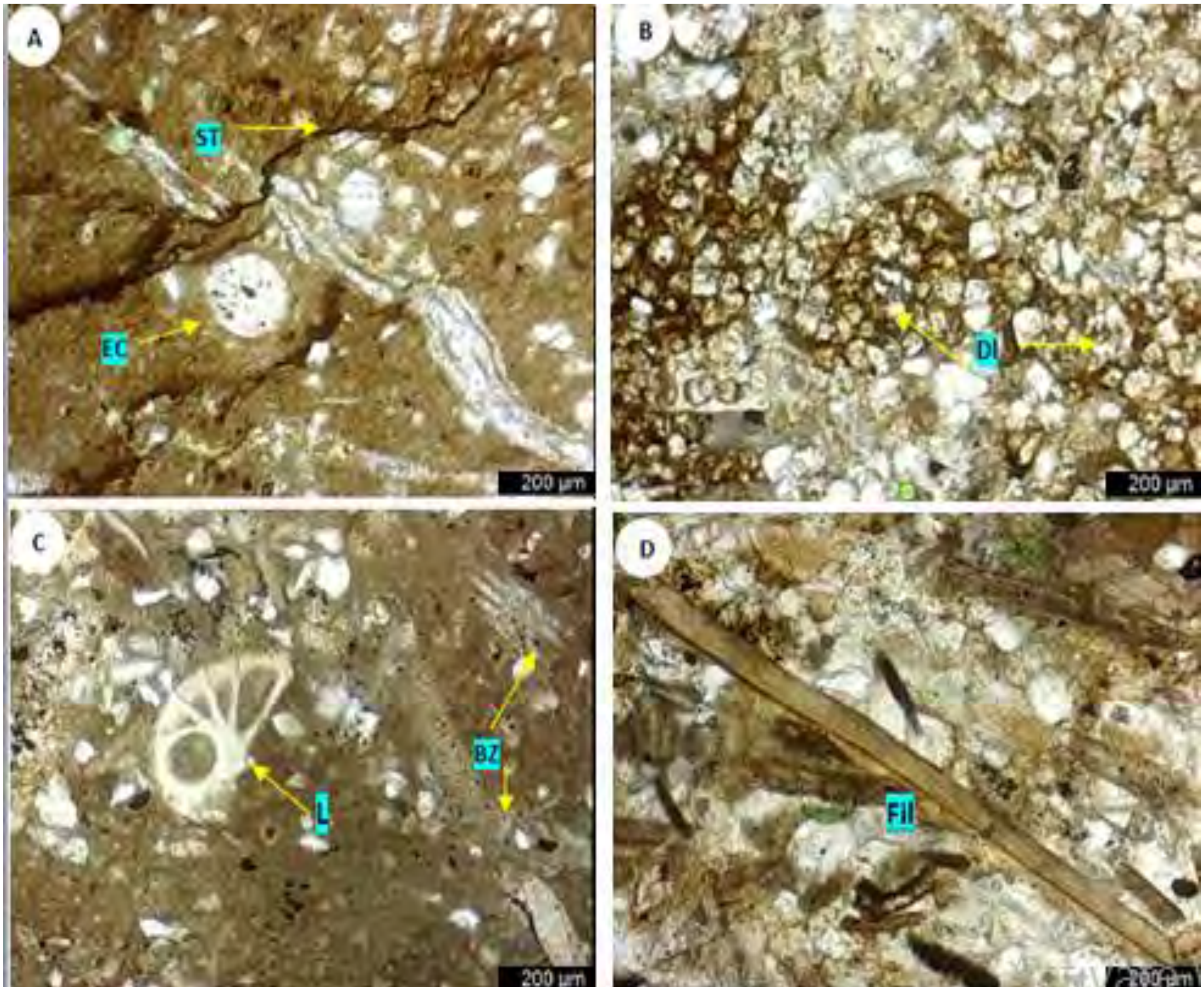

Figure 3.12 Photomicrograph (A) of The Kawagarh Formation showing echinoderm (EC), stylolite (ST) and displacement of bioclasts along with spar filled fracture. Photomicrograph (B) of The Kawagarh Formation showing dolomitization (Dolomitized Limestone. Photomicrograph (C) of The Kawagarh Formation showing Lenticulina Sp and bryozoans. Photomicrograph (F) of The Kawagarh Formation showing filamentous algae (PPL, Mag. x4).

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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 endeavour involved performing lithological correlation of the well logs using the conventional log data from three wells in the Kohat Basin (Manzali-01, Manzali-02, Sumari Deep-01).

TechLog, a leading industry software, was utilized to correlate data and assess Petrophysical job flows. It is possible to record and interpret the Petrophysical rock parameters (resistivity, self-potential, natural radioactivity, density, sonic-velocity, bedding dips, temperature, formation pressure, etc.) using the wire line log data of Wells (Manzali-1, Manzali-2, Sumari Deep-1 and Tolang-1) in order to determine the depth, lithology, thickness, orientation, and porosity of the reservoir as well as to characterize any fluid types (G (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. $Vsh = GRlog - GRmin / GRmax - GRmin$
2. $\phi D = \rho ma - \rho b / \rho ma - \rho f$
3. $\phi A = \phi N + \phi D / 2$
4. $\phi s = \Delta tlog - \Delta tm / \Delta tf - \Delta tma$
5. $\phi E = \phi T \times (1 - Vsh)$

Where, GRlog = GR log reading, GRmax = maximumGR log, GRmin = minimumGR log; ρb = density from log, ρma = matrix density, ρf = fluid density; $\Delta tlog$ = 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:

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

1.

Where, 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.

2. $Shc=1-Sw$

4.2 Quality Control of well logs data for correlation

The effectiveness of wireline 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 essential for the collection of high-quality data (Schlumberger, 1991). The following log curve is subject to quality control, as are all conventional log curves.

1. An organized and complete logging Programme considers 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, wireline service provider, and wireline log witness.
2. 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.
3. Routine equipment checks that are 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.
4. 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.
5. Taken note of the factors influencing the survey and measurements. They were documented as soon as they were found to act as a guide for future attempts ("Lessons learned").
6. All equipment problems, the solutions employed to correct them, and the effects the changes would have on the data were all documented.
7. Confirmed that the values of the digitally (or electronically) recorded data (found in well logs) are in accordance with the surrounding circumstances. Comparing and matching the logs for depth

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(final depth control).

8. Checked for any missing or erroneous data, as well as the scale and scale compatibility of the density-neutron family curves. During analysis, the software analysed and contrasted all of the curves side by side.
9. Caliper log is 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) is utilised (density, neutron and Micro Resistivity logs). The calliper record also provides information on the location of less compacted layers.
10. A more 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 the Kawagarh Formation e-logs

The general standards and procedures below were followed by the lithologic correlation of the Kawagarh Formation.

1. The lithologic correlation work flow started at the bottom and worked its way up, following the direction that the rocks were deposited.
2. Used the patterns/signatures of the resistivity logs to correlate lithologies, but always take into account variances caused by fluid effects.
3. 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).
4. Correlated the Formation tops and markers as the starting point, then the minor modifications and beds, before correlating the large-scale alterations to the small-scale ones.
5. Checked twice for omissions and duplicate sections.
6. Merging correlation lines show units that pinch out between wells. Scale variations, casing shoes, and acoustic log cycle Skips are non-geological phenomena that carefully observed, deceiving the Formation.

4.4 Outcome of the Kawagarh Formation Logs Correlation

1. Three limestone and three shale facies were analysied. The limestone facies are argillaceous/marly limestone to planer laminated mudstone and grainstone.
2. As shown by lithologic correlation, the limestone facies LS-1 is present in the Manzalai-1 and Sumari Deep-1 well, however, it is not present in the Manzalai-2 and Tolamg-1 wells. Limestone facies are thicker in the Manzlai-1 and Sumari Deep-1 wells along the Kawagarh Formation which ranges from clean limestone to marly/argillaceous limestone and is sandwiched by dominant shale and silt/sandstone in some places.
3. Using the cross plot technique, the association between the Kawagarh Formation and lithofacies provides a strong base and level of control.
4. The Kawagarh Formation's poor reservoir quality was further corroborated by porosity and permeability analyses based on petrophysical log interpretation, which showed very low porosities & permeabilities across the section.

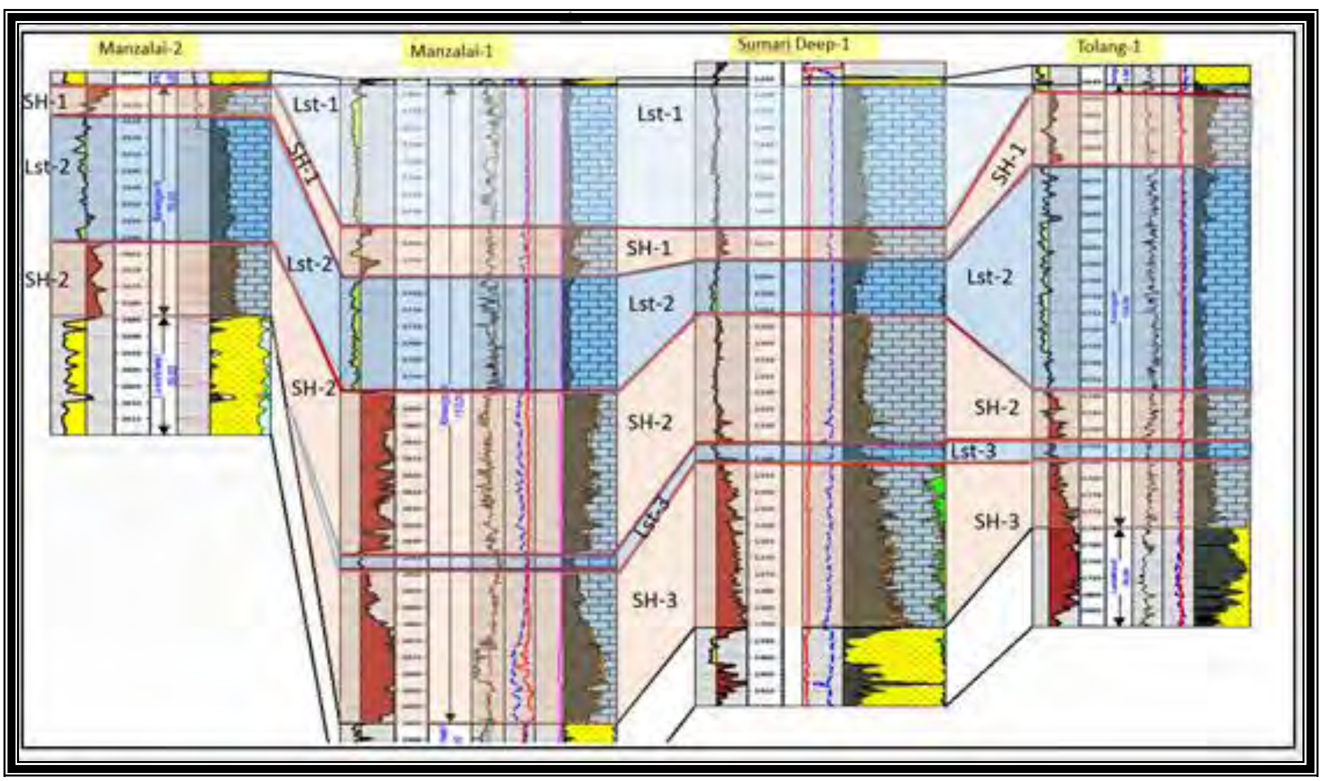

Figure 4.1 The Kawagarh Formation correlation of limestone litho facies of well Sumari-1, Manzali-1, and Manzali-2 & Tolanj-1 in the Kohat Basin.

4.5 Delineation of the Kawagarh Formation Lithofacies

The physical, chemical (mineralogical and petrological), and biological characteristics of a specific sedimentary environment is called as Lithofacies, moreover, as the presence of bioclasts and intraclast material in Mudstone, oolitic grainstone, and peloidal Packstone facies of marine strata that reflect the depositional environment (Dictionary of Earth Sciences 2006, Oxford Univ.Press). According to the Oilfield Glossary at www.Slb.com/glossary, lithofacies is "A mappable subdivision of a stratigraphic unit that may be differentiated by its facies or lithology-the texture, mineralogy, grain size, and the depositional environment that formed it. 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 are a high-resolution alternative with several potential pitfalls. Gamma ray (GR), Micro Spherically Focused Resistivity (MSFL), Resistivity Latrologs (LLS and LLD), Density (RHOB), Neutron (CNL), and Photoelectric factor (PEF) were correlated to depositional facies of the Kawagarh Formation in the current study. The conventional logs dataset of the Kohat Basin from four wells (Manzali-01, Manzali-02, Sumari Deep-1 and Tolanj-1) were used.

4.6 Electro Facies of the Kawagarh Formation

Based on interpretation of neutron porosity-shale volume cross plot and composite logs of the Kawagarh Formation exhibits three shale and three limestone electro facies as follow (SH1-SH3 & Lst1-Lst3).

4.6.1 Shale Facies of the Kawagarh Formation

Based on composite logs interpretation the reveal three shale facies within the Kawagarh Formation from top to bottom, which are characterized based on the higher GR values, on average from 70 to 110 API units, whereas range of neutron porosity of these shale facie is from 10 to 18% (Fig. 4.1). Shale facies are recognized from top to bottom of the Kawagarh Formation as (SH1, SH2 & SH3) which seems hydrophilic and considerable water adsorption. These shale facie are developed in all of the studied wells (Sumari Deep-01, Manzalai-1 & Manzalai-2), showing (Figure. 4.1).

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4.6.2 Limestone Facies of the Kawagarh Formation

Based on the composite log correlation of the selected wells, three limestone facies (Lst1-Lst3) were identified in the Kawagarh Formation, with variable facies thickness. These limestone facies are composed of argillaceous to clean limestone having the GR values ranges 20-40API. From top to second identified limestone facie is (Lst2) which is slightly argillaceous. Its thickness varies in studied wells from 10-30m. From top to bottom limestone facie is identified as Lst3, it is slightly clean limestone having same GR values as of Lst1 in the eastern well (Tolanj-01). Where as in the western wells, it is slightly argillaceous and the GR value increased up to ~40API.

4.7 Cross plots technique (Neutron Porosity and Shale Volume)

Crossplot is effective ways to display how different combinations of logs respond to the reservoir property being investigated, such as lithology and porosity. Additionally, crossplot provide a visual representation of the kind of combinations that the log combination is regarded to best disclose (Liu, 2017). The density-neutron cross plot is a popular and effective method for estimating porosity and determining lithology because it has strong lithological resolution and can determine porosity independently 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 either through petrography or core data for reliable assessment of the sandstone matrix. Hole rugosity and the use of heavy drilling muds are limitations of the density-neutron crossplot that have an impact on the accuracy of the density log data.

4.8 Lithofacies Analysis of the Kawagarh Formation

Using Techlog software, neutron porosity and Shale volume data of the wells (Manzalai-1, Manzalai-2, Sumari Deep-1 and Tolang-1) from Kohat Basin were plotted on a neutron porosity-Shale volume cross plot to identify the lithofacies of the Kawagarh Formation . Schlumberger (CP-1a, neutron porosity vs. shale volume) has chosen the relevant and accepted industry standard for the Shale vloume (Vsh) and neutron porosity (NPHI) curves in figure 4.2 neutron porosity-Shale volume cross plot. Neutron porosity (NPHI) data are always presented on the Y-axis, Shale volume (Vsh) data on the X-axis, and graduated lines for porosity are practically diagonally oriented in the three primary reservoir rocks (Sandstone, Limestone, and Dolostone) to depict higher lithology resolution. Valid Shale volume data displays the corresponding porosity value on the X-axis for rapid inspection. Following are the integrated color-coding of Computed Gamma-Ray Tomography makes all the lithologies' appear on the composite logs showing in Figure (4.1). Furthermore, by using Techlog software, in order to clearly distinguishing between different lithofacies, cross plotting of Shale and Limestone facies are not only zoned with specific color but also highlight the corresponding facies interval on the main composite log (Figure 4.1). Bellow neutron porosity – Shale volume cross plots of three wells ((Manzalai-1, Manzalai-2, Sumari Deep-1 and Tolang-1)) from Kohat sub basin (Figure 4.2-4.4).

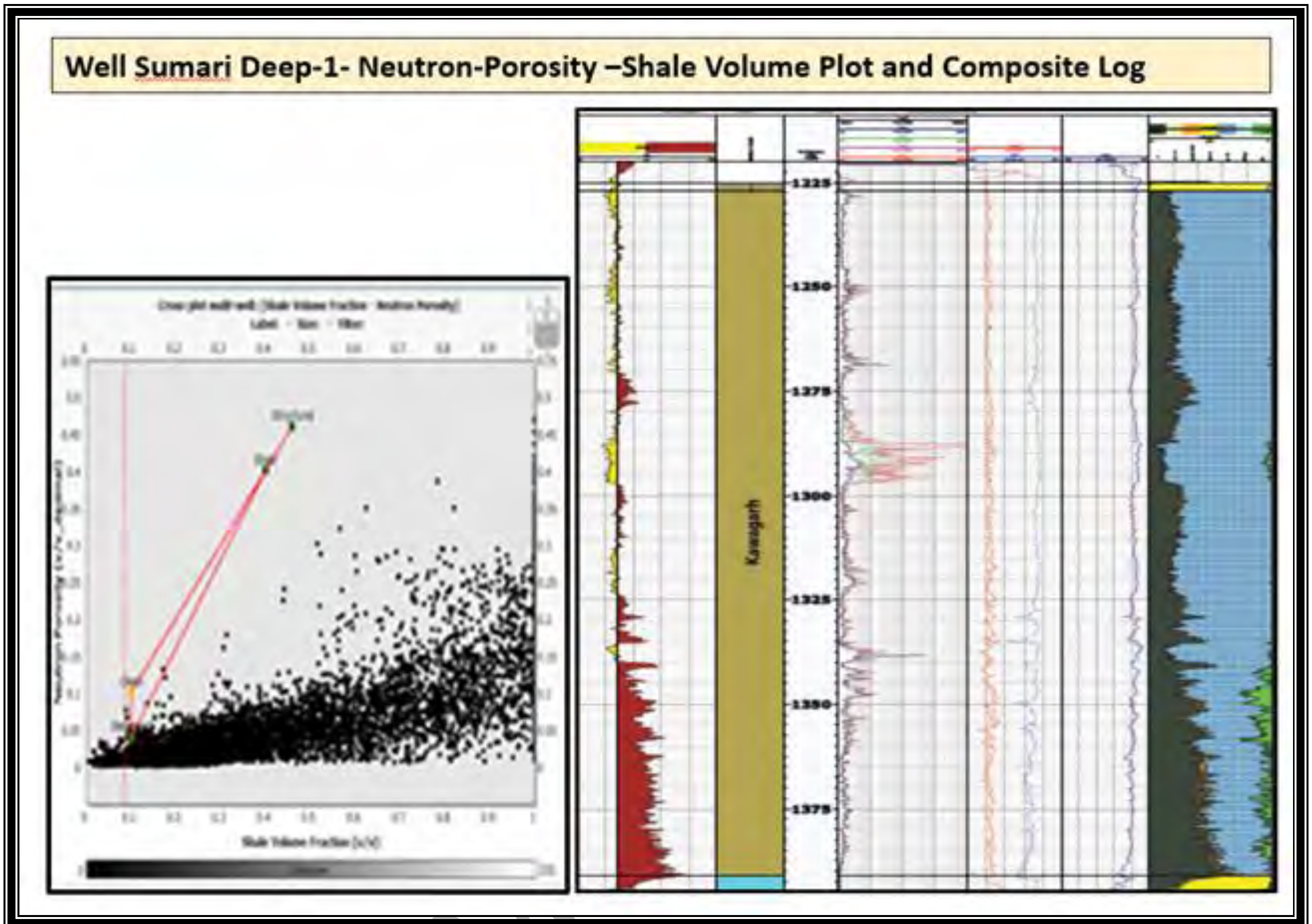

Figure 4.2 Well Sumari Deep-1; Neutron porosity-Shale volume cross plot and Composite log of Computed Gamma-ray (GR) clearly distinguishes Marly/Shale and Limestone facies.

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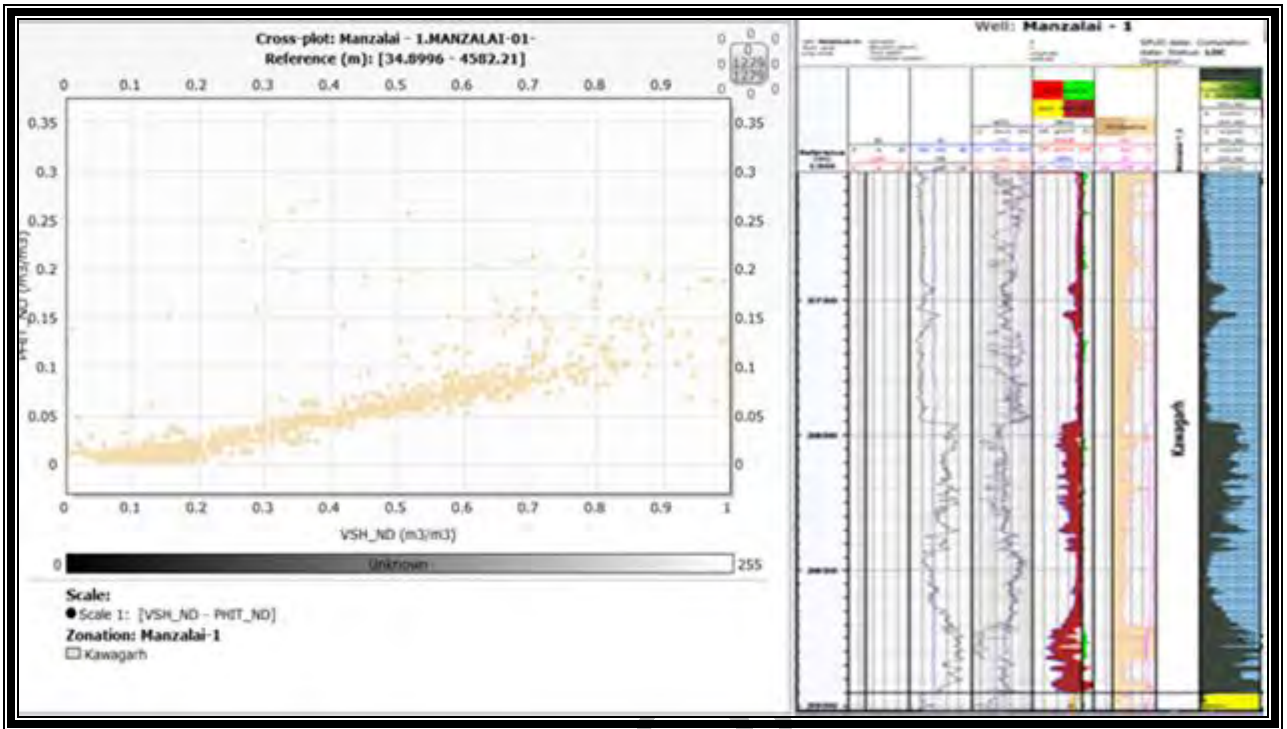

Figure 4.3 **N**eutron porosity & Shale volume cross plot with corresponding intervals of the composite log well Manzalai-01.

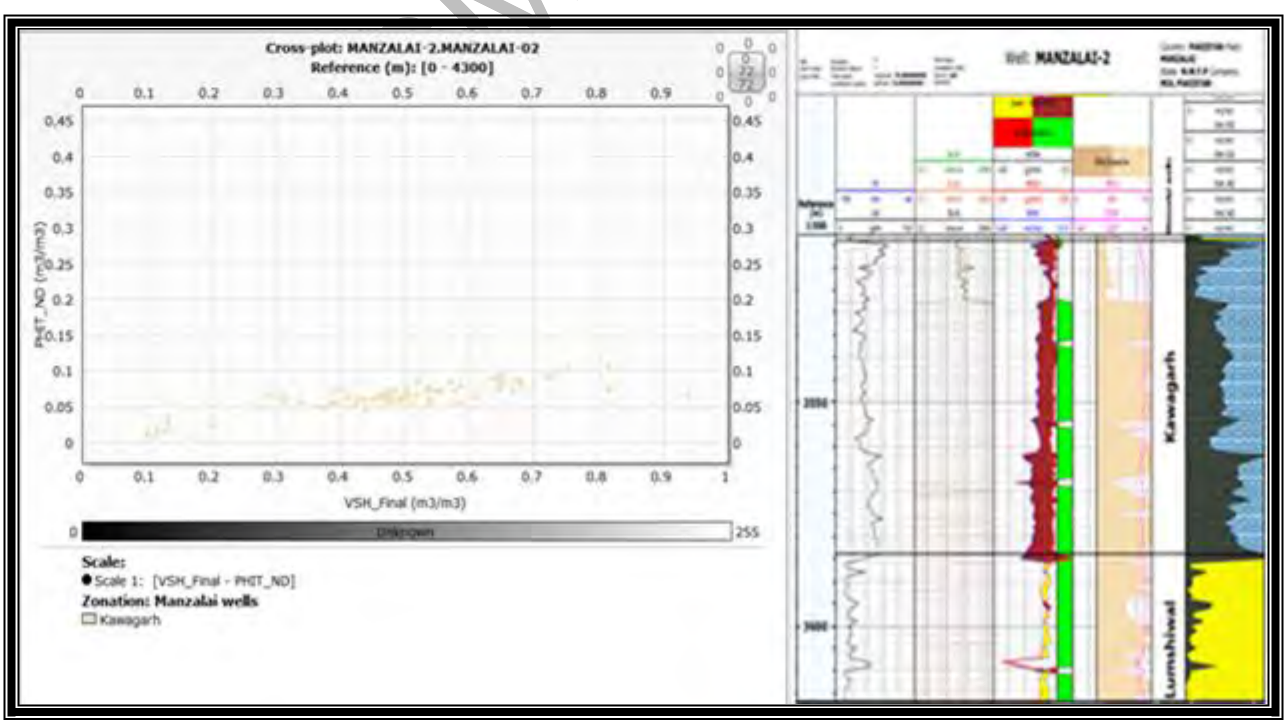

Figure 4.4 **N**eutron porosity & Shale volume cross plot with corresponding intervals of the composite log well Manzalai-02.

4.9 Electro Facies of the Kawagarh Formation

Based on interpretation of neutron porosity-Shale volume cross plot and composite log of the Kawagarh Formation exhibits following three shale lithofacies, (SH1, SH2&SH3).

4.9.1 Limestone Facies of the Kawagarh Formation

Neutron porosity- Shale volume (Vsh) cross plotting and composite log of The Kawagarh Formation exhibits three shale facies and three Limestone facies were identified in the Kawagarh Formation. These Limestone facies are marly/argillaceous limestone to clean limestone, based on neutron porosity-shale volume cross plot and composite log interpretation limestone facies are categorized as (Lst-1, Lst-2 and Lst-3).

Top part of the Kawagarh Formation is (Lst-1) which is encountered only in Manzalai-1 and Sumari Deep-1 wells, however, it has not been penetrated in the Manzlai-2 and Tolanj-1 wells, Based on location of the wells, it is interpreted that this Limestone facies is developed in the outer ramp and the wells located in the middle/shallow shelf environments does not encountered this Limestone facies.

Lst-2 is composed of relatively clean limestone and present from west to eastern side of the basin which is target zone for exploration.

Lst-3 is very thin with thickness of 8-12m, it is not penetrated in Manzlai-2 well, however, it is encountered in Manzlai-1 and eastern side of Kohat Basin Tolanj-1 well.

Neutron porosity-shale volume (Vsh) confirms carbonate matrix of these facies. TheGR values on an average is Lst-1 and Lst-2 (20-30) API where as in Lst-3 the GR value is ranging from (20-40) API. In the studied wells thickness of this facie is 10-40 m (Figure 4.1).

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 is on carbonate reservoir, so we will discuss the carbonate rock as 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 and 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 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 is generated by diagenesis at any time after deposition, such as by fracture, dissolution, or dolomitization, primary porosity forms during the pre-depositional stage and depositional stage. Boring and burrowing organisms can cause porosity to form. The capacity of a rock to permit fluids to move through it is measured 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). To effectively manage the output of carbonate reserves, this heterogeneity presents several challenges.

Carbonate reservoirs heterogeneity dictates 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; Van Golf-Racht 1982; 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 The Kawagarh Formation following parameters were used.

- Diagenesis impact on reservoir Potential.
- Thin section visual porosity & 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 Kawagarh 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 forces that reduce their porosity and permeability. Cementation is an essential diagnostic procedure that decreases porosity.

Micrite is the dominant matrix type in the Kawagarh Formation while calcite cement and ferruginous clays are present as fracture filling matrix along stylolites respectively (Fig5.1 & 5.2). The presence of stylolites indicates deep burial diagenesis while fracturing may be associated with telogenetic stage of diagenesis. High concentration of kaolinite encountered in XRD analysis can be attributed to the direct precipitation from supersaturated fluids during later stages of digenesis. The fracture porosity, high dissolution and inter and inter granular porosity may have increased the pore volume in the formation and boosts its reservoir potential

5.3 Thin section Analysis

Characterization of conventional reservoirs is done using thin section analysis. High resolution photomicrographs are created using secondary and backscattered electron imaging. Rock's mineral morphology has been studied which also defines pore geometry and flow path (Brains, 2015). The Kawagarh Formation's thin-section study revealed micropores, calcitic and micritic cementation, and vuggy porosity shown in (Fig 5.1 & 5.2). 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 and quartz in the intergranular pores and vugs.

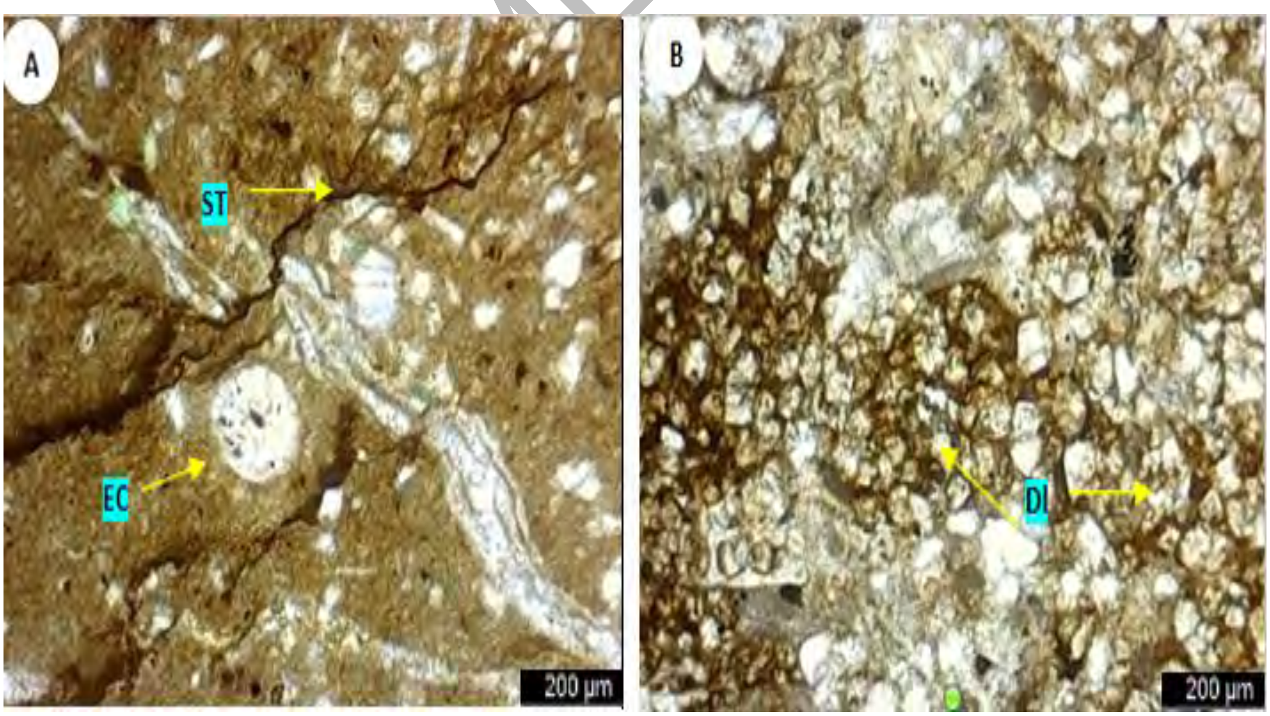

Figure 5.1 Thin-section images of Dolomitized and Bioclastic Grainstone, Photomicrograph (A) showing Stylolite and fracture porosity with some vuggy and intergranular porosity, Photomicrograph (B) Showing inter-crystalline porosity and dolomite grains within micritic lime mud matrix. (PPL. Mag. X4).

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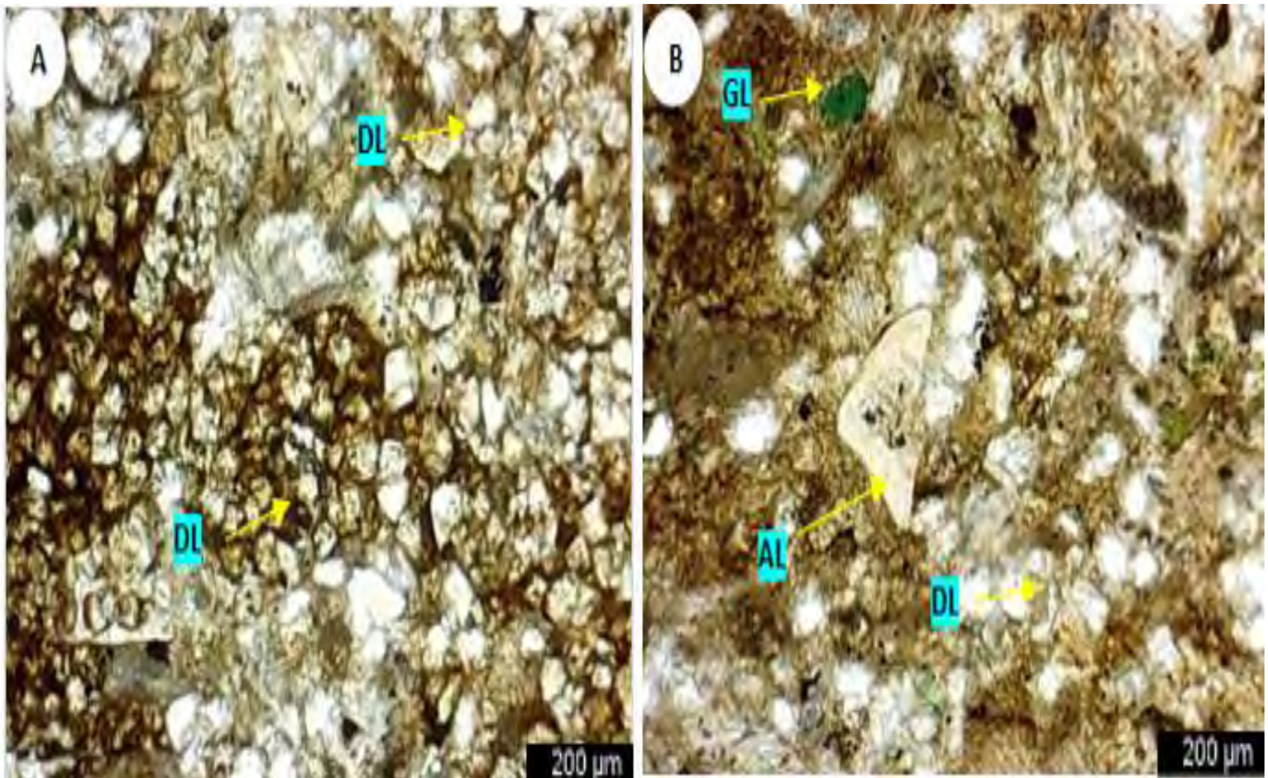

Figure 5.2 Thin-section images (A-B) showing predominantly skeletal debris/ bioclast and intraclast, inter-crystalline porosity and zoning of quartz in vuggy porosity (black), dolomite grains within micritic lime mud matrix, (PPL. Mag. X4).

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 (Brains, 2015). The SEM study of the Kawagarh 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 (Fig 5.3 & 5.4). The porosity is divided as macro porosity and micro porosity. Macrospores are clearly visible in thin sections and are quantify by visual percentage estimation, whereas the micro porosity that results from grains dissolution or it's directly associated with detrital mud is also visually estimated. The intergranular pores are 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 Kawagarh 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 witch is created by the breakdown of grains and shelter porosity which 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 quartz being deposited in the vugs and grains. The partial disintegration of grains that created the microspores found in the formation may increase the porosity.

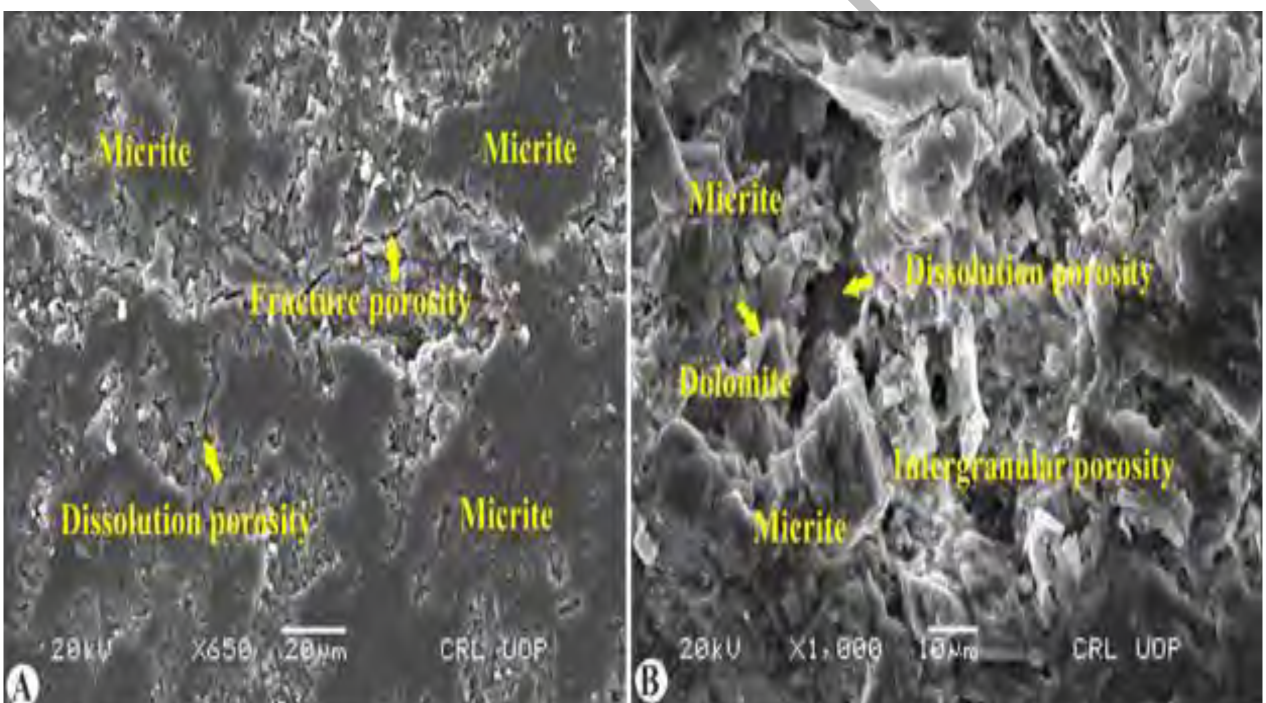

Figure 5.3 Limestone facies of the Kawagarh Formation, (A). The SEM image showing dissolution porosity and fractured porosity within micritic Limestone, (B) Showing dissolution and inter granular porosity within dolomitized matrix The Kawagarh Formation, Nizampur Basin.

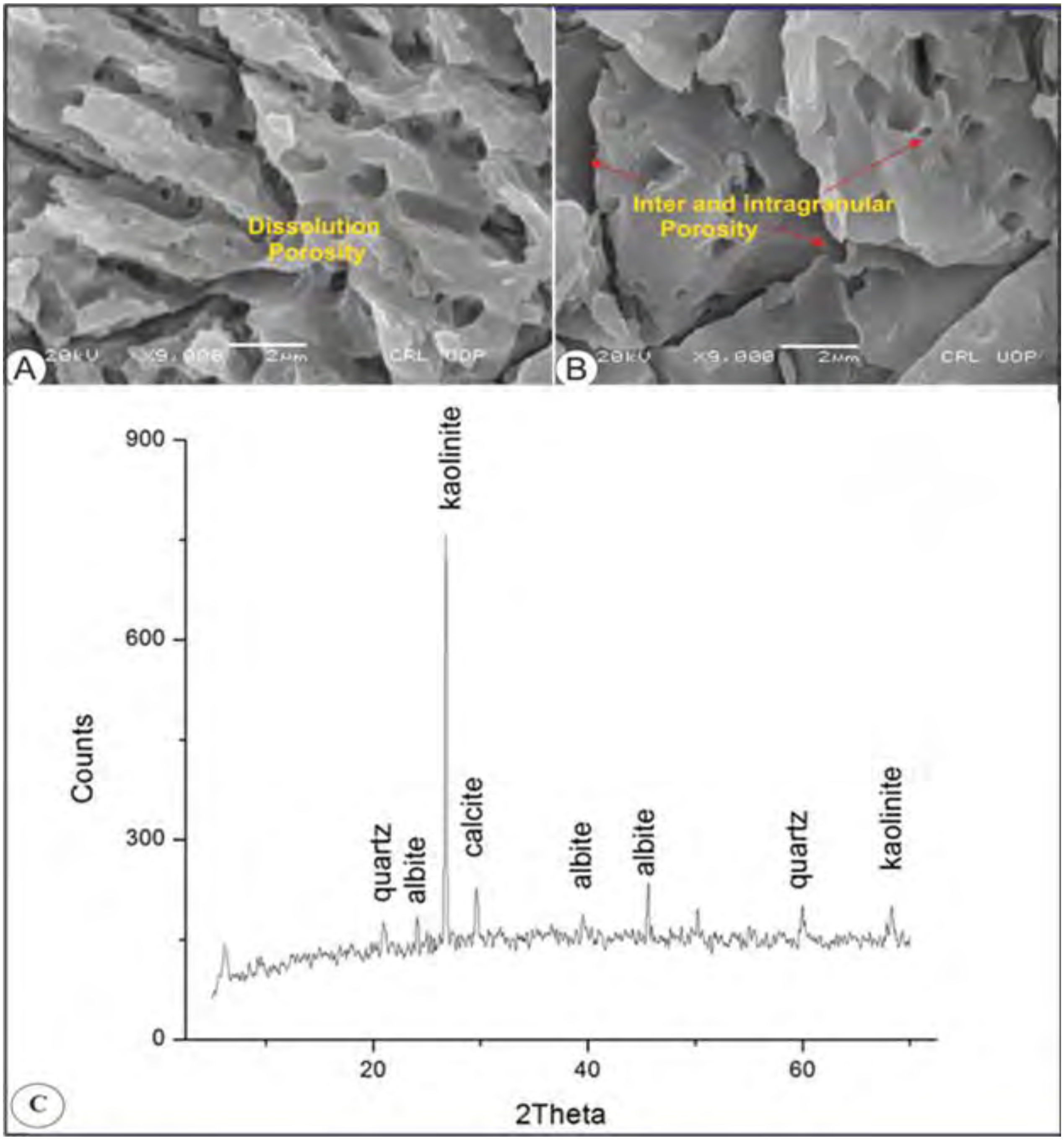

Figure 5.4 Limestone facies of the Kawagarh Formation, (A). The SEM image showing dissolution porosity within micritic limestone, (B). Showing inter and intergranular porosity porosity within matrix The Kawagarh Formation, Nizampur Basin. (C): X-ray Diffractogram showing peak positions of various constituents within The Kawagarh Formation Nizampur Basin, Pakistan.

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5.5 Petrophysical investigation of The Kawagarh 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 Kawagarh Formation, which penetrated in most of the wells drilled in the Kohat Basin is characterized by a combination of geophysical log and petrophysical reservoir analysis (Figure 5.1). The thickness of the Kawagarh Formation varies from well to well. The overall formation behaviour in the studied wells was thought to be a reservoir but tight formation, because it fails to meet the cutoff factor criterion. The wells data from the Kohat Basin was analysed quantitatively and qualitatively, which was done by calculating the porosity neutron porosity (NPHI), volume of Shale (Vsh), water resistivity (RW), and water saturation using composite wire line logs.

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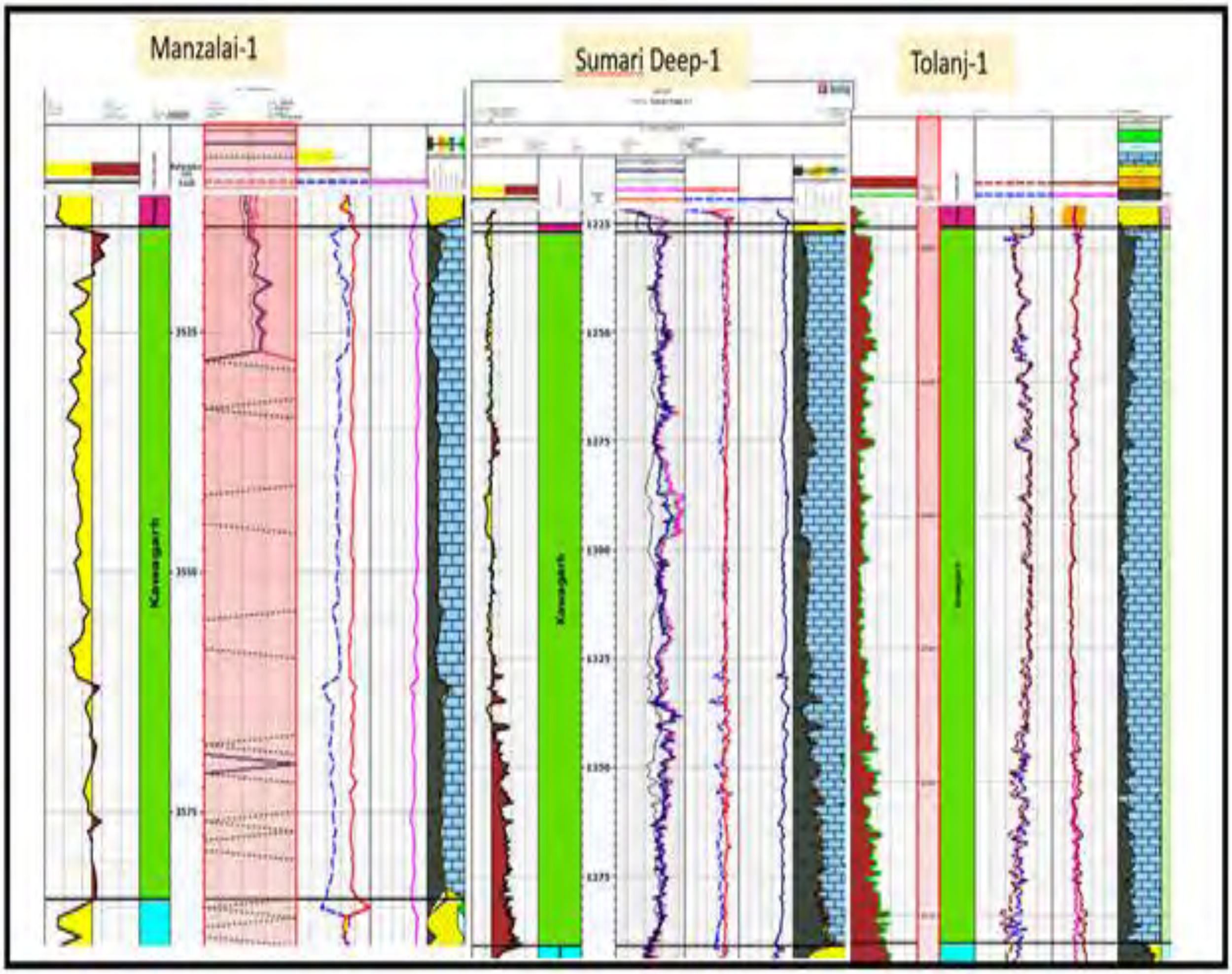

Figure 5.5 Petrophysical analyses of the wells data (Manzalai-1, Sumari Deep-1 & Tolanj-1) by using composite log for confirmation and validation of lithofacies.

5.5.1 Cut off Factor

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

CHAPTER-6

DISCUSSIONS

6.1 Discussions

This study was a detail investigation of available wells E-log and outcrop analogue data (thin section) to analyse Facies and reservoir characterization of the Kawagarh Formation of late cretaceous age exposed in Nizampur Basin Cement Factory Nala Section. Wire line data of wells (Tolanj-1, Sumari Deep-1, and Manzali-01 & Manzali-02) from Kohat sub basin was used for correlation with outcrop analogue data of study area. The study puts an effort to utilize microfacies and electrofacies analysis, in order to understand the depositional history and reservoir characteristics of the Kawagarh Formation. This study also includes analyses of porosity, permeability, biostratigraphy and petrographical interpretations. The Kawagarh Formation is dominated by a mix of limestone, shale, marls and mudstone units. Microfacies analysis suggests that deposition of the Kawagarh Formation occurred in middle to outer shelf setting. This interpretation is supported by sub-types of standard in (Tyson, 1995) sedimentary organic matter, (Ali et al., 2019). Following the determination of the lithofacies of the Kawagarh Formation (Chapter- 4) using the Neutron porosity and Shale volume cross plot technique on conventional well logs from the (Manzalai-1, Manzali-2 and Sumari Deep-01) in the Kohat basin, the next step involved identifying these facies in the well correlation panel primarily by Gamma-ray log shape analysis. 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 that stratigraphic interval to be associated with, or discriminated from, others"

6.2 Facies Analysis and Correlation

The work flow initially included the obligatory quality control of all the relevant curves and well logs correlation (Chapter-4), use 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 lithofacies and microfacies by using targeted wells petrophysical data from Kohat Basin with analogue data from exposed section of the Kawagarh Formation in Nizampur cement factory Nala section (study area). By using the composite well logs three lithoofacies were recognized (MF1-MF3) and correlated with lithological measured section with incorporation of microfacies recognized from thin section study of representative samples of The Kawagarh 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 are used as a crucial tool for the characterisation of the underlying sedimentary facies (Chow et al. 2005). Consequently in the investigation of the Kawagarh Formation, litho/electrofacies were first found and then in placed with lithology and microfacies correlation. Lithofacies and microfacies have been discussed (Chapter 3& 4), analysis of electrofacies begins with the recognition of a similar pattern of gamma ray signatures, which are then singled out to interpret each electro facies. 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 electrofacies.

Electro facies analysis and the framework offered by lithofacies and microfacies (in 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, 1978; Serra, 1985; Cant, 1992; Posamentier, 2001; Chow et al., 2005). To illustrate the sequence relationship of various facies and gamma-ray log patterns, which was utilised to assess and construct litho/electrofacies and microfacies correlation based on study of gamma-ray log trends in the targeted wells petrophysical data and representative analogue data of study area (Figure 6.1).

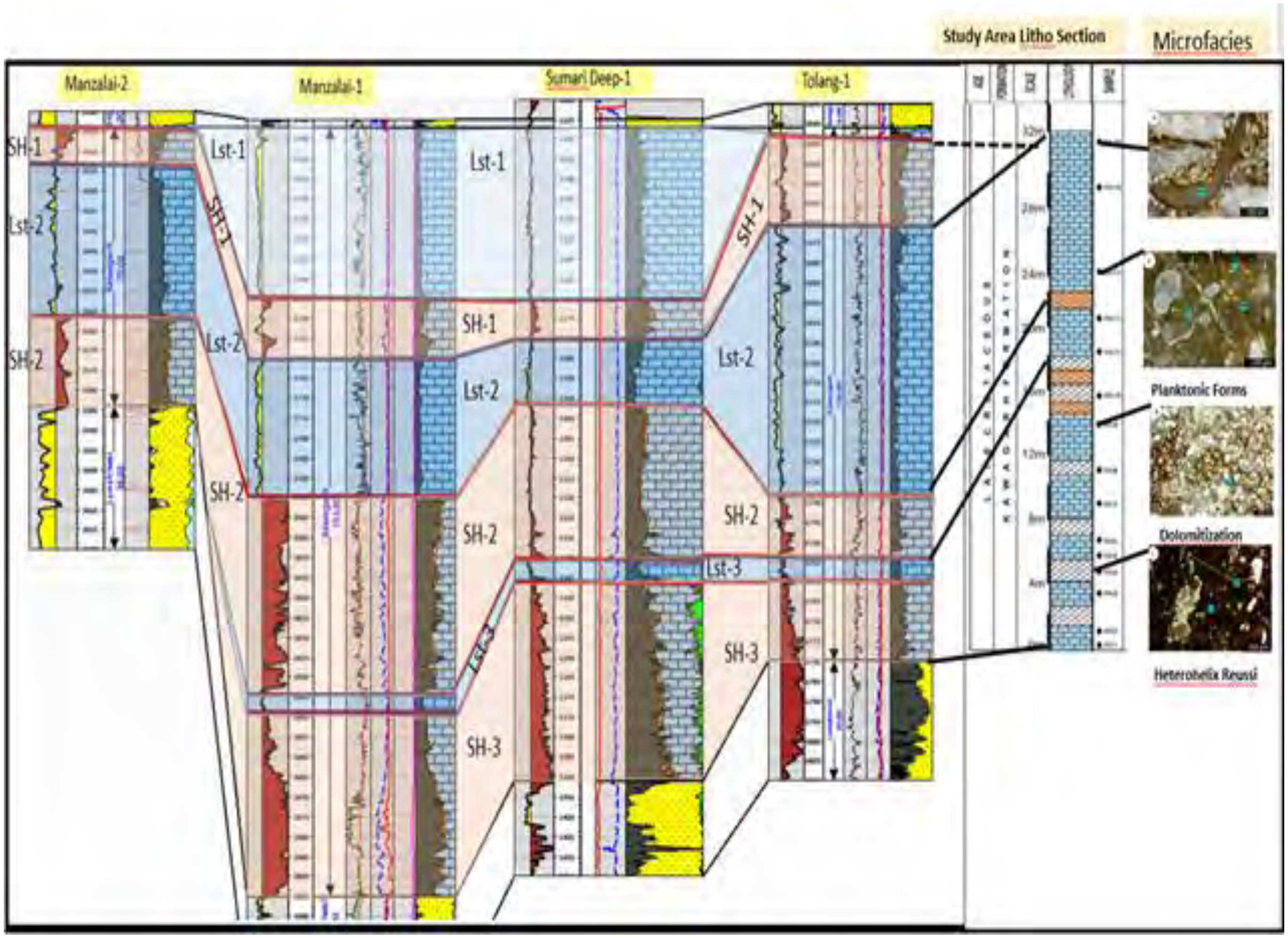

Figure 6.1 Facies correlation and validation by using microfacies and lithofacies, based on petrophysical and analogue data analyses.

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6.3 Petrophysical investigation of The Kawagarh Formation

Three wells (Tolang-1, Sumari Deep-1, Manzali-1, and Manzali-2) in the Kohat Basin, the Kawagarh Formation was analysed quantitatively and qualitatively. This was done by calculating the porosity neutron porosity (NPHI), volume of Shale (Vsh), water resistivity (RW), 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 Kawagarh 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 5.1). The thickness of the Kawagarh Formation varies from well to well, ranging from 176m in Manzalai-1, 50 meters in Manzalai-2, 164m in Sumari Deep-1 well and 145m in Tolanj-1 well respectively. The Kawagarh Formation based on various petrophysical characteristics three electrofacies were identified which were correlated and validated with lithofacies and 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 The Kawagarh Formation in study area (Nizampur Basin) it is interpreted that the dolomitized grainstone found in the representative samples (thin section) study which is the evidence of secondary porosities that may be developed in this area which can be potential exploratory targets.

6.4 Depositional Environment/ Paleoenvironment

The depositional model of the Kawagarh Formation represents a portion of late cretaceous 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 middle to outer ramp. This view is based on the vertical succession of the microfacies and playnofacies 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, Peloid / Pelletal Wackstone, and Arenaceous Packstone is indicative of shifts in energy state. Facies assessments were carried out utilizing conventional facies model for ramps, homogeneous and non-fossiliferous micrite carbonate deposition present the lagoonal environment according to Wilson 1975, Flügel 2010, Hussein et al.

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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, foreshore, inner ramps and middle-inner ramps (Fig. 6.2).

The shale samples were investigated thoroughly for the depositional examination of the Kawagarh Formation, which is a significant stratigraphic unit. By comparing with the standard literature of Flügel, (2004, 2010) the presence of planktonic foraminifera 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 Kawagarh 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.

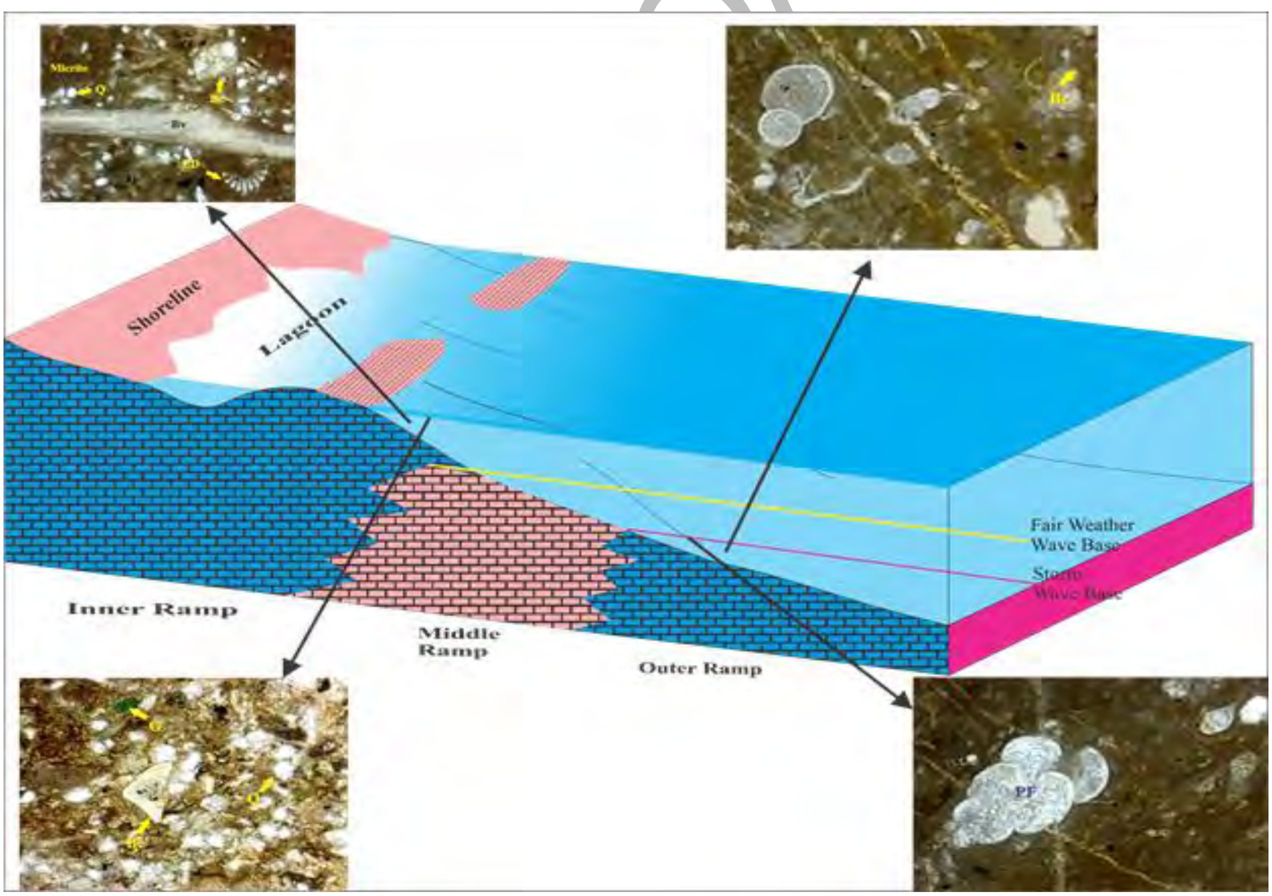

Figure 6.2 Schematic diagram of ramp-type setting (modified after Meng et al. 1997) showing the distribution of sedimentary facies

CHAPTER-7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

All data consistently supported the observation and as a result of this research the following conclusions have been made.

1. In Nizampur Cement Factory Nala Section a total of three microfacies were identified in the Kawagarh Formation from MF-1 to MF-3. Diversification of the facies occurred in the Kawagarh Formation in study area in Nizampur and in the Kohat Basin. It is identified within field from the lithological units of carbonate (Limestone) and small-interbedded siliciclastics assemblages (Shale, Marl and Mudstone units).
2. Identified microfacies and lithofacies interpreted from the studied samples enlightening depositional environments from middle shelf to outer shelf poor reservoir potential in the study area, whereas, the eastern wireline logs show very good reservoir qualities.
3. From facies variation the Kawagarh Formation representing deposition under changing sea level fluctuation in form of different sedimentary packages. About 32m thick carbonate and clastic sediments of The Kawagarh Formation represent the digenesis resulted 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-developed calcite cement further reduced the intergranular micro porosity, secondary porosity is almost completely absent with the exception of rare micro-fractures.
4. Integrated outcrop analog and petrophysical data analysis suggested poor reservoir facies (exception of few rudstone facie zone, which is later occluded by cementation/ authigenic Shales) encountered in the Kawagarh 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 microporosity.
5. The diagenetic analysis is the fundamental requirement for the feasibility of reducing exploration risks. Hence, the study has analyzed the main diagenetic processes that may have considerably affected the original rock fabrics and characteristics after deposition.
6. 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.

7. Additionally, the present study may offers a sound basis to evaluate the parameters that impact the fluid flow within carbonate reservoirs rocks along with diagenetic controls.
8. Interestingly, the study would have significant implications in investment making decisions that would reduce the risk associated in the target reservoirs exploitation.
9. Moreover, 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.
10. This study aims to introduce an integrated method combining both electrofacies and microfacies and quantitatively characterize the pore structure of carbonates and gain insights into fluid flow and lithology of carbonate reservoir rocks. This study examines three types of carbonate rocks - grainstone, Packstone, and Mudstone from Kawagarh Fm.

7.2 Recommendations

From the above study it is considered that the drilled the Kawagarh Formation possesses poor reservoir properties in the study area of Nizampur Basin, however, based on the correlation and Petrophysical properties of the wells used in the study show that the reservoir qualities are better in the western part of the basin. The recent discovery of hydrocarbons in Wali-1 located in the western part of the Kohat Basin proof that the reservoir qualities are better in this part of the basin.

Based on available data from Kohat Basin there is possibility to be a potential reservoir in the western margin and commercial quality of hydrocarbon may exist in the Kawagarh Formation.

Based on above facts and conclusions it is recommend to establish a possible correlation for identification of good reservoir potential facies in the study area to establish a basin scale model of reservoir behaviour of the Kawagarh Formation

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