INTERPRETATION OF PALEOENVIRONMENTS BASED ON FAUNAL ASSEMBELAGES & DIAGENESIS OF KOHAT FORMATION AT SUMARI VILLAGE, LACHI, KOHAT SUB BASIN, PAKISTAN

BY

ALI HASSAN

Department of Earth and Environmental, Sciences Bahria University Islamabad

2024

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ABSTRACT

The Kohat formation of Eocene age was developed in the Kohat basin of the Himalayan Fold and Thrust Belt in Northern Pakistan. The Kohat Formation shows variable thickness comprising mainly from thin to thick bedded nodular limestone, with intercalations of thinly laminated shales. For micropaleontological examination, the Eocene Kohat formation at outcrop level was measured in the Sumari Village, Lachi, District Kohat, northern Pakistan. Eighteen thin sections were obtained from different samples. Based on primary sedimentary features and lithology, the Kohat formation is subdivided into eight different lithofacies. Thin section studies revealed the depositional environments of formations leading to the identification of three foraminiferal genera as Nummulites, Assilina & Alveolina.

Based on petrographic data, six microfacies have been identified, i.e., Nummulitic Pack stone Microfacies. Algal-Miliolid Wackestone-Packstone Microfacies. Bioclastic Pack stone Microfacies. Bioclastic Wacke stone Microfacies. Nummulitic Grain stone Microfacies. Bioclastic Mudstone Microfacies.

The characterization of these above facies supports deposition in shallow marine environment. The diagenetic fabric consisting of neomorphism, dissolution, micritization of Kohat formation indicates meteoric-deep burial environment of diagenesis.

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CHAPTER 1

INTRODUCTION

1.1 General Statement

The intricate tectonic region in northern Pakistan is known as the Kohat basin. Numerous asymmetrical buildings with steep dips and a titled plateau were created by faults are seen there. The exposed data from the Jurassic to Quaternary eras are composed of clastic, carbonates, and evaporites. In certain places, it is thicker than 4 km. The Kohat Plateau (KP), in particular its north-east ward, is located on the Himalayan foreland and thrust region. The Kohat foreland and belts have maintained the sedimentary strata of the Himalayan belt. Kohat sub basin have become extremely importance due to recent oil and gas discoveries with huge HC potential in northern Pakistan. The KP is connected to the north by the Main Boundary Thrust (MBT), and to the south by the Surghar Range Thrust (SRT). The study area (Figure 1.1) is located along Indus Highway near Sumari village bus stop, Lachi, Kohat, Khyber Pakhtunkhwa, Pakistan. (Abbasi, 1991)

Kohat Formation is exposed in Sumari village which is of Eocene age (Fatimi, 1973; Meissner et al., 1974). The upper Indus basin is further divided into Potwar in east and Kohat in west separate by Indus River (Kadri, 1995).

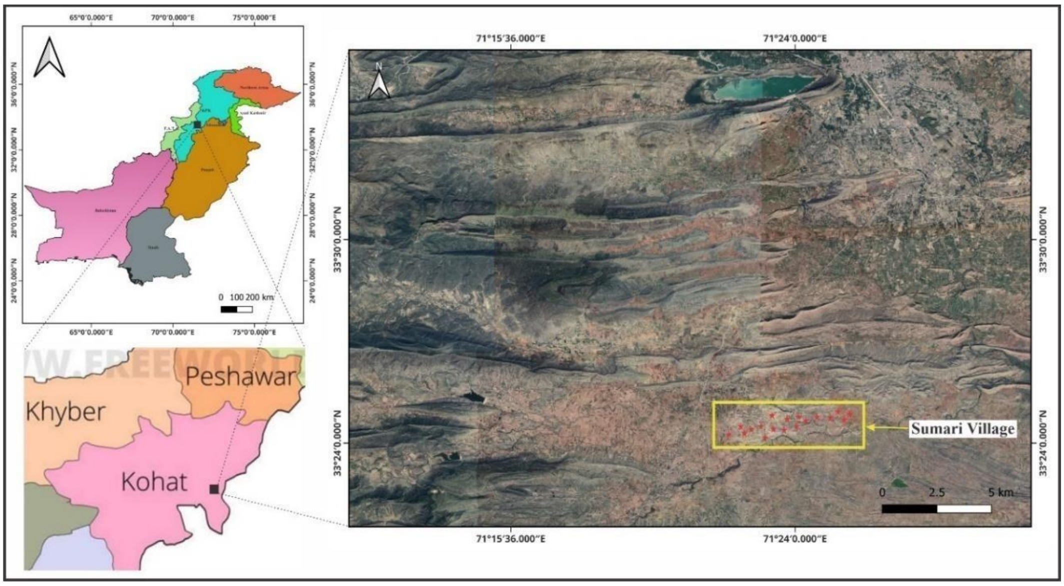


Figure 1.1: Location Map of the Study Area (Adopted Geographical map of Pakistan from Google &)

1.2 Location

The study area (Latitude N 33° 26' 45" to 33°26' 50" and longitude E 71° 21' 47" to E 71° 21' 50") are exposed along Indus Highway near Sumari village bus stop, Lachi, Kohat, Khyber Pakhtunkhwa, Pakistan. From Bahria University Islamabad, the region is conveniently accessible. The distance from Islamabad to the study area, which is about 197 kilometers, could take 3 to 4 hours (Figure 1.2).

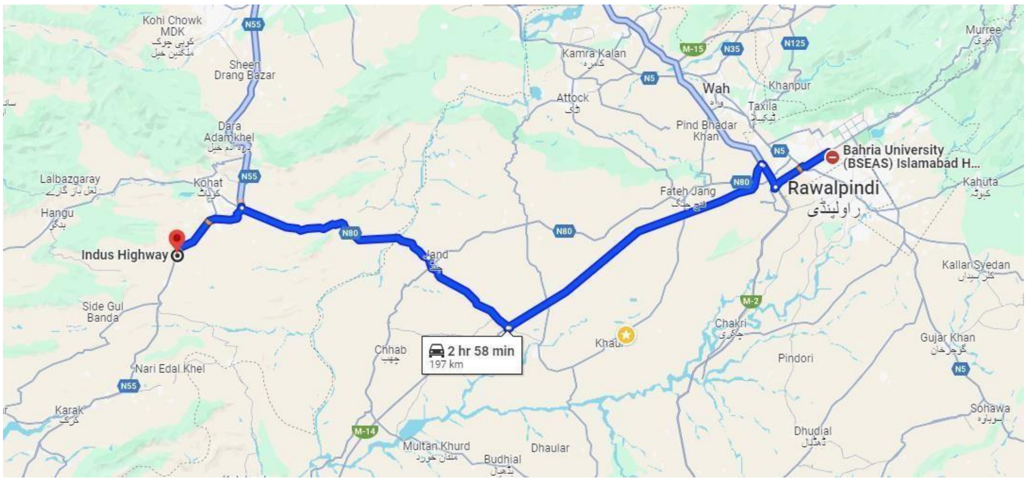


Figure 1.2: Location Accessibility Map (Adopted from Google Maps)

1.3 Geography

The Sumari village is located in Kohat's northeastern region. This area is located 20 kilometers from Kohat and 56 kilometers from Khushal Garh. Khyber Pakhtunkhwa relates to the regions of Punjab here. The region's climate is similar to that of Peshawar city; summer are generally hot occurs in June, July, and August with maximum temperature 40 degree, while winter are extremely cold occurs in November, December, and January with minimum temperature 5-10 degree. There are numerous minor year-round and perennial streams in the area connects with Kohat Toi River that drain into the Indus River. Less than 85mm of rain fall each year on average falls in the year. The area local language is Pashto and source of their income is agriculture.

1.4 Economic Importance of the Area

The economic importance of study area is that highly Oil and Gas reserves were discovered by OGDCL, POL, PPL & MOL by past years. The other economic minerals like gypsum (Raza & Khattak, 1972) (Jatta Gypsum), salt (Burnes, 1832; Karsten, 1846; Oldham, 1864) (Bahadar Khel Salt) & building material were found in abundance. Gypsum is greenish white, white, grey or black in color. Black or grey color marks HC Glaze on splintered planes which gives distinctive Petroliferous odor.

1.5 Topography

The Kala Chitta Ranges are located at lower altitudes topographically than the Attock Cherat Ranges. In the foothills of the Chinji and Nagri formation, low-line ridges are covered in a dense layer of alluvial material.

1.6 Aims and Objectives

The study was conducted to accomplish the following goals:

1.6.1 To document the fossil content of Kohat formation.

1.6.2 To identify the Microfacies of the Kohat formation.

1.6.3 To find out diagenetic changes in Kohat formation.

1.6.4 To reconstruct the paleoenvironment history of the Kohat formation based on the identified fossil.

1.7 Methodology

The following methodology was used to accomplish the aforementioned goals and objectives (Table 1.2):

1.7.1 Field Work

Field work was done to collect unaltered, unweathered & compact samples for petrographic analysis. Lithological units measured, identified based on grain size, color etc. distinctive criteria. The contact relationship or lithological characteristics were also noted (Figure 1.4).

The Kohat formation's roadside section was chosen for careful measurement and sampling in order to describe the fossil assemblage and diagenetic changes (Figure 1.3). From the outcrop, 18 samples were taken (Table 1.1). These samples were appropriately packaged, numbered, and sent to the Institute of Geology's rock cutting and thin section making facility of Charsadda lab, to detect and characterize the facies assemblage, a total of

18 thin sections were obtained for microscopic investigation. Forillustration, the well-preserved foraminiferal specimens were photographed.

Table 1.1: Showing details of sample collected from location.

Sample No.	Longitude(° E)	Latitude(° N)	Distance interval(meters)
1.	71° 21' 47.15"	33° 26' 45.42"	5.8
2.	71° 21' 48.22"	33° 26' 46.31"	2.2
3.	71° 21' 49.24"	33° 26' 47.22"	2.1
4.	71° 21' 49.28"	33° 26' 48.17"	2.9
5.	71° 21' 49.12"	33° 26' 49.00"	2.75
6.	71° 21' 50.14"	33° 26' 50.93"	2.32
7.	71° 21' 50.13"	33° 26' 49.87"	2.95
8.	71° 21' 50.11"	33° 26' 49.82"	2.1
9.	71° 21' 50.00"	33° 26' 49.69"	2.01
10.	71° 21' 50.01"	33° 26' 49.56"	2.07
11.	71° 21' 50.99"	33° 26' 50.46"	2.35
12.	71° 21' 50.88"	33° 26' 50.35"	2.93
13.	71° 21' 50.74"	33° 26' 50.20"	2.73
14.	71° 21' 50.64"	33° 26' 50.11"	2.44
15.	71° 21' 50.46"	33° 26' 50.95"	2.61
16.	71° 21' 50.38"	33° 26' 51.89"	2.04
17.	71° 21' 49.27"	33° 26' 49.76"	2.08
18.	71° 21' 49.53"	33° 26' 49.84"	2.01

Figure 1.3: Kohat Formation

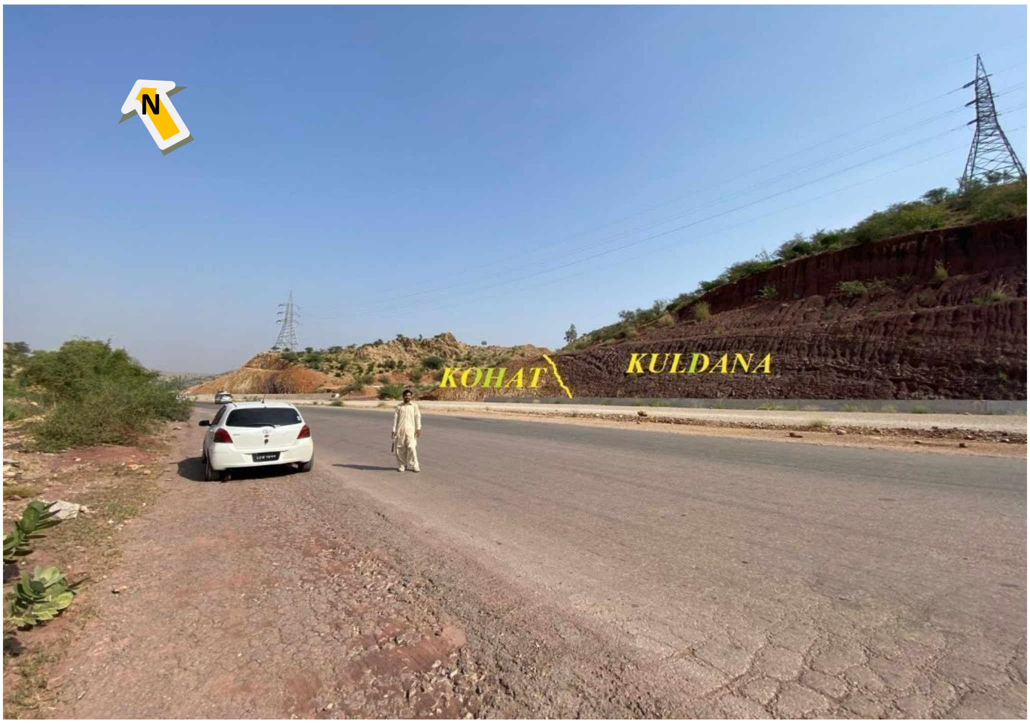


Figure 1.4: Contact between Kohat & Kuldana Formation

1.7.2 Lab Work

Lab work contains the cutting rock samples crushed and to prepare thin sections followed by certain precautions like Proper orientation of sample to get maximum details, followed for the fossil assemblage identification by microscopic study (Figure 1.8), on the basis of previous literature classified and taking Photomicrographs of different features of the fossils & fossil itself. The Arc GIS & Corel draw were used for the preparation of map and marking the lithological sections of study area.

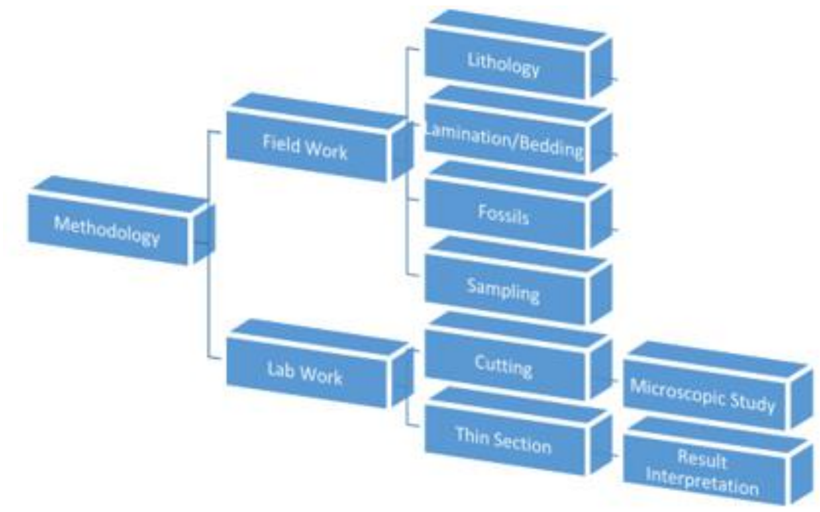


Table1.2: Flow chat of method adopted in microfacies analysis.

1.7.3 Data Compilation & Write Up

Field & Laboratory data compiled & interpreted in order to produce depositional setting, reconstruct paleoenvironment history, diagenetic changes and systematic Paleontology in detail for the Kohat Formation.

1.9 Instruments

The instruments used throughout the current research are:

1. GPS

Figure 1.5: GPS

2. Geological Hammer

Figure 1.6: Geological Hammer

3. Microscope

Figure 1.7: Microscope (Olympus BX51), Camera (Meiji Techno Japan: HD 1500T)

CHAPTER 2

GEOLOGY & TECTONICS

Pangaea, a supercontinent that included all the continents, split into two shards around 200–225 Ma; Gondwanaland was in the south and Laurasia was in the north. Gondwana continent include subcontinents like Arabia, Antarctica, Africa and Australia while the Eurasian continent includes further subcontinents like northern Europe and mostly Asia. Tethys Ocean breaks to two parts, Paleo-Tethys to North and Neo-Tethys to South. Paleo-Tethys, an ocean, split these two pieces in half. The Indian plate began to move northward for around 4000 km after separating from Gondwanaland at around 130 Ma. The Neo-Tethys plate subducting beneath the Eurasian plate caused the Kohistan- Ladakh Island Arc to form (Klootwijk, 1985).

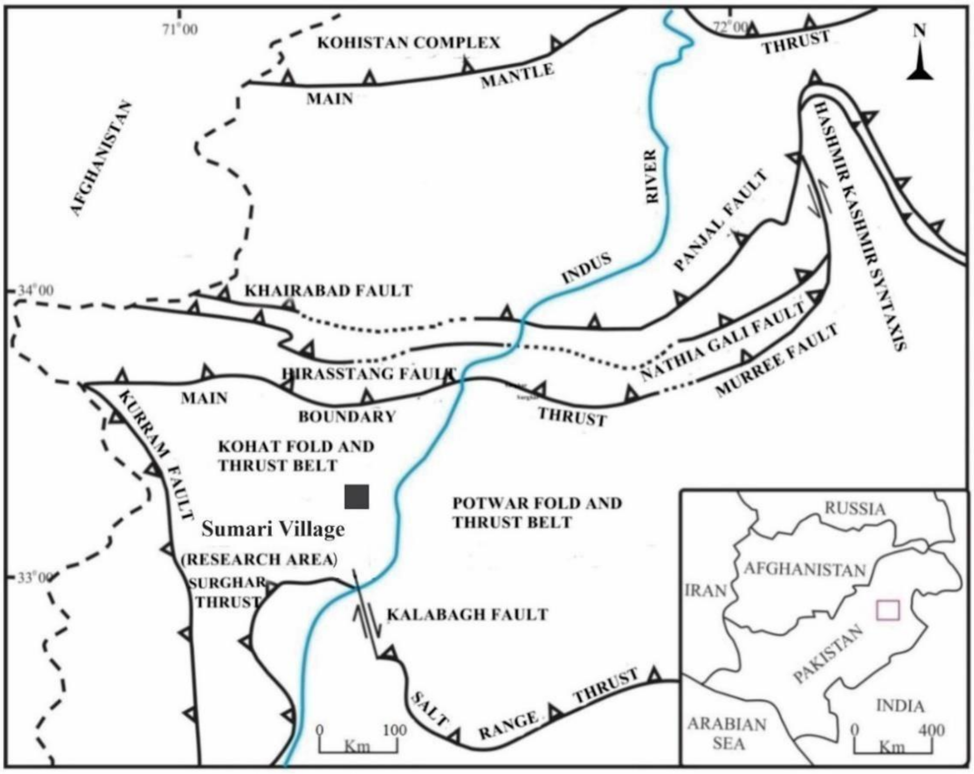


Figure 2.1: Tectonic Map of Pakistan, Box showing the study area [(Hussain, H & Zhang, S., (2018)].

The Laurasian domain, Tethyan domain, and Gondwanian domain are the three main geotectonic domains that make up Pakistan. The Himalayas, the world's youngest and highest mountain range, was created when the Indian and Eurasian plates collided 65–50 Ma ago.

The Chaman Transform fault extends from Kharan to Kabul marks the western boundary of Indian plate and connects the convergence zone of Makran in south and Himalaya in north is about 100-200km (Kazmi, 1979 and Lawrence et al, 1979). The Chaman Fault established in SE of previous plate boundary so, the thick succession of ophiolites was exposed on its EW boundary.

The stratigraphy of Pakistan has been separated into five zones by four regional thrust fault systems. These faults include the Main Mantle Thrust (MMT), Main Karakoram Thrust, SRT, MBT, and Trans Indus Range Thrust (TIRT) (MKT). The following are the domains that begin in Pakistan's north:

2.1 Karakoram Block

The Karakoram block contains heavily deformed strata from the Eurasian plate's sedimentary, igneous, and meta-sedimentary record. It is surrounded by the Kohistan- Ladakh Arc to its south and the Pamir to its north (KLA). Around 70–150 Ma, the KLA and Karakoram collided, causing the formation of the northern suture or MKT. The Main Karakoram thrust delineates the southern border of the Karakoram block and separates the meta-sedimentary rocks of the Kohistan Island Arc from those of the Asian Plate.

2.2 Main Karakoram Thrust (MKT)

The MKT forms the southern boundary of the Karakoram block. Between 70 and 150 Ma, the KLA and Karakoram collided, causing MKT to develop. It is sometimes referred to as the Shayok suture's northern suture. It is the Pakistani thrust system's most northern element. It is hypothesized that the ocean that lies between the Karakoram and the Kohistan Island Arc (KIA) was closed during the LateCretaceous period (Yoshida, 1997).

2.3 Kohistan Island Arc (KIA)

In the Late Jurassic to Cretaceous, Neo Tethys subduction beneath Eurasian plate resulted in the formation of KIA (Hamidullah, 1992). Blue schist or glaucophane is a characteristic of the separation of Indian plate from KIA. In the eastern Hindukush, Karakoram, and western Himalaya, ultramafic, mafic, and volcanic rocks span an area of 36,000 km^2. With sedimentary rocks that are deformed and metamorphosed, the KIA is an east-west oriented orogeny that mostly consists of igneous intrusive and extrusive rocks. Due to an indentation made by the Nanga Parbat Hara mosh Massif in Ladakh to the east and the KIA to the west, the KLA is split into two halves. But beneath it is an Indian plate. MMT to the south and MKT to the north are located between KIA. These faults are truncated into Kunar fault that is present in the territory of Afghanistan (Ahmed, 2003).

2.4 Main Mantle Thrust (MMT)

North of the Northern Deformed Fold and Thrust belt lies the Main Mantle Thrust (MMT) (NDFTB). It involves the bottom crust and is dipping roughly 25–450 degrees northward (James, 1983). Nanga Parbat Hara mosh Massif, which is made of Schists and Proterozoic gneisses with a thickness of around 15 km in KIA, is the result of MMT. The disparity on the north or south of MMT has been stopped since 15 Ma. However, the convergence has not stopped and is still occurring at a rate of up to 5 mm per year, which causes collisions between continents and continental arcs. (Zeitler, 1982)

2.5 Northern Deformed Fold and Thrust Belt (NDFTB)

Metasedimentary, igneous, and sedimentary rocks make up NDFTB. It is separated from the Southern Deformed Fold and Thrust Belt, which is located in the south, by the

MMT and MBT, which are wedged between it to the north and south, respectively. From the Kashmir basin in the east to the Afghan border in the west, NDFTB extends laterally (Ahmad, 2011). Due to the distribution of deformation towards the south, a succession of thrusting with advancing age has produced southward. These set of flaws contain crucial elements such as the SRT and MBT.

2.6 Main Boundary Thrust (MBT)

The Hazara-Kashmir syntaxes are encircled by MBT, which is stretched in front of NDFTB in a manner that marks the transmission of deformation from MMT. The hanging wall is made up of the folded strata of the Miocene foreland basin, which represent the post collisional phase, while the footwall is made up of the pre-collisional NDFTB strata, which mostly contain rock records from the Mesozoic and Paleozoic (Ahmad, 2011). A succession of parallel thrust faults on MBT cause a divide in the severely deformed and transformed Himalayan sequence (Ahmad, 2011).

The MBT has split into the Hazara and Murree faults, which serve as the northern boundaries of the Kala Chitta and Hazara ranges. MBT is visible on the plateaus of Potwar and Kohat, where it runs parallel to molasses deposits (Seeber, 1979) and (Yeats, 1987).

2.7 Southern Deformed Fold and Thrust Belt (SDFTB)

SDFTB is available from South Waziristan in Pakistan to India, notably the Ganges delta. It is followed by a thick fluvial stratum. The Kohat Plateau (KP) is located to the west of the SDFTB (Ahmad, 2011). The Plateau underwent successive southerly deformation in the late Miocene. MBT is the northern limit of KP, where massively deformed Mesozoic rocks are pushing over Eocene to Miocene strata (Yeats, 1987). Along the Kurram Fault, both Eocene-Miocene and Mesozoic rocks are exposed. Salt Range, where Paleozoic rocks are pushing above the Punjab Foredeep, serves as the Kohat Plateau's southernmost limit. The Banu Basin sediments encircled the KP from the south (Ahmad, 2003).

2.8 The Punjab Foredeep

The Himalayan chain's southernmost point is delineated by Punjab Foredeep. Punjab Foredeep is thought to be the depocenter for the debris that is being eroded from the Himalayas because it is covered by Quaternary layers (Ahmad, 2003).

2.9 Salt Range and Trans Indus Thrusts

The two newest thrusts in Pakistan are the Trans Indus Range Thrust and the Salt Range Thrust. The Precambrian strata were brought onto the Pleistocene shelf by these thrusts (Grelaud, 2002).

Due to pushing, the Permian rocks of Surghar and the Jhelum group are overlain by the Punjab Foredeep. Between the Jhelum and Indus plains is where this fault is located.

2.10 Structural Setting of Study Area

The Kohat-Potwar plateau was created by compressional tectonics in the southern Himalayan and Karakorum orogenic belts following the Indo-Eurasian collision. To the north, the Kohat-Potwar plateau is bounded by the Kala Chitta Hills and MBT which brings Mesozoic highly deformed rocks over Eocene-Miocene sediments (Yeats and Hussain, 1987). The Trans-Indus Range and the Salt Range serve as the border to the south. The southeastern boundary of this plateau with Mesozoic rocks in the Surghar Range are emplaced onto the Indo-Gangetic foredeep southwards in south. From southern boundary of this plateau Undeformed sediments of Banu basin are present. The western boundary is marked by the Kurram-Parachinar Range and Kurram fault juxtaposes Mesozoic highly deformed rocks of Darsamand, Samana, North Waziristan Agency and Thal with Eocene- Miocene sediments. The Kurram Fault is known as transpressive left lateral body. The Kohat-Potwar Plateau is divided into the Potwar and Kohat regions to the east and west, respectively, by the Indus River (Figure 2.1). The Kohat Plateau is made up of structurally elevated and severely deformed thrust sheets. (Treloar, 1993)

The study region is located in Lachi near Sumari Village Kohat. Kohat Basin contains massive bedded sedimentary packages that are aging from Miocene to Eocene (Table 3.1). Following are the Formations along with their ages are present.

2.1 Eocene Sequence

The Eocene Sequence, together with the Kohat Plateau, is made up of the Panoba Shales, Sheikhan Limestone, Kuldana Formation, and Kohat Limestone. This exposure is only present in the northwest quadrant of the plateau, where this sequence makes up the bulk of Panoba Anticlonorium.

2.1.1 Panoba Shales

Green Shales Parson (1926) were given a new name by Eames (1952), Panoba Shales, which was accepted by Pakistan's Stratigraphic Committee (SCP). Shale that is somewhat silty and calcareous is present in the formation. It can be anything from light grey to olive green in terms of color. Additionally, it possesses gypsum veins and some flaky limestone interbeds. The lateral facies of the Panoba Shale, or Bahadur Khel Salt, is exposed in Kohat's southern region. Assilina and nummulites are among the fossils found there.

2.1.2 Sheikhan Formation

In 1930, Davies coined the phrase "Sheikhan Limestone," which was eventually abbreviated to “Sheikhan Formation” (Fatmi, 1973). It is made up of noduled limestone that ranges in color from light grey to grey and features interbedded shales. In the Sheikhan Limestone, microfossils such Alveolina and Nummulites can be found. A component of SF, Jatta Gypsum can be found on Kohat's southern border. Gypsum with gypseous shale interbeds make up Jatta Gypsum. Additionally, it has larger echinoids, corals, mollusks, and foraminifers.

2.1.3 Kuldana Formation

Kuldana Formation was given the name first by (Wynne, 1874) as "Kuldana Beds" while (Middlemiss, 1896) coined it as "Kuldana Series", then (Meissner et al. 1974) gave it name as Mami Khel Clay & after further renamed this formation as "Kuldana Formation" by (Latif, 1970), and SCP just approved it (Fatmi, 1973). It also has clay that appears in the form of thin bands and shale that ranges in color from reddish brown to scarlet. It came from a fluvial environment and was dumped in a semi-arid region once marine regression came to an end (Wells, 1984). In Lachi with respective thicknesses of around 50-60 meters. We were able to detect the presence of Sulphur in the Kuldana Formation near Sheikhan Nala thanks to its overpowering smell. Foraminifera and Assilina fossils can be found there.

2.1.4 Kohat Formation

The Kohat shales and Kohat Limestone, which were formally referred to as the Kohat Formation by the SCP (Fatmi, 1973), were first used by Eames in 1952. In study area its overall thickness is 95 meters. The majority of it is made up of light grey, thin- bedded limestone with shale intercalations, and the top is made up of calcareous shale with a greenish grey color and greyish-green limestone. It includes nummulites, Alveolina and Assilina.

Kohat formation lies conformably with Kuldana or unconformably with Miocene age Kamlial Formation which marks the non-deposition time of Late Eocene to Oligocene period prior to Molasse sedimentation in the area

2.2 Miocene Sequence:

The Rawalpindi group, which includes formations like Kamlial and Murree, is part of the Miocene sequence on the Kohat plateau.

2.2.1 Murree Formation

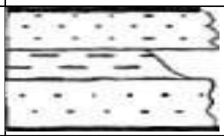
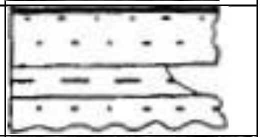
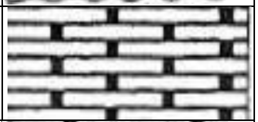
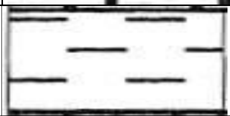
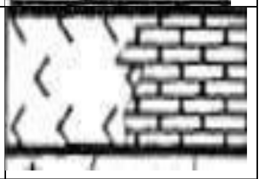
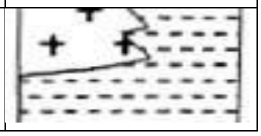
It is only found in the Northern and Central Kohat Plateaus and is made up of reddish-purple colored sandstone and shale that contains marl with a whitish color (Fatmi, 1973). The unconformity in the Kohat Formation indicates where the Murree Formation bottom is. It is known that there are not many fossils in this deposit. Bivalves, oncolites, gastropods, and bits of invertebrate bones are its distinguishing features.

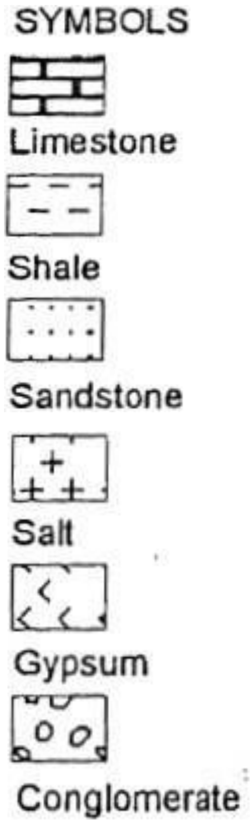
2.2.2 Kamlial Formation

The Miocene-aged Kamlial Formation is made up of yellow or purple intraformational conglomerates and purple or grey sandstone with purple shale intercalations. It has fossilized remnants of fish, mammals, and plants.

It has unconformable contact with Kohat and Nagri formation of Siwalik Group in the study area.

Table 2.1: Generalized Stratigraphic Column of study area, Kohat

Age		Formation	Description	Lithology
Cenozoic	Miocene	Kamlial Formation	Sandstone, Shale, Conglomerates	
		Murree Formation	Sandstone with shale (Marl)	
	Eocene	Kohat Formation	Limestone	
		Kuldana Formation	Shale	
		Sheikhan Formation	Nodular Limestone, Jatta Gypsum	
		Panoba Shales	Shale & Salt	



CHAPTER 3

FAUNAL ASSEMBLAGES

3.1 Introduction

Biostratigraphy is the branch of stratigraphy through which it concerned with strata organization and its identification based on fossil content. Zones and bio stratigraphic units are strata with distinct material of the fossils. William's Smith gives the observation which follows that "the same strata were always found in the same sequence of superposition and contained the same fossils". After 1800 in France and England biostratigraphy independently emerged. Interval zones, range zones, lineage zones, abundance zones and assemblage zones are five types recognized by biostratigraphers of bio stratigraphic zones. Biochronology is the recognition of geologic time intervals by fossils. Biochron is any organism's fossil indicates a specific period of geologic time. A method of stratigraphic correlation is commonly used by biostratigraphy which is age identification process or stratigraphic location of stratified rocks using biostratigraphy in different areas. The major basis for generating the relative geological timeline is biostratigraphy due to its utility in stratigraphic correlation.

A rich assemblage of foraminifera features Kohat Formation and is well exposed in Kohat basin in several locations. A triple divide of the Kohat Formation following Meissner (1968), in the northern section of basin can be seen: the Sadkal member, the Kaladhand member and the Habib Rahi Limestone member in order of superposition. In the southern regions and middle of the basin, this separation does not exist, however. The Hangu Section and Sheikhan Nala portion of the Kohat Formation, which are located in northwestern and northeastern parts of the basin, respectively, in the depth for foraminiferal assemblages were examined (Yasin and Munir, 2007).

Kohat Formation mainly contain foraminifera, Assilina and Alveolina and is fossiliferous. Based on the faunal assemblage the formation's age thus verified as late early Eocene to early Middle Eocene.

3.2 Systematic paleontology

3.2.1 Genus: Nummulites Lamarck, 1801

3.2.1.1 Nummulites atacicus (Leymerie, 1846)

Remarks:

This specie is uncommon in Kohat Formation. We can find it only in the center of the Formation. With bigger proloculus Megalospheric types are the most common. The pillars aren't as well developed as they may be. A good amount of preservation has the marginal chord and is extremely noticeable (Figure 4.1).

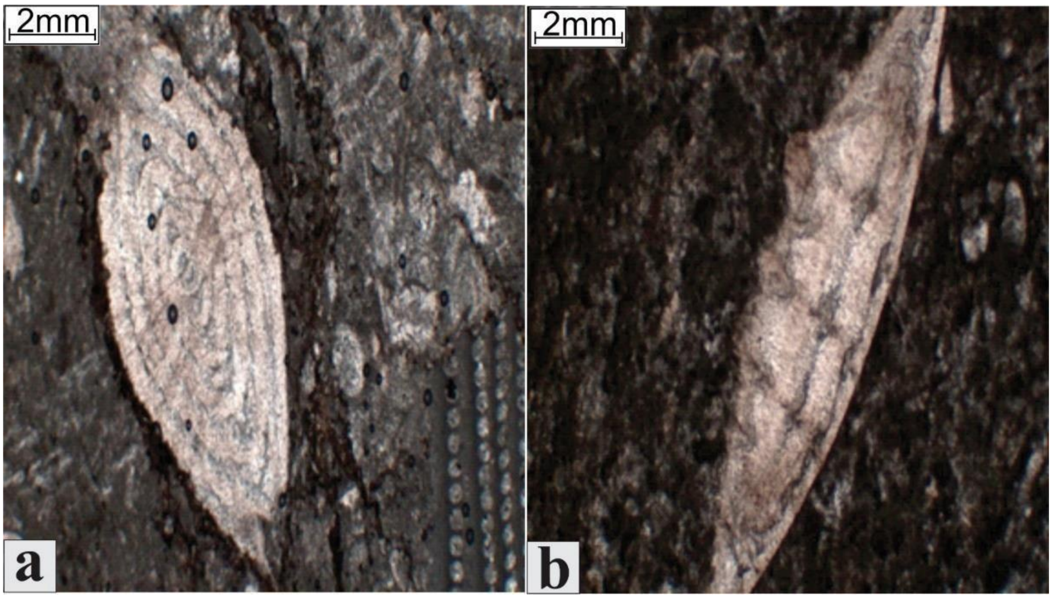


Figure 3.1: (a-b) An Axial View of *Nummulites atacicus*

3.2.1.2 Nummulites globulus (Leymerie, 1846)

Remarks

There are only a few individuals of this species in the Kohat Formation. A shell distinguished it that is highly biconvex and its shape is more globular. The well developed and prominent Umbilical pillars are present and the shell's wall is quite thick (Figure 4.2).

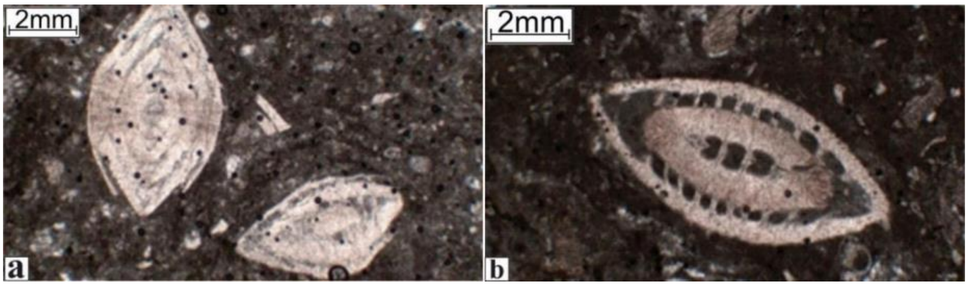


Figure 3.2: (a-b) An Axial View of *Nummulites globulus*

3.2.1.3 Nummulites sub irregularis (De la Harpe, 1883)

Remarks

In Kohat Formation only a few specimens of this specie have been discovered. This structure has been reported first time in northern Pakistan. The thin walls and thin shells relatively distinguished it (Figure 4.3).

Figure 3.3: (a) An Axial View of *Nummulites subirregularis*

3.2.1.4 Nummulites mamillatus (Fichtel and Moll, 1798)

Remarks

Throughout the formation, this specie occurs in large amount. In the central region with large umbilical pillars, it has biconvex shells that distinguished it. There is a marginal chord present. However, it is quite thin, in comparison to other Nummulites species (Figure 4.4). In lower section of Kohat formation it is detected and its range is considered to be from lower to middle Eocene.

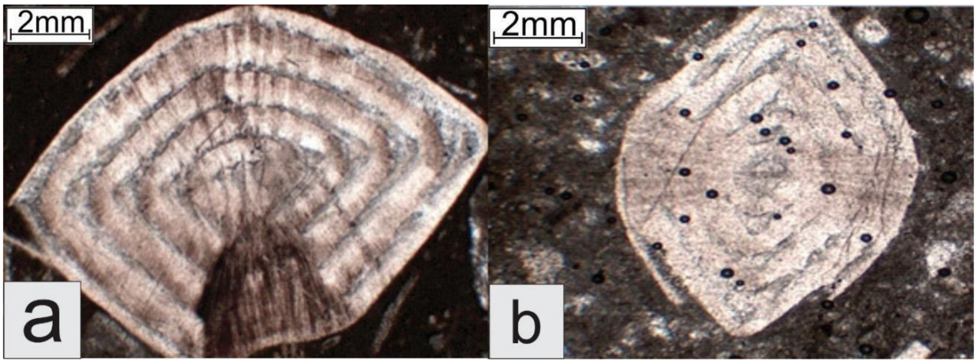


Figure 3.4: (a-b) An Axial View of *Nummulites mamillatus*

3.2.2 Genus: Assilina, d'Orbigny 1826.

3.2.2.1 Assilina granulosa (d' Archiac, 1847)

Remarks

Kohat Formation is full of species and is shale (Sadkal Member) found in the middle portion of the Formation. The shell is normally flat and has sharp edges. There are many granules on the surface of the shells. These granules rather visible at the times may be (Figure 3.5).

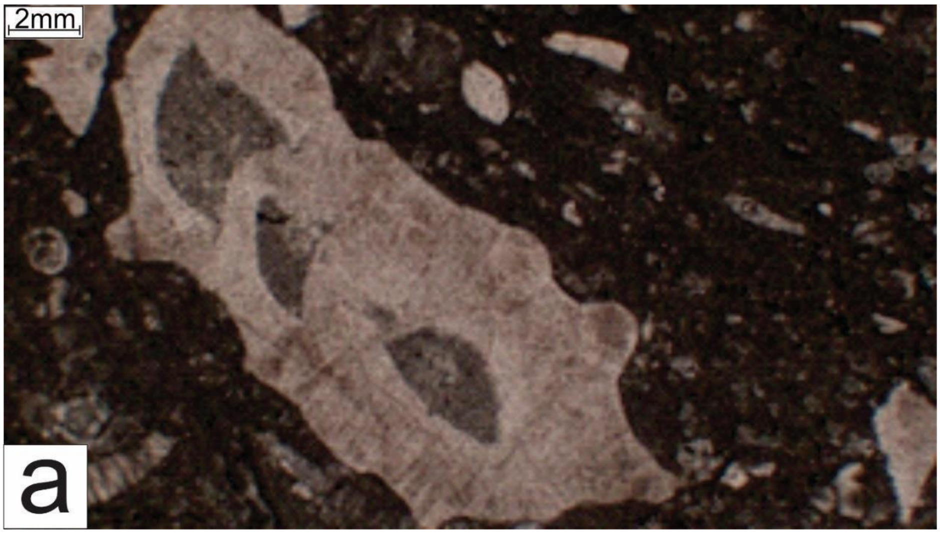


Figure 3.5: (a) An Axial View of *Assilina granulosa*

3.2.2.2 Assilina laminosa (Sowerby, 1840)

Remarks

There are only a few individuals of this species, in the middle of the Formation. The strong walls and thick borders distinguished species, with conspicuous laminations visible in cross section (Figure 3.6).

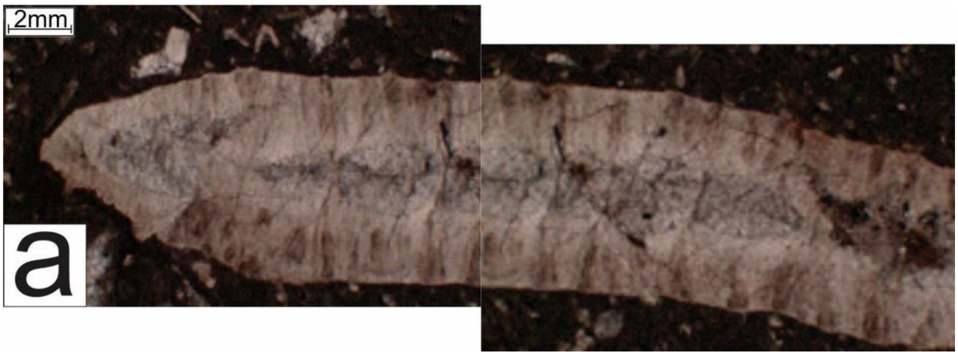


Figure 3.6: (a) An Axial View of *Assilina laminosa*

3.2.3 Genus: Alveolina, d'Orbigny 1826.

3.2.3.1 Alveolina elliptica (Sowerby, 1840; Hottinger, 1960; Silvestri, 1937; Smout,1954)

Remarks

By early flosculinization followed by regular whorls this species is distinguished (Figure 3.7).

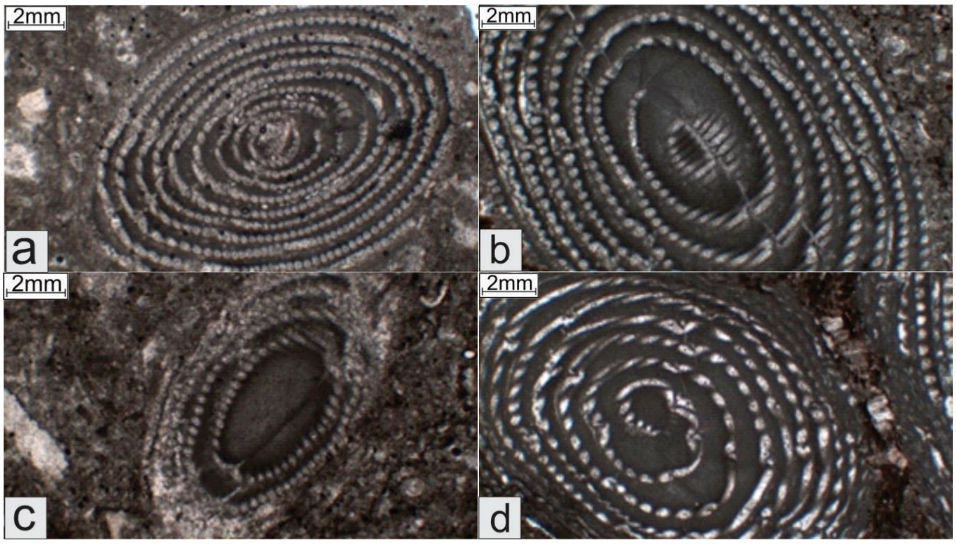


Figure 3.7: (a, b & d) An Axial View of *Alveolina elliptica*, (c) An Equatorial view of *Alveolina elliptica*

3.2.3.2 Alveolina stercusmeris (Hottinger L., 1960)

Remarks

The early stage flosculinization lacks this form that is characteristic of Alveolina elliptica, and the whorls are relatively close together (Figure 3.8).

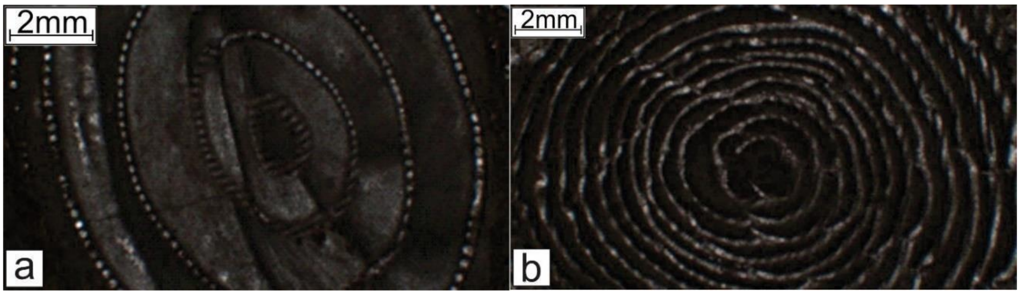


Figure 3.8: (a) An Axial View of *Alveolina stercusmeris,* (b) An Equatorial view of *Alveolina stercusmeris*

3.2.3.3 Alveolina globula

Remarks

From uppermost section of Kohat limestone it is detected and its range is late Eocene (Figure 3.9). The shell is cylindrical. The early spherical whorls are followed by 6–7 irregular ones. The chamberlets are fine and rounded.

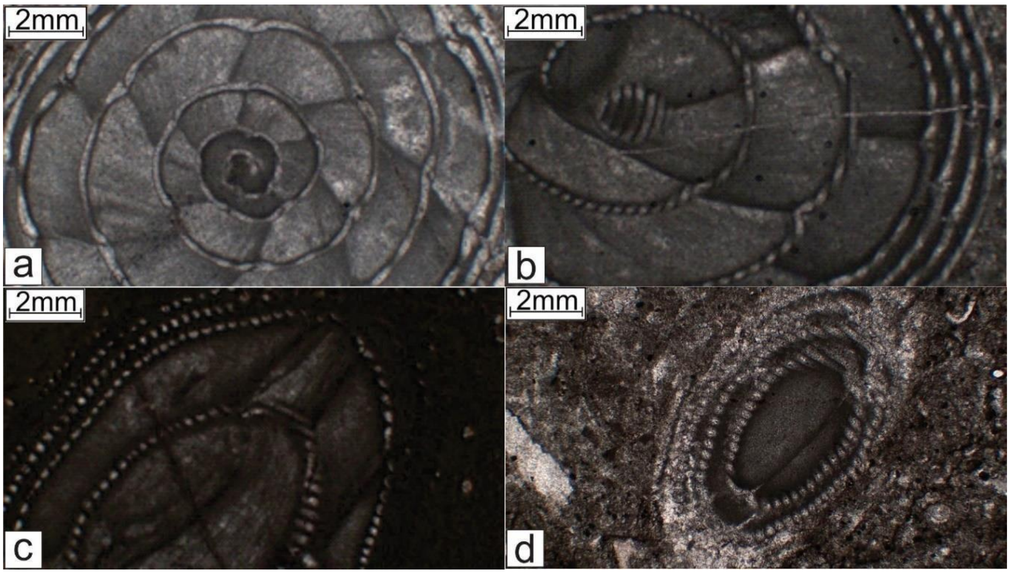


Figure 3.9: (a-b) An Axial View of *Alveolina globula*, (c-d) An Equatorial view of *Alveolina globula*

3.2.3.4 Alveolina frumentiformis

Remarks

In Kohat Formation it is detected. It is usually present in middle to upper portion in this Formation (Figure 3.10). This specie contain specimen which are generally elongated to fusiformis & subcylindrical in shape. Numerous whorls are also present & it's Axial Thickness not uniform.

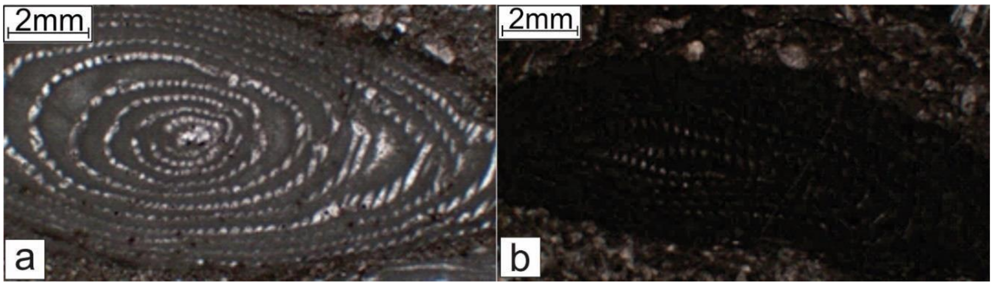


Figure 3.10: (a-b) An Axial View of *Alveolina frumentiformis*

3.2.3.5 Alveolina indicatrix

Remarks

In Kohat Formation, it is detected usually in upper part (Figure 3.11). It's shape is spherical to-globular. Pillar and proloculus are absent. The first few coils are loose while the outer whorls are tightly coiled.sssss

Figure 3.11: (a) *Alveolina indicatrix*

3.3 Bio facies

A section of a stratigraphic unit in which the fossil flora or fauna differs markedly from that of the rest of the unit is called bio facies. The thin section study identified three types of larger foraminifera (Assilina, Nummulites, and Alveolina).

The following species of larger foraminifera have been encountered during the detailed thin section study under microscope with 4x magnification.

- Nummulites atacicus
- Nummulites globulus
- Nummulites subirregularis
- Nummulites mamillatus

Remarks:

Observed in thin sections (KF-1, 2, 5, 7, 10, 13 & 14.)

- Assilina granulosa
- Assilina laminosa

Remarks:

Observed in thin section KF-9.

- Alveolina elliptica
- Alveolina stercusmeris
- Alveolina globula
- Alveolina frumentiformis
- Alveolina indicatrix

Remarks:

Observed in thin sections (KF-7, 8, 10, 12,13,14,15 & 16.).

CHAPTER 4

DIAGENESIS OF KOHAT FORMATION

4.1 Introduction

Carbonates shifts from development to arrangement influences by Diagenetic process or, potentially development inside where the progressions occur vertically or along the side. It likewise influences porosity & permeability of the formations. Incorporate cementation, neomorphism, dolomitization, microbial micritization and compaction forms by diagenesis (Tucker & Wright, 1990). Carbonates Diagenetic processes have 3 types of principle environment that includes burial, meteoric and marine environments of deposition. In deep burial Carbonates are subjected to lithospheric pressure, leading to rocks compaction, controlling circulation of fluid, pressure & temperature, texture & grain size of limestone. The major effects are porosity reduction, chemical and mechanical compaction, micro fracture, dewatering, cementation, replacement of Ca by Mg (dolomite) and other minerals. While hot or fresh water comes in contact directly with carbonate rocks, termed as meteoric diagenesis. In meteoric diagenesis there are 3 main processes which are precipitation, dissolution and mineralogical transformation of different minerals, (Mujtaba, 2001).

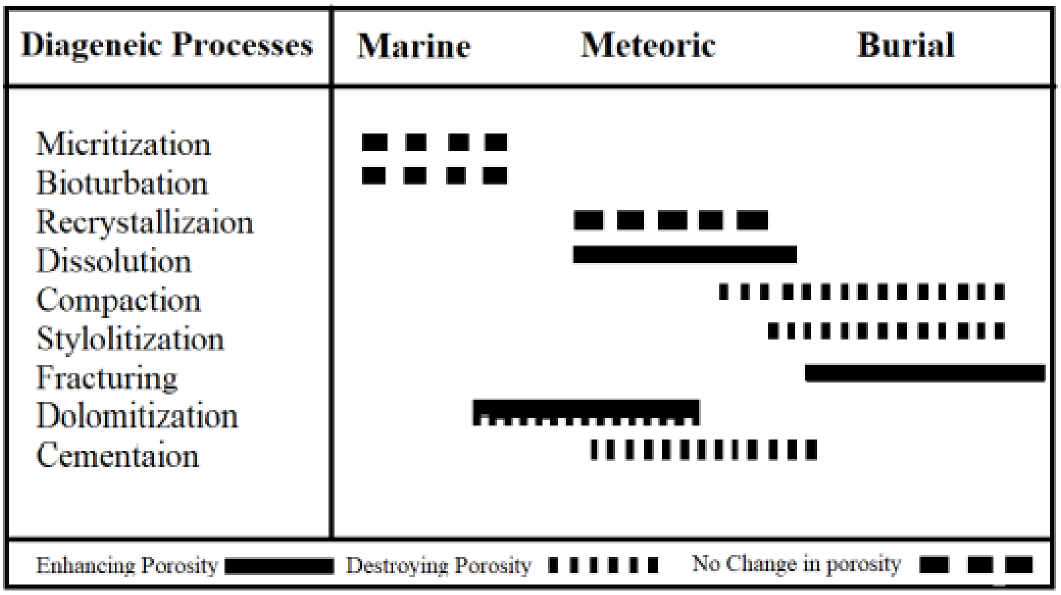


Figure 4.1: Diagenetic process effecting porosity (Ali et al., 2006).

The burial digenesis mainly effects because of lithospheric pressure in the reduction of carbonates porosity, but sometimes the carbonates porosity may increase due to fracture development and dissolution. In the process during neomorphism and cementation porosity is also reduced by which the quality of carbonates ultimately reduces. (Figure 4.1)

Changes in character and the sediments content at the time of deposition that occur into the domain of metamorphism until the materials are transported or subjected to the effects of atmospheric weathering which is called as Diagenesis. In both the domains of the metamorphic cycle denudation and accumulation huge number of widely diversified types of occurrences are regulated by the following elements such as;

- Physical and chemical processes.
- Tectonic and morphological conditions.

In order to find out effects in fossils deposition of the diagenetic phases, the diagenetic features of the Kohat Formation have been studied.

To the compaction fossil diagenesis refers, early mineralization and replacement of minerals in later stages which were formed, followed by repeated dissolution sessions. The overgrowth of minerals also includes that were formed in early stages.

4.2 Diagenetic Evaluation of Kohat Formation

Diagenesis is a sedimentary phenomenon including all physical and chemical changes which are taking place before the onset of metamorphism and after deposition, (Tucker, 2001).

Detailed microscopic studies shows that the Kohat Formation has undergone following changes;

a. Cementation/Micritization
b. Recrystallization
c. Neomorphism
d. Calcite Filled Microfractures
e. Compaction (Micro Fractures/Stylolitization)

4.2.1 Micritization

A limestone type component a small as four millimeters in diameter called Micrites made up of calcareous particles that form by recrystallization of lime mud. A mud grade lime carbonate is a Micrite. According to the Folk classification, it is considered to be the carbonate rock that has the abundance of fine-grained calcite. Allochems are classified along with calcite as Oo-micrite, biomicrite, intra-micrite, or pel-micrite depending on the predominant allochem. Micrite can be found as a matrix in carbonate rocks, which envelopes around allochems, or Peloid's. Chemical precipitation, Peloid's disaggregation, or micritization can be used also to make micrite. Folk Robert, (1969) coined the word to represent for carbonate rocks classification system. Micrite is made up of microcrystalline materials that are calcite crystals. In the fossils of Kohat Formation this was seen. Cementation also seen in Alveolina fossil (Figure 4.3).

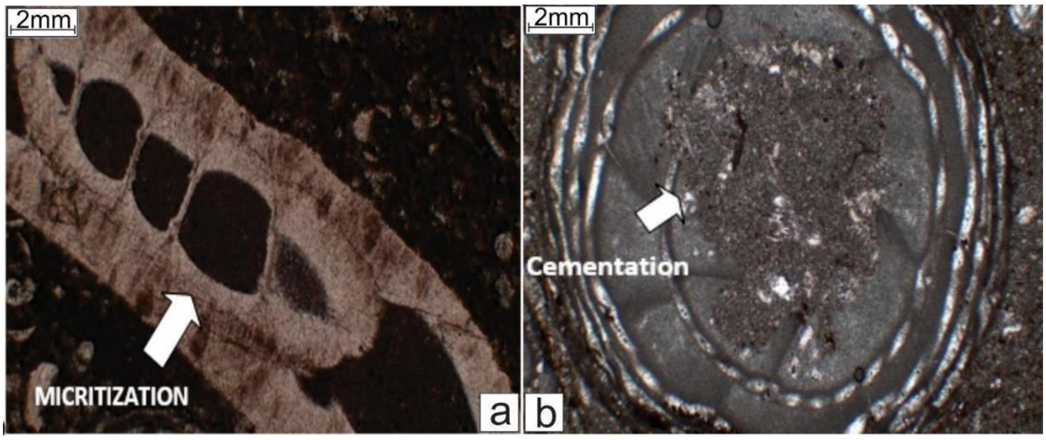


Figure 4.3: Photomicrograph showing (a) the process of micritization in internal structure of Assilina, (b) the process of cementation in Alveolina.

4.2.3 Recrystallization

A fossil's bone or original shell fil into a new material which is made up with the same chemical components by the transition of the minerals is known as recrystallization. A more stable variant of the same chemical, (Calcite) from aragonite fossil shells frequently recrystallizes. By recrystallization the original fossil's shape keeps, albeit minute features as new crystals emerge which may be lost. In Nummulites they are recrystallize by calcite, widely observed this phenomenon (Figure 4.4).

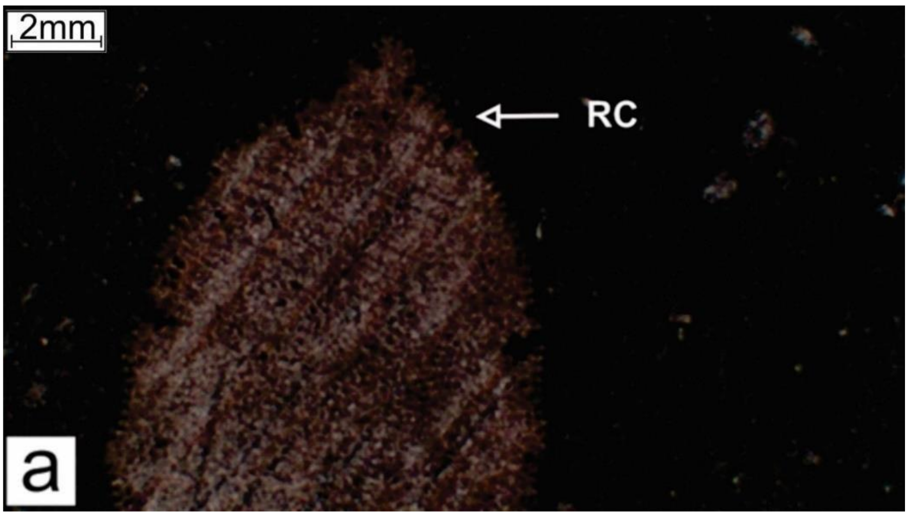


Figure 4.4: (a) Photomicrograph showing the process of Recrystallization (RC)

4.2.4 Neomorphism (Aragonite to calcite transformation)

When aragonite unstable mineral is transformed by low magnesium calcite iscalled Neomorphism (Figure 4.5).

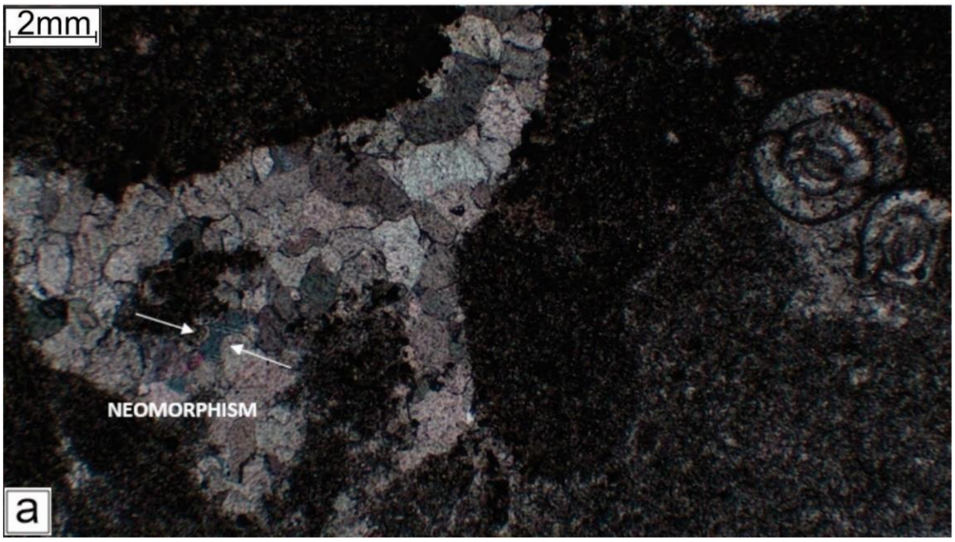


Figure 4.5: (a) Photomicrograph showing the transformation of aragonite to low Mg calcite

4.2.5 Calcite filled microfractures

By overlying rocks pressure or due to tectonic forces the fractures are normally produced in carbonate sediments (Tucker and Wright, 1990; Flugel, 2010). The porosity and permeability present in the rocks due to the presence of fractures is enhanced. However, in the rocks when fluid circulating, fill these fractures, are called as veins (Figure 4.6).

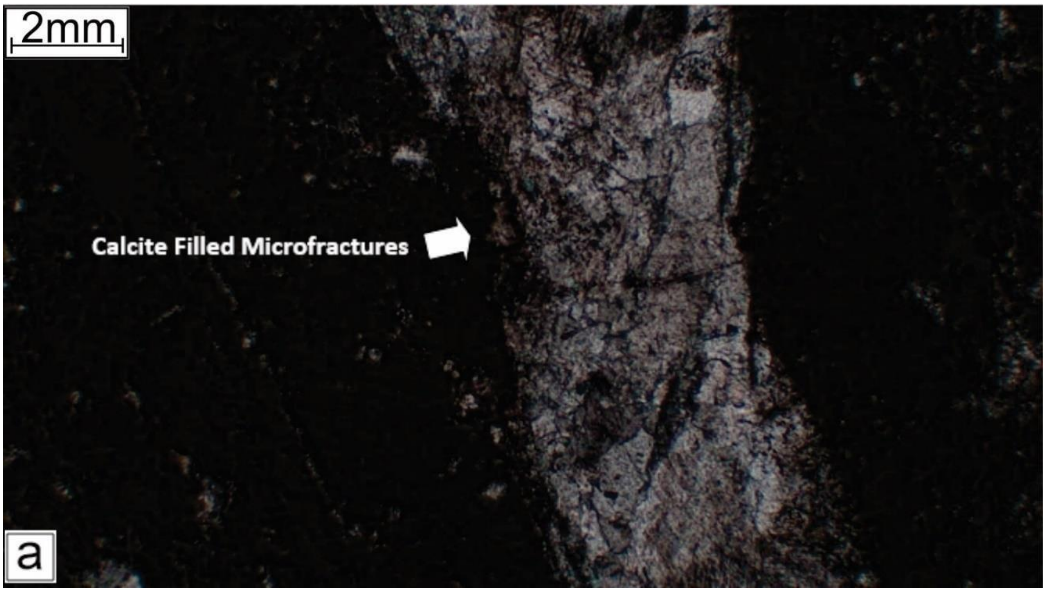


Figure 4.6: (a) Photomicrograph showing the calcite filled microfracture.

4.2.6 Compaction

The overlying rocks pressure refers compaction that influence to change the original Rock fabric that are further divided into 2 types;

1. Physical compaction
2. Chemical compaction

In-situ brecciation of the allochems resulted by Lithospheric pressure and related to shallow burial process. Stylolite's were one of the striking features of chemical compaction, which is also formed by pressure solutions or by tectonic process, (Park and Schott, 1968) during early stage mostly stylolite initiated because of burial activity can be seen in (Figure 4.2).

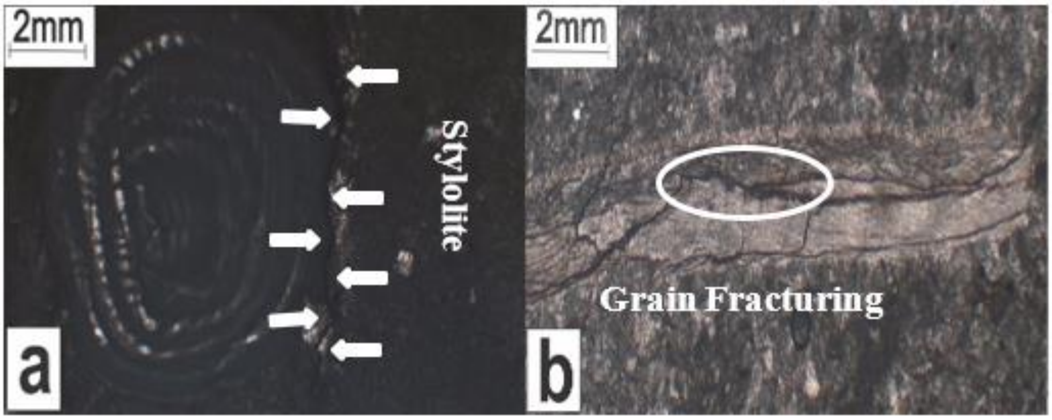


Figure 4.7: (a-b) Photomicrograph showing the process of compaction (Stylolite and fracture in grains).

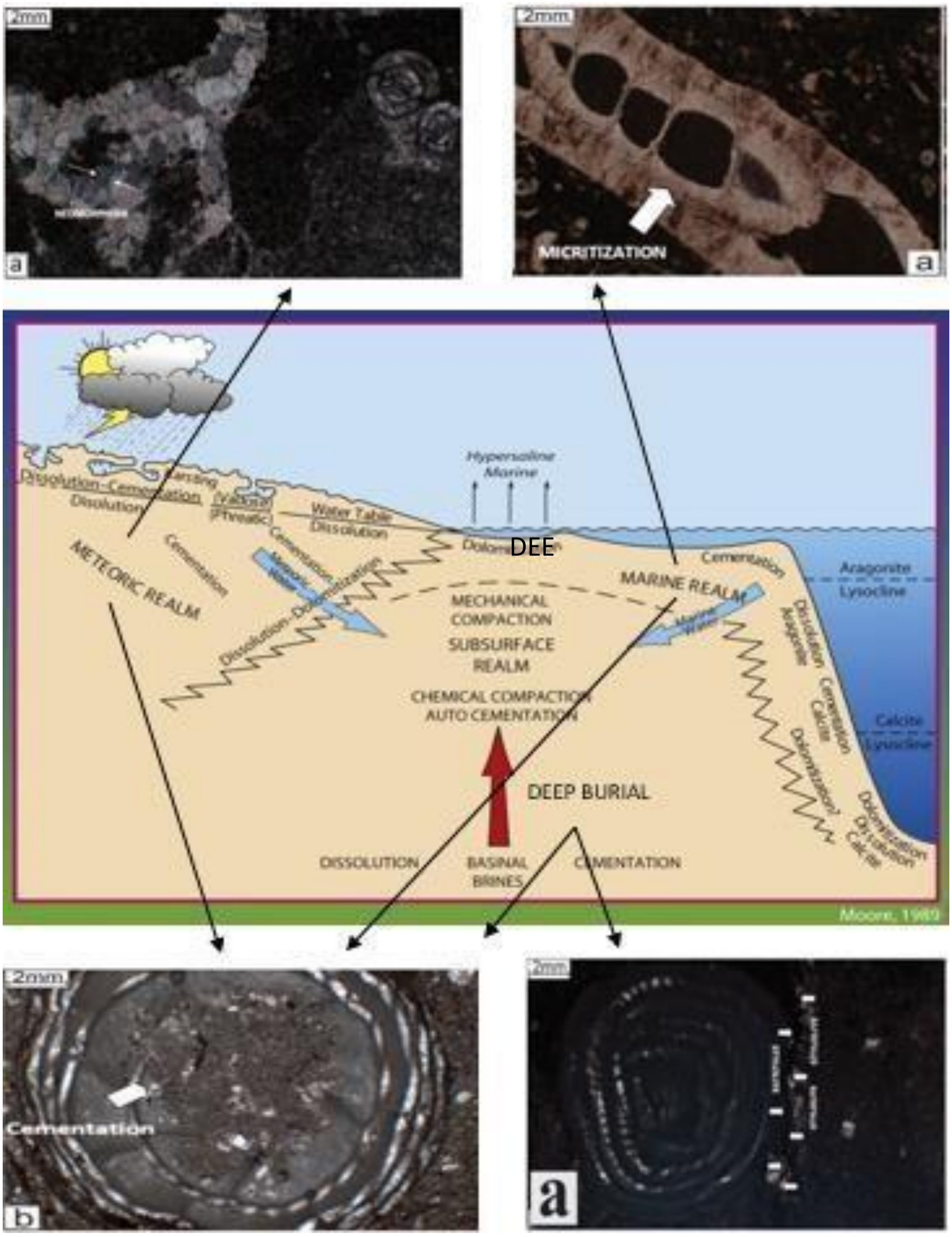
4.3 Diagenetic Environment

The diagenetic environments based on Recrystallization, Compaction, Micritization, Neomorphism, and Calcite filled microfractures indicates marine-meteoric-burial environment (Figure 4.7).

Stylolite's calcite filled veins micro fractures results from physical & chemical compaction that are observed in the current study of Kohat Formation

Micritization and Cementation in this study shows marine diagenetic environment, while Neomorphism shows the sign of meteoric environment in Kohat Formation (Flugel, 2010)

Neomorphism **Micritization**



Cementation **Stylolization**

Figure 4.7: The simplified scheme shows major diagenetic environments for KohatFormation (Moore, 1989)

CHAPTER 5

MICROFACIES ANALYSIS

5.1 Introduction

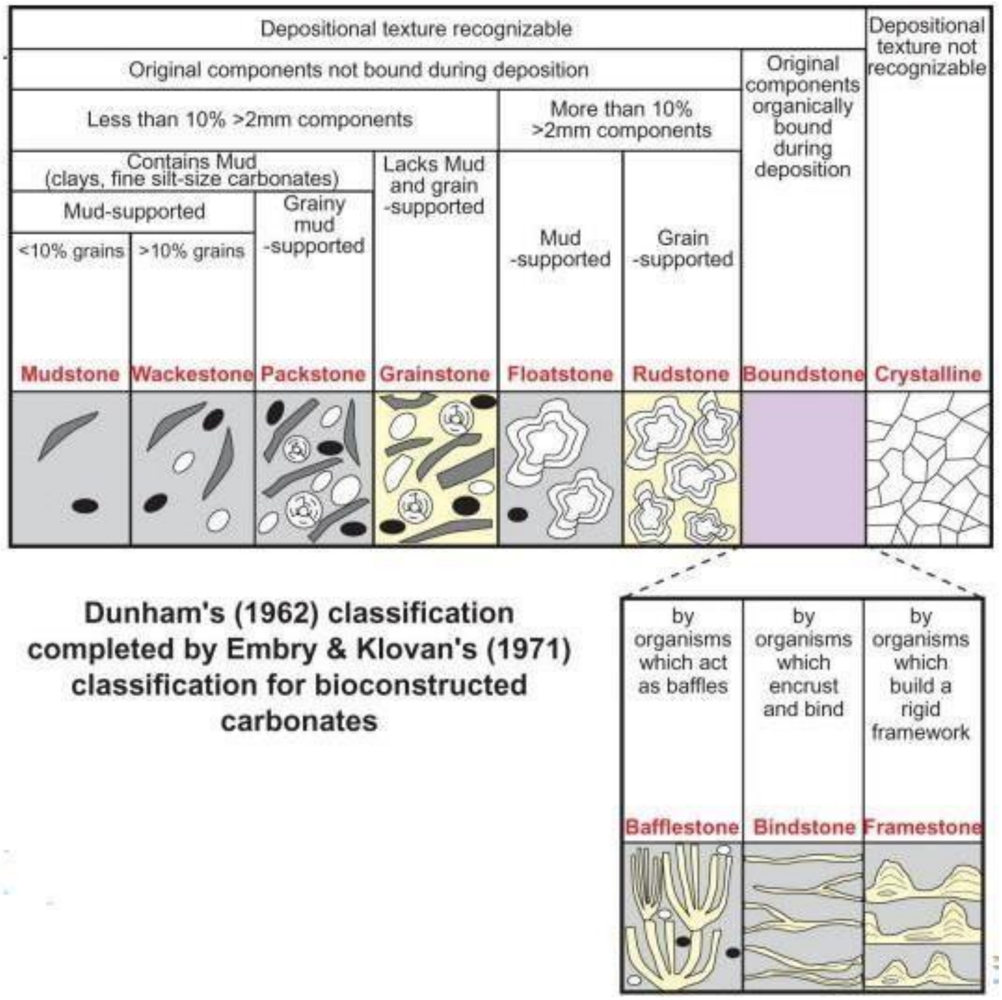
Microfacies described by the Brown (1943) and after by Cuvillier (1952) as "microfacies referred only to petrographic and paleontological criteria studied in thin sections". On the other hand, Flugel (2010) described microfacies as "today microfacies is considered as "the total of all sedimentological and paleontological data that can be described and classified from thin sections, peels, polished slabs or rock samples".

Tucker and wright (1990) defined facies as a set of sedimentary attributes like fossils content, a suite of sedimentary structures, color, texture and characteristics lithology. Based on lithology, fauna, trace fossils and the lateral subdivision of a stratigraphic unit are called Bio facies. Lithofacies and Ichno facies respectively. Facies have some significance and are genetically related are grouped as facies association. Although in vertical succession facies described by a change in one or more parameters, e.g. facies succession is sedimentary structure, abundance of sand and grain size. Facies model is a depositional system involving many examples from ancient rocks and recent sediments. When interpreted under fixed pattern of processes a facies model is said to be static at the same time for interpreting lateral and vertical facies distribution a dynamic facies model is used under different conditions (Flugel 2004).

5.2 Microfacies analysis

The eighteen fresh rock samples, were collected from Kohat Formation, exposed at Sumari village, Lachi, Kohat. The microfacies analysis details the allochems, matrix, textural features, fossils content of the lithofacies. Valuable information for the interpretation of depositional environments provided by abundance, size and type of the foraminiferal tests along with invertebrate fauna (bivalves, bryozoans, brachiopods, gastropods and echinoids). The petrographic classification of rocks follows the Dunham (1962) classification of carbonate rocks (Table 5.1)

Table 5.1: Dunham classification scheme of carbonate rocks (after Dunham 1962)



5.3 Field observations

For different sedimentary deposits we must need some field observation, Geologywithout field is no geology. The basic criteria studied in the field observations lithology, texture composition, bedding, rock type, sedimentary structures, color of rock or lamination, and diagenetic features and fossils and biogenic structures. Tucker (1982) gave a highly recommended description of field methods.

5.4 Lithology, texture and rock colors

5.4.1 Lithology

A major portion of i.e. 20-25 % of all sedimentary rocks are made up of Carbonates rock and are classified into limestone and dolostones (Figure 6.1). Dolostones is mainly composed of >50 percent of Ca Mg (CO3)2 while Limestone is mainly composed of 50% of CaCO3 and they are further divided into dolomites and calcitic dolostones (50-90% dolomite). Mixed siliciclastic-carbonates lithologies consist of argillaceous limestone, marls (65-35%) carbonates and (35-65% clay) and sandy limestone (Tucker 1982).

5.4.2 Textures

For identification of different texture of Limestone, Dunham (1962), classification is mainly used. On the presence of fossils in the studied formations this classification is totally quantitative based.

5.4.3 Rock color

Ranging from grey to light gray, creamy, pale yellow, Limestones are present in various color shades but depends upon the condition at the time of deposition.

By taking fresh and weathered outcrop samples rock color can be prepared. Color of the carbonate rocks are strongly affected by the factors like weathering, depositional settings and diagenesis.

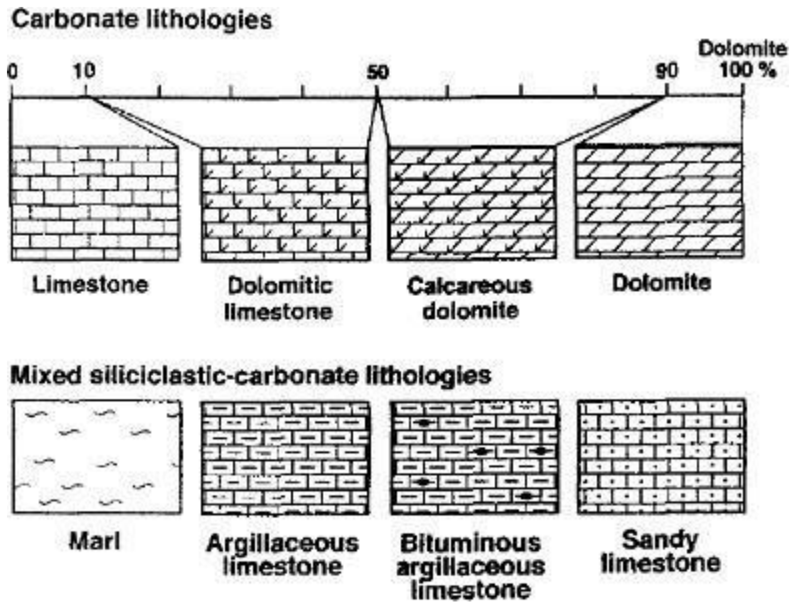


Figure 5.1: Common lithologies of carbonates rocks and mixed carbonate-siliciclastic rocks. The symbols used are those from the standard Shell Legend.

5.5 MICROFACIES OF KOHAT FORMATION

At Sumari village the carbonates of the Kohat formation have been grouped into six microfacies. During the deposition of formation these microfacies are compared to Flugel (2004) which describes the different depositional settings prevailed.

5.5.1 Facies Analysis

5.5.1.1 Nummulitic Packstone Microfacies KF 2

This unit is represented by massive bedded limestone with interbedded shale and is present at the base of the Kohat formation composed of hard grey limestone. The KF-2 microfacies is characterized by a rich allochem constituents of Nummulites with algae- corals suggested by petrographic studies (Plate 5.1; Fig a). 3:1 grain to matrix ratio were observed in this vary microfacies. The matrix observed is almost 29% and the grain abundance is almost 71%. The main allochem constituents are bioclasts, Nummulites and algae corals having an average of 71% to total constituent. The allochems are dominantly composed of bioclasts (40%), Nummulites (7%) and algae corals (25%). Sparry cement filled intergranular spaces.

Depositional Environment

Current observation of Nummulites and other foraminifera in current study thin sections suggest open marine and inner ramp environment of deposition. (Adabi et al., 2008).

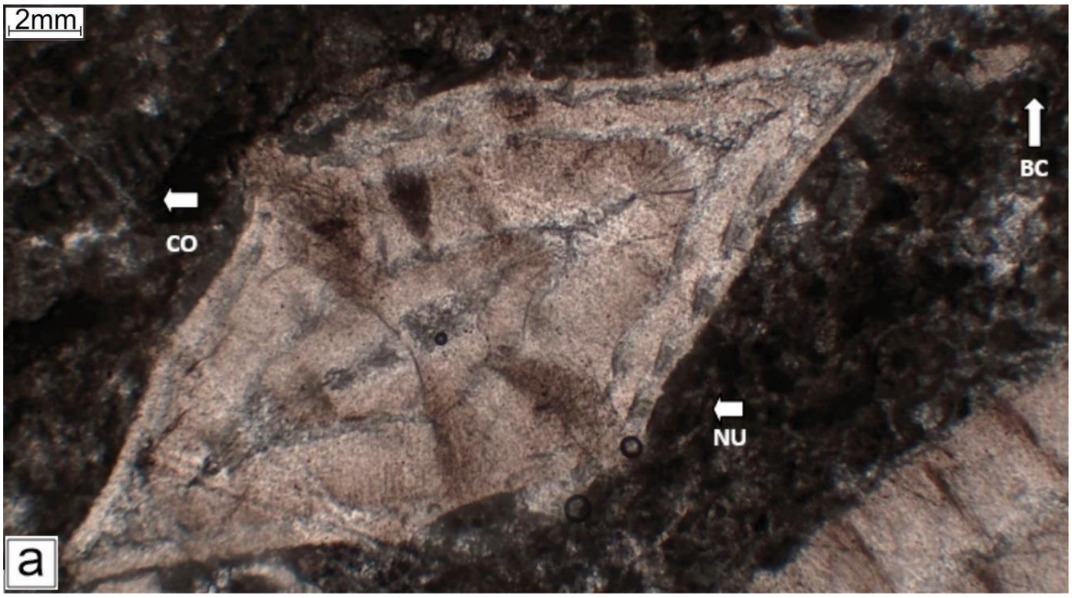


Plate 5.1: Photomicrographs of KF-2 microfacies. The Allochems of this microfacies is dominated by Nummulites (NU), Bioclasts (BC) & Corals (CO) in [A].

5.5.1.2 Algal-Miliolid Wackestone-Packstone Microfacies KF-5/6/11/13

This rock unit is represented by thick to medium bedded, grey color nodular limestone. These facies are highly fossiliferous and fractured. The original fabric was lost as intensity of bioturbation was very high. Microfacies reveals depositional texture of wackestone-packstone when thoroughly studied under microscope. The grains in the 18 microfacies are mainly composed of miliolid shells and algae. Therefore algae, Bioclasts and Nummulites are also present (Plate 6.2; Fig a, b, c & d). Calcite veins are clearly visible (Plate 5.2; Fig a).

1:1 grain to matrix ratio is observed, having abundance of 53% of grains and 47% of matrix. Percentage of allochems varies in different range mainly from 48-56%, with an average of 52%, mainly composed of 20% of bioclasts, along with 14% of Miliolid, 12% of algae, and 6% of Nummulites. Mainly empty structures are filled with calcite having 8-12%with an average of 10%.

Depositional Environment

Association of Miliolid (Hypersaline) warm water condition, along with nutrient rich and Algae (open marine) environment suggests deposition in low to moderate energy in transition zone between sand shoal and a lagoonal environment of deposition. (Heckel, 1972; Flugel 1982, Tucker and Wright, 1990; James and Dalrymple, 2010).

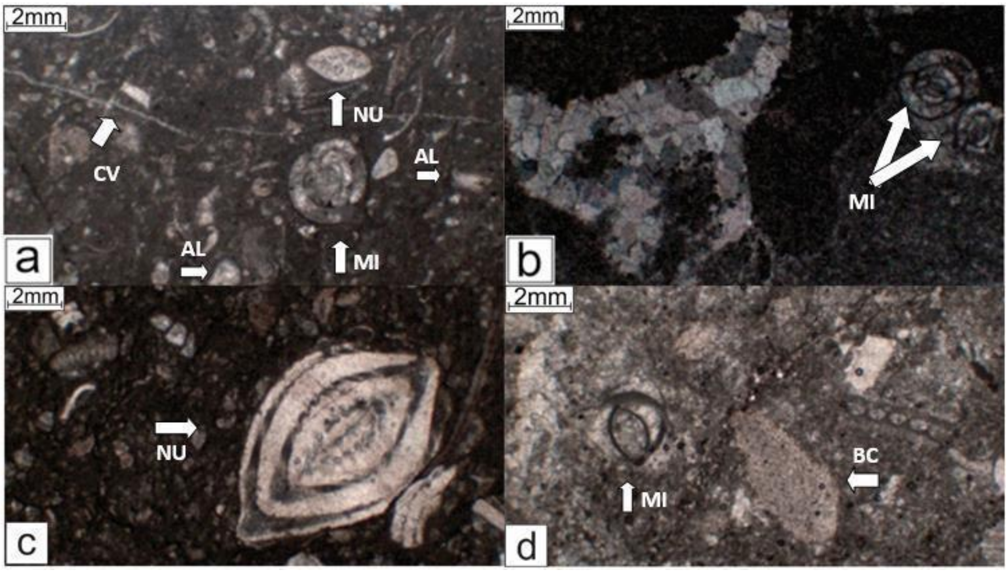


Plate 5.2: Photomicrographs of KF-5/6/11/13 microfacies. The Allochems of this microfacies is dominated by Miliolids [MI in (a), (b), (c) and (d)], Nummulites [NU in (d)], Algae [AL in (B) and(a)], Calcite veins [CV in (c)].

5.5.1.3 Bioclastic Packstone Microfacies KF-12/14

Medium-thick bedded, dark gray to light grey nodular limestone represents Bioclastic Packstone Microfacies. With variable bioclasts this microfacies is highly fossiliferous. The identifiable fossil includes Bioclasts and Nummulites. Thorough study under microscope reveals Packstone depositional texture of this microfacies. Large variety of bioclastic grains and including Nummulites are observed during the study of KF-12/14 thin section (Plate 5.3; Fig a & b).

1:3 ratio of grain to matrix observed in this Plate. The allochems abundance in the microfacies varies from 45-55%, with an average percent of 50, which are dominantly composed of bioclasts (28%), Nummulites (9%), corals (6%). Calcite filling structures varies from 5-8%, with an average of 7%.

Depositional Environment

The enrichment of this microfacies shows a stabilized condition of transgression. The bioclastic packstone indicates a relatively high energy environment and shows a shoal sequence within the shallowing upward sequence (Flugel, 2004).

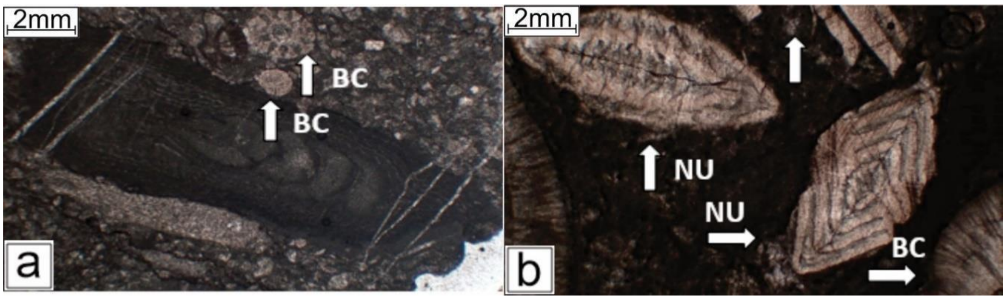


Plate 5.3: Photomicrographs of KF-12/14 microfacies. The Allochems of this microfacies is dominated by Nummulites [NU in (b)], Bioclasts [BC in (a) and (b)].

5.5.1.4 Bioclastic Wackestone Microfacies KF-7/8/15

This unit is represented by thick bedded limestone, dark grey to yellowish grey in color. This microfacies is richly fossiliferous and moderately bioturbated. The fossil includes Nummulites and other Bioclasts, under microscope the study suggests depositional texture of wackestone. A variety of grains including Nummulites, Miliolid algae, Alveolina elliptica and corals are observed in KF-7/8/15 thin section, Allochems were encountered during the study (Plate 5.4; Fig a, b, c & d). Calcite veins were also observed in this microfacies (Plate 5.4; Fig c & d).

Allochems are the main constituent in this microfacies, which ranges 41-45%, having an average of 42%. This microfacies has 1:3 grain to matrix ratio, dominantly composed of allochems and having 16% of Alveolina elliptical, along with 8% of bioclasts, 9% of Algae-Miliolid, 4% of Nummulites. 4-6% structures are filled by calcite with an average of 5%.

Depositional Environment

The micritization of bioclasts, bioturbation and presence of the fossils like Miliolid's & Alveolina suggests deposition of the KF-7/8/15 microfacies in the distal inner ramp to proximal middle ramp setting (Tucker & Wright, 1990).

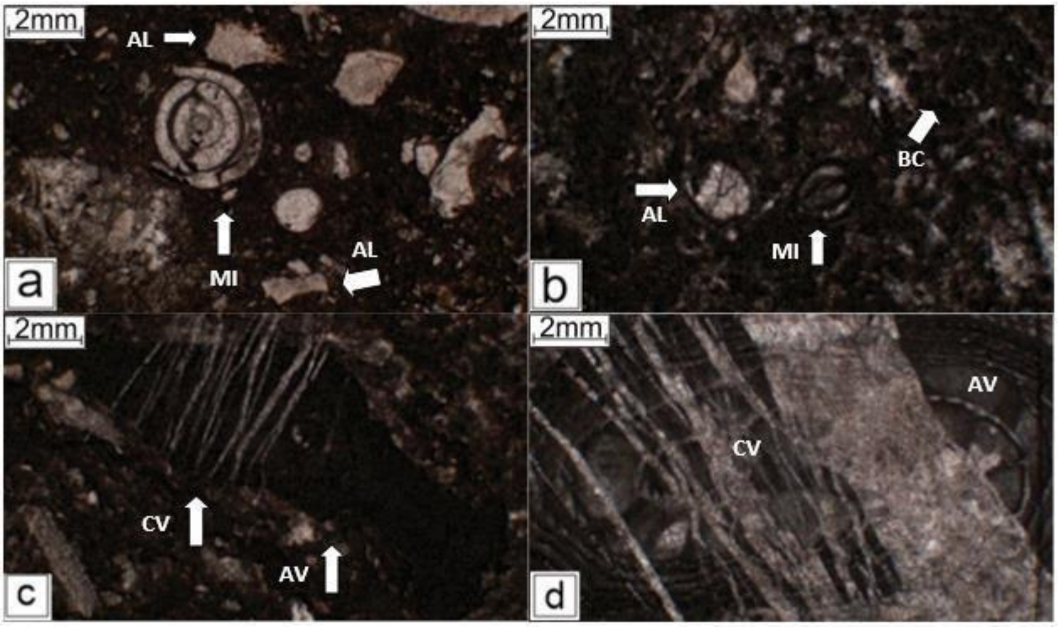


Plate 5.4: Photomicrographs of KF-7/8/15 microfacies. The Allochems of this microfacies are dominated by Miliolids [MI in (a) and (b)], Alveolina elliptica [AV in (c) and (d)], Algae [AL in(B)], Corals [CO in (a) and (b)], Calcite Veins [CV in (c)].

5.5.1.5 Nummulitic Grainstone Microfacies KF-9/10/16

The Nummulitic grainstone microfacies comprised of limestone which is argillaceous in nature and yellowish grey in color. The depositional texture in grainstone is shown in the petrographic studies. The KF-9/10/16 microfacies is characterized by diverse allochems that include Assilina, Nummulites exponents and Bioclasts (Plate 5.5; Fig a, b, c,& d) Calcite replacement have also been observed (Plate 5.5; Fig c & d).

Dunham (1962), termed rock as grainstone which contains more the 10% of grains. 9:1 matrix to grain ratio with an average have these microfacies. The abundance of matrixis almost 8% while rest 92 % is almost grain. Allochems ranges from 60-75% with an average of 65%, dominantly composed of Nummulites (27%) Assilina (23%) and bioclasts (15%).

Depositional Environment

Presence of Nummulites, Assilina, and micritic matrix indicate that the KF-9/10/16 microfacies was deposited in open marine conditions of the distal middle ramp settings (Wright, 1992; Flugel,2004).

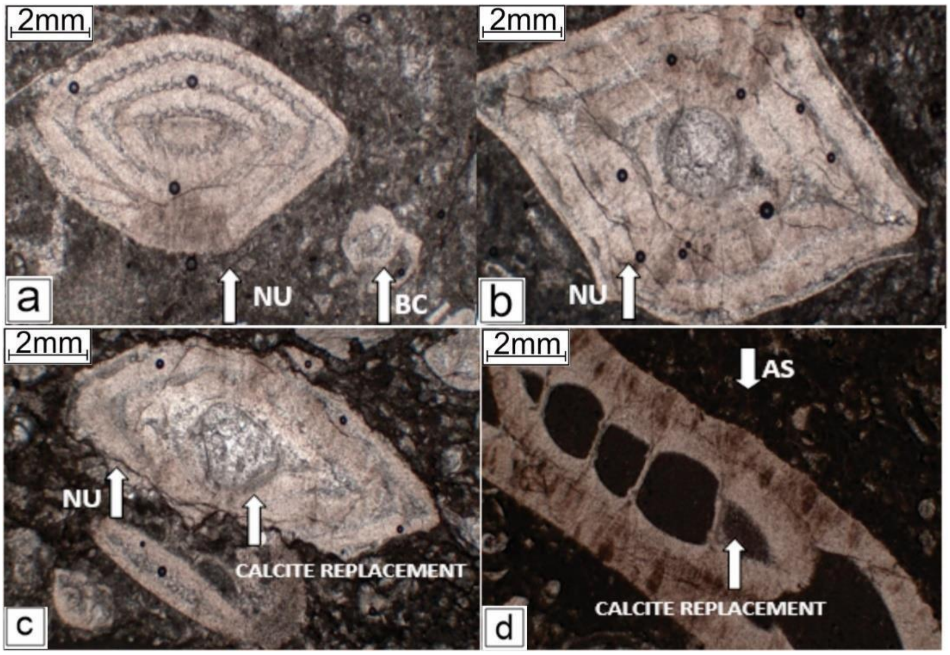


Plate 5.5: Photomicrographs of KF-9/10/16 microfacies. The Allochems of this microfacies is dominated by Nummulites [NU in (a), (b) and (c)] Assilina exponents [AS in (d)] Bioclasts [BC in (a)], Calcite replacement in [(c) and (d)].

5.5.1.6 Medium Bedded Mudstone Microfacies KF-9/1/3/4

In the upper part of Kohat Formation this medium bedded mudstone microfacies is present and is represented by thin bedded limestone with interbedded shale. The limestone is light-to dark grey in color. Due to high bioturbation the original texture of this microfacies has been destroyed. Microfacies has a depositional texture of mudstone is revealed by the petrographic study. The KF-9/1/3/4 microfacies is characterized by diverse allochems that include Nummulites, Assilina, Algae and Corals (Plate 5.6; Fig a, b, c & d), while lime mud is acting as cementing material in these facies.

Dunham (1962), termed rock as Mudstone which contains less the 10% of grains. 1:9 grain to matrix ratio, having 92% matrix and 8% grains, Allochems in the microfacies varies from 10 percent to 18 percent, with an average of 14 percent. The allochems are dominant in Nummulites (2%) Assilina (2%), algae (1%), corals (2%) and bioclasts (5%). The microfracture are filled with spar.

Depositional Environment

The presence of lime mud and presence of fossils like Nummulites, Assilina indicate that the KF-9/1/3/4 microfacies was deposited in the open marine inner shelf environment (Wright, 1992; Flugel, 2004).

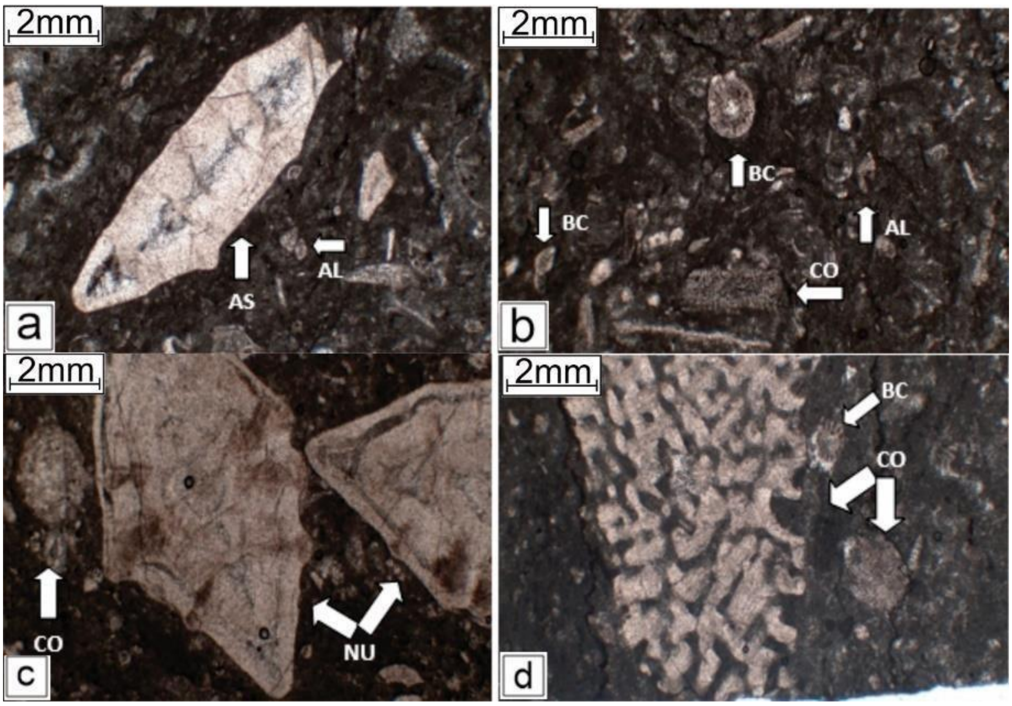


Plate 5.6: Photomicrographs of KF-9/1/3/4 microfacies. The Allochems of this microfacies is dominated by Nummulites Mammalitus [NU in (c)], Assilina Indicatrix [AS in (a)], Bioclasts [BCin (B) and (d)], Algae [AL in (a) and (b)], Corals [CO in (c) and (d)]

Table 5.2: The petrographic table of microfacies of Kohat Formation at Sumari village, Kohat.

	Allochems											
Thin Section No	Assilina %	Nummulites %	Alveolina %	Bioclasts %	Corals %	Miliolids %	Algae %	Calcite Veins %	Allochems %	Grain Matrix %	Matrix %	Classification Dunham 1962
KF-2	-	7	-	40	25	-	-	-	71	3:01	29	Packstone
KF-5/6/11/13	-	6	-	20	-	14	12	10	53	1:01	47	Wackestone-Packstone
KF-12/14	-	9	-	28	6	6	-	7	50	1:03	28	Packstone
KF-7/8/15	-	4	16	8	-	9	-	5	42	1:03	47	Wackestone
KF-9/10/16	23	27	-	15	-	-	-	-	65	9:01	8	Grainstone
KF-9/1/3/4	2	2	2	5	2	-	1	-	14	1:09	92	Mudstone

5.6 Depositional Model

Generalized model for depositional system was given by (Walker, 1992). Following model (Figure 5.2), illustrate different microfacies and their environment of deposition based on detailed microscopic studies which suggest marine to meteoric burial environment of deposition, ranging from inner ramp to middle ramp settings.

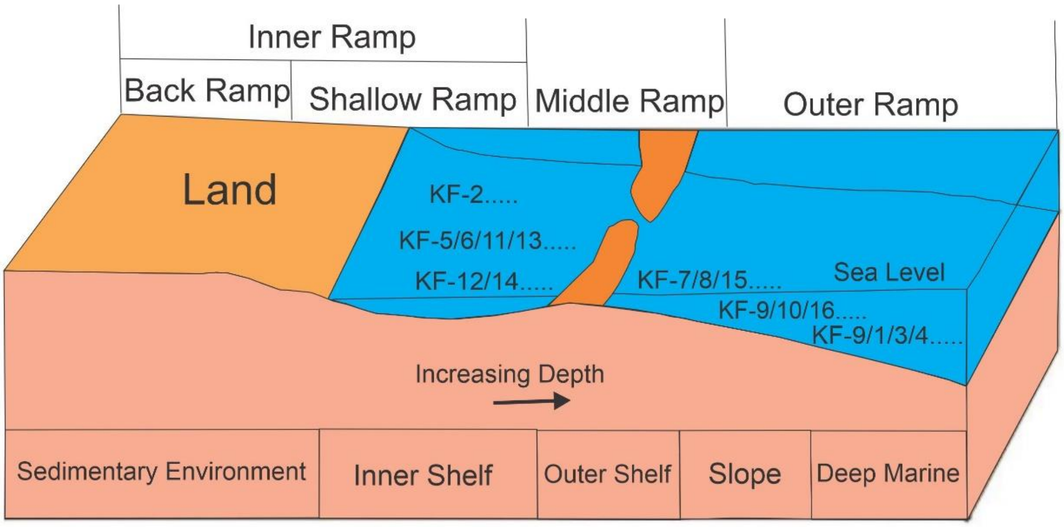


Figure 5.2: Schematic depositional model of Kohat Formation based on the interpretation of Microfacies

Table 5.3: Showing Microfacies Analysis from some specific Thin Sections

Thin Section no	Microfacies
KF-2	Nummulitic Packstone
KF-5/6/11/13	Algal-Miliolids Wackestone-Packstone
KF-12/14	Bioclastic packstone
KF-7/8/15	Bioclastic Wackestone
KF-9/10/16	Nummulitic Grainstone
KF-9/1/3/4	Medium Bedded Mudstone

CONCLUSIONS

Based on thorough geological studies of the Kohat Formation at Sumari Village,Kohat Pakistan, the following conclusions are;

To achieve the objectives in the current research done conclude;

The faunal assemblages in Kohat Formation which are identified belongs to three Genera's; Nummulites (Nummulites atacicus, Nummulites globulus, Numulites subirregularis, Numulites mamillatus), Assilina (Assilina granulosa & Assilina laminose) and Alveolina (Alveolina elliptica, Alveolina stercusmeris, Alveolina globula, Alveolina frumentiformis & Alveolina indicatrix.

Based on primary sedimentary features and lithology, fourteen lithofacies (KF-1 toKF-16)) are recognized. In the study area the formation is mainly sub-divided into six microfacies,which are vertically repeated in the various sections. These microfacies are;

1. Nummulitic Packstone Microfacies KF-2.
2. Algal-Miliolid Wackestone-Packstone Microfacies KF-5/6/11/13.
3. Bioclastic Packstone Microfacies KF-12/14.
4. Bioclastic Wackestone Microfacies KF-7/8. /15.
5. Nummulitic Grainstone Microfacies KF-9/10/16.
6. Bioclastic Mudstone Microfacies KF-9/1/3/4.

Interpretation of diagenetic features such as recrystallization, compaction, micritizations, neomorphism and calcite filled microfractures indicates marine to meteoric to burial environment of deposition.

Stylolite's, Microfractures or calcite filled veins result from physical & chemical compaction in the Kohat Formation.

Neomorphism indicates Meteoric while Micritization/Cementation indicates Marine Diagenetic Environment of deposition in the Kohat Formation.

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