BIOSTRATIGRAPHY AND MICROFACIES OF THE UPPER CRETACEOUS KAWAGARH FORMATION, GARHI HABIBULLAH SECTION, HAZARA BASIN, KHYBER PAKHTUNKHWA, PAKISTAN

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"Dedicated to my beloved parents, teachers, and friends".

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ABSTRACT

This research is focused on the petrographic investigation of the Cretaceous Kawagarh Formation exposed in Garhi Habibullah section of Hazara Basin. The Formation is composed of thick to medium bedded, hard, highly fractured, argillaceous and marly limestone with steep dip angles. A total of 17 representative samples were collected at regular interval of 5meters for petrography. In petrography, a large number of fossils of planktonic foraminifera, radiolarians, bioclasts, sparite, micrite and matrix were identified. On the basis of these features four microfacies including planktonic foraminiferal wackestone, planktonic foraminiferal mudstone, bioclastic mudstone and radiolarian bioclastic wackestone were established. The environment of deposition for the formation is concluded as outer ramp to deep basins. The biozone in this study for the Kawagarh Formation is globutruncana ventricosa biozone revealing the age of the formation as early to middle Campanian. The recorded diagenetic processes include cementation, pyritization, micritization, fracturing, pressure dissolution and neomorphism are common in the rock unit. These diagenetic features impart vuggy porosity to the formation, but the reservoir potential of the Kawagarh Formation is relatively poor due to diagenetic episodes. Thus, the Kawagarh Formation, Garhi Habibullah section, is an early to middle Campanian age with poor reservoir properties.

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LIST OF ABREVIATIONS

PYR	Pyritization
GBG	Globogerinilloids
GB	Globotruncana
RD	Radiolaria
RE	Heterohelix Reussi
CAL	Calcite
FR	Fracture
ST	Stylolites

CHAPTER 1

INTRODUCTION

1.1 General Description

This study deals with the biostratigraphy and microfacies analyses of the Late Cretaceous Kawagarh Formation at Garhi Habibullah section, Mansehra, Hazara Basin. The stratigraphy of the basin deals with the chronological and geographical relationship among the various sedimentary bodies (Earle., 2015). Geoscientist uses biostratigraphic data to associate different rock units in a single basin or across various basins (Miall., 1990). It also helps us to separate the stratigraphic pinch outs. Another importance of facies examination lies in that only a limited amount of facies occur frequently in rocks of dissimilar ages across the world (Selley.,1985). This gives us a significant arrangement in the investigation of sedimentary rocks, which would not happen if every rock bed were treated as a unique body (Boggs., 2001). Though, facies have limited value when taken in separately. The nano and microfossils are widely used as compared to macrofossils because microfossils are common and abundant while the distribution of macrofossils is limited because of their biological niches. The study of fossils also helps in understanding of the depositional settings of the distinct basin fill.

The main purpose for selecting Cretaceous rock unit is the paleoclimatic conditions which played an important role in geology. These paleoclimatic situations effected the development of planktons in the Cretaceous rock units. These planktons are highly preserved in carbonate units of Cretaceous age (Leckie et al., 2002). These planktons become extinct due to the depletion of oxygen at ocean depths over a large geographic area. Due to the paleo-oceanographic and paleoclimatic significance of the

Cretaceous period this study is intended to examine the fossils present in carbonate unit of upper Cretaceous strata of Garhi Habibullah section, Hazara basin.

1.2 Location and Accessibility

Study area is located between latitudes 34º24’42.91”N to 34º25’11.39”N and longitudes 73º22’20.07E to 73º22’14.64E at an elevation of 890m from mean sea level. The study area is easily accessible along the Balakot-GarhiHabibullah Road at a distance of about 195km from Islamabad via jeep.

Figure 1.1 Google earth image of the Hazara Basin representing the location of the study area.

1.3 Literature review

The name of the Kawagarh Formation is refined after various names e.g. Davies (1930) assigned the name “sub lithographic Limestone” to the Kawagarh Formation in Samana Ranges, The name “Darsamand limestone” was assigned by Fatmi and Khan (1966) in Kohat quadrangle (Meissner 1974), while “Durban Limestone” was assigned by Khan (1966), The “Sattu Limestone” was assigned by Calkin and Matin (1968) while in Hazara area “Channeli Limestone” name was assigned by Latif (1970).

The eastern Kohat, Nizampur, Kalachitta and Hazara areas are the prominent localities where the Kawagarh Formation is well exposed (Shah., 2009). The Kawagarh Formation is characterized by thick to thin bedded limestone with marls (Qureshi., 2006). In eastern and western Kohat its thickness varies from 70-90m and 110-120m while in Hazara and Kala Chitta Ranges the Formation thickness relatively varies from 40-70m and 40-200m. At the Sarbaroot area of Hazara basin, the minimum thickness of the Kawagarh Formation is 15m. It predominantly contains light grey to dark grey limestone and marls having dolomitic limestone and calcareous shales (Fatmi., 1977; Ahsan and Chaudhry., 2008; Shah., 2009; Rehman et al.,2017). Khan and Fatmi (1966) divided the Formation into two distinct members, i.e. Lower Chalor Silli member and Upper Tsukail Tsuk Limestone. In Southern Hazara there is another member whose upper part is dominantly arenaceous that is Nara Sandstone (khan, 1966). According to Fatmi and Ahmad (1966) this member is thick bedded, calcareous, having brownish to dark grey color and small limestone interbeds.

The Kawagarh Formation lack macrofossils except in the lower part at the localities like Darsamand of Samana Range (Fatmi., 1977) and Changla Gali of the Hazara basin (Ahsan., 2008). Latif (1970) established detailed micropaleontology and biozonation of the formation in Hazara basin, on the basis of planktonic foraminifera; he reported Globotruncana lapparenti, H.globulosa, G. elevate-calcaratai, G.fornicata, Ruboglubogerina rugosa and estimated Conacian to Companion age. Later on Sameeni et al., (2007) reestablished biostratigraphy of the Kawagarh Formation using planktonic formainifera, assigning Late Turonian- Early Maastrichtrian age to the formation.

As discussed earlier, extensive work has been done on Kawagarh Formation exposed in different areas. This research work is basically focused on the biostratigraphy and microfacies analysis of Kawagarh Formation.

1.4 Aims and Objectives

The objectives of this research are,

I. To find out the microfacies of Kawagarh Formation in Garhi Habibullah section.

II. To establish the biostratigraphy of Kawagarh Formation in Garhi Habibullah section.

III. To demarcate the environment of deposition of Kawagarh Formation.

1.5 Methodology

The methodology adopted to attain the above objectives is mentioned below.

1.5.1 Field work

A geological field was conducted to the study area. Cretaceous strata were identified. Upper and Lower contacts of the formation were marked. The precise geographic location of the strata was marked using GPS. Total thickness of the Kawagarh Formation was measured. The sedimentary structures and lithological characteristics of the rock unit were observed. A total of 17 fresh samples were taken at regular interval of 5meters based on the lithological variations. Scaled field photographs were taken.

1.5.2 Laboratory Study

In laboratory work, standard sized thin sections were prepared for petrography at the thin section preparation Laboratory of National Centre of Excellence in Geology, University of Peshawar. Thin sections study was performed using polarizing microscope for fossils identification, establishing microfacies and other digenetic features at the petrographic lab of Bahria University Islamabad Campus using microscope (LeicaDM750P). The parameters created by Wilson (1975), Dunham (1962) and Flugel

(2004), are used for microfacies identification and environment of deposition for the Kawagarh Formation.

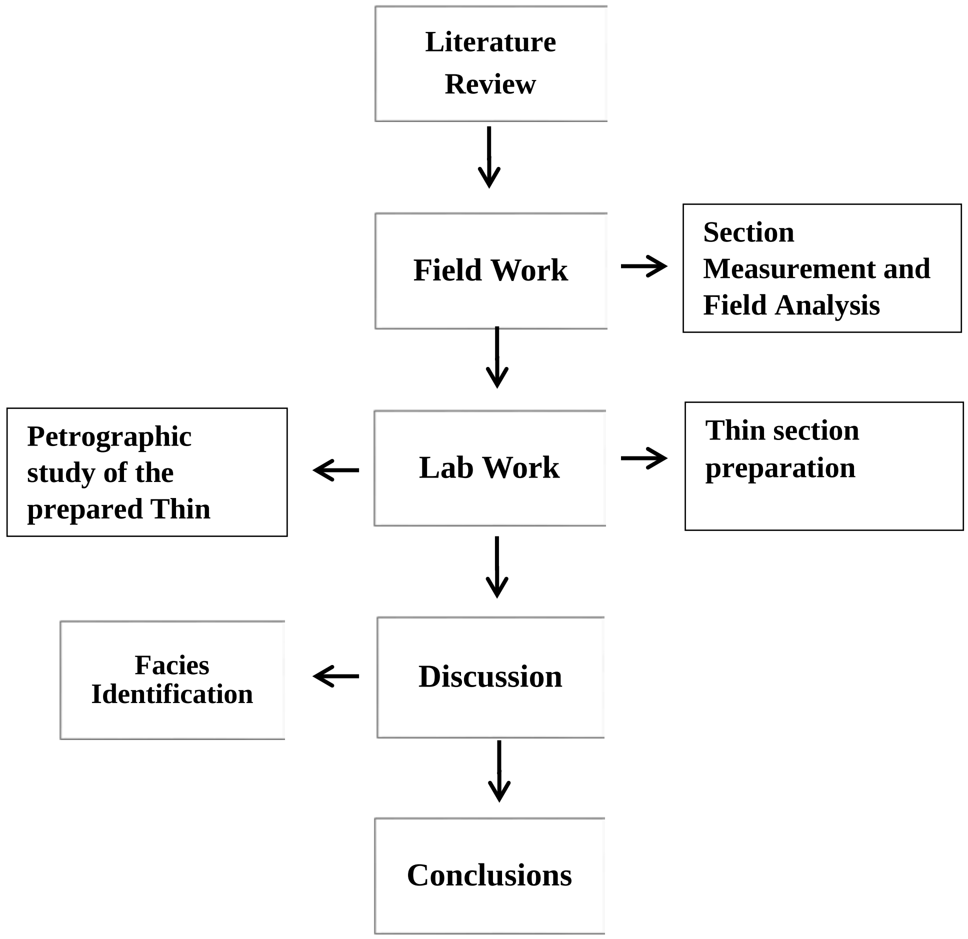

Figure 1.2 Flowchart for the methodology followed in this research.

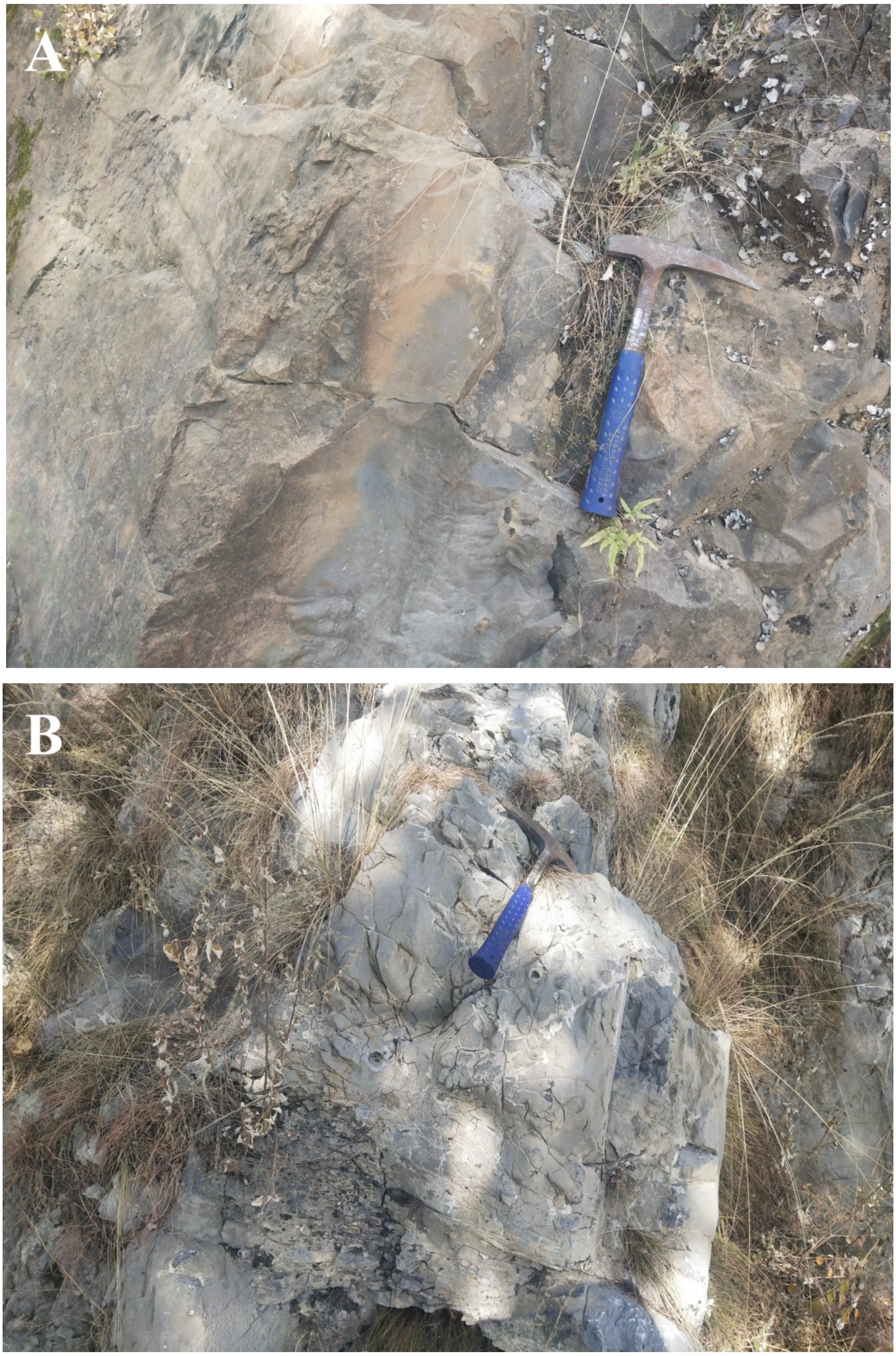

Figure 1.3 Field photographs showing carbonate unit A) shows the color variation identified in the field B) shows the fractured limestone unit of the Kawagarh Fomation, Garhi Habibullah section, Hazara basin.

Figure 1.4 Field photographs of the Kawagarh Formation, A) showing iron leaching indicated by brown patches and B) showing pyritization (Pyr).

CHAPTER 2

REGIONAL GEOLOGY

2.1 Regional Geology

The breaking of supercontinent, Pangaea (Scotese et al., 1979; Condie, 1984), initiated in carboniferous to early Permian, leading to division of supercontinent into smaller tectonic plates and a new ocean, called Neo Tethys was created (Angiolini et al., 2003). The newly created Indo-Pakistan continent initiated movement towards southern hemisphere across the Indian Ocean (Mattauer et al., 1986; Farah and DeJong, 1984; Searle, 1991). This caused squeezing of Neo-Tethys Ocean in Eocene (45-55 Ma) which extended from Pacific Ocean to Mediterranean Ocean (Jaeger et al., 1988; Chaudhry et al.,1993; Valdiya, 2002). In Cretaceous age the intra oceanic subduction of the oceanic part of Indian plate occurred beneath the oceanic part of Asian plate and as a result KIA (Kohistan Island Arc) was formed (Ghazanfar; 1993; Burg et al., 2005; Ahsan, 2008). Later on, in Turonian age the Kohistan Island Arc accreted to Eurasia. The Indo-Pakistan Plate collided with the Kohistan Island Arc at about 67 Ma (Spencer, 1993; Valdiya, 2002; Burlini et al., 2005). Chaudhry et al (1993) further described this conclusion as a result of sedimentological study and biostratigraphy. Many researchers (Klootwijk, et al., 1979; Powell, 1979) have accepted that the collision among India and Eurasia has occurred at 55 Ma leading to development of Himalaya Orogeny.

The Himalayas are the world’s youngest mountain ranges, present among the Eurasian plate in the northand Indian plate in the south(Gansser., 1966).Geologically, Pakistan lies on the north western edge of the Indian plate and it has preserved the collisional orogenic imprints of Himalayas (Dipietro et al., 2000). The uplifting of Himalayas and Tibetan Plateau are due to the collision of Indian plate with Eurasian plate about 55Ma (Zhao et al., 2012). It is assumed that thrusting in Himalaya is a late stage phenomenon in reaction to the adjustment of Indian and Euraisian collision in Neogene time (Gansser, 1966; Chaterjee et al., 2012). Major uplifting of the Himalayas and thrust faulting is an outstanding expression of the Indian Eurasian collision (Chaterjee et al., 2012). This collision is still an ongoing process (Searle., 2019).

The Himalayas is a typical example of an orogenic system created because of continent-continent collision (Dewey and Bird, 1970; Dewey and Burke, 1973). From the northwest it is bounded by Nanga Parbat syntaxes and by Namche Barwa Syntaxes in the northeastern side. It consists of a series of lithological and tectonic terrains (Gansser, 1964, 1966; Chatterjee et al., 2012). From the north to south it is subdivided into; The Trans-Himalayan batholiths, The Indus-Tsangpo Suture Zone, The Tethyan (Tibetan Himalaya), The Higher (Greater) Himalaya, The Lesser (lower) Himalaya, The sub-Himalaya. The lesser Himalayas lie parallel to the south of Higher Himalayas. The width of lesser Himalayas is 32-80 km having average height of 3900-4500 m. The lesser Himalayas mostly consist of detrital sediments resulting mainly from the passive Indian margin of late Proterozoic to early Cambrian with some intercalated granites and acid volcanic of Early Proterozoic age (Frank et al., 1977, Chatterjee et al., 2013). These sediments were thrusted along the Main Boundary Thrust and frequently appear as tectonic windows (Gansser, 1966, Chatterjee et al., 2012).

The sub-Himalayas are present to the southern side of lesser Himalayas, which are forming the foothills of the Himalayan range. The width of sub-Himalayas is 8 to 80 km with an average height of 900 m. It is mainly consisting of the sediments of Eocene age, followed by Miocene to Pleistocene molasse deposits, also known as Murree and Siwalik Formations. These sediments are very rich in vertebrate fossils. Since Eocene age the Indian plate is converging continuously at a rate of 5 cm per year leading to the progressive growth of a series of thrusts in the Himalayas causing 2500 km of crustal shortening (Patriat and Achache 1984; Chatterjee et al., 2012). Following the collision in Early Eocene, it looks like a steady southward sequence of thrust faulting, beginning at the Indus-Tsangpo Suture Zone (ITSZ). The various regional thrusts that were created includes Main Karakoram Thrust (MKT) which is the northern most suture zone which was formed in Cretaceous period (Coward et al., 1986) as a result of the collision between Kohistan Ladakh Arc and the Karakoram block. Later on, it was declared as a North Suture (Pudsey et al., 1985). Along this thrust the distorted igneous and metasedimentray rock units of Karakorum block are separated from Kohistan Island Arc. This zone is consisting of red shales, slates, limestone and volcanic greenstones (Coward et al., 1986). The Main Mantle Thrust is a regional thrust which dips in the north direction and it disconnect Kohistan Island Arc from Indian plate. It was formed because of the subduction of Indian plate beneath the Kohistan Island Arc in Eocene times (Tahirkheli., 1979). In western side it is extended from the region of Khar (Bajaur Agency) up to the area of Naran in the east. The Composition of MMT is gneisses and Proterozoic schists (Madin., 1986). The Main Central Thrust is an intracontinental thrust fault which is dipping in the north direction along the Himalayan mountain range that separates Higher and Lesser Himalayas (Auden, 1934; Le Fort, 1975). For the first time it was depicted by Heim and Gansser (1964).

The Main Boundary Thrust is an unusual tectonic peculiarity beside the entire Himalayan Belt. It is a northward dipping thrust which has thrusted over the meta sedimentary rocks of lesser Himalayas over un-metamorphosed rocks of Himalayan foredeep (Meigs et al., 1995). The MBT drift across the east-west foreland basin and move up to north, west of Jhelum River forming a major Syntaxis termed as Hazara-Kashmir Syntaxis. The displacement of Main Boundary Thrust is expected to be over 40 km and also at the south of the MBT, reduction is interpreted along the blind thrusts accompanied by shallow (0–3 km deep) back thrusting. The Salt Range Thrust is the southernmost thrust which encloses the southern edge of Salt range bisecting the Jhelum and Indus rivers. It has thrusted Paleozoic/Precambrian strata over the Quaternary/Neogene alluvium of Punjab platform (Nakata, 1972, 1989; Gee 1945; Yeats 1984). Generally, this thrust is covered by alluvium but still in some areas it is exposed, showing the Paleozoic rocks overlying the Neogene deposits of Jhelum plain (Gee 1945; Lawrence and Yeats 1984). SRT end in west next to Kalabagh fault while in the east it vanishes near the right bank of Jhelum River.

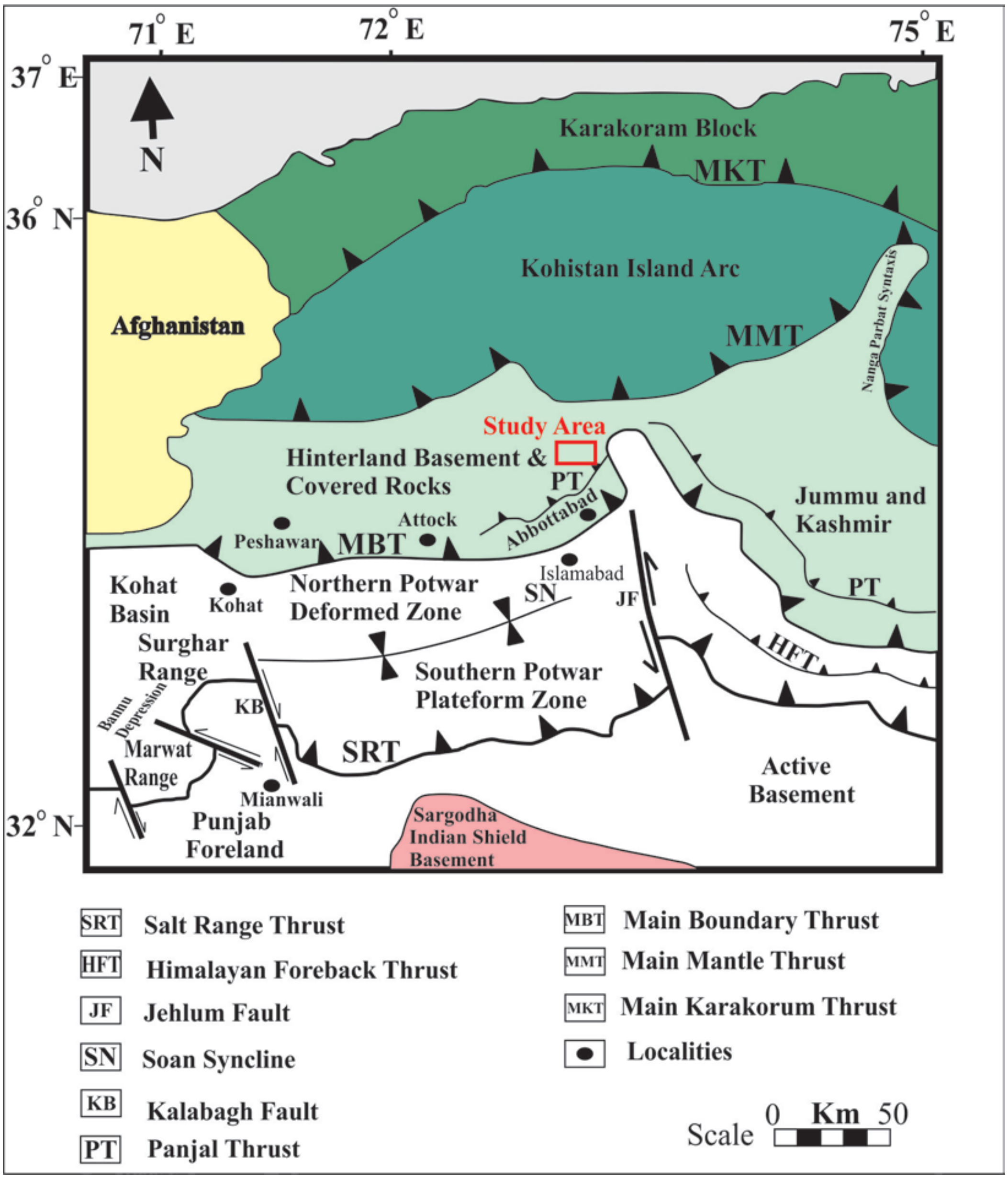

Figure 2.1 Tectonic map of northwest Himalayas of Pakistan, while the red square is showing the study area (after Kazmi and Rana, 1982).

2.2 Local Geology

The study area is located in the Garhi Habibullah which is a part of Hazara Basin situated in Lesser Himalayas (Gensser, 1964 and Coward et al., 1987). The Hazara Basin is bounded on the north by Panjal Thrust (Ahsan., 2008) while in south by a regional tectonic boundary, known as Main Boundary Thrust (MBT). It is present in the northeast and east of Kalachitta Block of Pogue et al., (1999). Hazara Basin comprises of East-West trending Sedimentary belt which join into the western limb of Hazara Kashmir Syntaxis in east and northeast, the Indus River bisect it in west and Kalachitta Range in southwest. The stratigraphy exposed in the study area has broader sequence from Precambrian up to upper Eocene and Oligocene age (Ahsan., 2008). The tectonic history shows that various deformation periods have occurred in the area and since then the compressional tectonic stresses are still active.

Geologically, the Northern Hazara is surrounded by Main Mantle Thrust in north, Panjal Fault in south, and among Indus River on the west and the Panjal Fault in east. It is tectonically illustrated by East-West oriented faults that turn north laterally and join the North-South Panjal and Thakot Fault. In this area the Mansehra Granite and the Tanol sequence outcrop are also present. Lately Coward et al (1987) and Treloar et al (1989) inferred the Northern Hazara as an imbricate thrust pile. The sedimentary section of Southern Hazara consists of foreland sedimentary sequence, exposed like an extensive belt to the south of metamorphosed hinterland. This extensive belt is further divided into a northern Cambrian to Eocene sequence between the Panjal Fault and the MBT and further towards south a Miocene and younger foredeep molasses sequence between MBT and MFT, considered as continuation of Lower Himalayas (Ahsan., 2008).

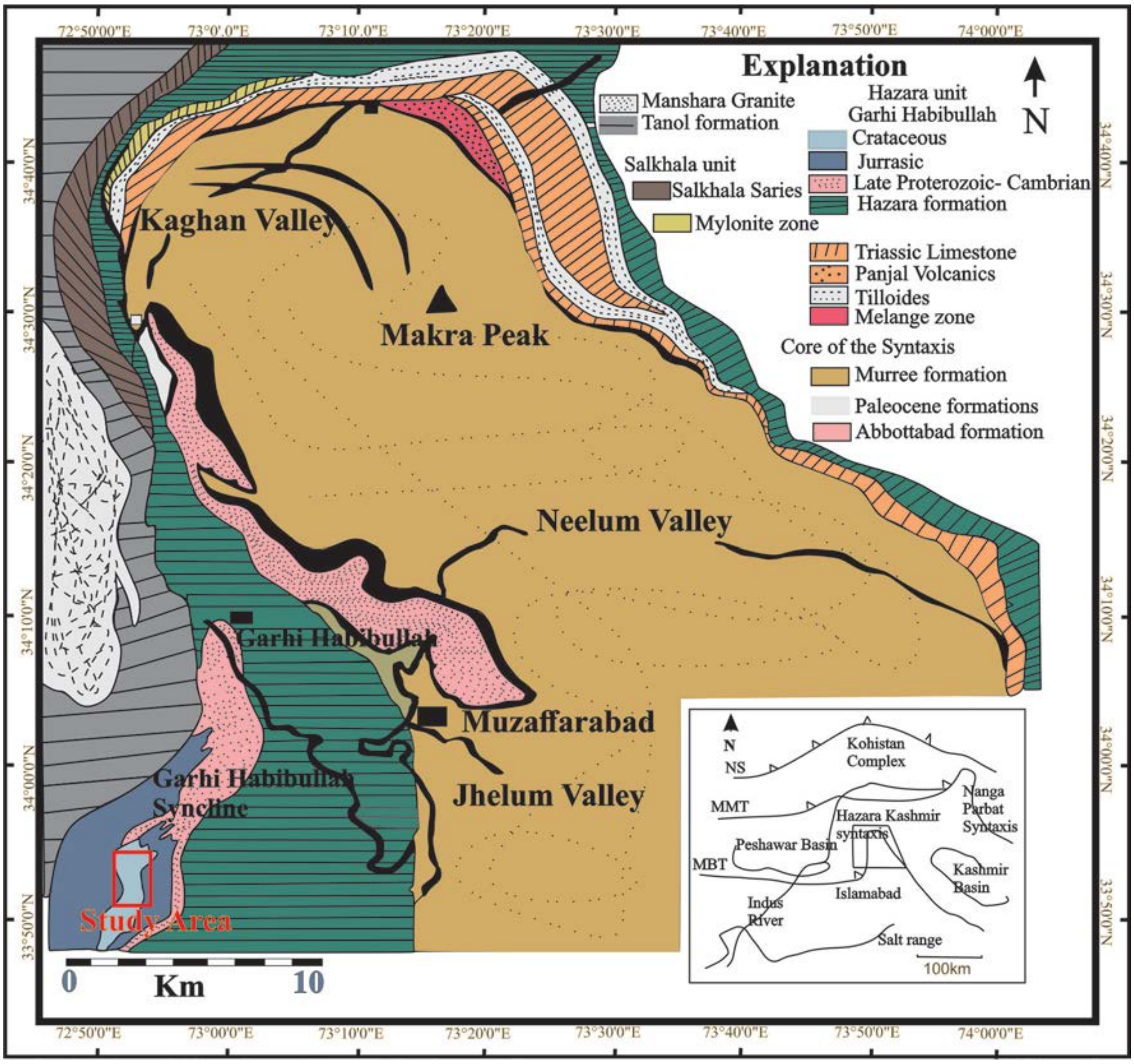

Fig 2.3 The geological map of the study area, (Modified after Bossart., et al 1988).

2.3 Stratigraphy of the Hazara Basin

The stratigraphic succession of the area ranges from Pre-Cambrian to Miocene which includes; Pre-Cambrian age Hazara Formation consisting of dark green, green and black phyllite and slate. It also contains fine to medium grained sandstone, unmetamorphosed shale and Limestone beds. The Hazara Formation is conformable with the Dogra Slates of Poonch area in Kashmir, which are overlained by the fossiliferous Cambrian rocks (Fermor., 1931). Latif (1973) associated the Hazara Formation with the Salt Range Formation by the virtue of evaporite facies which is present in these two Formations. The Hazara Formation is unconformably covered by the Tanawal Formation in the west of Panjal fault while in GarhiHabibullah the upper contact of Hazara Formation is unconformable with the Abbottabad Formation. Abbottabad Formation contains Dolomite with sandstone while the basal portion of Formation contains shale and boulder beds. Abbottabad Formation has conformable upper contact with the Hazara Formation containing calcareous siltstones and shales/quartzites. Hazara Formation has unconformable upper contact with the Datta Formation of Jurassic age.

The Datta Formation comprises of sandstones, quartzites and micro-conglomerates. Datta Formation is covered by Samana Suk Formation having limestones with dolomite patches and oolites which has unconformable upper contact with Chichali Formation of Cretaceous age. Chichali Formation contains interbedded shales and sandstones. Chichali Formation grades upward into Lumshiwal Formation comprising of glauconitic sandstones in basal part and carbonate unit in upper portion. Lumshiwal Formation has conformable upper contact with the Kawagarh Formation comprising of micritic limestone. Kawagarh Formation has unconformable upper contact with the Hangu Formation of Paleocene age having sandstone, claystone and laterite beds. Hangu Formation is overlain by Lockhart Formation containing nodular limestone which in turn is covered by Patala Formation. Patala Formation consists of shales and limestones. Margalla Hill Formation of early Eocene covers the Patala Formation. It contains nodular limestone as major lithology. Thin bedded limestone and marl of Chorgali Formation covers the Patala Formation. Chorgali Formation is covered by Kuldana Formation which contains variegated clays and marls. Upper contact of Kuldana Formation is unconformable with Murree Formation of Miocene age. Murree Formation contains sandstone, claystone and shale which are covered by alluvium of Quaternary age.

Table 2.1: Stratigraphic column of the Formations exposed in the Hazara Basin.

Age	Formation	Lithology
Quaternary	Alluvium	Rounded to sub-rounded boulders, pebbles, cobbles, gravels of metamorphic, igneous and sedimentary rocks.
Unconformity		
Early Miocene	Murree Formation	Reddish shale, greenish sandstone, claystone
Unconformity		
Early-Middle Eocene	Kuldana Formation	Siltstone, variegated shale, calcareous sandstone
Early Eocene	Chorgali Formation	Black to dark brown shale
Early Eocene	Margalla hill limestone	Highly fractured and jointed limestone
Late Paleocene	Patala Formation	Nodular limestone, splintery shale
Early-Middle Paleocene	Lockhart Limestone	Highly fossiliferous nodular limestone.
Early Paleocene	Hangu Formation	Coal seams of medium to, ferruginous, sandstone.
Unconformity		
Late Cretaceous	Kawagarh Formation	Planktonic limestone
Early Cretaceous	Chichali Formation	Coal seams and dark shale.
Jurassic	Samana Suk Formation	Oolitic limestone
Unconformity		
Cambrian	Abbottabad Formation	Dolomitic and cherty stromatolitic limestone,
Unconformity		
Precambrian	Hazara Slates	Fine grained slates with quartz veins.

CHAPTER 3

PETROGRAPHIC STUDY OF THE KAWAGARH FORMATION

3.1 Introduction

Thin section petrography became the standard method of rock study with the publication of Henry Clifton Sorby on the microscopical structure of ‘calcareous grit’ in 1851. Presently, petrographic analysis of sedimentary rocks using polarizing microscope is a basic tool for geological research. Prime objective of a thin section analysis is reading rock history. The most useful and general tool for close study of the mineral composition, texture and general makeup of a rock is petrographic analysis using polarizing microscope. In this study, with the help of petrography microfacies and biostratigraphy of the Formation are established to determine the sedimentological and biostratigraphic factors characterizing the limestone of Cretaceous age. The petrographic details of the Kawagarh Formation are mentioned in Table 3.1. The major components identified in the limestone of Kawagarh Formation include the grains and mud or matrix.

3.1.1 Grains

The variation in mineral composition of limestone is minimum. But they reflect major diversity in texture (Blatt and Tracy., 1996). However, most limestones consist of sand-sized grains in a carbonate mud matrix. Limestones are often of biological origin and usually consist of sediments, deposited close to where it formed, therefore, their classification is usually based on the grain type and mud content (Blatt and Tracy., 1996). The dominant types of grains present in limestone are skeletal fragments of marine organisms including corals and foraminifera (Blatt, Middleton and Murray., 1980). Other carbonate grains present in the limestone are ooids, peloids and limeclasts (Blatt and Tracy., 1996). Composition of skeletal grains present in limestone reflects the environment of deposition in which the rock unit was deposited (Blatt, Middleton and Murray., 1980).

The dominant grain type present in the Formation under study include skeletal grains of planktonic foraminifera with average abundance of 2.6% by volume including globotruncana, heterohelix, lenticuliana, diacrinilla and globogerinelloids, radiolaria with average abundance of 0.8% by volume and unidentified bioclasts with an average of 7% by volume.

3.1.2 Matrix

The grains of limestone are embedded in a matrix. Matrix, carbonate mud, is the largest fraction of carbonate rocks (Blatt and Tracy, 1996). Matrix can be divided into micrite and sparite (Boggs, 2006; Blatt, Midlleton and Murray, 1980). Mud consisting of individual crystals less than 5microns in length is described as micrite while larger crystals ranging in size from 0.02mm to 0.1mm are termed as sparry calcite or sparite. Recrystallized sparite isn’t diagnostic of environment of deposition (Boggs, 2006).

The matrix type identified in the studied section includes micrite and sparite. Micrite is the dominant type matrix identified having an average of 86% by volume ranging from 75% by volume to 93% by volume. The other type of matrix identified is sparite ranging from 1% by volume to 5% by volume.

3.2 Microfacies of the Kawagarh Formation

3.2.1 General Description

The term micro facies is defined by Brown (1958) and Cuvillier (1952) as “all those characteristics and distinct features of sedimentary rocks visible and identifiable only under the microscope.” The term microfacies can also be describe as “all the sedimentological and paleontological data which can be described and classified from thin sections, peels and polished slabs (Flugel, 2004). Microfacies are established on the basis of rock texture, composition and fossil assemblages and are helpful in interpreting the accurate environment of deposition of the specific facies.

3.2.2 Microfacies Identified in the Kawagarh Formation

Usually the Folk classification and Dunham classification schemes are used for identifying the types of carbonate rocks. Based on the Dunham classification (1962) and detailed modification of parameters by (Flugel, 2004), four microfacies have been established in the Kawagarh Formation of Garhi Habibullah section, Hazara Basin.

3.2.2.1 Planktonic Foraminiferal Wackestone Microfacies

In the field study, this microfacies is identified as highly fractured, thick to massive bedded, dark grey at weathered surface and light grey in fresh surface. This microfacies is characterized by the presence of planktonic Foraminifera (5-7%), including Globotruncana and Heterohelix as dominant biota along with Dicarinella, Globigerinelloides and few radiolarians. All these planktons are embedded in micrite having presence of 70% by volume. Stylolites, pyrite precipitation, grain compaction and micro fractures are present in this microfacies.

Depositional Environment

This microfacies can be correlated with ramp microfacies type RMF-2, reflecting outer ramp as the depositional setting for this microfacies (Flugel, 2004).

3.2.2.2 Planktonic Foraminiferal Mudstone Microfacies

This microfacie is marked as fractured, thick bedded and light grey at fresh surface. The presence of high percentage of lime mud greater than 85% by volume (with an average of 88% by volume) characterizes this microfacies in the top portion of the Formation. Planktonic forams averaging 2 to 4 % by volume including globotruncana, heterohelix, globogerinilloids and few echinoderms can be observed in this microfacie. Pressure dissolution, pyrite precipitation and compaction can be identified under microscope. Micro fractures and calcite filled veins can be marked in this microfacie.

Depositional Environment

The matrix is fine grained and can be correlated to the ramp microfacies type of RMF-5 according to the Flugel, 2004. The environment of deposition for this microfacie can be interpreted as outer ramp setting (Flugel, 2004).

3.2.2.3 Radiolarian Bioclastic Wackestone

In field analysis, this microfacies is observed to be highly fractured, highly jointed, and medium to thick bedded, light grey in coloration and highly vegetated. While in thin section the presence of an average of 86 % by volume of lime mud as matrix and an average of 14% by volume of allochems including planktonic foraminifera, radiolarian and bioclasts reflect this microfacies according to Dunham Classification. The amount of bioclasts present in this microfacies range between 7% by volume to 12% by volume. Cementation, pyrite precipitation, pressure dissolution, presence of micro fracture and filled veins are notable features in this microfacies.

Depositional Environment

The presence of radiolarian and bioclasts are indicative of deep basins as the environment of deposition for this microfacies (Flugel, 2004).

3.2.2.4 Bioclastic Mudstone

Like the above mentioned microfacies, this microfacies have been observed as massive bedded and fractured in field analysis. This microfacies consist of lime mud as matrix with an average presence of 92 % by volume. It also contains an average presence of globotruncana 3% by volume, heterohelix 4 % by volume, calcisphere 1 % by volume and bioclasts 6% by volume. Cementation, pressure dissolution, pyrite precipitation, echinoderms, filled fractures by calcite and compactions are the common features in this microfacies.

Depositional Environment

The presence of lime mud, planktons and echinoderms reflect that this microfacies was deposited in outer ramp environments. This microfacies is analogous to RMF-3 of Flugel, 2004.

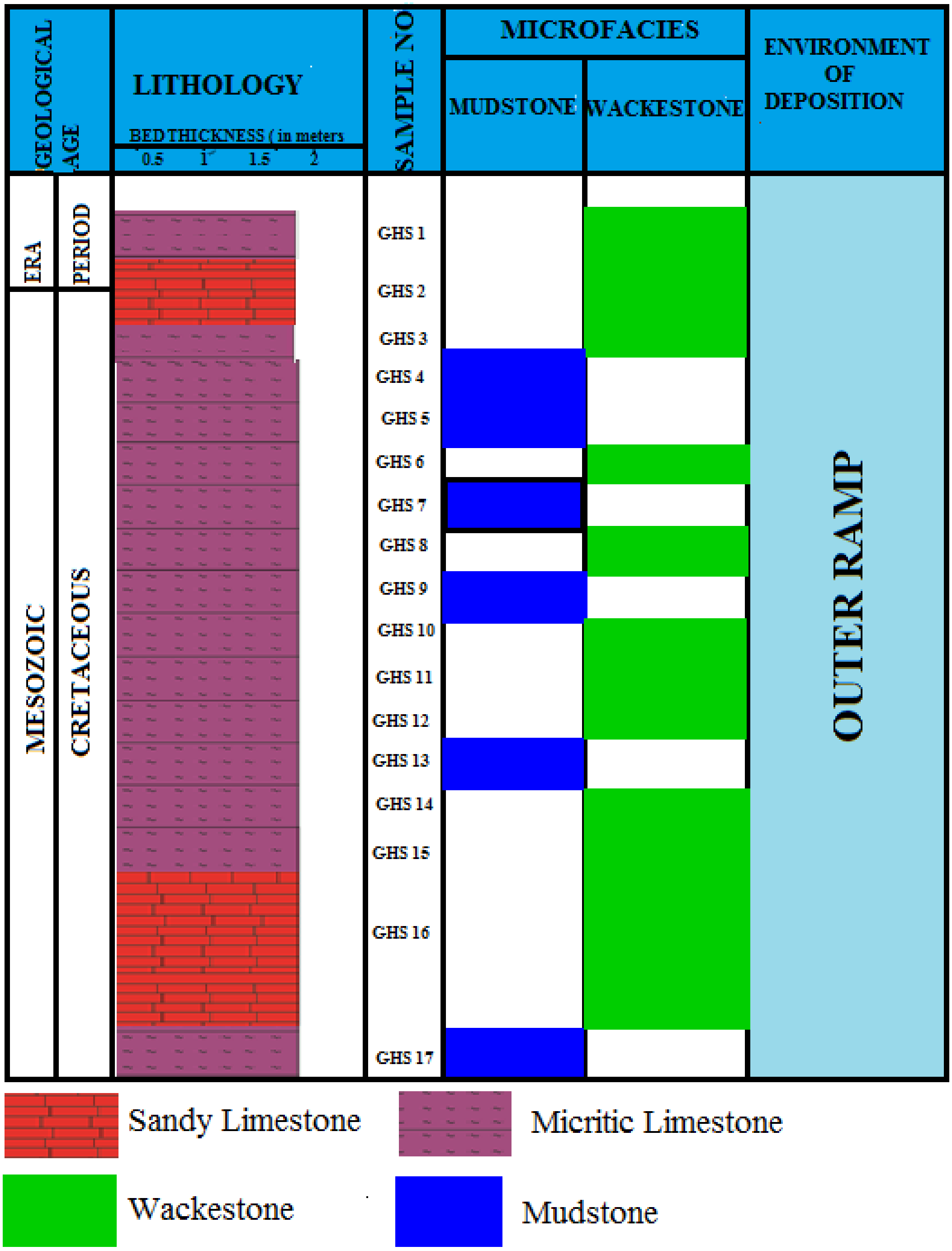

Figure 3.1 Stratigraphic Log showing microfacies of Kawagarh Formation, Garhi Habibullah section, Hazara Basin and depositional environment as outer ramp (Flugel,2004).

Table 3.1: Petrographic details and by % volume abundance of Allochems and Matrix identified in the Kawagarh Formation, Garhi Habibullah section and their classification based on Dunham (1962) and Folk (1962) classification for carbonate rocks.

Thin Section	Allochems (by %vol.)								Matrix (% vol.)		Classification	
	Foraminifera											
	Dicarinella	Globogerinilloids	Globutruncana	Heterohelix	Lenticuliana sp.	Calcisphere	Radiolarians & Echinoderms	Bioclasts	Micrite (% by vol.)	Sparite (% by vol.)	Folk (1962)	Dunham (1962)
1	-	1	3	2	-	1	2	11	75	5	**Biomicrite**	**Wackestone**
2	-	1	4	2	-	-	1	9	79	4	**Biomicrite**	**Wackestone**
3	1	-	4	1	-	-	1	3	88	2	**Biomicrite**	**Wackestone**
4	-	1	3	2	1	-	-	2	90	1	**Micrite**	**Mudstone**
5	-	-	2	2	1	-	1	3	90	1	**Micrite**	**Mudstone**
6	-	1	3	4	-	-	1	5	84	2	**Biomicrite**	**Wackestone**
7	-	1	2	2	-	-	1	2	90	2	**Micrite**	**Mudstone**
8	-	-	2	4	1	1	-	9	82	1	**Biomicrite**	**Wackestone**
9	1	-	3	1	-	-	-	3	90	2	**Micrite**	**Mudstone**
10	1	2	1	3	-	-	-	5	85	3	**Biomicrite**	**Wackestone**
11	2	-	3	3	-		1	3	86	2	**Biomicrite**	**Wackestone**
12	-	-	2	4	-	-	2	7	81	3	**Biomicrite**	**Wackestone**
13	-	1	1	1	-	-	1	1	94	1	**Micrite**	**Mudstone**
14	-	2	3	2	1	-	-	5	85	2	**Biomicrite**	**Wackestone**
15	-	2	2	4	-	1	1	4	85	1	**Biomicrite**	**Wackestone**
16	-	-	3	3	1	1	-	5	87		**Biomicrite**	**Wackestone**
17	-	-	1	2	-	1	-	3	92	1	**Micrite**	**Mudstone**

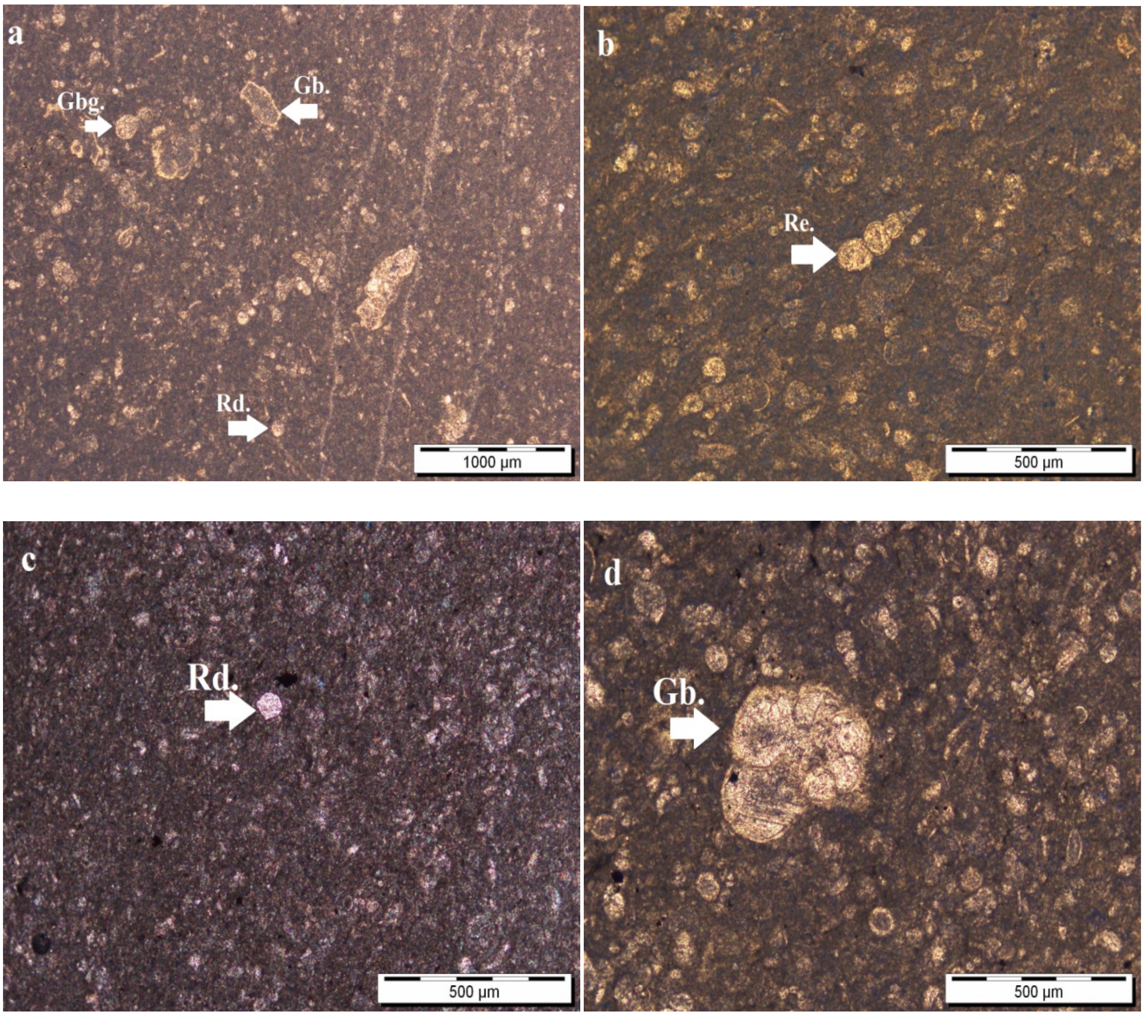

Figure 3.2 Photomicrographic plate showing microfacies identified in the Kawagarh Formation, Garhi Habibullah section, Hazara basin. a)Planktonic Foraminiferal Wackestone Microfacie, b) Planktonic Foraminiferal Mudstone Microfacie, c) Radiolarian Bioclastic Wackestone, d) Bioclastic Mudstone Gb.(Globotruncana linneana),Gbg. (globogerinlloid), Rd. (radiolarian), Re. (heterohelix reussi).

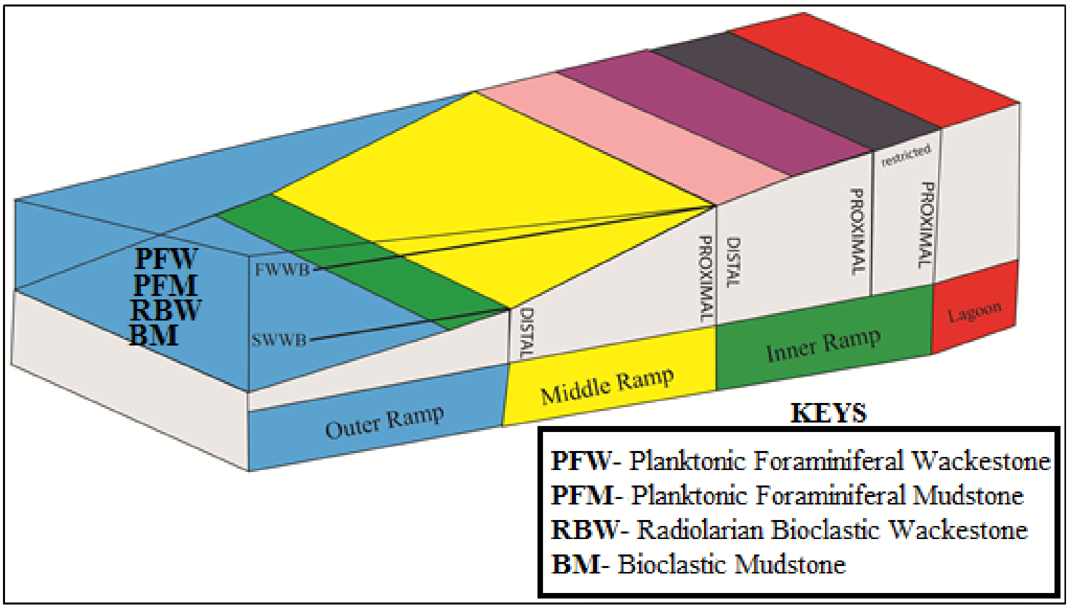

Figure 3.33D model of environment of deposition for Kawagarh Formation in Garhi Habibullah section, Hazara Basin (Flugel, 2004).

3.3 Biostratigraphy of Kawagarh Formation

3.3.1 General Description

In biostratigraphy, the relative age is assigned to rock unit on the basis of fossils preserved. The fossil record is used to identify and correlate the strata exposed in different stratigraphic sections. From the habitat of the fossil preserved, the environment of deposition of the rock unit can easily be predicted. Also, the fossil record is important in assigning age to the rock strata.

3.3.2 Microfossils Identified in the Kawagarh Formation

In the past, intense research has been done on the Kawagarh Formation. A vast variety of planktonic foraminifera have been reported by many workers at different localities. The species identified during this study include: Dicarinella concavata, Dicarinella asymetrica, Heterohelix reussi, Heterohelix globulosa, Globotruncana linneiana, Globotruncana lapparenti, Globotruncana hilli, Globotruncana ventricosa, Globigerinelloides bentonensis, Lenticuliana sp etc. The detail abundance of these species by % volume is mentioned in Table 3.1.

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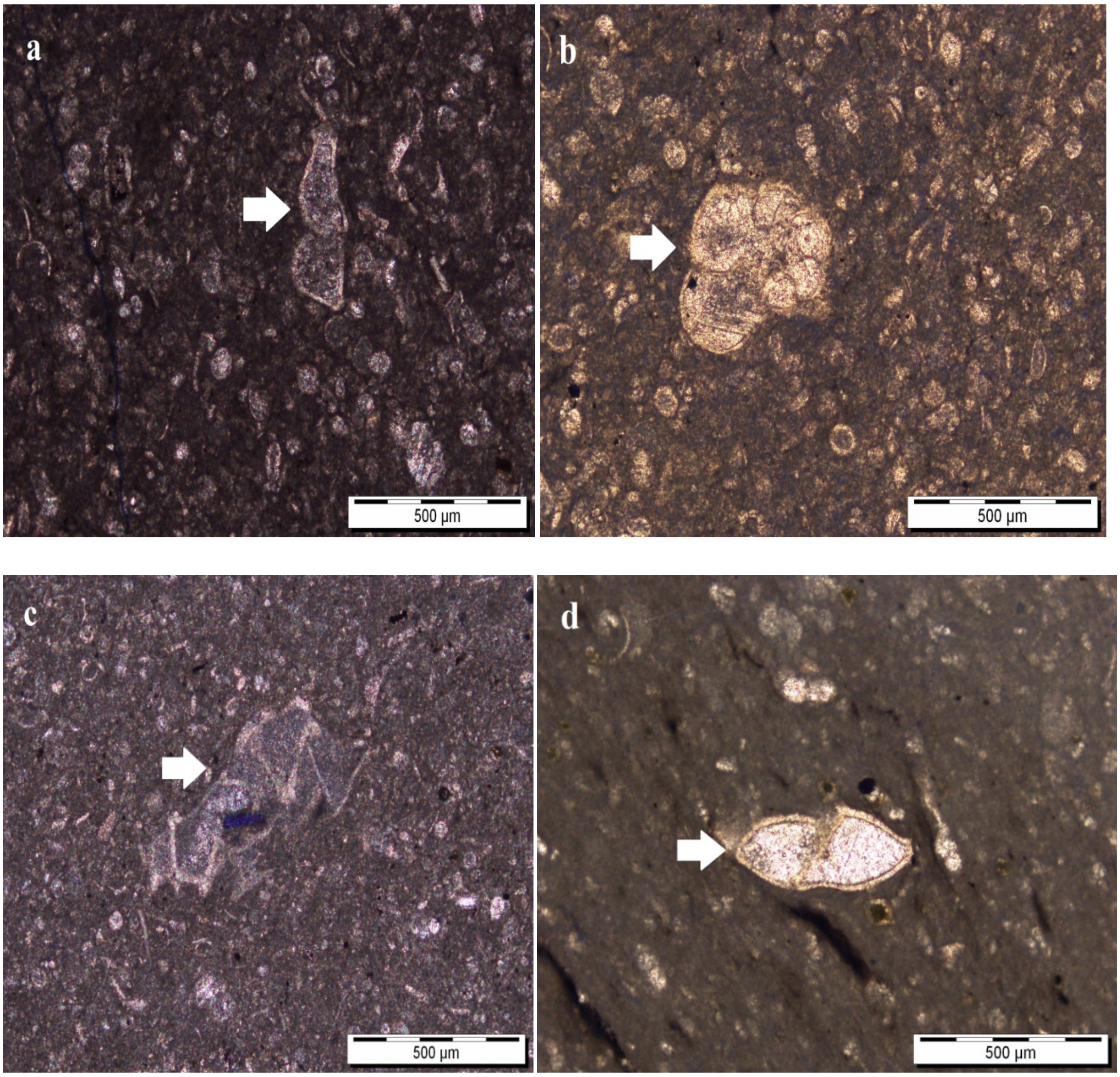

Figure 3.4 Representing the planktonic foraminifera including a) Globotruncana Lapparenti b) Globotruncana linneana c) Globotruncana arca d)Globotruncana hilli

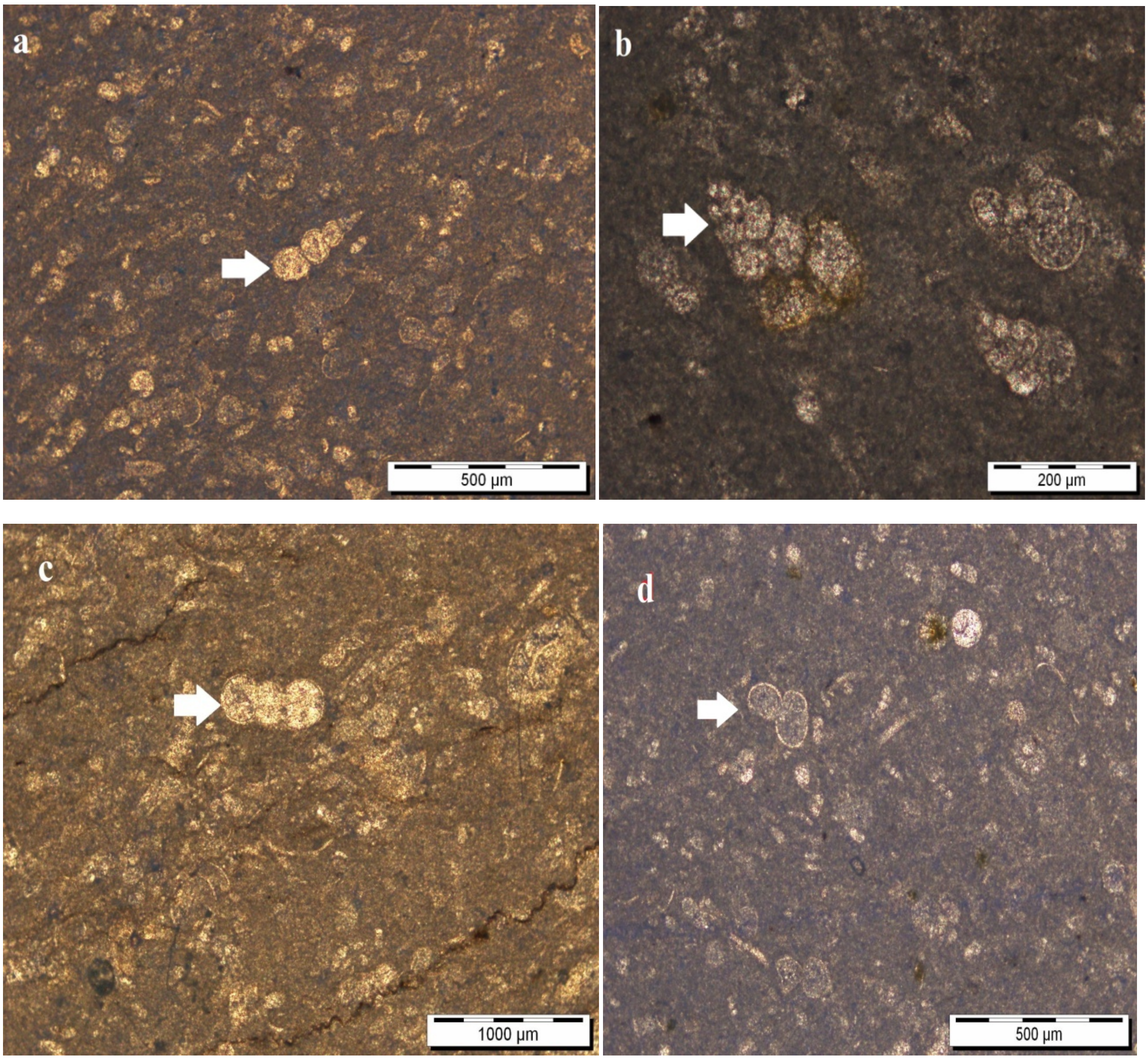

Figure 3.5 Representing the planktonic foraminifera including a) Hetrohelix reussi b) Hetrohelix straita c) Hetrohelix carinata d) Hetrohelix globolosa

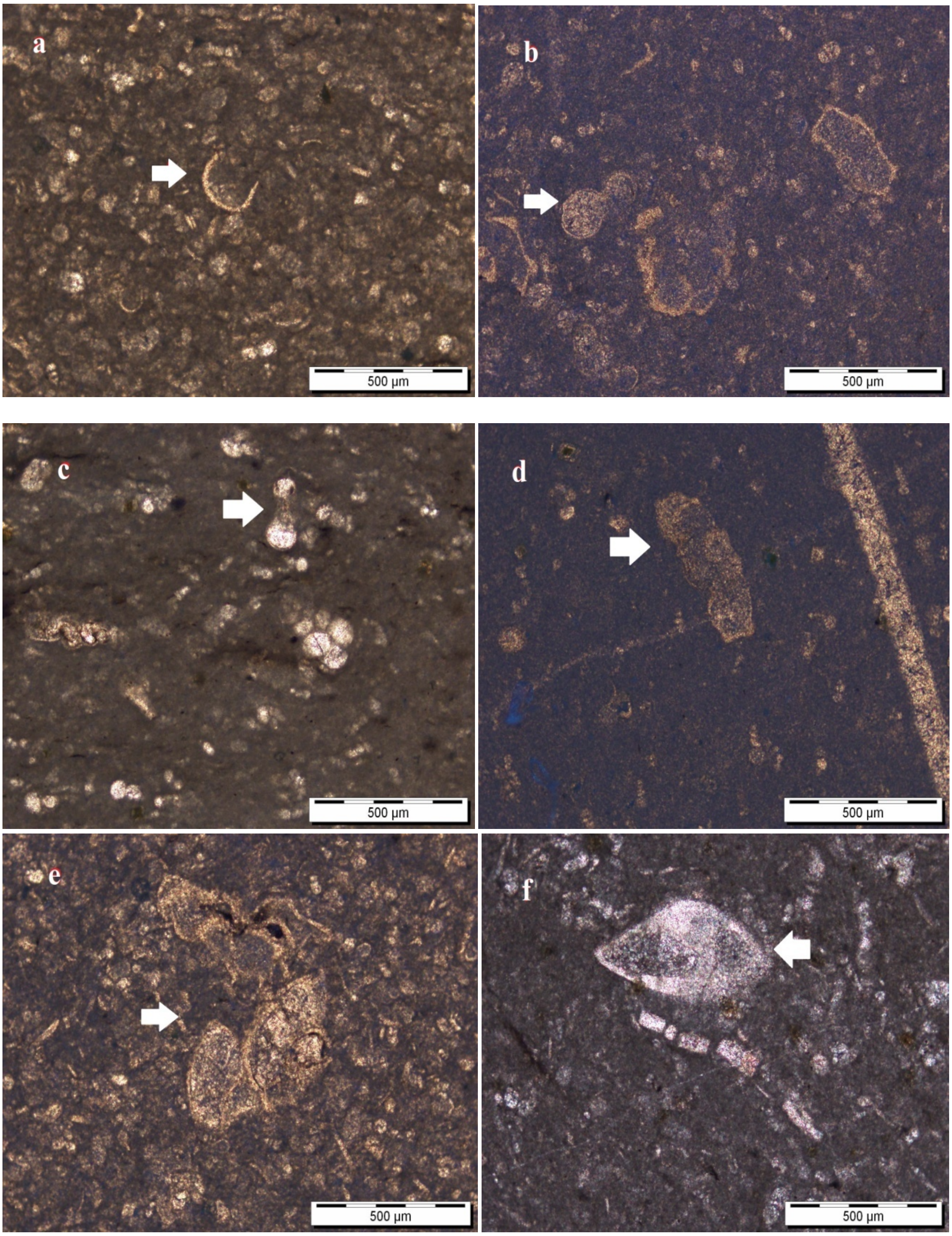

Figure 3.6 Representing the planktonic foraminifera including, a) Globigerinelloide bentonensis, b) globogerinlloid barri, c) globogerinlloid blowi d) dicarinella concavata e) Hedbergella trocoidea f) Lenticuliana sp

3.3.3 Biozonation of the Kawagarh Formation

3.3.3.1 General Description

Biozone is the fundamental unit of biostratigraphy which is defined as “A sedimentary strata characterized by specific kind of fossils” (Nichols, 2009). Biozones makes it an easy job for the stratigraphers to identify and classify the rock units, confirm the age of rock units and establish environment of deposition.

3.3.3.2 Biozone Established in Kawagarh Formation

Based on the abundance of age diagnostics planktonic foraminifers’ species, Globutruncana ventricosa Biozone is established in the Kawagarh Formation of Garhi Habibullah section, Hazara basin.

Definition: Localized interval zone from the first appearance to the last appearance of Globotruncana ventricosa.

Author: First defined by Dalbeiz (1955) and then recorded by Dalbeiz (1955)), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004).

Characteristics: This zone is defined by the presence of Globotruncana ventricosa along with assemblage of Globotruncana elevata, Globotruncana stuartiformis, Globotruncana bulloides, Contusotruncana fornicata, Globotruncana arca, Globotruncana linneiana and Globotruncana lapparenti.

Age: Middle to Late Campanian.

Remarks: In this localized Biozone Globotruncana linneina, Globotruncana lapparenti, Heterohelix reussi, Heterohelix globulosa, Globotruncana hilli, Globotruncana ventricosa, Dicarinella concavata and Dicarinella asymmetrica are reported.

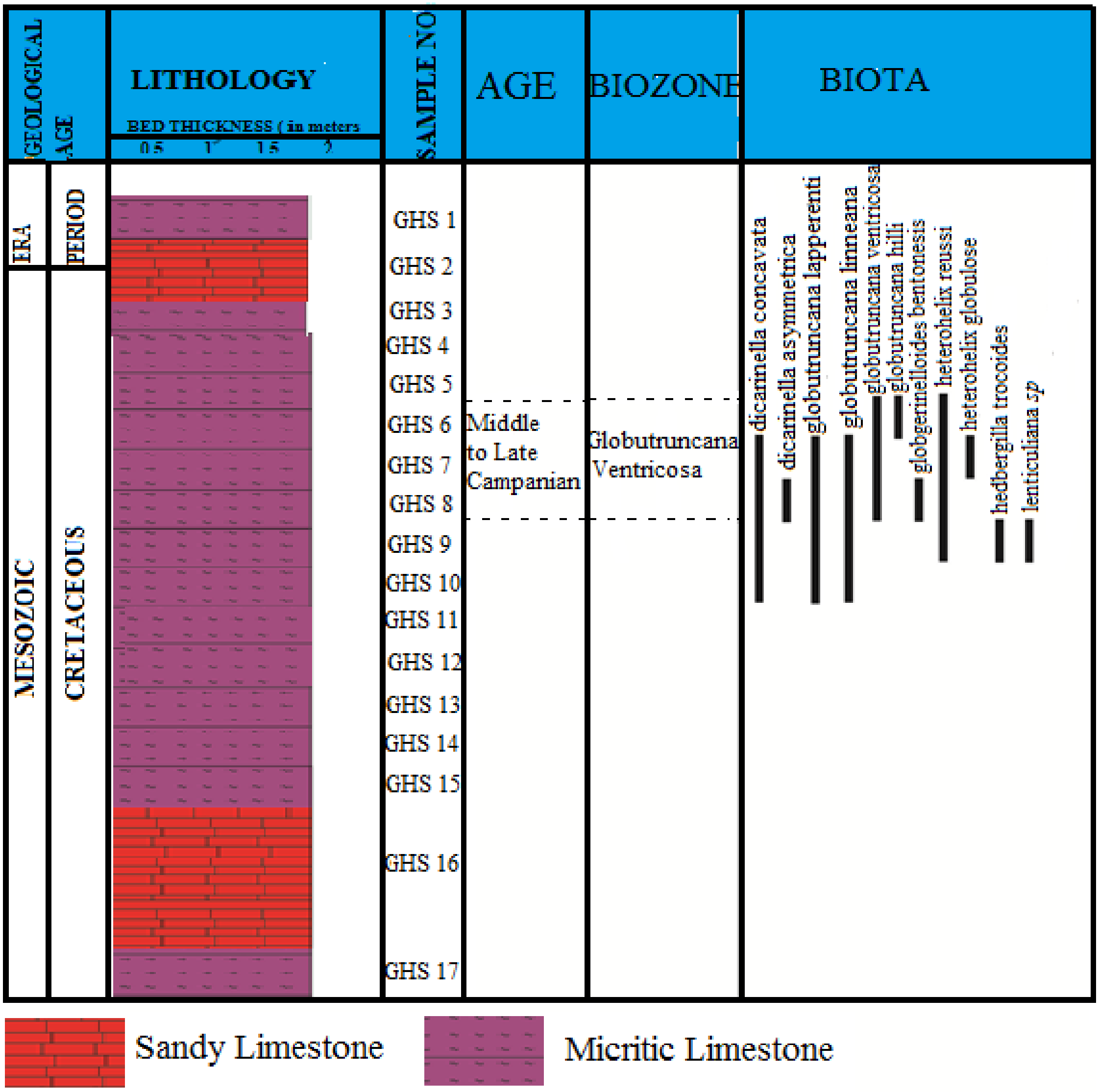

Figure 3.7 Lithostratigraphic log showing the localized Globotruncana ventricosa Biozone for the Kawagarh Formation, Garhi Habibullah section, Hazara Basin marked on the basis of fossil assemblages (Dalbeiz, 1955).

CHAPTER 4

DIAGENESIS AND ENVIRONMENT OF DEPOSITION

4.1 Diagenetic Features

Diagenesis is defined as “all the chemical, physical and biological changes undergone by sediment after its initial deposition, during and after its lithification, exclusive of surficial alteration and metamorphism (Jackson, 1997). Carbonate rocks are always prone to the diagenetic alteration due to its high rate of solubility in acidic water in comparison to other sedimentary rocks (Flugel, 2004). The study of processes and results of diagenesis in the carbonate rock units is critical to the analysis and optimal development of hydrocarbon reservoirs. The outcrops and fields containing hydrocarbons often possess fundamentally the identical carbonate diagenetic fabrics. The process of diagenesis is continuously active in the carbonate rocks preserving the basin history (Flugel, 2004). The processes of dissolution, cementation, lithification and alteration of the sediments during the interval between deposition and metamorphism are included in diagenetic fabric.

In this study, the diagenetic fabric of the Kawagarh Formation, Garhi Habibullah section has been observed to identify its diagenetic setting and impact of diagenesis on its reservoir properties. The diagenetic features observed in petrography of the Cretaceous carbonate rock unit include;

4.1.1 Cementation

Cementation is the process of precipitation of chemicals from the solution in pore spaces. Cementation basically occurs in the early stages of diagenesis, marine diagenetic environments, reflecting the saturation phase of $CaCO_3$ (Ehrenberg et al., 2012). The loose rock grains become compacted by the infilling of cementing materials in the pore spaces between the grains (McLane, 1995). As a result of cementation process, porosities are reduced (Tucker and Wright., 1991).

In the present study, the dominant cementing material is calcite precipitated in the form of sparry and blocky cement. Sparry calcite cement has filled the fractures while the block calcite cement is identified as filling the fractured zones and dissolution cavities. Blocky calcite cement is usually associated with meteoric and burial environments or may be a product of recrystallization of prior cement (Flugel, 2004).

4.1.2 Neomorphism

The replacement of pre-existing rock minerals by chemically metastable minerals is known as neomorphism (Tucker, 2001). Neomorphism directly affect the porosity of a rock unit. Neomorphism may occur as a result of recrystallization, polymorphism and replacement. Recrystallization, a type of neomorphism, has no direct impact on parent mineralogy and composition but only crystal size expands. Polymorphism is type of neomorphism in which the crystal shape alters into another crystal having major impact over the rock porosity e-g; transformation of aragonite into calcite or e-g replacement of calcite by dolomite. Neomorphism is of two type’s i-e; aggrading neomorphism in which crystal size increases and degrading neomorphism in which crystal size decrease.

In the Kawagarh Formation, Garhi Habibullah section, the aggrading neomorphism was recognized in carbonates indicated by the presence isolated and equigranular patches of micro spar with a grain size of 4 to micrometers. Also, the bioclast replacement by calcite or spar indicates neomorphism process of diagenesis.

4.1.3 Pyritization

Pyritization refers to the process of the formation of pyrite crystals i-e FeS_2. Usually pyrite is formed in reducing conditions during the decay of organic matter induced by anaerobic bacteria (Hudson, 1982). It is the most abundant ferrous iron disulphide minerals in carbonate sediments (Flugel, 2004).

In petrography of the Kawagarh Formation, cubic and euhedral crystal shaped very black fine sized grains are identified as pyrite. Presence of pyrite indicates reducing environments for the carbonate unit under study.

4.1.4 Fractures

Fractures are naturally occurring planar discontinuity in the rocks due to deformation or physical compaction (Nelson, 2001). They are secondary features developed due to mechanical compaction in a regionally active tectonic regime (Flugel, 2004). The scale of fractures varies from hairline size to few centimeters termed as micro fractures. Depending upon the nature of rock, the process of dissolution and environmental conditions the micro fractures may be filled or unfilled. The dominant filling materials are calcite and quartz termed as calcite veins and quartz veins respectively (Folk, 1962).

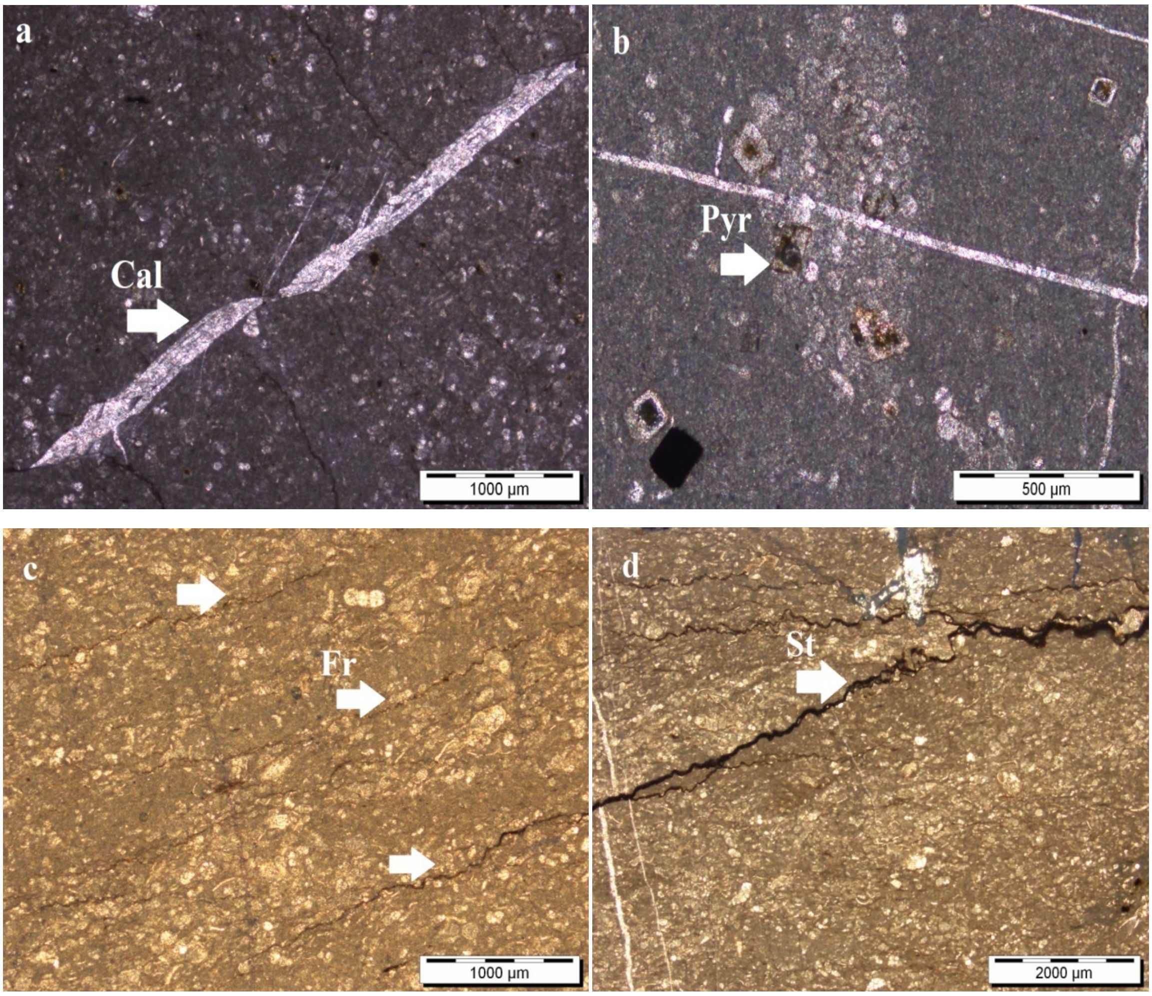

Figure 4.1 Photomicrographs showing the diagenetic features observed in the Kawagarh Formation, Garhi Habibullah section, Hazara Basin a) showing calcite vein (Cal), b) showing pyritization (Pyr), c) showing fractures (Fr), d) showing stylolites (St).

The fractures observed in the Kawagarh Formation, Garhi Habibullah section are both macro scaled and micro scaled filled fractures. In the petrography, dominant type of filling material observed include both calcite and quartz. These fractures have cross-cut relationship with the rock grains and other fractures, indicating multiple episodes of digenesis.

4.1.5 Stylolites

Stylolites are saw-edged surface in a rock unit along which the mineral has been eroded by pressure dissolution in a deformation process reducing the total rock volume. Insoluble residual material including clay, oxides and pyrites are common along the stylolites. Stylolites are formed as a result of physiochemical phenomena initiated by burial compaction and tectonic compression (Buxton and Duncan, 1981).

Stylolites are identified in abundant amount in petrographic study of the Kawagarh Formation, Garhi Habibullah section. The stylolites cross-cut all the diagenetic fabric present within the carbonate unit and thus can be established as youngest and final diagenetic event. Stylolites occur in different modes including parallel relation to each other revealing same phase to each other while few cross-cut each other reflecting multiple and repeated episodes in the burial stages of diagenesis.

4.1.6 Reservoir Characterization

In this research, the reservoir characterization of carbonates is based on the thin section visual porosity and diagenetic features. On the basis of the diagenetic features discussed above, it is observed that the Kawagarh Formation, Garhi Habibullah section has undergone marine, meteoric to deep burial diagenetic episodes. During these episodes the reservoir potential of the Formation has been affected and redistributed. In many scenarios, the porosity has been decreased while in some cases it has been enhanced. At some intervals the porosity is enhanced due to less cementation. Overall porosity of the Formation is supported by vuggy porosity. The presence of high amount of fracturing may have enhanced the permeability but it cannot be observed accurately (Roehl and Choquette, 2012).Since, the fractures are not connected, the formation may not exhibit effective permeability. The nature of stylolites does not explain the reactivation process indicating the negative impact on permeability of the rock unit.Sparry calcite and micrite cements filling the fractures resulted in reduction of pore spaces. Similarly, micritization, pyritization and neomorphism are the other diagenetic features having negligible impact on the reservoir properties of the rock unit. The Kawagarh Formation of Garhi Habibullah section, Hazara Basin has relatively poor and heterogeneous reservoir potential.

4.2 Environment of Deposition

As discussed in the microfacies of the Kawagarh Formation, the environment of deposition for this Formation is interpreted as outer ramp using the Flugel, 2004. This environment of deposition is established on the basis of allochems, fossils record and grain texture. In Pakistan, the environment of deposition for the Cretaceous age Kawagarh Formation has been established by many authors at different localities. Qureshi et al., 2006 proposed outer ramp as environment of deposition for the Kawagarh Formation of Kala Chitta Range.

Conclusions

- The microfacies identified in the Kawagarh Formation include planktonic foraminiferal wackestone, planktonic foraminiferal mudstone, and bioclastic mudstone and radiolarian bioclastic wackestone.
- The environment of deposition interpreted for the carbonates of the Kawagarh Formation is outer ramp to deep basin.
- The biozone identified in the Formation is globotruncana ventricosa biozone revealing the age of the Formation as middle to late Campanian.
- The Formation has recorded many episodes of diagenetic alterations including cementation, pyritization, fracturing, micritization, pressure dissolution, sparitization and neomorphism.

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BIOSTRATIGRAPHY AND MICROFACIES OF THE UPPER CRETACEOUS KAWAGARH FORMATION, GARHI HABIBULLAH SECTION, HAZARA BASIN, KHYBER PAKHTUNKHWA, PAKISTAN

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