DEPOSITIONAL AND DIAGENETIC SETTING OF LOCKHART LIMESTONE, NAMMAL GORGE SECTION, WESTERN SALT RANGE, PAKISTAN

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of M.S in Geology

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APPROVAL OF EXAMINATION

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DEDICATION

I dedicated my thesis to my family and teachers

ACKNOWLEDGEMENTS

All glorification and reverence belong to Allah S.W.T and it is of utmost significance to bow my head before Allah almighty, who is the solitary provider of all erudition. The greatest of all, who refine my heart with enhanced perceptions and blessed me robustness to complete my research.

I am appreciative of my dear parents well wishes, prayers and unwavering love for helping us to accomplish our objective. I owe a great deal of gratitude to my supervisor Dr. Mumtaz Ali Khan, Senior Assistant Professor, Bahria University H-11 campus in Islamabad Department of Earth and Environmental sciences. I appreciate the trust you placed in me, and I would always remember your support during the entire time.

ABSTRACT

This research is unified sedimentological approach to analyze microfacies, diagenetic characteristics and evaluate the biostratigraphy of Lockhart Limestone of Nammal Gorge area, Western Salt Range, Pakistan. The Paleocene rocks of Nammal Gorge form one of the important stratigraphic sections in Pakistan. This study investigated 4 main microfacies and 13 sub-microfacies of Lockhart Limestone by comparing each microfacies with Dunham Classification Scheme (1962) and points counting menthod. The grainstone, packstone and boundstone microfacies and their sub-types dominate the observed thin sections, whereas the wackestone microfacies are less common in the study area. There are six sub-microfacies of grainstone and three sub-microfacies of packstone and boundstone respectively, strongly suggests that the Lockhart Limestone was deposited in moderate to high energy environment. The presence of Foraminifera; like *Lockhartia sp, Miscellanea sp, Assilina sp, Operculina sp, Ranikothalia sp, Millliods, Textularia sp, and Globogerina linaperta* etc has helped to determine the environment of deposition was shallow marine. *Lockhartia sp*, was dominantly found in the studied thin sections, that is index fossil of these Paleocene rocks. Moreover the diagenetic alterations like aragonite to calcite conversion, diagenetic alterations like physical compaction, chemical compaction, stylolamination, suture seams, brecciated stylolitic fabric, stylolitization, Nodular stylolitic fabric, aragonite to calcite conversion etc, was observed in the study. Nodular stylolitic fabric alongwith aragonite to calcite conversion is believed to be occurred in Inner Ramp facies. The establishment of micorfacies, biostratigraphy and diagenetic alterations patterns of Lockhart Limestone suggest that these rocks were deposited in Inner Ramp Lagoonal environment.

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CHAPTER 1
INTRODUCTION

Massive oil and gas deposits can be found in carbonate rocks, which also include valuable minerals that provide crucial insights into Earth's history. The basis of carbonate systems is the reaction between soluble carbonate and carbon dioxide to create bicarbonate, which, when heated, releases carbon dioxide and turns back into carbonate. Carbonates have an advantage over amine-based systems in that they require a lot less energy to regenerate.

Carbonate rocks have high porosity and permeability, making them ideal reservoirs for petroleum. The main uses of carbonates are as raw materials in different industrial processes like, glass making, pulp and paper industry, soap and detergent preparation, paper production and clay production, etc.

Sedimentary rocks constitute an essential portion of the sedimentary record in the Salt Ranges. The massive sedimentary strata spanning (in age from Precambrian to Paleocene- Eocene) have significant exposure along the southernmost thrust (known as Salt Range Thrust (SRT)) in the Lesser Himalayas, with major unconformities intervening (Kasmi and Jan, 1997). The Nammal Gorge section exhibits a peculiar outcrop where most lithologies depict marine and non-marine (environmental conditions) in the western area of Salt Range.

Rocks (Western Salt Range) have also been studied extensively in various disciplines (stratigraphy, biostratigraphy, paleontology, micropaleontology, sedimentology, structural geology, etc.). This study is an integrated sedimentological approach to microfacies analysis, diagenetic features, and biostratigraphic analysis of Paleocene rocks of the Lockhart Limestone in the Mianwali region of Pakistan. The different microfacies (Lockhart Limestone) were established according to Dunham's classification scheme (1962). Mianwali District contains a sedimentary province that is considered as museum of geology. Earlier research workers who devoted their efforts to the area were Shah(1977), Fatmi (1973, 1972), Kummel and Tiechert (1970), etc.

The Salt Range is restrained between the latitudes 32° 18' to 33° 06' N and longitudes 71° 50' to73° E, developing a mountain range in the province of Punjab. The Salt Ridge is about 175 km long and runs East-West. The Salt Ridge was created by the collision (Indo-Pakistan Plate and the Eurasian Plate) since the Eocene, resulting in the southern Himalayan foreland fold and thrust belt (James and Lillie, 1998).

1.1 Location and access

The particular subject is the Lockhart Limestone (Nammal Gorge) Mianwali, Pakistan. Lockhart Limestone is very well exposed in Nammal Gorge (Pakistan Regional Topographic Map No. 38P/8). Nammal Gorge occurs around 200 km south of Islamabad, on the Talagang- Mianwali Highway (Musa Khel Road), and about 28 km from Mianwali town. The coordinates of Nammal Gorge are 3239’ 54” N and 71 48’ 07” E (Figure 1.1).

Fig. 1.1 Location (Google map) of Lockhart Limestone Nammal Gorge area, Western Salt Range, Punjab, Pakistan.

The geological map of the Salt Range and adjoining areas is given below, where the blue box in the map represents the study area (Fig.1.2).

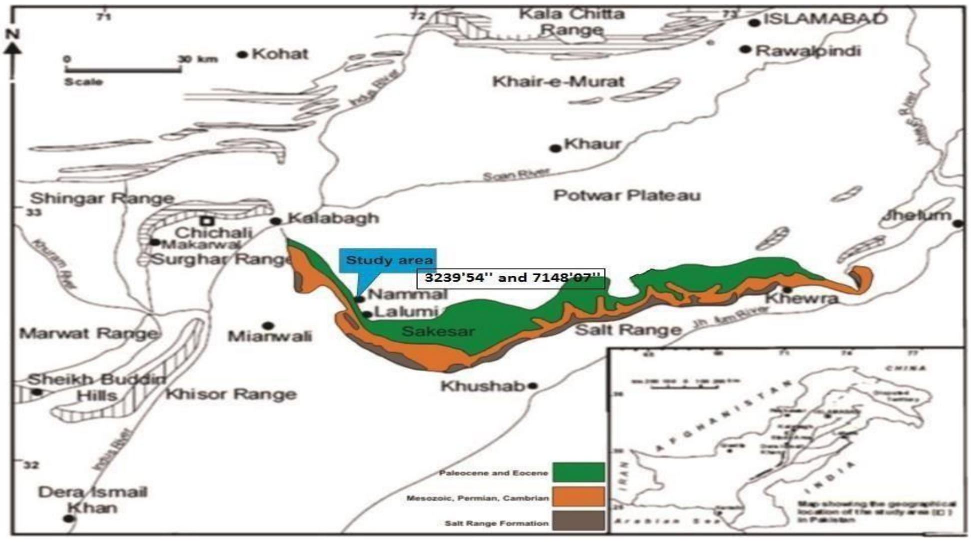


Fig. 1.2 Geological map of Salt Range and adjoining area depicting the location of study area in Nammal Gorge Section by blue box (after Gee, 1989).

1.2 Literature Review

Geologists were attracted from all over the world to the Salt Range, also known as the "Geological Museum," where the entire strata (Precambrian to Recent) were exposed. Gee (1935–1955) spent his entire geological career in studying the Salt Range. Fatmi (1973) examined the Triassic ceratides. Wignall and Hallam (1993) investigated Griesbachian (earliest Triassic) paleoenvironmental conditions (in the Salt Range).

Hermann and colleagues (2011) added fresh data from lithology, organic matter (POM), total organic carbon (TOC), to their understanding of the Early Triassic (marine and non-marine paleoenvironmental) conditions. New carbon-isotopic data enables comparison with other Tethyan areas (for example, South China). The Early Triassic record (Salt Range and Surghar Range) is a one-of-a-kind archive that contains valuable information on C-isotopes.

Some researchers have analyzed the lithostratigraphy and structural history of the Salt Range (Fatmi 1973; Shah 1977; Kazmi and Jan 1997). Many researchers analyzed the faunal successions (Schindewolf 1954; Sarjeant 1970; Grant 1970; Sweet 1970; Balme 1970; Guex et al. 1978; Bruwhiler et al. 2001(a), 2011; Hermann et al. 2011, 2012) to determine the Permian-Triassic boundary.

Shah, 1977 gave the Triassic-aged rocks in the Salt Range a name, "Musa Khel Group," in 1980. The phrase "Mianwali Series" was given by Gee and was later renamed Formation by Kummel in 1966. Waagen (1879, 1895) classified this formation into various components, which Kummel (1966) later recognized. Gee (1945) renamed the Middle Triassic non-marine unit of the Musa Khel Group the "Kingriali Sandstone" after modifying it (Tredian Formation). However in-depth Sedimentology of these successions and Paleoenvironmental relevance remain poorly understood, necessitating a comprehensive and complete depositional and diagenetic investigation of the succession (Mianwali and Tredian Formations) in the Salt Ranges.

The Paleocene-Eocene rocks of Nammal Gorge form one of the most significant stratigraphic exposures in Pakistan. The rocks in Nammal Gorge (Paleocene and Eocene) have been studied for the larger and smaller foraminifers. Moreover the researches have been made on the distribution of important microfossil groups (the calcareous Nannofossils), (Köthe, 1988; Dinoflagellates (Köthe, 1988).

Davies and Pinfold (1937) explained bigger foraminifers of the Hangu Formation (Nammal Gorge). Another researcher Haque (1956) conducted research on the smaller foraminifers (Paleocene and Eocene of Nammal Gorge). He explained new species of (Benthonic and Planktonic foraminifers) and made generalized paleo-environmental analysis of these rocks.

1.3 Lockhart Limestone

Davies (1930a) used the word "Lockhart Limestone" to describe limestone (Paleocene) in the Kohat region that was previously known as the "Nummulitic Series" of Middle Miss (1896). Its type section is found in the Samana Range near the Fort Lockhart area.

The limestone in the type locality is gray and beds are medium to thick, massive and foggy at the base. The limestone in the Salt Range Nammal area is grey to light grey in color (medium to thickly bedded, nodular), with modest amounts of grey marl and dark bluish-grey calcareous shale in the bottom section.

The Formations (Hangu and Patala) are both conformably and transitionally overlain and underlain by the Lockart Limestone.

The Nammal area (Paleocene rocks) is believed as important location in respect of regional studies (Hunting Survey Corporation, 1961) and interregional researches (Nagappa, 1959; McGowran, 1968; Adams, 1970). A researcher Adams (1970) identified significance of this locality. He concluded that there should be detailed investigation in this area.

1.4 Objective of the study

a. To analyze the different microfacies, diagenetic characteristics of Lockhart Limestone based on petrographic data. This is determined by using Dunham Classification Scheme (1962).

b. To evaluate the biostratigraphy of the Lockhart Limestone.

c. To determine different diagenetic alterations in Lockhart Limestone.

d. To reconstruct the paleo-environment and depositional setting of the Lochkhart Limestone.

1.5 Materials and methods

The methodology includes following work.

1.5.1 Field work

In field work, changes have been noted in lithology and many other characteristics like (color, nodularity, texture, fossil contents and bedding style etc.). Field photographs are given to depict the studied rocks (Fig.1.3, 1.4, 1.5).

Fig. 1.3 Lockhart Limestone of Nammal Gorge at top.

Fig. 1.4 Nodular bed of Lockhart Limestone in Nammal Gorge area.

Fig. 1.5 Lockhart Limestone is indicated by arrow in Nammal Gorge.

1.5.2 Sampling

Samples from the field were collected on the basis of facies change and bed to bed variations. The data such as sample description, lithology, field photographs, was recorded to improve the way of investigation.

1.5.3 Laboratory research

For biostratigraphy and sedimentological research, preparation of thin sections is the important laboratory work. In petrographic laboratory, thin sections were prepared very carefully. The polarizing microscope was used to analyse the prepared thin sections. This helped to determine the various constituents of Lockhart Limestone and to develop the biostratigraphy and microfacies of the Lockhart Limestone. With a digital camera attached to the microscope, microphotographs were taken at preferred locations from thin sections.

Microscopic data such as percentages of cement, matrix and grains was evaluated, based on the petrographic data obtained. The different microfacies of Lockhart Limestone were categorized by using the Dunham classification system (1962). A model of research procedure is given below (Fig.1.6).

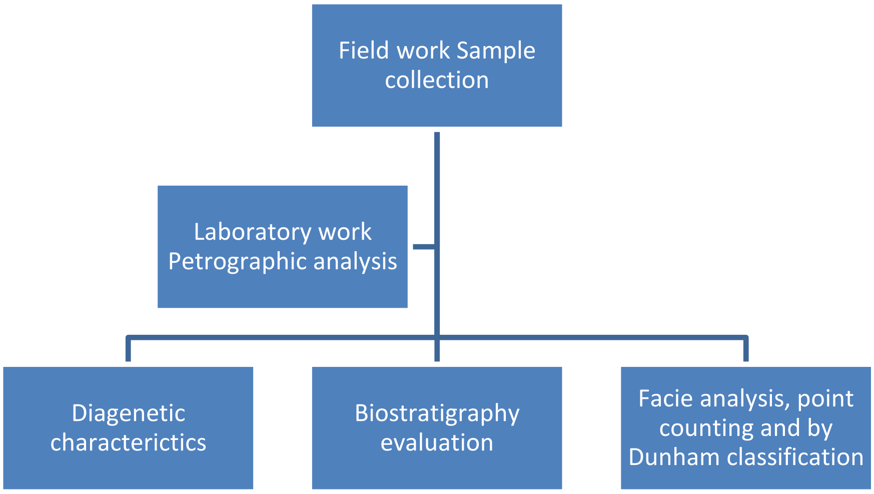


Fig. 1.6 Generalized sketch/model of research procedure.

CHAPTER 2
REGIONAL GEOLOGY

2.1 Tectonic structure

The Himalayan orogeny belt is the world's youngest mountain chain. The Cenozoic tectonic activity known as the Himalayan orogeny characterizes the Geology of northern Pakistan. The Himalayas formed when the Indian Plate clashed with the Eurasian Plate at its northernmost boundary.

2.2 Tectonic movements

The Himalayan active mountain range is the result of geodynamic processes that lasted from the middle-late Cretaceous to the early Cenozoic. These procedures are thought to have taken place in three stages (Le Fort, 1989). These are the following:

a. Neo-Tethys closure, oceanic crust subduction towards the north, and the creation of the (Trans-Himalayan Karakoram axial batholiths, middle cretaceous and Kohistan Island Arc) within Neo-Tethys up to the Eocene.
b. Middle cretaceous-Eocene colliding phase, during which two continental masses, the Indian and the Southern Tibet-Karakoram, came into collision, sandwiching the island arc (KohistanIsland Arc).
c. Eocene-Recent (Alpine-Himalayan stage) with thickening of the northern Indian edge andthe piling of a nappe system.

2.2.1 Phase 1

The breakup of Gondwana was caused by a series of events, each of which resulted in the rifting and separation of continental blocks, followed by drifting to the north. Before India was split from Gondwana, a significant chunk of Gondwana was rifted around 250 million years ago (Ma), which eventually became the Mega-Lahasa Block, which included various micro-continents such as Central Iran, Afghanistan, the Karakoram, Northern Lahasa, and Southern Lahasa. This split is marked by widespread volcanism, known as the Panjal Volcanics. When India separated from the rest of Gondwana around 200 million years ago, the Lahasa Block collided with and accreted to Eurasia in the middle Jurassic (Gaetani, 1997), effectively shutting down the Paleo-Tethys. Kohistan-Ladakh Island Arc (KIA) was created on a Neo-Tethyan intra-oceanic subduction zone that later accreted to the Karakoram (during the middle Cretaceous, 100–90 Ma). Towards North, (Kohistan Magmatic Arc aggregated rocks to the Karakoram tectonic block), which includes a combination of tectonically deformed rocks (rangingfrom sedimentary to meta-sedimentary to igneous rocks) along the Main

Karakoram Thrust (MKT) (Tahirkheli and Jan 1979).

2.2.2 Phase 2

The Neo-Tethys closure occurred when the Indian Plate collided with the accreted Eurasian, which included the Kohistan-Ladakh Arc in the northwest and Lahasa in the east. The collision occurred near the Indus Suture Zone (Gansser, 1964; 1979), also known as (MMT) in north Pakistan (Tahirkheli et al., 1979).

2.2.3 Phase 3

The stage of intra-continental tectonics occurs after the collision and suture. This stage is dividedinto two distinct eras.

A time in which south-divergent nappes occur within the suture zone.

The second stage included crustal shearing and doubling.

This is the key Himalayan orogenic event that caused the continental crust to thicken twice.

The shortening has been generally accommodated (by the development of thrust faults) from north to south, namely the Main Central Thrust (MCT), the Main Boundary Thrust (MBT), and the currently active Main Frontal Thrust (MFT),(1984, Burbank and Areynolds). The Salt Range Thrust (SRT) occurred in the southern Himalayas of Pakistan. It is the most southern thrust and is similar to the Main Frontal Thrust in the Central Himalayas. The Himalayan mountain belt is rimmed by the, (Yeats et al., 1984).

2.3 Himalayan Tectonic Subdivisions in Northern Pakistan

The lateral continuity of the Himalayan orogeny's primary tectonic constituents is one of its mostimpressive features. Initially, the Himalayas were separated into many tectonic units. According to Gansser (1964), the Himalayas are divided into the Tethyan, Highter, Lesser, and Sub-Himalayan ranges as shown below (Fig.2.1).

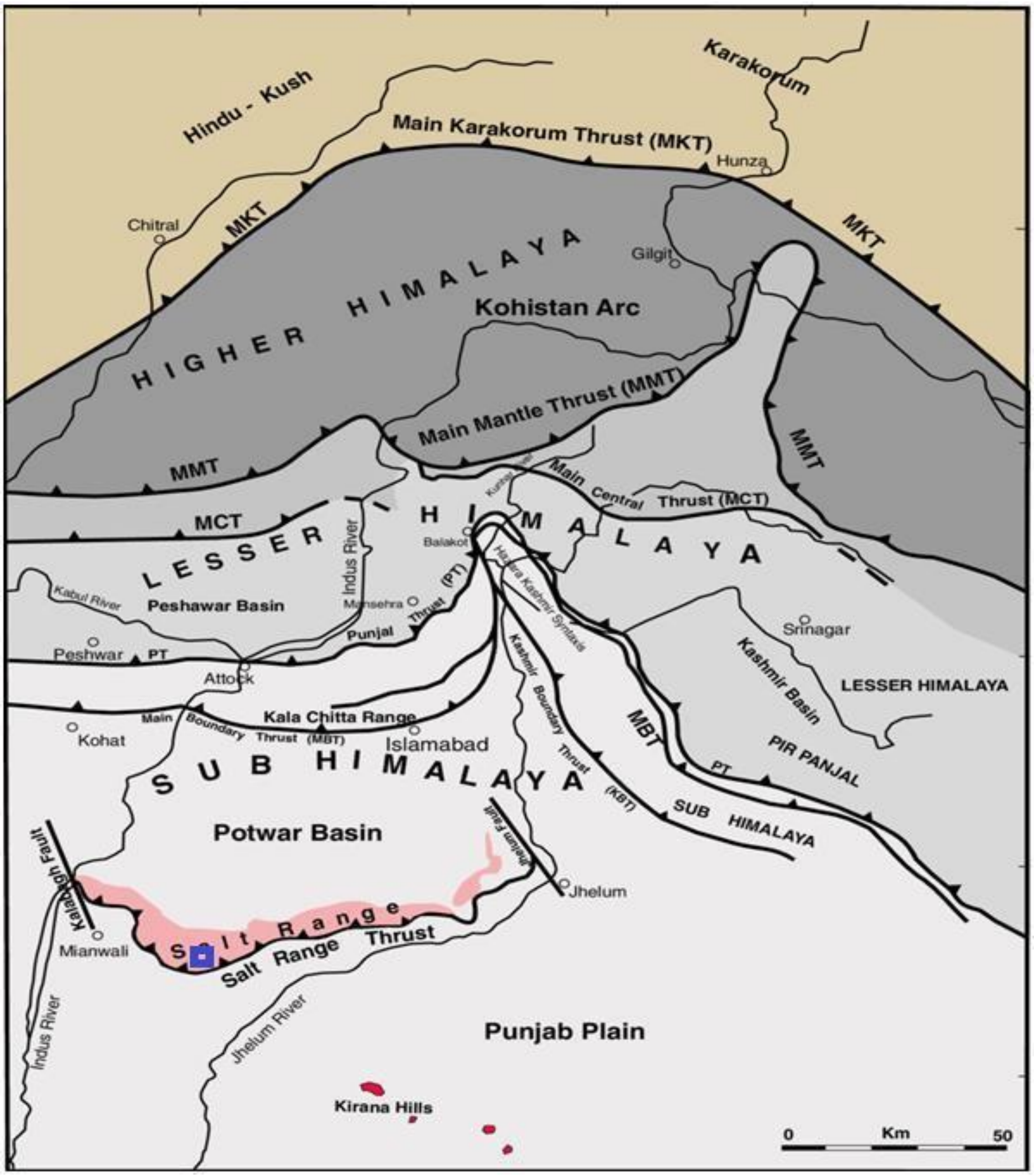


Fig. 2.1 Generalized tectonic map of northern Pakistan, showing a subdivision of the Himalaya Mountains where the blue box shows the study area in Salt Range (Gansser 1981; Kazmi and Rana 1982).

2.3.1 Tethyan Himalayas

The Tethyan Himalayas (TH) is a synclinorium about 100 kilometers wide, produced by severely folded, minimally metamorphosed sedimentary layers. Within this area, other nappes, known as Northern Himalayan nappes, have also been identified. The sediments of the Tethyan Himalayas have an almost complete stratigraphic record spanning the upper Proterozoic to the Eocene and are widely distributed throughout the Eastern and Central Himalayas.

2.3.2 Higher Himalayas

It is comprised of tectonically disintegrated, folded, and overlapping metamorphic and igneous rocks ranging in age from the Precambrian to the early Mesozoic. The MMT is towards the north, whereas the MCT is towards south.

A folded imbricated basement-cover succession, often distorted in amphibolite and green schist facies assemblages, dominates the higher Himalayas (Coward et al., 1987). These facies are extensively intruded by Tertiary granites and pegmatite (Scharer, 1984; Scharer et al., 1986), which were formed by partial melting of the Indian Plate (the subducting one).

2.3.3 The Lesser Himalayas

These are located south of the Main Central Thrust and north of the Main Boundary Thrust. These are various thrust sheets of low-grade metamorphic to non-metamorphosed rocks dating from the Precambrian to the Paleocene epochs.

The Precambrian slates and greywackes of the Lesser Himalayas lie beneath the lower Paleozoic quartzite and a sequence of varying thicknesses of clastic material (Calkins et al., 1975; Latif, 1970). The mountainous hills to the north of Islamabad include carbonates dating from the Mesozoic to the lower Tertiary periods. Carbonates (Mesozoic to Cenozoic) are believed to be taken on to the Cenozoic molasses via several faults, which are likewise connected in India with the Main Boundary Thrust. (198, Windley).

2.3.4 Sub-Himalayas

They are located between (Main Boundary Thrust, the Salt Range, and the Trans-Indus Ranges). The Kurram Thrust, a north-south adapted fault, finishes it westward, while the belt continues eastward as the Himalayan foothills (Kazmi and Rana, 1982).

Precambrian to Neo-gene rocks have been found in the subsurface of the Sub-Himalayas, where the fold belt is coated with Neo-gene sediments that form enormous folds. Precambrian evaporites had an active role in the tectonics of this belt, separating the crust from the basement and inducing southerly translation through thrusting up to 100 kilometers (Lillie et al., 1987).

2.4 Local tectonic setting

Pangea was surrounded by two vast oceans named Panthalassa and Tethys in the early Triassic (Tozer 1982; Ricou 1994; Ehiro et al., 2005). The Salt Range and Surghar Range were located about 30 degrees south on the Northern Gondwanan shelf (Smith et al. 1994; Stamfpli and Borel 2002). The Northern Indian Margin's lower Triassic successions are made up of siliciclastics and carbonates (Galfetti et al., 2007a; Bruhwiler et al., 2009).

The Indian subcontinent's mixed siliciclastic-carbonate shelf was restricted to the northeast by the Neo-Tethyan rift zone. During the Quaternary, Cambrian to Pliocene rocks were thrust southward along the Salt Range Thrust over late Tertiary sediments due to the Himalayan orogeny (Gee, 1989). Permian and Early Triassic rocks are revealed in a structural stack of narrow, trusted plates running roughly parallel to the Salt and Surghar Ranges. The Salt Range and the Surghar Range are divided by a dextral Kalabagh strike-slip fault.

2.5 Regional stratigraphy

Numerous regional and local-scale unconformities interrupted the whole strata of the Salt Range. The Permian Tobra Formation overlies the Cambrian strata unconformably, indicating the first significant stratigraphic break (Ghazi et al., 2012). Another significant unconformity is the Permo-Triassic (PT) border that separates the Permian Chiddru Formation from the Triassic Mianwali Formation.

A lateritic bed between the Jurassic Samana Suk Formation and the Paleocene Hangu Formation marks the third unconformity. Another stratigraphic gap is the unconformity between the Early Eocene and Mio-Pliocene strata. The latest and youngest sedimentation gap in the Salt Range area is the one between Mio-Pliocene sediments and recent conglomerates (Lei conglomerates).

The following geological formations are found in the Nammal Gorge (study area), (Fig 2.2).

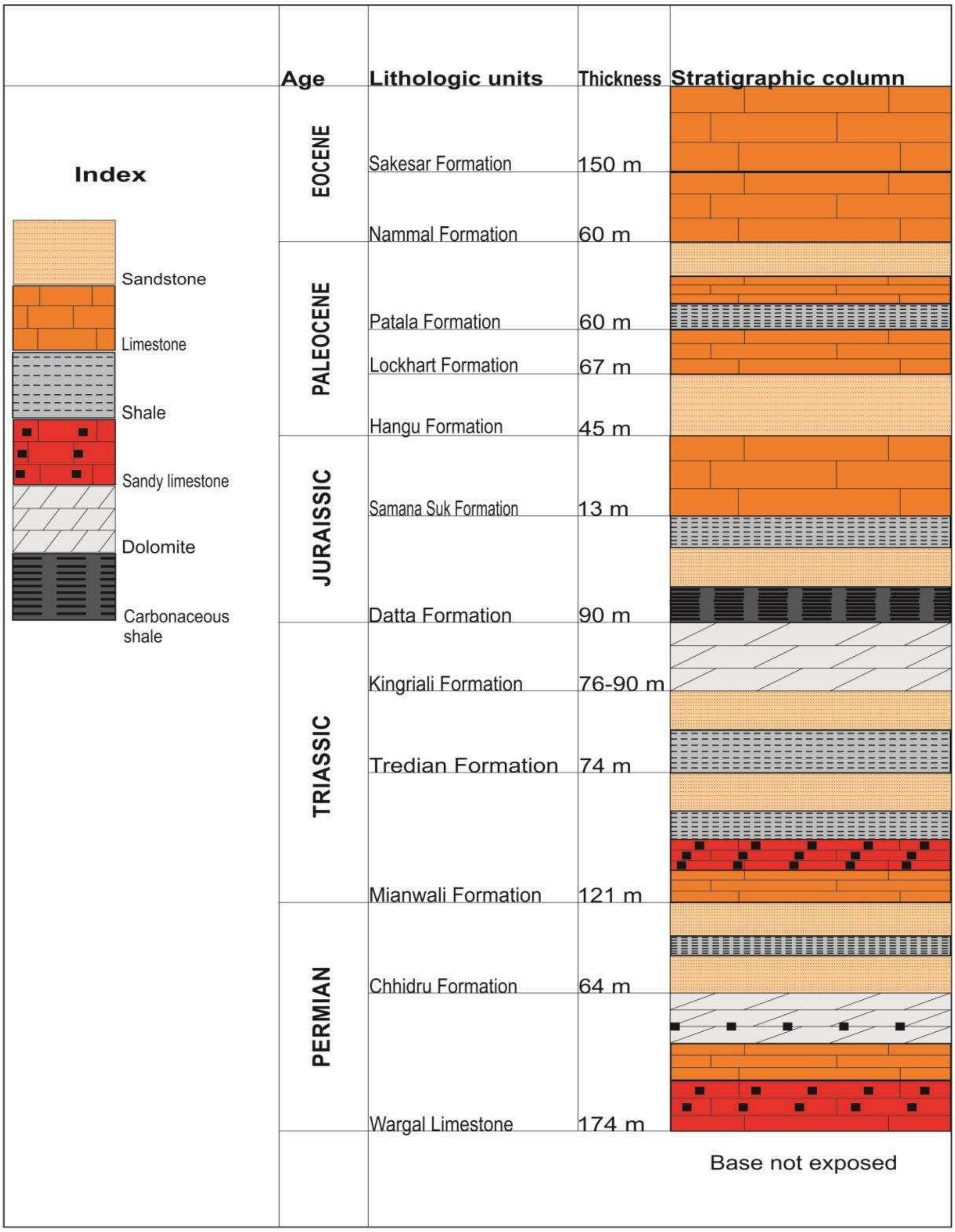


Fig. 2.2 Generalized stratigraphic succession of Nammal Gorge Salt Range, Punjab, Pakistan.

2.6 Late Permian Sequence

From bottom to top, it is made up of the Zaluch Group, which contains the Amb, Wargal and Chiddru Formations.

2.6.1 Amb Formation

The Amb Formation is widely exposed in Amb village, Punjab province's Central Salt Range. This formation comprises of sandstone, limestone, and shale. Fusulinid also found in calcareous sandstone strata. The Amb Formation limestone is generally sandy, brownish gray, medium-bedded, and contains products (Dorloyia, Neospirifer). The shale is dark gray and carbonaceous. The Sardhai Formation is at lower contact. The upper contact is with the Wargal Formation.

2.6.2 Wargal Formation

The Wargal Formation's type locality is located one mile west of the Wargal hamlet in the Central Salt Range. The Wargal Formation is dominated by limestone and dolomite. The Wargal limestone is widely dispersed in the Salt Range and Trans-Industrial Ranges. This formation is abundant in fossils such as *brachiopods, sponges, bryozoans, corals, bivalves, gastropods, nautiloids,* and other groups of fossils such as *ostracods and fishes*. Pascoe (1959) and Ustritsky (1962) date the Warghal Formation as late Permian based on thepresence of *brachiopods.* The Wargal Formation's top and lower contacts are conformable with the Chiddru and the Amb Formations, respectively.

2.6.3 Chiddru Formation

The type locality of the Chiddru Formation is Chiddru Nala, which is found in the Western Salt Range, Mianwali, and Punjab provinces. The term "Chidder Formation" is officially sanctioned by Pakistan's Stratigraphic Committee. It was mostly sandy limestone and shale. The Chiddru Formation is rich in fossils such as *brachiopods, bryozoans, gastropods, bivalves*, etc.

2.7 The Triassic Period

From bottom to top, the Triassic rock sequence is comprised of the Mianewali, Tredian, and Kingriali Formations.

2.7.1 Mianwali Formation

Nammal Gorge is a typical section of the Mianwali Formation in Punjab province's Western Salt Range, Miawali district. The Stratigraphic Committee of Pakistan has recommended the term Miawali Formation. Marl, limestone, sandstone, and dolomite make up the formation. Kummel (1966) recognized three members: Narnia, Mittiwali, and Kathwai. The lowerKathwai Member comprises dolomite in the bottom part and limestone in the top portion. The middle Mittiwali Member is considered the thickest member of the Mianwali Formation,containing limestone, marl, and shale with subordinate sandstone. This member's limestone is gray and rich in ammonites. The shale, on the other hand, is brownish and greenish. The upper Narmia Member generally contains dark gray to brown limestone.

2-7-2 Tredian Formation

Tredian Hills, which are typically found in the Mianwali District, are thought to be the type locality of the Tredian Formation. Gee (1945) adopted the word "Tredian Formation" to replace the phrase "Kingriali Sandstone" that he had previously used. The sandstone ranges in color from black to pink to red to greyish- grey. Its lower and upper contact with the Mianwali and Kingriali Formations is conformable. The Middle Triassic age is classified as a formation based on the presence of pollen and spores. There is no fossil record in the formation other than carbonaceous remnants.

2.7.3 Kingriali Formation

The type location of the Kingriali Formation is designated for rocks exposed along the Kingriali peaks in the Khisore Range. Gee's (1945) term "Kingriali Dolomite" is renamed Kingriali Formation after the Kingriali Peak in the Kishore Range. The Kingriali Formationis mostly made up of light gray to brown dolomite and dolomitic sandstone. The upper part of the formation is interbedded with marl and greenish dolomite shale. Although fossils are uncommon, Shah (1977) reported *bivalves, brachiopods, and crinoidal* remnants.

2.8 Jurassic Sequence

2.8.1 Datta Formation

Danilchick (1961) and Shah (1967) coined the term Data Formation, which is named after Data Nala, also known locally as Sardhai Nala, where the Data Formation is most visible. Data Formation is primarily composed of variegated sandstone, silt, shale and limestone. Datta Formation Sandstone is medium-bedded at the bottom and massive at the top. It also contains coal lenses in some spots.

2.9 Paleocene Sequence

2.9.1 Hangu Formation

The Hangu Formation's type location is in the Samana mountain ranges to the south of Fort Lockhart. Its color ranges from gray to brown. Some areas have carbonaceous shale as well as gray argillaceous limestone. The lowest contact of this formation with several Paleozoic and Mesozoic formations is unconformable. The Hangu Formation is dated to the early Paleocene based on the fossil record. The Hangu Formation contains a variety of fossils, such as *mollusks, corals, and foraminifers.*

2.9.2 Lockhart Limestone

The particular section in the Samana mountain range near Fort Lockhart is considered its type locality. The limestone in the type locality is gray, medium to thickly bedded, massive, brecciated and rubbly in spots, and foggy at the base. The limestone in Nammal area is mainly grey to light grey in color, medium to thickly bedded, and nodular, with a small quantity of (grey marl and dark bluish-grey shale) in the bottom section. *Corals, algae, mollusks, echinoids, and foraminifera* are found in the Formation (Davies and Pinfold 1937; Davies 1943; Latif 1970). The Lockhart Limestone (Paleocene age) comprises foraminifera such as *Opercilina subsala, Lapidocyclina punjabensis, Ascolina biotica,* and others.

At the type locality, the limestone has become well-established and 60m thick. It is approximately 70m thick in Nammal Gorge and 242m thick in the Hazara area.

2.9.3 Patala Formation

It is mostly made up of shale and subordinate marl, limestone, and sandstone. Sandstone is likely to be found in the Patala Formation's upper section (Warwick and colleagues, 1988, 1990). Lower contact between the Patala Formation and the Lockhart Limestone is conformable.

The Patala formation dates from the late Paleocene and is rich in fossils such as *mollusks, ostracodes, foraminifera,* etc. (Davies and Pinfold, 1937; Eames, 1952; Latif, 1970).

Nummulities globosa, Lockhartia conditi, and Assilina dandotica are among the larger foraminifera.

2.10 The Eocene sequence

This sequence has following rocks in the research area.

2.10.1 Nammal Formation

The Nammal Formation is well exposed in the Western Salt Range. This formation contains (shale, marl, and limestone). The Nammal Formation is rich in fossils, primarily *foraminifera and mollusks. Numnulities atacicus, N. laharii, N. irregularis, and Assilina granulosa* are larger foraminifera (Haque 1956).

Smaller foraminifera, such as *Alabamina wilcoxensis, Dentalina plummerae, Globogerina linaperta,* and so on, are plentiful. The Nammal Formation's lower and upper contact zones are transitional with the Patala and Sakesar Formations, respectively.

2.10.2 Sakessar Formations

The type location of the Sakessar Formation is the Sakessar peaks in the Salt Range. Gee (1935) referred to the term "Sakessar limestone" in the Salt Ranges as well as the Trans- Industrial Ranges. The Sakessar Formation is made up primarily of limestone and subordinate marl. It is widespread in the Salt and Surghar Ranges.

In the Nammal Gorge, the upper contact is not revealed, while the lower contact is consistent with the Nammal Formation. The formation is dominated by limestone that ranges in color from creamy to light gray and has nodularity.

CHAPTER 3
MICROFACIES

Paleocene carbonate rocks are readily visible in Pakistan's Salt Range. The western portion of the Salt Range has one of these rocks' greatest exposures. The Patala, Lockhart, and Hangu Formations are among these rocks.

Numerous studies of the Paleocene Lockhart Limestone have been conducted in the past. Gee (1935–1945) worked on the Salt Range throughout his geological career. Many researchers, including Davies and Pinfold (1937), Haque (1956), Kazmi and Abbas (2001), Wignall and Hallam (1993), Fatmi (1973), Middle Miss (1896), Köthe (1988), and Davies (1930a).

For both interregional and regional stratigraphic research (Nagappa, 1959; McGowran, 1968; Adams, 1970), the Nammal Gorge Paleocene section is an essential location (Hunting Survey Corporation, 1961). Considering this locality's significance to the region, Adams (1970) recommended more research be done there.

In the research area, nodular limestone (light gray to dark gray) makes up the majority of the formation in the Salt Range Nammal Gorge. Calcite-filled fractures can be seen at various places. The medium- to thickly bedded limestone is observed at the outcrop. There are additionally other instances where stylolites are seen. The minor amount of dark bluish-gray calcareous shale and gray marl in the bottom section, whereas the formation is highly fossiliferous.

In Nammal Gorge, the middle Paleocene Lockhart Limestone exhibits an appropriately complete exposure. These rocks show a range of microfacies, from packstone to mudstone. Numerous notable fossils and microfossils, including *foraminifera, algae, and foraminiferal bioclasts* that demonstrate the Inner Ramp depositional environment, can potentially be found in these microfacies.

3.1 Research methods

Sedimentary rocks, known as facies, are distinguished from nearby sediments by their unique characteristics, which are the result of varying depositional environments. Microfacies are the characteristics and makeup of a portion of a facies that is small enough to be seen and studied in a thin section. The modified Embry and Klovan (1971) categorization system is employed in this study in addition to the Dunham (1962) classification system. The microfacies that were identified and observed in thin sections of laboratory samples are categorized using this system.

The primary factors used in the Dunham (1962) classification system are the rock's texture, the proportion of carbonate mud in the rock, and the structural components of the rock unit. Based on the percentage of mud that makes up less than or more than 50% of the matrix, the carbonates are primarily separated into mud-supported and grain-supported categories.

Grain-supported carbonates are defined as grainstone that have less than 50% mud, whereas mud-supported carbonates are defined as mudstones that contain more than 50% carbonate mud.

More over The other carbonate categories based on the rise in energy in the depositional environment are mudstone, wackestone, packstone, grainstone, and boundstone.

The microfacies in the Lockhart Limestone that were identified and observed during the study are listed below.

A thorough examination of the thin sections taken from the Lockhart Limestone cuttings allowed for the identification of the following microfacies and sub-microfacies, each having a unique texture, allochem kinds, fossil content, etc.

3.2 Packstone microfacies

The packstone is classified as a carbonate rock with 10–49% carbonate mud by Dunham (1962). Because packstone contains more grains than wackestone, the amount of deposition energy has gradually increased in Packstone.

More than 50% of the grains that make up the packstone microfacies are skeletal grains (50%); the remaining include calcite crystals (10%), micrite (30%), and calcite cement (10%). The microfacies have a medium- to fine-grained texture and are primarily brownish-gray in color, while they also exhibit a medium- to coarse-grained texture in certain places.

Petrographically, the packstone microfacies of the Lockhart Limestone in Nammal Gorge comprise the skeleton grains of many organisms, including bivalves, gastropods, echinoderms, and foraminifera. The following microphotographs illustrate the differences in the grain-to- matrix ratios of 4:1 and 3:1 (Fig.3.1, 3.2).

The packstone microfacies of the Lockhart Limestone in the research region contain foraminiferal bioclasts and many micro-algae species, including *Lockhartia sp., Miscellanea sp., Operculina sp., Dasycladale green algae, Assilina sp., Rotalia sp., Bigerena sp., Ranikothalia sp.,* etc. The fossils are clearly visible and can be clearly identified in the thin section and under a microscope (Fig.3.1, 3.2).

Plate 3.1

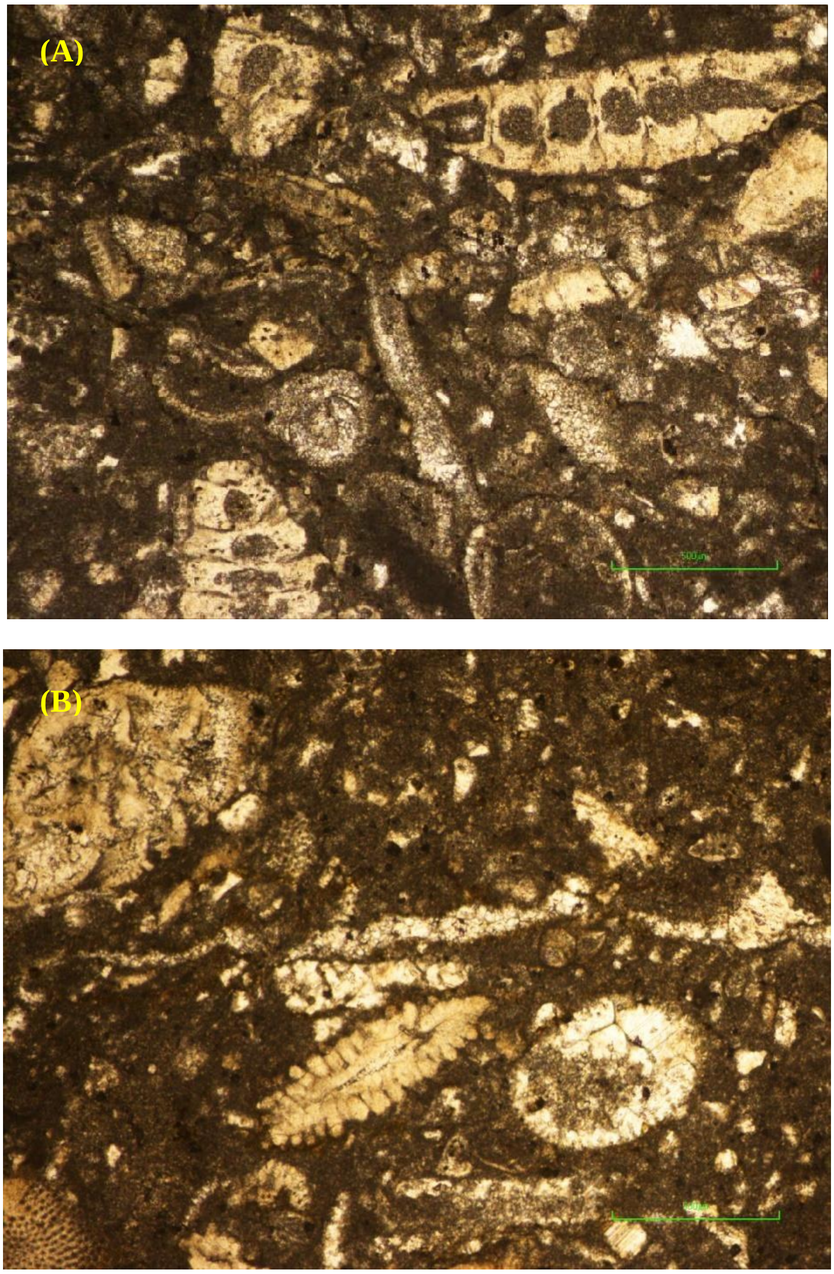


Fig. 3.1 (A and B) Depict packstone where *Lockhartia sp.*, *Miscellanea sp.*, *Operculina sp.*, *Dasycladale green algae*, *Assilina sp.*, *Rotalia sp.*, etc. The packstone microfacies has 3:1 grain to matrix ratio,

Plate 3.2

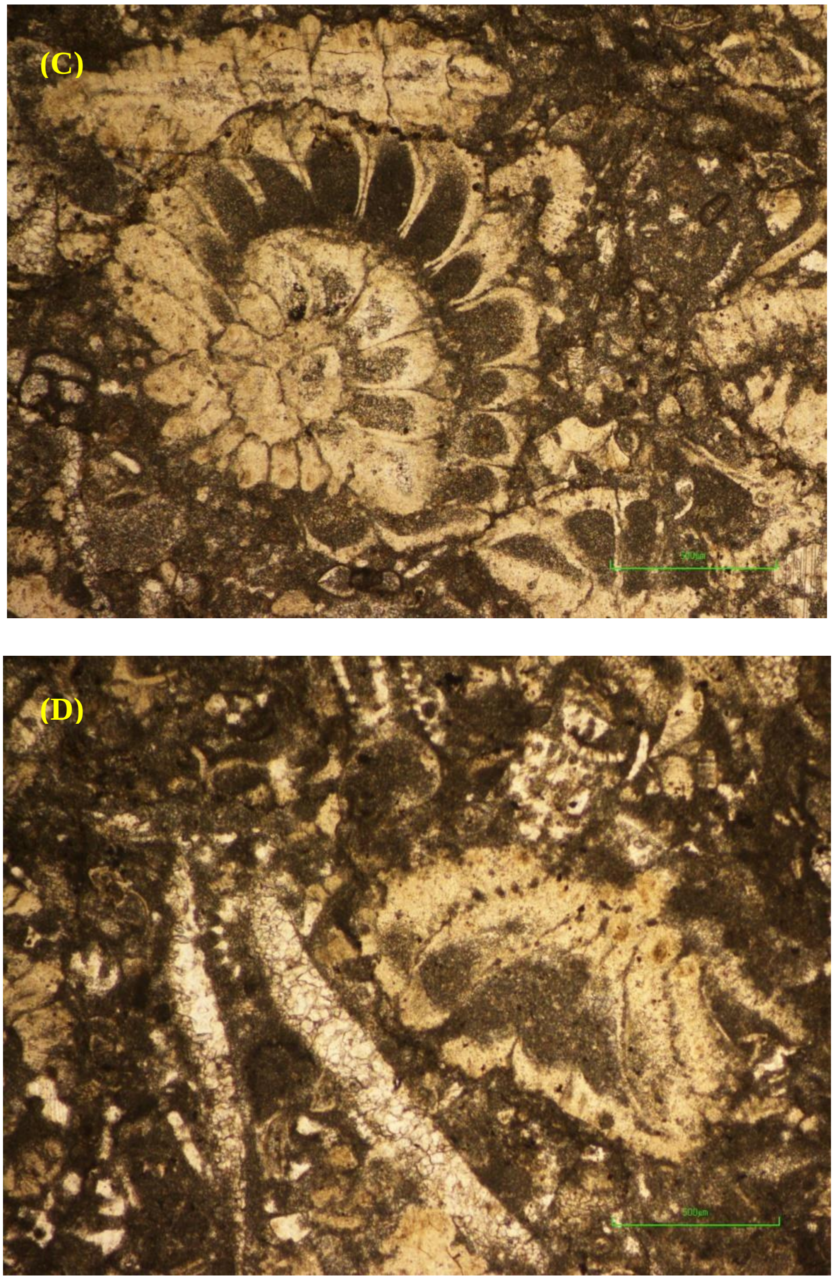


Fig. 3.2 (C and D) Indicate 4:1 grain to matrix ratio. *Lockhartia sp.*, *Miscellanea sp*, *bioclasts* are visible.

3.2.1 Mix bioclastic packstone microfacies (sub-microfacies)

The following microfacies has varying amounts of fossils, it mostly contains a variety of fossil fragments and distinct algae types, *Miscellanae sp., Lockhartia sp., Bigenerena sp., Planorotalia pseudominaradae, and Assilina sp*. In fig 3.3 (E), the grain-to-matrix ratio is 4:1; in fig.3.3 (F), it is 3:1 and in fig 3.3 (G), the grains make up 79% and the matrix 21%. The (grain-to-matrix) ratio in plate 3.3 is 3:1, with grains making up 72% and the matrix 28%. While the algae make up 6 to 9% of plates 3.3*, the bioclasts, Lockhartia sp., Miscellanae sp., Assilina sp., and Planorotalia sp*., make up the majority of the mixed bioclastic packstone microfacies. There are 3–4% *Gastropods* and *Echinoids* (Fig.3.3).

Plate 3.3

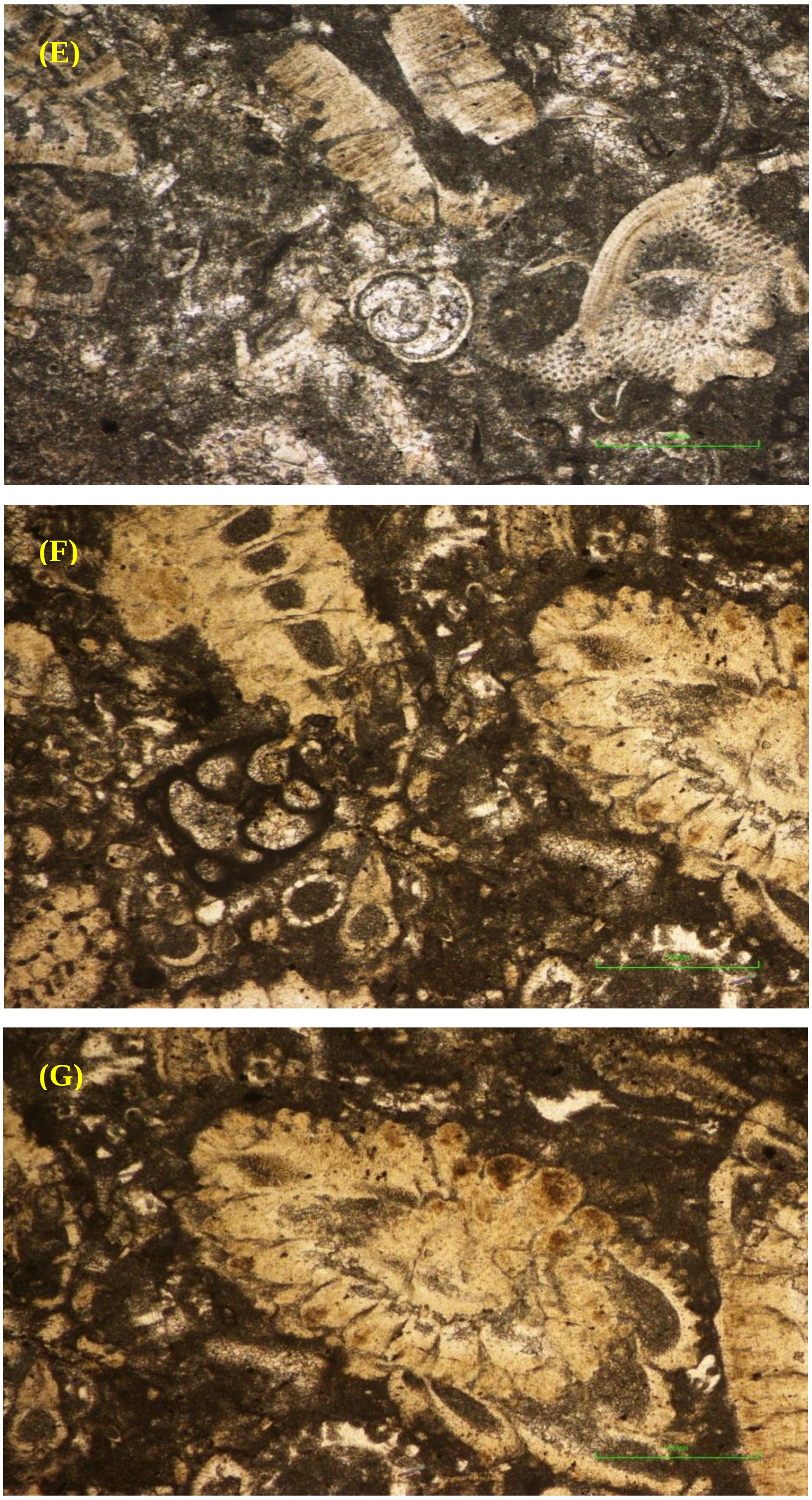


Fig. 3.3 (E, F and G) shows the mixed bioclastic packstone sub-microfacies. Fossil fragments and distinct algae types, *Miscellanae sp., Lockhartia sp., Bigenerena sp., Planorotalia pseudominaradae, and Assilina sp* are visible.

3.2.2 Bioclastic foraminiferal packstone sub-microfacies

This microfacies include *Lockhartia and Miscellanae sp.*, which are rich and prominent in the given facies. It contains both larger and smaller foraminifers, along with fossil fragments and different algae types. *Dasycladale green algae and indet dasycladalean algae* are also observed. The (grain-to-matrix) ratio in fig.3.4 (H) is 3:1, while it is 4:1 in fig.3.4 (I). The matrix is 27%, while the grains are 73% in fig.3.4 (H). Moreover, in Fig.3.4 (I), the grains are 78%, while the matrix is approximately 22%.

Plate 3.4

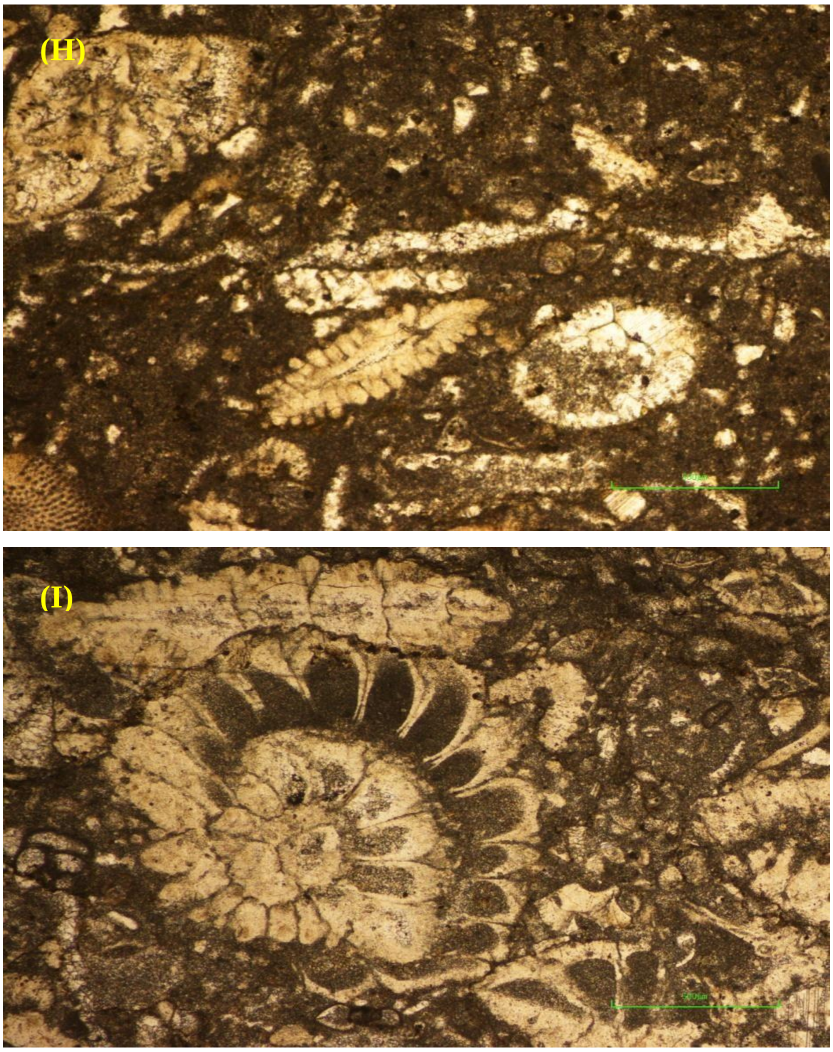


Fig. 3.4 (H and I) Exhabit bioclastic foraminiferal packstone sub-microfacies. Bioclastic foraminiferal packstone sub-microfacies include *Lockhartia and Miscellanae sp.,*which are rich and prominent in the given facies.

3.2.3 Bioclastic algal foraminiferal packstone sub-microfacies

This microfacies contains a significant amount of *Algae* and its various types. Some of the *Algae* are very small, and others can be visualized easily. The fossil fragments, or bioclasts, are in comprehensive amounts. Smaller foraminifers are also abundant. The (grain-to-matrix) ratio in this microfacies is 3:1. The grains are 73% and the matrix is 27%. *Dasycladale green algae* and *indet dasycladalean algae* are also found in this facies type. Fossil fragments of different fossils are also common (Fig.3.5).

Plate 3.5

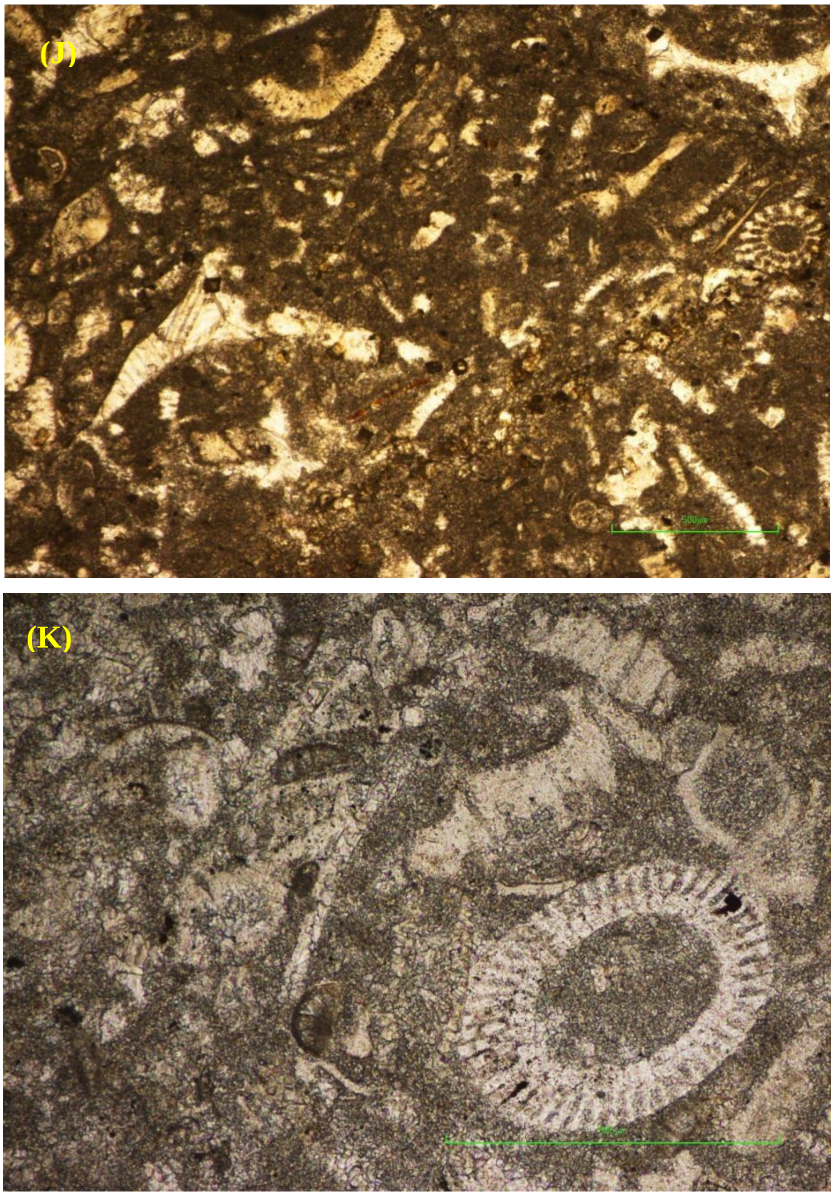


Fig. 3.5 Bioclastic algal foraminiferal packstone sub-microfacies contains a significant amount of *Algae* and its various types. Some of the *Algae* are very small, and others can be visualized easily.

3.3 Grainstone microfacies

The Dunham (1962) classification suggests that grainstone microfacies are a kind of microfacies that are predominantly composed of grains (grain-supported carbonate rock) and lack carbonate mud that is only less than 10% in amount. Grainstone microfacies have a greater amount of energy for deposition of material than packstone or wackestone microfacies, as they carry more grains that are more tightly packed, indicating a moderate-to-high energy depositional environment.

This microfacies is dominant with skeletal grain in composition, like *Foraminifera, Echinoderms,Gastropods, Algae, bioclasts, bivalves, etc. Lockhartia sp., Miscellanea sp., Assilina sp., Rotalia sp., Operculina sp., Bigerena sp., Ranikothalia sp., Dasycladale green algae, etc., and foraminiferal bioclasts* are observed in the microfacies (Fig.3.6).

Plate 3.6

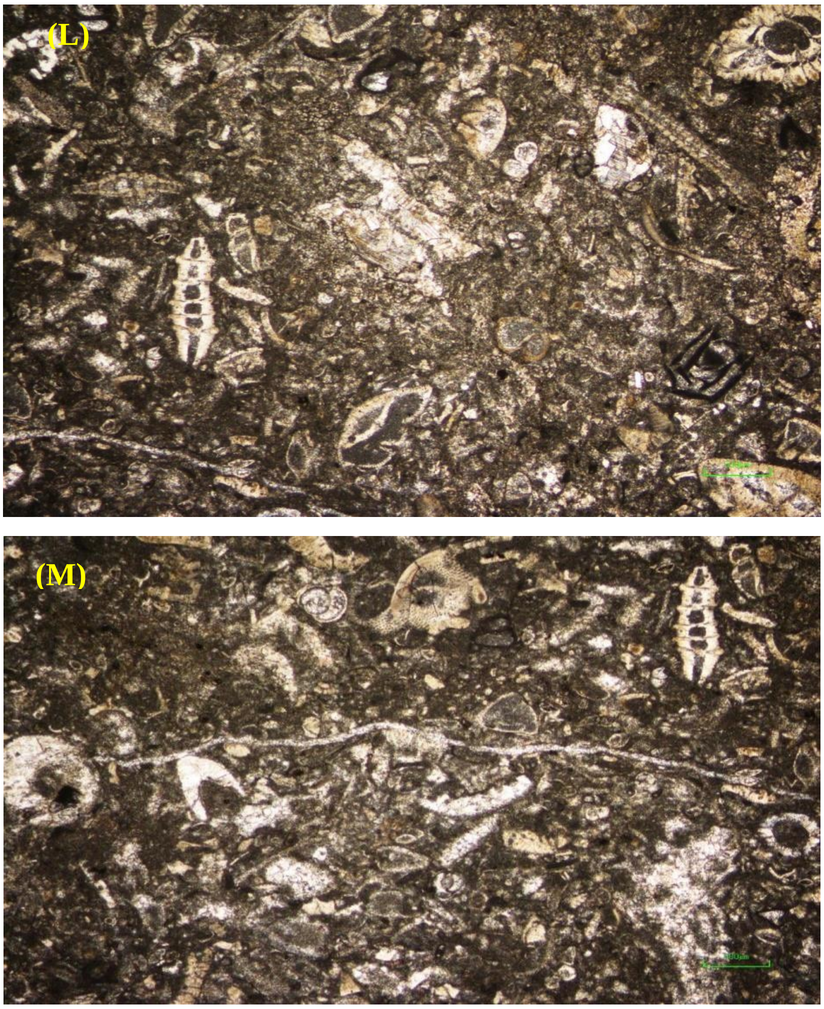


Fig. 3.6 Show grainstone microfacies dominant with skeletal grain, like *Foraminifera, Echinoderms, Gastropods, Algae, Bioclasts, Bivalves, etc.*

3.3.1 Mixed bioclastic grainstone microfacies (submicrofacies)

Predominantly, the mixed bioclastic grainstone submicrofacies are comprised of skeletal fragments (parts of megafossils). These are large in number and are highly packed with each other, leaving very little space for the carbonate mud or cement. Larger foraminifera and smaller foraminifera are prominent and can easily be distinguished and determined in the microfacies microphotographs.

The carbonate mud or the cement is only less than 10% of the total. The remaining 90% or even more are the bioclasts or fossil fragments: *foraminifera, Algae, bivalves, Gastropods, Ascolina sp., Lockhartia sp., Miscellanae sp.,* etc.

In respect of grain-to-matrix ratio, it is 5:1. It suggests that if the mixed bioclastic sub-microfacies is divided into six equal parts, then five parts will be the grains (skeletal grains*, bioclasts, bivalves, other foraminifera, Assilina sp., Gastropods*, etc.), and only one part will be the matrix. The following microphotographs depict the characteristic features of the stated sub-microfacies (Fig 3.7).

Plate 3.7

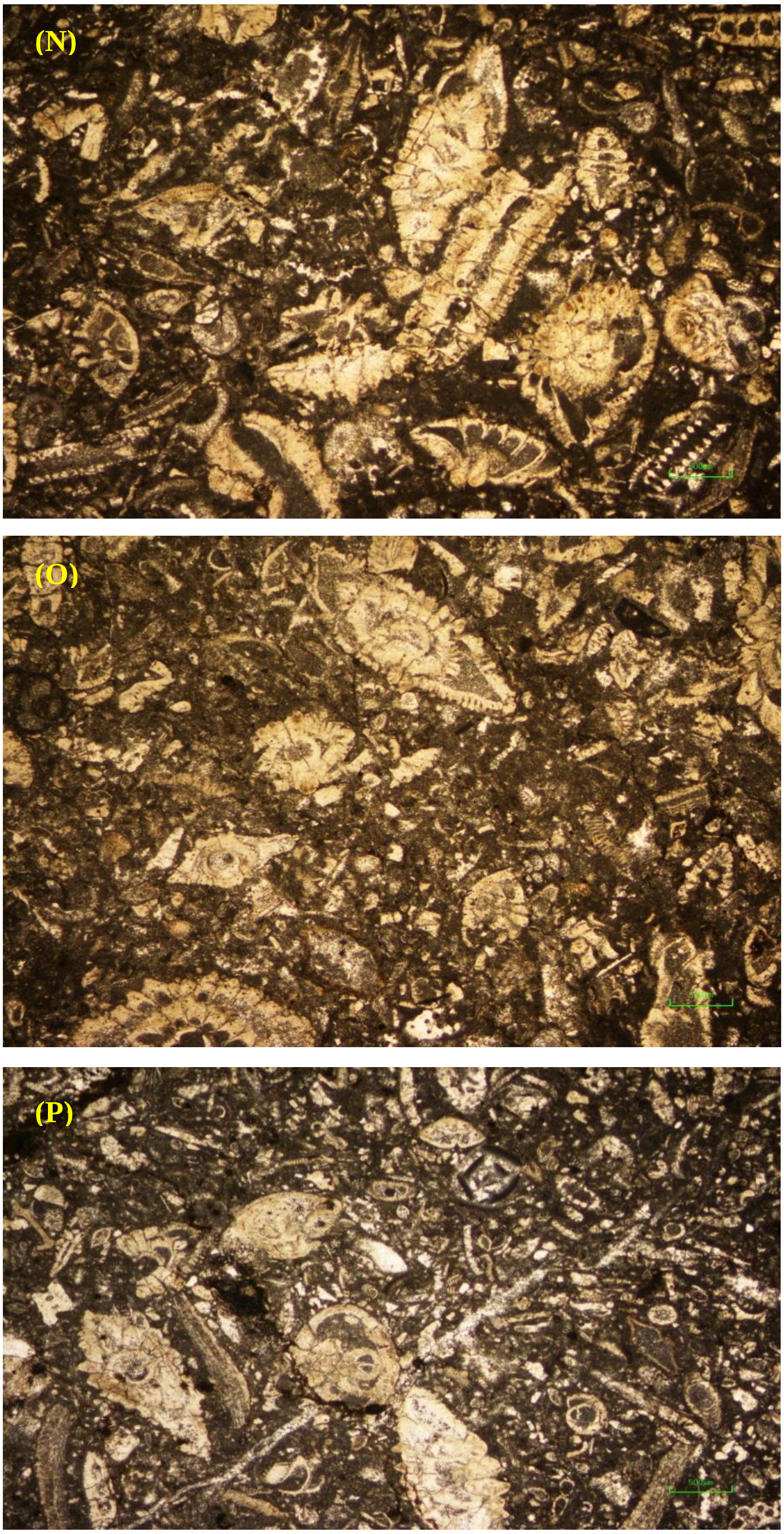


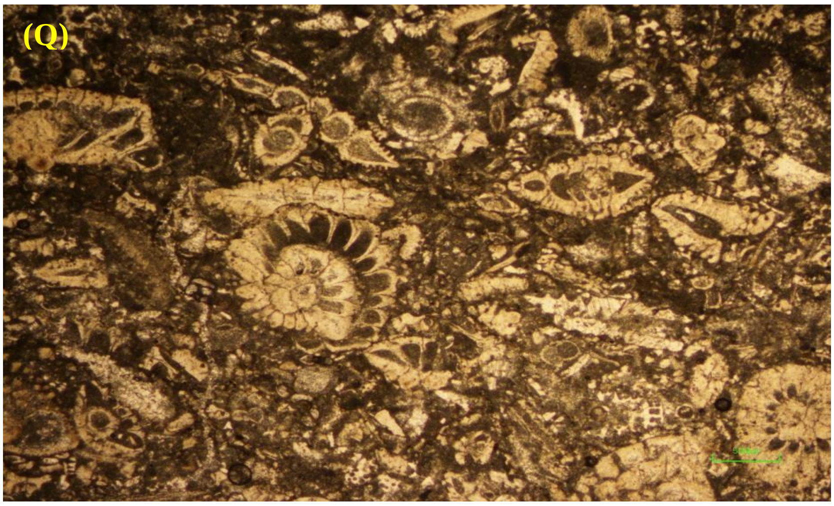
Fig. 3.7 Suggest that if the mixed bioclatic sub-microfacies are divided into six equal parts, then five parts will be the grains (skeletal grains, Bioclasts, Bivalves, other *Foraminifera*, *Assilina sp.*, *Gastropods*, etc).

3.3.2 Bioclastic foraminiferal grainstone microfacies (sub-microfacies)

Bioclastic foraminiferal grainstone microfacies are dominantly comprised of prominent and distinctive *foraminifera, Miscellanae sp., Lockhartia sp., bioclasts or fossil fragments, Algae and bivlaves,* etc. There are well-recognizable smaller and larger foraminifera and other fossils that show the characteristics of the given microfacies. The skeletal grains are well packed with each other so that they minimize the space for the carbonate mud, or matrix, among them (Fig.3.8).

In the following microphotographs (Fig.3.8), the grain-to-matrix ratio is 5:1. The bioclasts, or skeletal grains, are so abundant in number that they exceed 90% in amount. The matrix, or carbonate cement, is only less than 10% in amount. The following figures indicate only 8–9% matrix; the grains are about 92%. Moreover, this also indicates that the environment of deposition of these microfacies was moderate to high, as they contain a large number of grains.

Plate 3.8



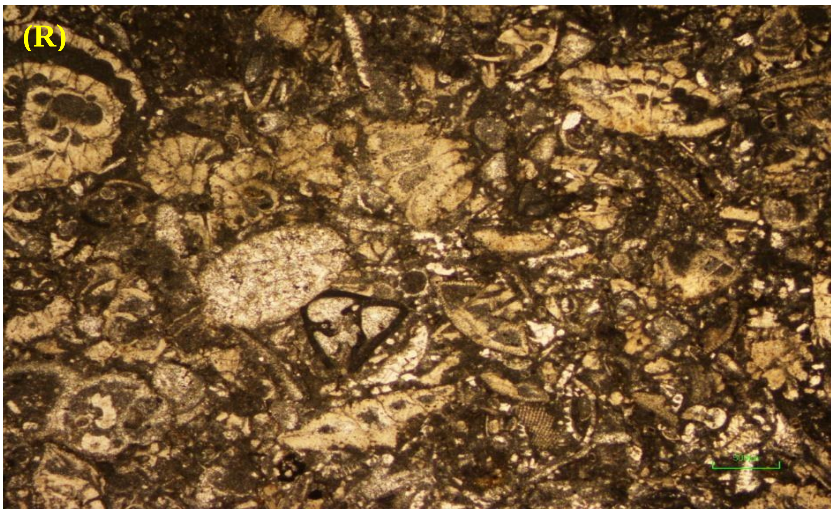


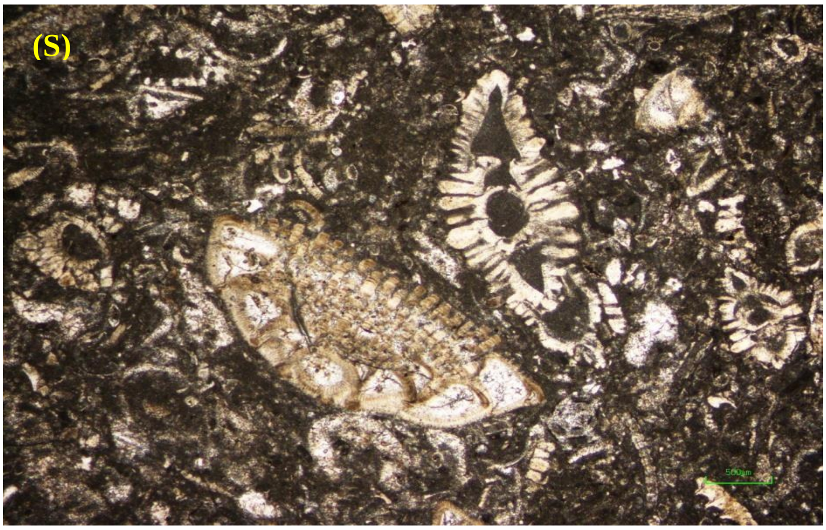
Fig. 3.8 Show *Lockhartia sp, Miscellanea sp, bioclasts* etc.

3.3.3 Lockhartia miscellanea rich grainstone microfacies (sub-microfacies)

Lockhartia miscellanea rich grainstone submicrofacies depict a large portion of the microfacies, covered with *Miscellanea sp., Lockhartia sp.,* and others, including *bioclasts, fossil fragments, Algae, bivalves, Assylina sp., etc. Lockhartia and Miscellanea* species are comprehensively dominant in the following (Fig.3.9), which is well recognizable and can be distinguished very easily.

Smaller foraminifers and other fossils like Algae, fossil fragments, Assilina, bilalves, etc. are distinguishable in the given microphotographs (Fig.3.9). The matrix is only less than 10%, and it is estimated to be 9 or 9.5% in amount. In the given microfacies, the calcite cement has replaced the carbonate mud at some places. The grain-to-matrix ratio is 5:1 in the following microfacies. Skeletal grains are very rich in number, while carbonate mud is very small in amount.

Plate 3.9



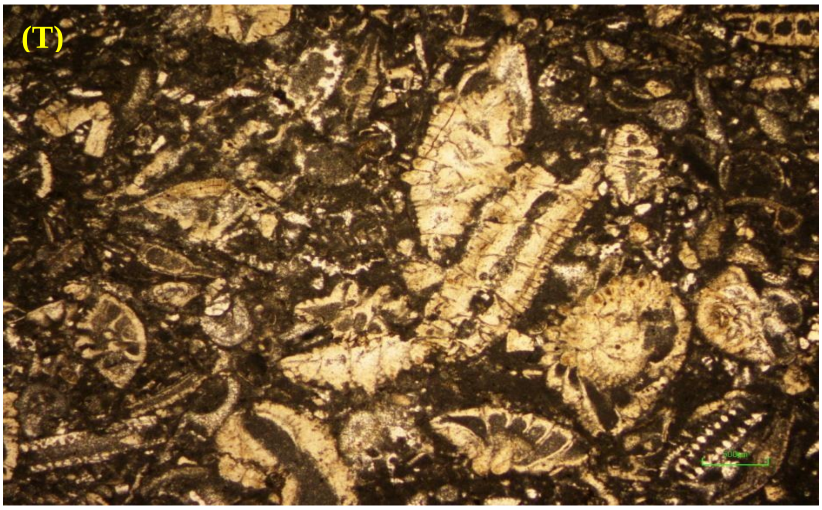


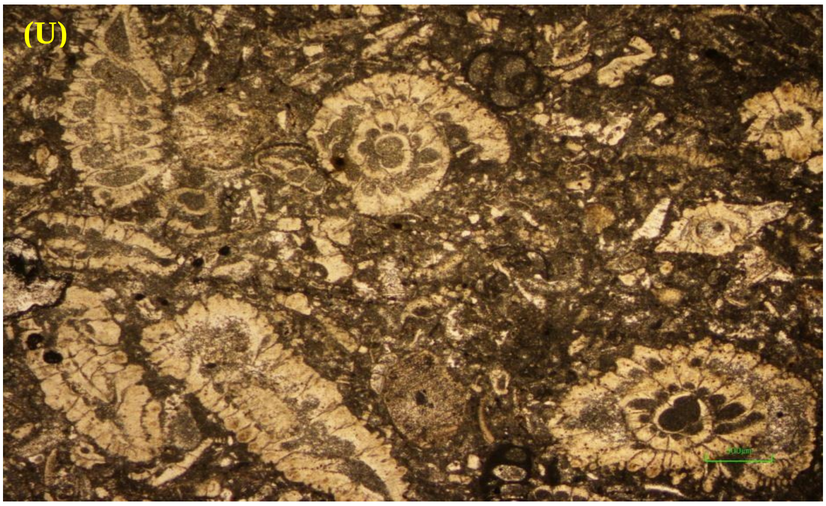
Fig. 3.9 Depict *Lockhartia sp, Miscellanea sp, Assilina sp,* etc.

3.3.4 Miscellanae-rich grainstone microfacies (sub-microfacies)

The following miscellanae-rich grainstone microfacies demonstrate the greater portion is covered by *Miscellanea* species. Other fossils include *Planorotalia Pseudominaradae, Bigenerena sp., Algae, Assilina sp., bivales*, etc. Approximately 50 to 55% of the skeletal grains in the given microfacies are estimated to be covered with *Miscellanae* species.

The remaining 30 to 35% of the skeletal grain is mainly comprised of fossil fragments, smaller *foraminifers, bivlaes, Planorotalia Pseudominaradae, Bigenerena sp., Algae, Assilina sp.*, etc. As far as the matrix is concerned, it is estimated to be less than 10% in amount. In the following microphotographs, it is 8 to 9% in amount. Miscellanea-rich grainstone microfacies demonstrate that its environment of deposition was moderate to high-energy (Fig.3.10).

Plate 3.10



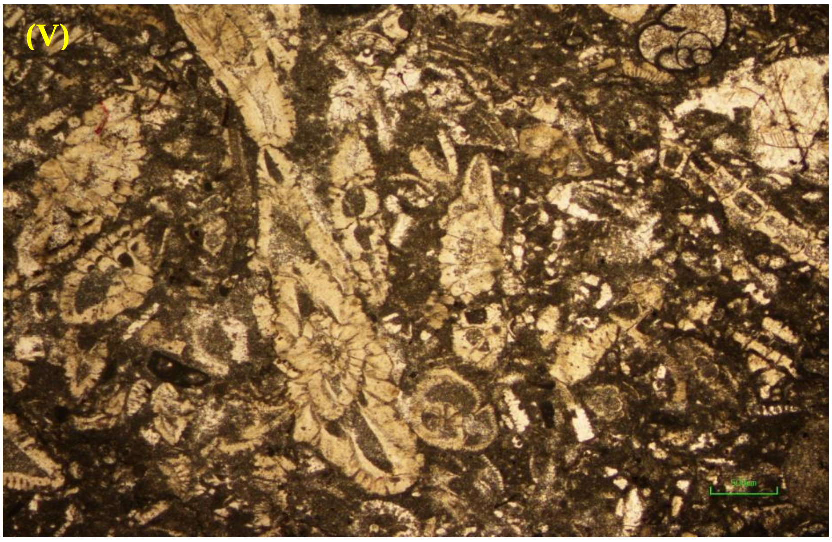


Fig. 3.10 Show the *Miscellanea sp, Lockhartia sp and bioclasts* etc.

3.3.5 Mixed bioclastic lockhartia rich grainstone microfacies (submicrofacies)

Mixed bioclastic lockhartia-rich grainstone microfacies are predominantly composed of *Lockhartia species*; others include fossil fragments and smaller foraminifers in large amouts. *Miscellanae species and Operculina patalenses* are also very prominent to be distinguished.

Different types of *Algae, Ranikothaliasendensis and Bigenerena sp.*, etc., are also observed in the following microphotographs (Fig.3.11).

Skeletal grains are abundant and comprise more than 90% of the space in the Mixed Bioclastc Lockhartia-rich Grainstone submicrofacies. The matrix occupies only less than 10% of the space, which is nearly 8 to 9% in amount. A large amount of the fossils and their fragments demonstratethat the environment of deposition is moderate to high energy (Fig.3.11).

Plate 3.11

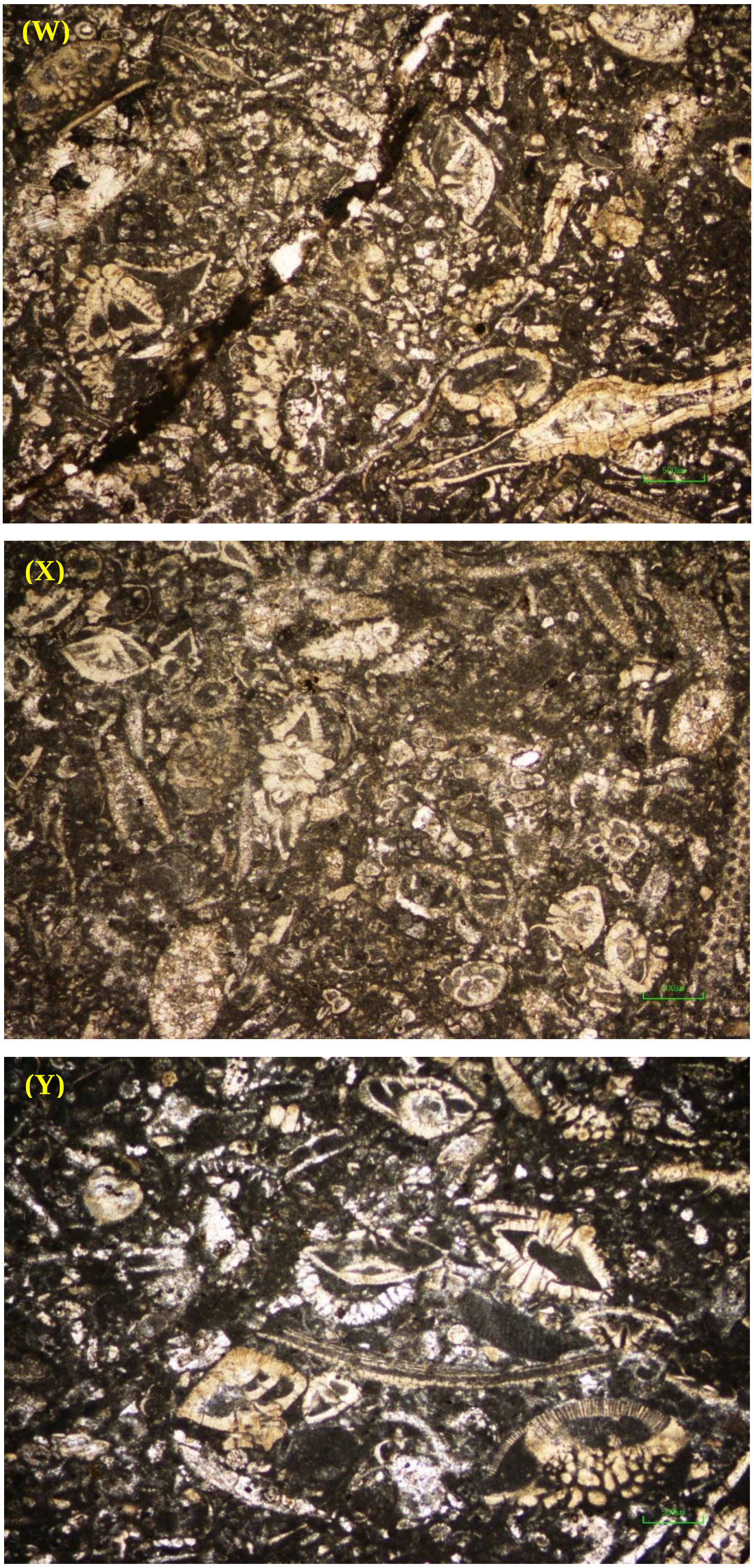


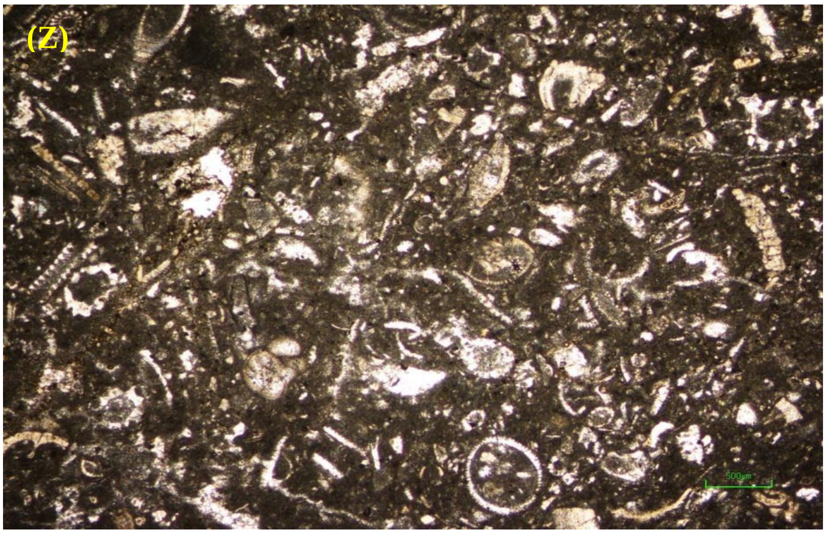
Fig. 3.11 Indicate *Lockhartia sp*, *Miscellanea sp*, *Ranikothalia sp*, etc.

3.3.6 Algae-rich bioclastic grainstone microfacies (sub-microfacies)

Algae-rich bioclastic grainstone microfacies (sub-microfacies) are highly abundant with different types of *algae*. *Dasycladalean green algae and Indet dasycladalean algae* are very common. These are very large in number and can be distinguished and observed easily. Smaller foraminifera and fossil fragments are also in comprehensive amounts.

Lockhartia sp., Bigenerena sp., Gastropods, etc. are also found in the given microfacies, but they are smaller in number. The grain-to-matrix ratio is 5:1, which means that if we have six equal portions of the following microfacies, then five portions are covered with skeletal grains and only one portion would be matrix. The skeletal grains are 91%, while the carbonate mud or cement is 8 to 9% (Fig.3.12).

Plate 3.12



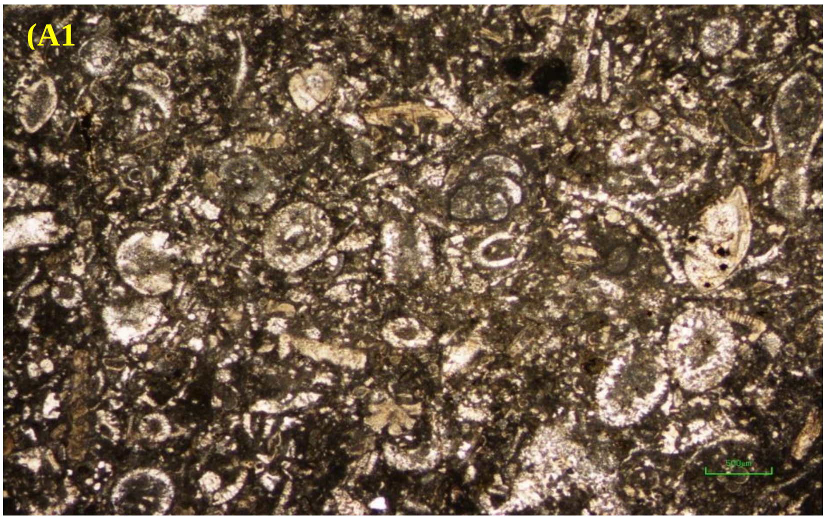


Fig. 3.12 Show *Algae, Bioclasts and Lockhartia sp*, etc.

3.4 Wackestone microfacies

Wackestone microfaces are the microfacies that contain more than 50% carbonate mud and less than 50% grains (*bioclasts*, *foraminifera*, *Gastropods*, *Algae*, etc.). In wackestone microfacies, the skeletal grains are between 10 and 49%.

Carbonate mud, or cement, is dominant in these microfacies. This means that the energy of the depositional environment has decreased as compared to packstone and grainstone microfacies. Wackestone microfacies are therefore found in low-energy depositional environments.

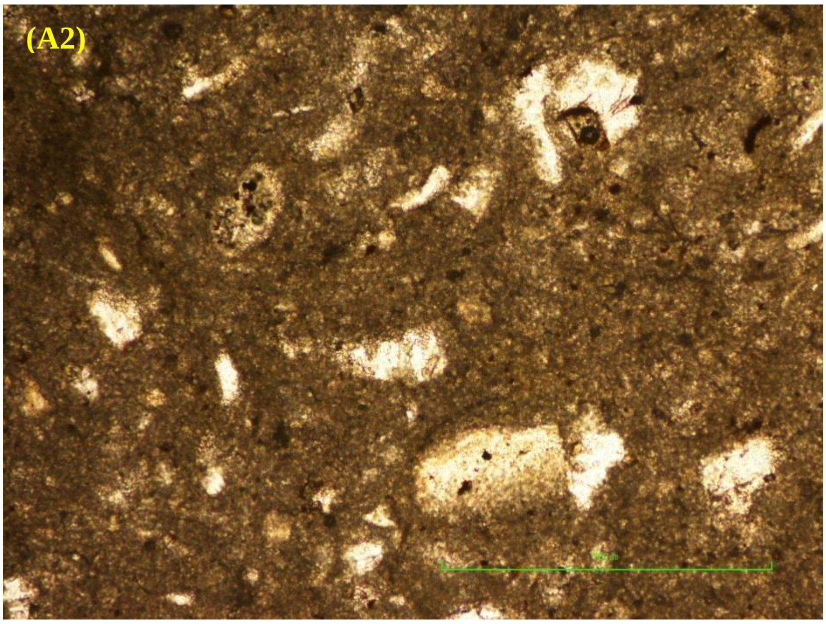
The following types of wackestone microfacies are found in the Lockhart Limestone of Nammal area.

3.4.1 Mixed bioclastic wackestone microfacies (sub-microfacies)

Mixed bioclastic wackestone sub-microfacies are predominantly composed of carbonate mud or carbonate cement. Carbonate mud is approximately 89 to 90% in fig.3.13 (A2), while in fig3.13 (A3); it is about 85 to 87%. The remaining portion is made up of fossil fragments and smaller foraminifera.

The skeletal grains in Figure 3.13 are 10 to 11%, while these are 13 to 15% in the second microphotograph. A small amount of the skeletal grains indicates that the depositional environment of the following microfacies is a low-energy environment. The fossil fragments are very few in number and there is no distinguishable fossil that can be clearly identified (Fig.3.13).

Plate 3.13



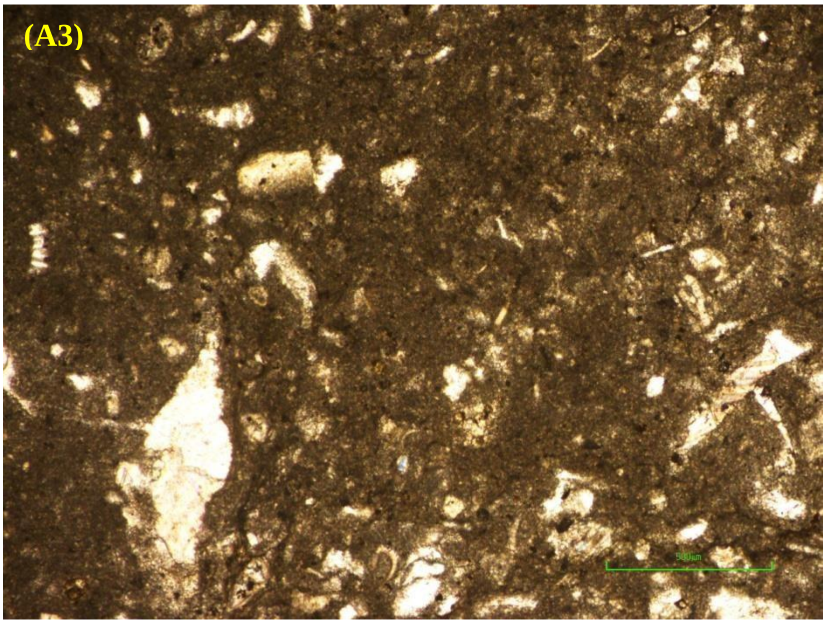


Fig. 3.13 Show Bioclasts of the fossils.

3.4.2 Bioclastic Algae-rich Wackestone microfacies (sub-microfacies)

This microfacies is significantly comprised of carbonate mud. It is about 75 to 80% in the case of the given sub-microfacies that are clearly depicted by the given microphotograph. The skeletal grains are 20 to 25% in amount. *Dasycladalean green algae and Indet dasycladalean algae* are dominant in the skeletal grains, while other fossil fragments are *bioclasts, smaller foraminifera,* etc., which are the least abundant. Algae are 12 to 13%, while other microfossils are 7 to 12% (Fig.3.14).

The following sub-microfacies of the wackestone have more energy from the depositional environment as compared to the mixed bioclastic wackestone sub-microfacies, which contain the least amount of the skeletal gains from the known micro-facies of the Lockhart Limestone in this research.

However, this particular microfacies contain less energy in the depositional environment than other types of microfacies, like packstone and grainstone microfacies, which have a moderate-to-high energy depositional environment.

Plate 3.14

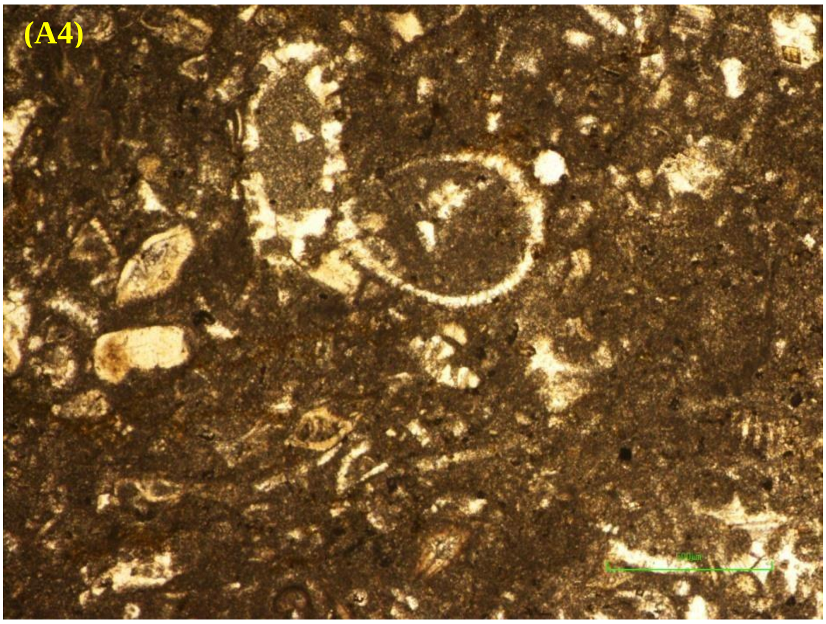


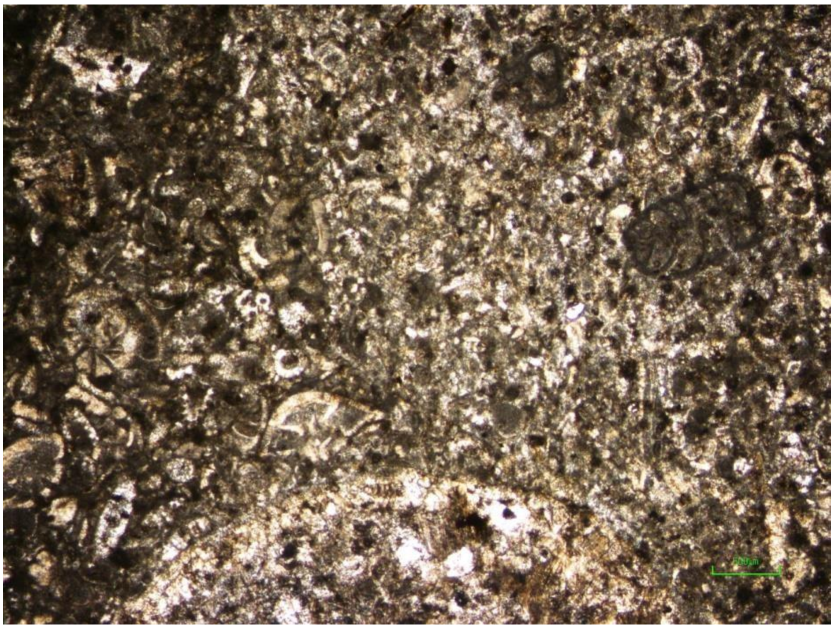
Fig. 3.14 Show *Algae, Bioclasts and Lockhartia*.

3.5 Boundstone microfacies

The Boundstone microfacies describe that the original component of the Lockhart Limestone was bound at the time of deposition of the material. It is hard and difficult to distinguish the fossil content from other types of material in most of the places in the following microphotographs (Fig.3.15).

Lockhartia sp., Bigenerena sp., Dyscoclina sp., etc. at some places are determined and distinguished. The smaller foraminifera, different types of *algae*, and fossil fragments are so closely bound to each other that they are very hard to distinguish and describe.

Plate 3.15



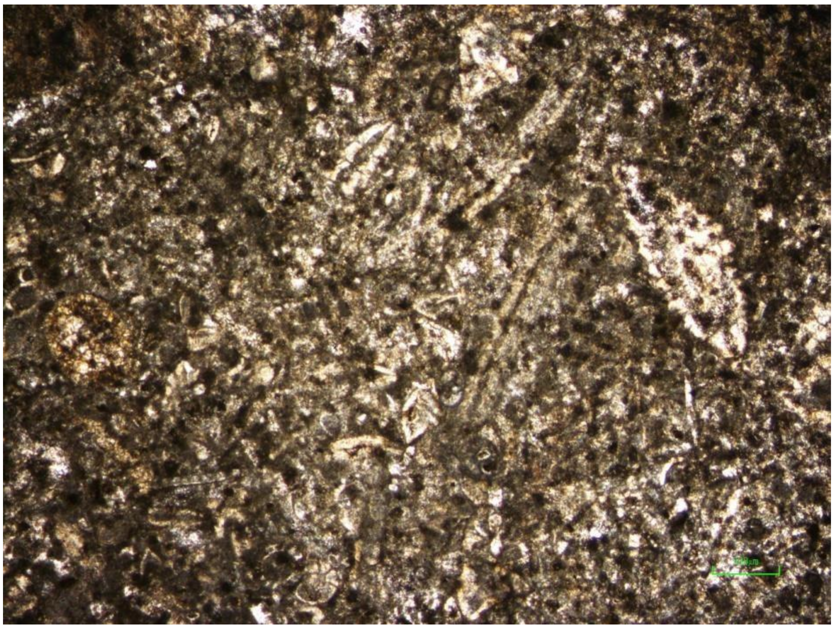


Fig. 3.15 Show Boundstone where cement and grains bounded altogether.

3.5.1 Algae coral framestone sub-microfacies

The framestone of the Lockhart Limestone in the Nammal Gorge was deposited in such a manner that the organisms at the time of deposition bind to each other in a way that makes a rigid framework.

Algae and Bigenerena sp., however, can be determined hardly. Other fossil types and bioclasts are not able to be identified or distinguished. *Corals and algae* are making a rigid framework for the organisms that covers almost the entire portion of the given microfacies (Fig.3.16).

Algae coral framestone microfacies are relatively different from the rest of the microfacies of the Boundstone. The arrangement of the fossils and their fragments is in a network shape rather than horizontal or vertical, which is prominently seen in bindstone and bufflestone microfacies. In the given microfacies,the arrangement of fossils and their fragments is rigid and hard, which bounds them very firmly (Fig.3.16).

Plate 3.16

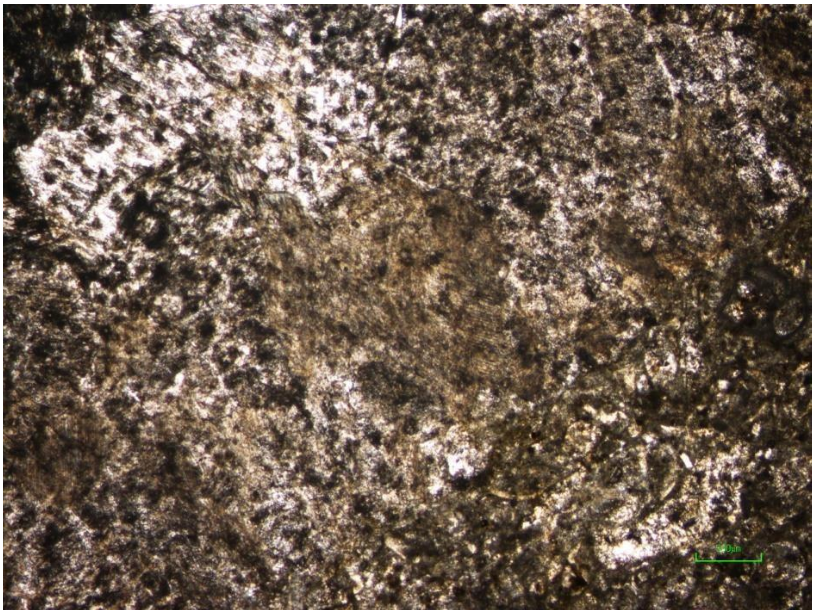


Fig. 3.16 Show *Algae and coral* are bouded to eachother.

3.5.2 Bioclastic foraminiferal bufflestone microfacies

Bioclastic foraminiferal bufflestone microfacies depicts that the ogranisms like *Lockhartia sp.*, *Ranikothaliasendensis*, *algae*, *Bigenerena sp*., etc. and other fossil fragments were bound and packed to each other, acting as buffles. These organisms were bound so tightly and cemented together at the time of deposition of these rocks.

Fossils and their fragments, acting as buffles, can be clearly seen in the microphotographs given below. Smaller forams and bioclasts are not able to differentiate in the given micofacies as the larger fossils and fossil fragments have cemented among them.

The depositional framework of the given microfacies is such that the fossils and fossil fragments were arranged in a nearly vertical symmetry. This kind of arrangement is quite unique in the bindstone or framestone microfacies (Fig.3.17).

Plate 3.17

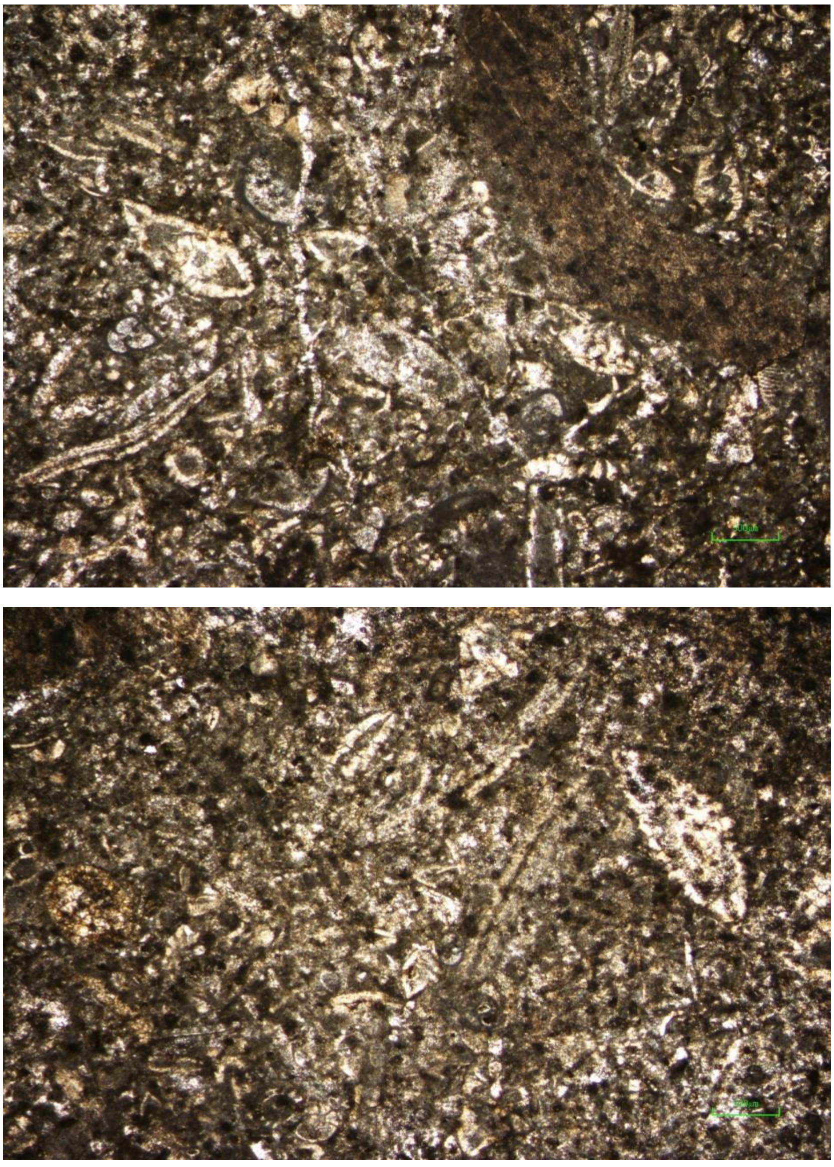


Fig. 3.17 Show boundstone where the *foraminifera and Bioclasts* are visible.

3.5.3 Bioclastic foraminiferal bindstone microfacies

The Bioclastic foraminiferal bindstone microfacies describe that the organisms were encrusted and bound to each other at the time of deposition. Their fossils and fossil fragments were horizontally embedded so that they were tightly packed and cemented to each other in the given microfacies.

Fossils like *Ranikothaliasendensis, Dyscocyclinaranitotensis, Lockhartia, Bigenerena, milliods,* different types *of algae, bioclasts,* and other smaller foraminifera were encrusted horizontally in a way that they were packed and cemented together firmly.

The framework for the deposition of bioclastic foraminiferal bindstone microfacies is unique and quite different from the bufflestone microfacies. The arrangement of the skeletal grains in the given microfacies is horizontal or near horizontal, while in the bufflestone microfacies it is near vertical (Fig.3.18)

Plate 3.18

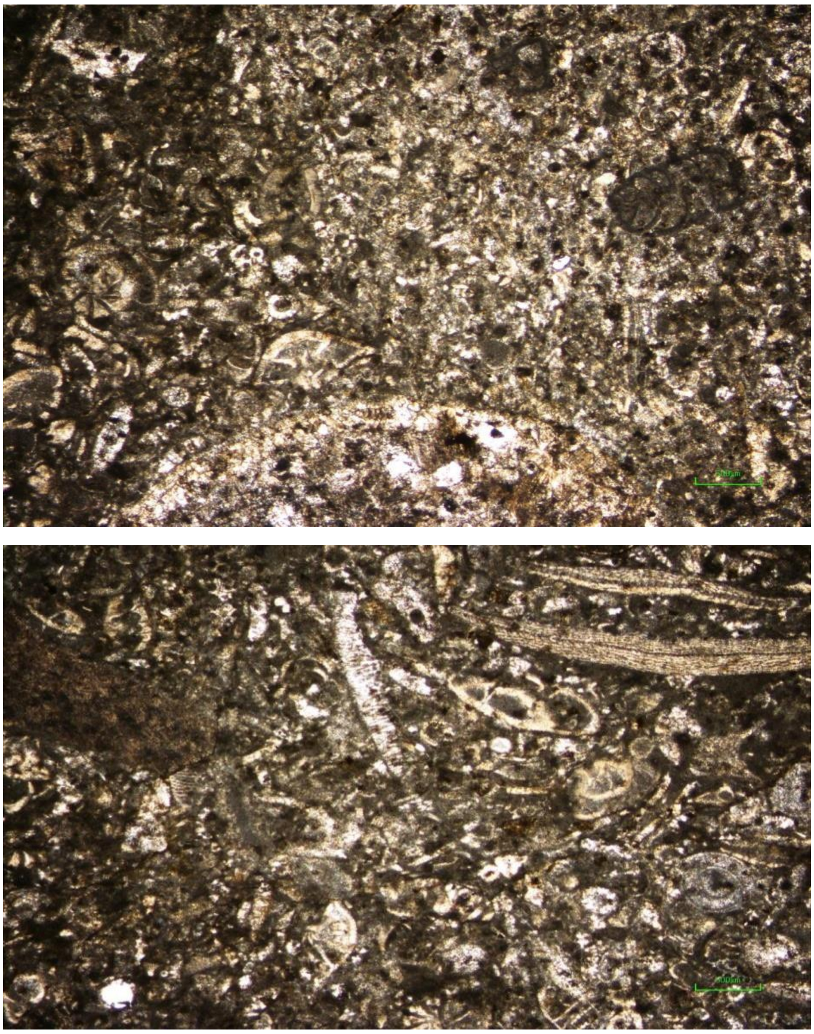


Fig. 3.18 Show *Foraminifera, Dyscoclina sp and Bioclasts* are visible.

CHAPTER 4
BIOSTRATIGRAPHY

4.1 *Miscellanae miscella*; Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotalia = Subclass
- Foraminifera = Order
- Nonionoidea = Superfamily
- Miscellaneidae = Family
- *Miscellanea* = Genus
- *Miscellanae miscella* = Species

Plate 4.1

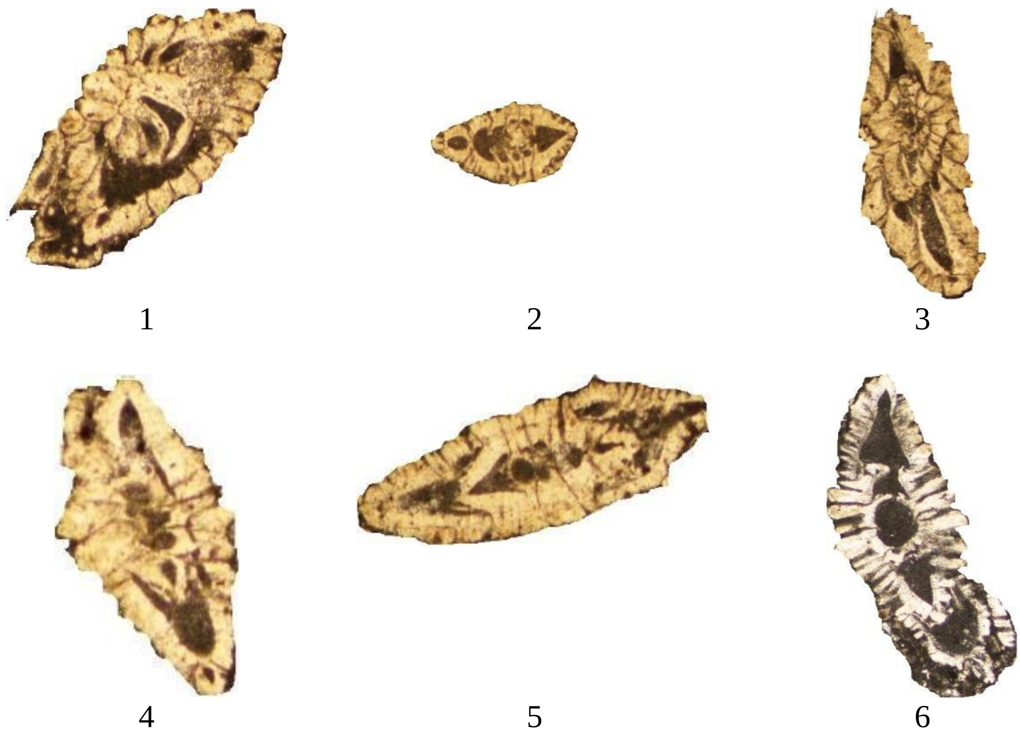


Fig. 4.1 Represent *miscellanea miscella* in both microspheric (1 and 2) and megalospheric (3, 4, 5, and 6) forms, with a lenticular shell.

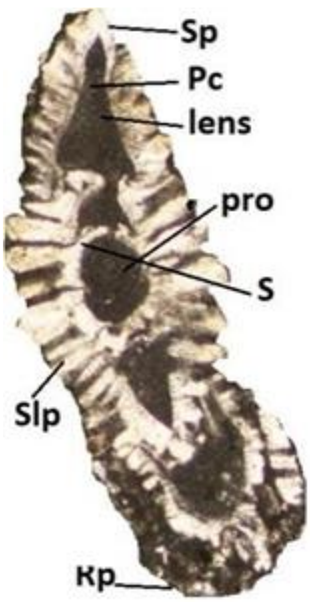
4.1.1 Description

Larger foraminifera belonging to the *Miscellaneidae* family were found in the Tethyan carbonate platforms during the Paleocene and early Eocene. *Miscellanea miscella and Miscellanea juliettae are* members of this family that commonly occur in the Lockhart limestone of the Paleocene. *M. miscella* is easily distinguishable from *M. juliettae,* which is comparatively small in size, has light ornamentation, and has thin walls. This is because of the former's vast size, thick walls, and dense decoration. M. miscella is frequently discovered in the Nammal Gorge, Pakistan's Lockhart Limestone deposits. The *Miscellanea miscella* often occurs in both microspheric (1 and 2) and megalospheric (3, 4, 5, and 6) forms, with a lenticular shell (Fig.4.1).

A series of piles that obstruct the polar region's structure in its megalospheric form have been observed. The megalospheric form's edges are pointed, but the microspheric form is rounded and covered with many pustules. But in the microspheric forms, the pustules on the periphery become slender piles at the poles. The septa that are visible in the equatorial portion have been curved and inclined backwards. In the axial segment, the deuteroconch envelops the protoconch, and the megalsphere is spherical.

4.1.2 Morphology

Plate 4.2



Miscellanae miscella

1

Fig. 4.2 *Miscellanea miscella (*megalospheric form), indicating septum, peripherial chamber, polar area, umbilical plate,sharp peripheries, rounded peripheries, slender piles at poles, biconch etc.

*Miscellanea miscella (*megalospheric form), Abbreviations: s: septum, pc: peripherial chamber, f: foramen p: polar area, up: umbilical plate, sp: sharp peripheries, rp: rounded peripheries; slp: slender piles at poles; bic: biconch, wall separating protoconch and deuteroconch, deuteroconch embracing the proloculus (terminologies adopted from Höttinger, 2006), typical heavy ornamentation of *M. miscella* in the given figure (Fig.4.2).

4.2 *Miscellanae juliettae*;Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotalia = Subclass
- Foraminifera = Order
- Nonionoidea = Superfamily
- Miscellaneidae = Family
- *Miscellanea* = (Genus)
- *Miscellanae juliettae* = Species

Plate 4.3

1

2

3

4

Fig. 4.3 Depict both the megalospheric (4) and microspheric (1, 2, and 3) forms of *Miscellanea juliettae*. The megaloshperic embryo is biconch, while the shells are lenticular.

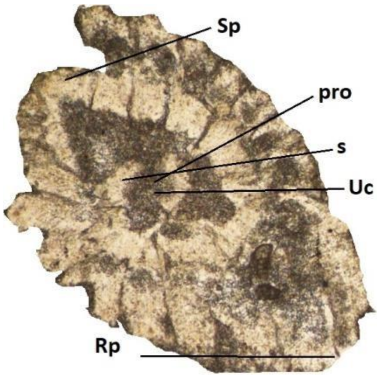
4.2.1 Description

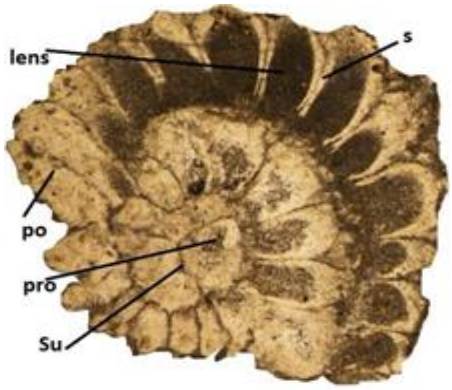
In the Lockhart Limestone of Nammal Gorge, Salt Range, both the megalospheric (4) and microspheric (1, 2, and 3) forms of *Miscellanea juliettae* have been discovered. The megaloshperic embryo is biconch, while the shells are lenticular. The edges of both types are pointed. Polar region is somewhat depressed in the microspheric form and slightly convex in the megalospheric form (Fig.4.3).

In the megalospheric form, the proloculus (first chamber) is large, whereas in the microspheric form, it is small. There is decoration, ranging from light to heavy, and 1 and 3 clearly display it. In (1 and 2), the lenticular ornamentation is well visible, but in 1, it is quite noticeable. The edges are rounded and mildly cured. When compared to *Miscellanea miscella*, which has thick walls, the thin walls of both forms—megalospheric and microspheric—help to differentiate them.

4.2.2 Morphology

Plate 4.4





1 2

Fig. 4.4 Show megalospheric (1) and microspheric (2) forms representing septum, convex poles,rounded peripheries, umbilicus, peripheral chamber tip, proloculus, sharp peripheries, biconch, wall separating protoconch and deuteroconch.

Miscellanea juliettae (Leppig, 1988), microspheric form (2), megalospheric form (1). Abbreviations: s:septum, cp: convex poles, rp: rounded peripheries, uc: umbilicus, pct: peripheral chamber tip, pro: proloculus, sp: sharp peripheries, bic: biconch, wall separating protoconch and deuteroconch (terminologies adopted from Höttinger, 2006), (Fig.4.4).

4.3 *Lockhartia haimei* Classification system

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- foraminifera = Order
- Rotalioidea = Superfamily

- Rotaliidae = Family
- Lockhartiinae = Subfamily
- *Lockhartia* = Genus
- *Lockhartia haimei* = Species

Plate 4.5

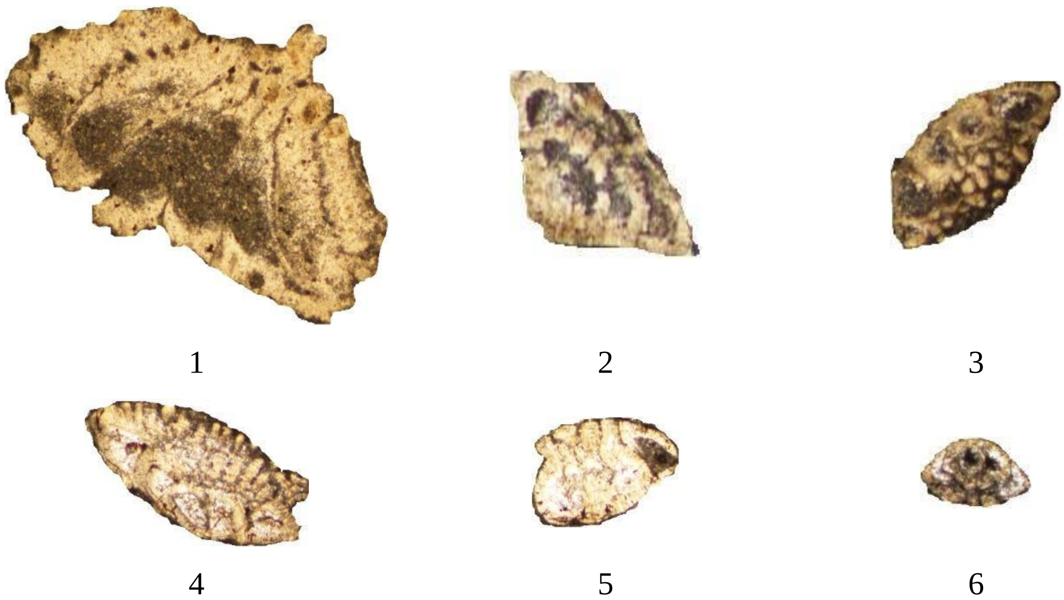


Fig. 4.5 Show spiral bars, also called pustules, on spiral side. The ventral side of the species has a large number of pustules, which are plainly seen in 3 and 4. The planoconvex side appears convex, and the tests are calcareous perforate.

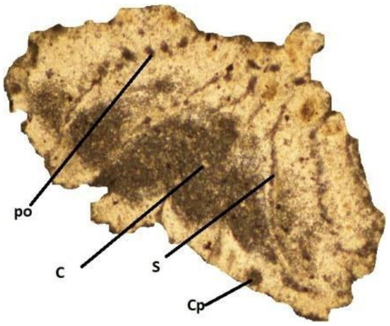
4.3.1 Description

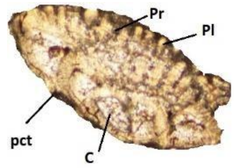
Lockhartia haimei is mostly found in the Lockhart limestone of Nammal area and is regarded as a reference fossil for Paleocene rocks. There appear to be a lot of pillars on the umbilical side. The species' walls are calcareous and typically perforate. On the spiral side, there are spiral bars, also called pustules, which form as coarsely perforate growths. The ventral side of the species has a large number of pustules, which are plainly seen in 3 and 4. The planoconvex side appears convex, and the tests are calcareous perforate. The knobs, which are clearly visible in 3 and 4, cover the proloculous (Fig.4.5).

One (1) clearly shows the chambers and ornamentation, while 5 shows the suture lines onthe spiral side. In Figures 1 and 5, the edges are sharp, whereas in Figures 2, 3, 4, and 6, they are rounded to sub-round. Knob ornamentation is often widespread. The diagonastic properties of Lockhartia haimei in the given research are planoconvex, spiralside with knobs, calcareous perforate, and coarsely porous.

4.3.2 Morphology

Plate 4.6





1 2

Fig. 4.6 Morphological features of *Lockhartia haimei*: there are chamber, suture, pillars or knobs, planoconvex test, etc. The planoconvex test and spiral side with knobs are diagonastic features of the species.

Lockhartia haimei (1and 2) shows morphological features. Abbreviations: c: chamber, s: suture, cp: coarse perforate, pl: pillars or knobs, Pct: planoconvex test, pr: coarsely porous. The planoconvex test and spiral side with knobs are diagonastic features of the species given above (Fig.4.6).

4.4 *Lockhartia tippri*

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Rotalioidea = Superfamily
- Rotaliidae = Family
- Lockhartiinae = Subfamily
- *Lockhartia* = Genus
- *Lockhartia tippri* = Species

Plate 4.7

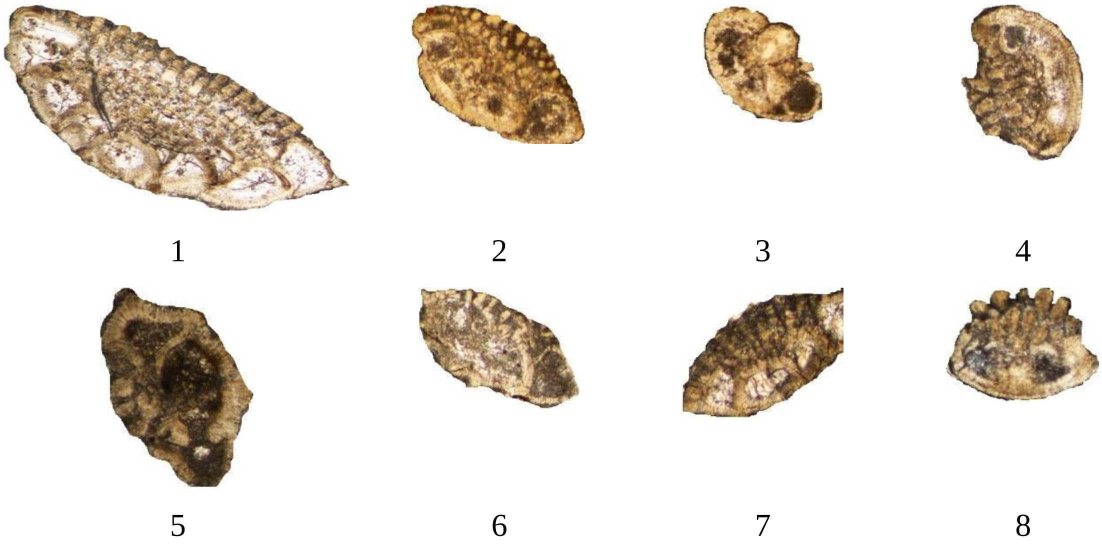


Fig. 4.7 Trochospiral test with a rounded to subrounded periphery border is depicted. On the umbilical side, thick pustules are visible. There are no obvious suture lines.

4.4.1 Description

In general, a low trochospiral test with a rounded to subrounded periphery border is a characteristic feature of *Lockhartia tipperi*. On the umbilical side, thick pustules are visible. The general morphology is bilaterally decorated, compressed, and biconvex. The shells are coarsely perforated and calcareous. There are no obvious suture lines. On the umbilical side, there is an interiomarginal aperture. The edges are often rounded, but they can be sharp.

The pillars are thick and uniform and the umbilical plates are well formed. The specified species is characterized by a biconvex compressed test, a large number of knobs and pillars on the umbilical side, rounded to subrounded peripheries, and dense pustules (Fig.4.7).

4.4.2 Morphology

Plate 4.8

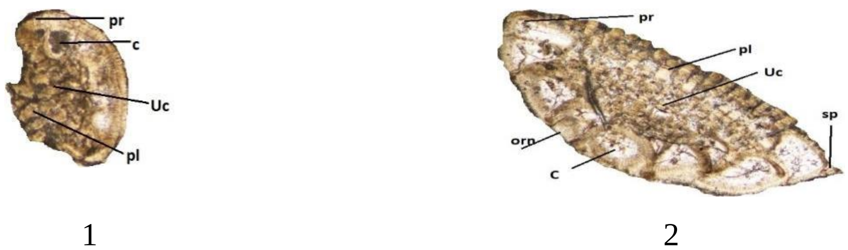


Fig. 4.8 Above 1and 2 show the morphological features of *Lockhartia tippri*.

Lockhartia tippri (1 and 2) shows the morphological features of the given species. Abbreviations, Uc: center of umblical plate; orn: ornamentation; sp: sharp peripheries; pr: rounded peripheries; c: chamber; pl: pillars; thick pustules and knobs present on the umblical side; and biconvex compressed test are the reliable diagonastic features of the given species *(Lockhartia tippri)*, (Fig.4.8).

4.5 *Lockhartia conditi*

4.5.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Rotalioidea = Superfamily
- Rotaliidae = Family
- Lockhartiinae = Subfamily
- *Lockhartia* = Genus
- *Lockhartia conditi* = Species

Plate 4.9

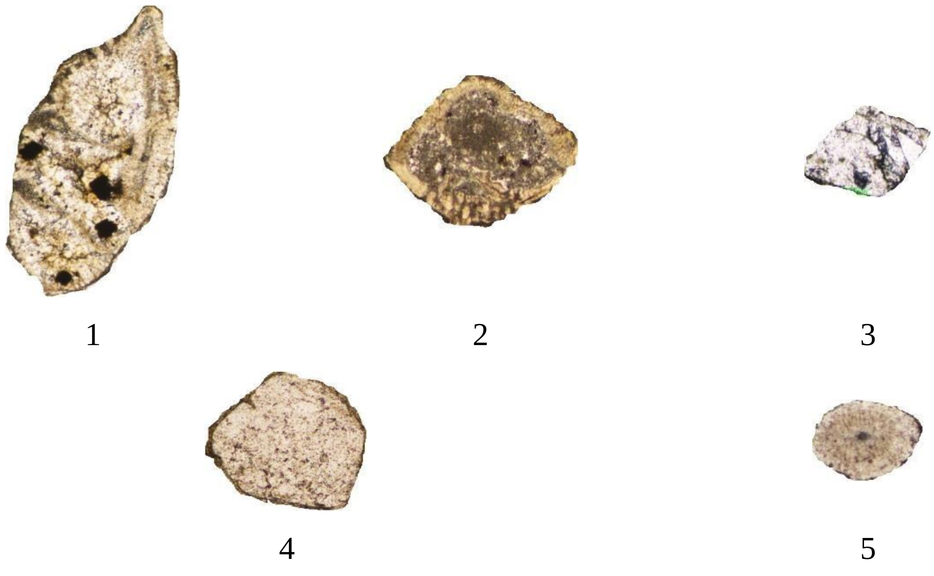


Fig. 4.9 *Lockhartia conditi*, has a high-spired shell with a few thick pillars. The umbilical part is filled with these pillars shown in figure.

4.5.2 Description

An important fossil is *Lockhartia conditi*. This species, which has a high-spired shell with a few thick pillars, was discovered in rocks of the Paleocene and Eocene ages. The umbilical part is filled with these pillars. Its trochospiral shell with a few large pustules on the umbilical side sets it apart from the other *Lockhartia species*. On the fossil's evolved side, the suture lines are hidden.

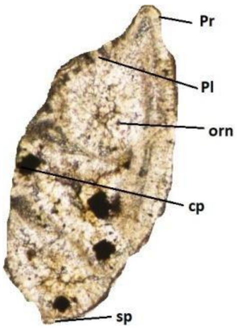
The test or shell is calcareous, perforate, and biconvex. In addition to the umbilical boss being present and a few knobs being placed, the spire is close. On the evolved side, the suture lines are hidden.

There aren't as many noticeable and thick pillars in 1 and 2 as there are in the other *Lockhartia species.*

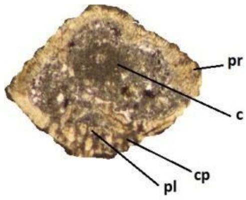
The peripheries of 4 and 5 are nearly rounded, but the remaining have sharp or subrounded peripheries (Fig.4.9).

4.5.3 Morphology

Plate 4.10



1



2

Fig. 4.10 (1 and 2) Depict the morphological features of *Lockhartia conditi*. Few thick pustules are present.

Abbreviations: Pl: pillars; pr: rounded peripheries; sp: sharp peripheries; c: chamber; orn: ornamentation; cp: coarse perforate. The given species is quite different from other species of *Lockhartia*, as it has a few thick pustules and a trochospiral shell that distinguish it from the others (Fig.4.10).

4.6 *Assilina subspinosa*

4.6.1 Classification

- Biota
- Chromista = Kingdom

- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily
- Nummulitidae = Family
- *Assilina* = Genus
- *Assilina subspinosa* = Species

Plate 4.11

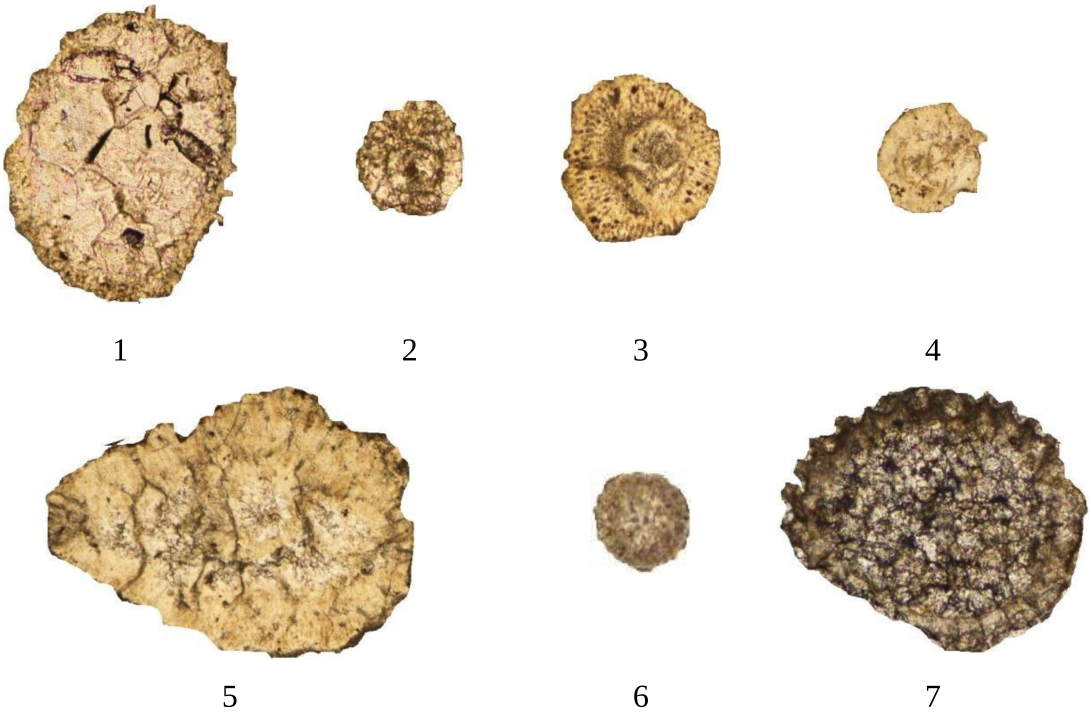


Fig. 4.11 Show Assilina subspinosa with thick, granule-covered, well- developed ornamented shell and spinose appearance.

4.6.2 Description

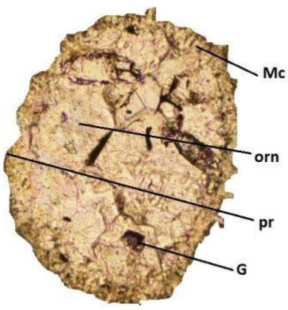
A well-known species that is commonly found in Paleocene and Eocene rocks is *Assilina subspinosa* (Davies and Pinfold). In the specified examination, this species is present in several thin-section cutting samples. *Assilina subspinosa* features a thick, granule-covered, well- developed ornamental shell. These surface granules give the area a recognizable spinose appearance.

In the preceding figures, the peripheries are rounded and subrounded. Thick granules that are transverse to the inner direction appear as pillar-like ornamentations within the shell. There is megalospheric generation in these tests.

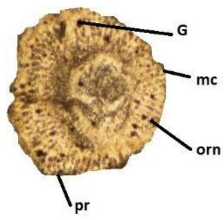
The distinguishing characteristics that help identify the species are the thick granules that are prominently ornamented and trend toward the inner side of the structure in the shape of pillars with rounded to subrounded edges (Fig.4.11).

4.6.3 Morphology

Plate 4.12



1



2

Fig. 4.12 Morphological features of *Assylina subspinosa*: marginal cord, ornamentation, granules, rounded peripheries.

Above 1 and 2 show the morphological features of Assylina subspinosa. Abbreviations: Mc: marginal cord, orn: ornamentation, G:granules, pr: rounded peripheries. Thick granules that transverse inward in the shape of pillars, giving spinose appearance and ornamentation, are the most prominent diagonastic feature of the species (Fig.4.12).

4.7 *Assilina exponens*

4.7.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily

- Nummulitidae = Family
- *Assilina* = Genus
- *Assilina exponens* = Species

Plate 4.13

1 2

Fig. 4.13 *Assilina exponens*, morphologically separated into several radial septal sutures, as shown by the microphotographs.

4.7.2 Description

Assilina exponens, one of the larger foraminifera, is discovered in eocene rocks; nonetheless, it has been found in two separate thin sections of lockhart limestone in Nammal Gorge. The species is morphologically separated into several radial septal sutures, as shown by the microphotographs.

The wedge-shaped chambers of the species are divided by the radial septal sutures that run the length of the specimen's body. The septa have a little inclination and are narrow. The lateral wall and marginal cord give the species a distinct body shape and appear thin.

The distinctive diagonastic features of the species include the wedge-shaped chambers that spread throughout the body like lenses and the radial septal sutures. Typically, the edges are sharp or rounded. In plate 4.13, the wedges and septa sutures are clearly visible (Fig.4.13).

4.7.3 Morphology

Plate 4.14

1 2

Fig. 4.14 (1 and 2) Depict the morphological attributes of *Assilina exponens*. Sharp peripheries, chamber and marginal cord are prominent.

This species is found in Paleocene and Eocene rocks. Abbreviations: sp: sharp peripheries; Pr: rounded peripheries; C: chamber; Mc: marginal cord; s: septa. Wedge-shaped lenses and thin septa that separate them areimportant features for recognizing the specimen (Fig.4.14).

4.8 *Operculina salsa*

4.8.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily
- Nummulitidae = Family
- *Operculina* = Genus
- *Operculina salsa* = Species

Plate 4.15

1

2

Fig. 4.15 Thick marginal chord is present, proloculus in both pictures shown.

4.8.2 Description

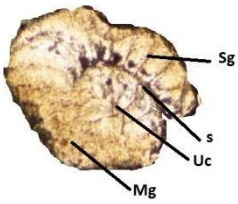
The specimens L40 and L47 contain *operculina salsa* (Davies, Pinfold, 1937). Although it has a thick marginal chord, it lacks a megalospheric proloculus. It is clear to see the proloculus in both of the pictures shown in Plate 8. There are granules at the poles as well, arranged in a little cluster. Above 2 shows the septa, which are ornamented with granular morphology.

With a clockwise whorl around the spire, it is thickest in the middle. The entire spire of the specimen has septa, which are dispersed throughout and clearly visible in the exterior morphology. Figures above clearly display the umbilicus, which is the coil's center.

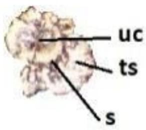
The shell is trochospiral, meaning that coils of chambers are added to form a spire that resemblesa snail shell. The spiral side view, which shows every chamber in the given images, is depicted (evolute). The diagonastic features of the species in question include the megalospheric proloculus, the trochospiral shell, and the conspicuous umbilicus (Fig.4.15).

4.8.3 Morphology

Plate 4.16



1



2

Fig. 4.16 Exhabit *Operculina salsa* in spiral view.

Above 1 and 2 exhibit Operculina salsa in spiral view. Abbreviations: Uc: umbilicus; ts: trochospiral shell; s: suture; Mg: granules at margins; sg: granulated septa. The umbilicus and trochosprial shell with granulated septa are the features that are helpful in identifying thespecimen (Fig.4.16).

4.9 *Operculina patalensis*

4.9.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily
- Nummulitidae = Family
- *Operculina* = Genus
- *Operculina patalensis* Species

Plate 4.17

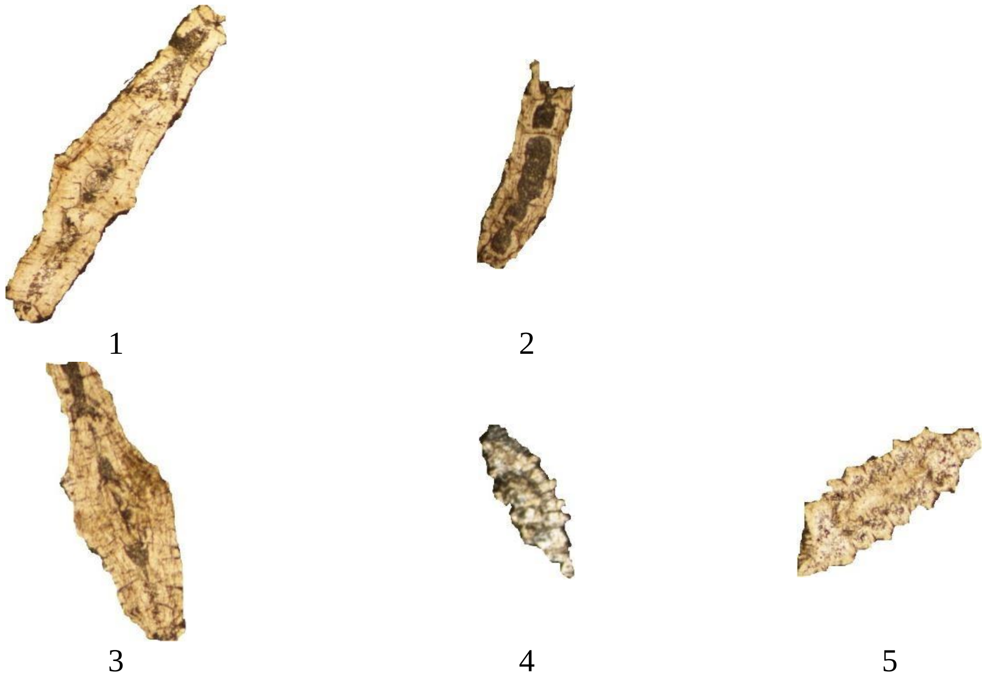


Fig. 4.17 Morphological characteristics of *Operculina patalensis*. Chambers are visible as lenses that extend in the middle of the structure.

The smooth, rim-shaped whorl is formed in the outermost margin by the marginal cord.

4.9.2 Description

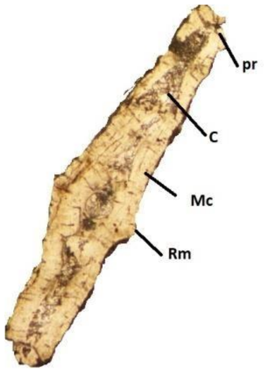
There is *Operculina patalensis* (Davies and Pinfold) in the specimens L37, L39, and L47a. The species is found in the Nammal Gorge area. The morphological characteristics listed below are what define it in this particular case.

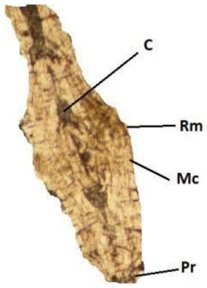
The chambers of the *Operculina patalensis* are visible as lenses that extend in the middle of the structure throughout the body. The septa, which are primarily curved in shape, divide thewedge-shaped lenses (Fig.4.17).

The smooth, rim-shaped whorl is formed in the outermost margin by the marginal cord. The peripheries are curved to round in shape and can be sharp. The presence of rim shaped whorl formed by marginal cord, lenses and curved septa are the diagonastic attributes of the fossil.

4.9.3 Morphology

Plate 4.18





1 2

Fig. 4.18 (1 and 2) indicate the morphology of *Operculina patalensis*. Chambers, marginal cord, rounded peripheries etc, are present.

Abbreviations: c: chamber; Rm: rim formed by marginal card; Mc: marginal cord; pr: rounded peripheries. The presence of rim whorls formed by marginal cord and wedge-like chambers are the identifying features of the species (Fig.4.18).

4.10 *Ranikothaliasindensis* (DAVIES)

4.10.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily
- Nummulitidae = Family
- *Ranikothalia* = genus
- *Ranikothalia sindensis* = Species

Plate 4.19

1

2

3

4

Fig. 4.19 *Ranikothalia sendensis* lacks true septal filaments, and the chamber usually extends the entire length of the spire. The marginal cord appeared thickly granulated over the entire geometry.

4.10.2 Description

In Pakistan's upper Paleocene rocks (Thanetian Sucession), the foraminiferal genus Ranikothalia is also commonly found. It is found in samples L40 and L41 of the studied thin sections. Regarding stratigraphic significance, the Ranikothalia sindensis Partial Range Zone needs to be included in the Upper Paleocene (Thaetian) of Cavelier and Pomerol's paleogene stratigraphic correlation scale (1983).

This species, Ranikothalia sindensis, was observed in association with the benthic foraminifera, Miscellanae miscella, in recent research. However, it can be found in association with Assilina laminosa, Nummulities, and Discoclina to inhabit early Eocene age.

Ranikothalia sendensis lacks true septal filaments, and the chamber usually extends the entire length of the spire. The marginal cord appeared thickly granulated over the entire geometry. These are peculiar identifying attributes of the given species (Fig.4.19).

4.10.3 Morphology

Plate 4.20

1 2

Fig. 4.20 Above 1 and 2 show *Ranikothalia sindensis*. Chamber, marginal cord is prominent.

Abbreviations: Mc: marginal cord, c: chamber, G: granules, pr: rounded peripheries, ps: sharp peripheries. The thick marginal cord extending the entire structure and the absence of septal filaments are characteristic features of the given species (Fig.4.20).

4.11 *Ranikothalia sahnii*

4.11.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily
- Nummulitidae = Family
- *Ranikothalia* = genus
- *Ranikothalia sahnii* = Species

Plate 4.21

1

2

Fig. 4.21 Show *Ranikothalia sahnii* having poles of the shell prominent and granulated. The septa and marginal cord are well developed in Ranikiothalia sahnii as it was in Ranikothalia sendinsis.

4.11.2 Description

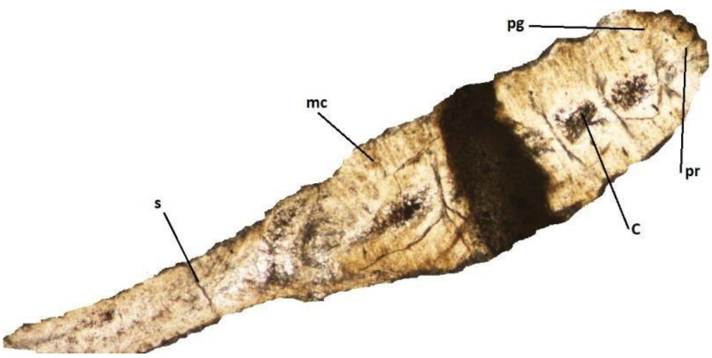
Ranikothalia sahnii is found in L44 and L47 of Lockhart limestone. Poles of the shell are prominent and granulated. The septa, or septal filaments, are strongly marked and developed. The marginal cord is as well developed in *Ranikiothalia sahnii* as it was in *Ranikothalia sendinsis.*

Suture lines are clearly visible. Chambers are separated by septal filaments, which are thick and strong, while chamber visibility is not prominent throughout the length of the species. The peripheries are rounded to subrounded. The granulated ornamentation is visible in the structure. The chamber's shape is irregular in nature.

The well-developed marginal cord, granulated poles, and strong and thick septa are the diagonastic features of the species. Chamber morphology is also helpful in identifying the fossil (Fig.4.21).

4.11.3 Morphology

Plate 4.22



1

Fig. 4.22 Indicate morphological attributes of *Ranikothalia sahnii.* Chambers and peripheries are visiable.

Here (1) depicts the morphological attributes of *Ranikothalia sahnii*. Abbreviations: C, chamber; pr: rounded peripheries; s: suture; Mc: marginal cord; pg: granulated poles. The species is observed in the lockhart limestone of Nammal Gorge. The given attributes are the identifying features of the fossil (Fig.4.22).

4.12 *Discocyclina ranikotensis*

4.12.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Nummulitoidea = Superfamily
- Discocyclinidae = Family
- *Discocyclina* = Genus

Plate 4.23

1 2 3

Fig. 4.23 *Discocyclina ranikotensis* depicts a discoidal and flat test with numerous chambers.

4.12.2 Description

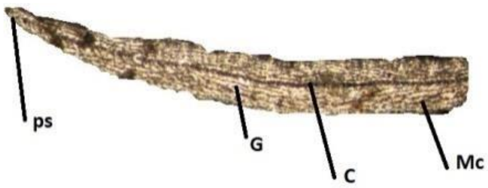
Discocyclina ranges in age are (from the Middle Paleocene to the Late Eocene), (Hottinger, 1960; Blondaeau, 1972; Schaub, 1981; Serra Kiel et al., 1998). The species is found in samples L48 and L49 of Lockhart limestone from Paleocene rocks in Nammal Gorge, Western Salt Range. Geologically, it is an important indicator of the late Paleocene age.

Discocyclina ranikotensis depicts flat test with multiple chambers. These chambers apparently resemble a line extending in the middle of the fossil from one end to the other. Some species of discocyclina show a central bulge; however, in this study, the species is flat, elongated, and thin, unlike *Discocyclina dispensa*, which has a central bulge.

The species has sharp perepheries at its poles. The marginal cord is prominent and extends throughout the structure along chambers. The scattered granules are also observed in the specimen. The diagonastic characteristics of the given species are flat, elongated, and thin. The marginal cord and chamber are also helpful in identifying it (Fig.4.23).

4.12.3 Morphology

plate 4.24



1

Fig. 4.24 Depict the morphological attributes of *discocyclina ranikotensis*. Elongated and flat shape is prominent to recognize

Abbreviations: Ps: sharp peripheries; G: granules; C: chambers; Mc: marginal cord. The elongated, flat, and thin shape of the fossil makes it easy to recognize (Fig.4.24).

4.13 *Miscellanites globularis Raghaghi*

Plate 4.25

1 2

Fig. 4.25 *Miscellanites globularis* Raghaghi exhibits Lamellar, spherical morphology, and planispiral chamber arrangement. The surface is covered with granular ornamentation. The test is megalospheric in shape, and the spiral arrangement is in a clockwise direction.

4.13.1 Description

The view is of an equatorial section in the above figures. The protoconch is separated from the deuteroconch by a thin wall. The diameter of the megalospheric shell varies in size. The septaand sutures can be observed in the structure.

Lamellar spherical morphology and planispiral chamber arrangement are helpful in identifying the species in the samples (Fig.4.25).

4.14 *Globorotalia angulata*

4.14.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Globigerinina = Suborder
- Globorotalioidea = Superfamily
- Globorotaliidae = Family
- *Globorotalia* = Genus
- *Globorotalia angulata* = Species

Plate 4.26

1

Fig. 4.26 *Globorotalia angulate has a* trochospiral shell. The sutures and septa are prominent. Spiral side is flat.

4.14.2 Description

Globorotalia angulate has a trochospiral shell, and the spiral side is flat. The fossils are planktic foraminifera and are scarcer than the other benthic foraminifera;

however, when they are in sufficient amounts, they are characterized as important zonal markers.

The sutures and septa are prominent, and the septa are clearly observed, which separates the chambers. The chambers of the last coil are visible, and this side is termed the umbilical side. However, this arrangement forms a spire like a snail shell.

The shell is microspheric, and the proloculus is small. The trochospiral shell, small proloculus, prominent septa, and suture are identifying characteristics of the given fossil (Fig.4.26).

4.14.3 Morphology

Plate 4.27

1

Fig. 4.27 The above figure exhibits morphological features of the *Globorotalia angulate*.

Abbreviations: pro: proloculus, c: chamber, and s: suture. If the proloculus is small, the reproduction is sexual. The morphological characteristics given above are helpful in identifying the fossil in samples (Fig.4.27).

4.15 *Daviesina khatiyahi*

4.15.1 Classification

Plate 4.28

1

Fig. 4.28 Show peripheries which are curved and rounded. The shell is granulated, megalospheric at poles depicting ornamentation. The proloculus is prominent and large.

4.15.2 Description

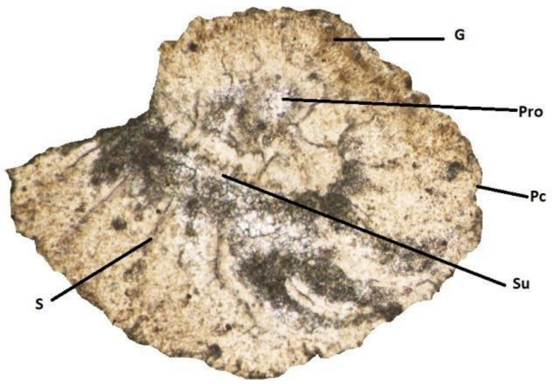
Daviesina khatiyahi is included in foraminifera and is found in sample no.L40 of the Lockhart Limestone of Nammal Gorge, Western Salt Range. The fossil is lamellar and has a low trochospiral, almost panispiral, arrangement. The shell is ornate on the dorsal sides.

The chambers on the outer portion of the shell are increasing in diameter. The peripheries are curved and rounded. The shell is granulated at poles depicting ornamentation. The proloculus is prominent and large. The shell is megalospheric in shape.

The true septa are visible in the last chambers of the shell. The coiling of the shell is also significant, and it has an umbilical plate. The coiling of the shell and its morphological attributes are diagonastic characteristics of the fossil in the samples (Fig.4.28).

4.15.3 Morphology

Plate 4.29



1

Fig. 4.29 Represent the morphology of *Daviesina khatiyahi*.

Abbreviations: G: granules, pro: proloculus, pc: curved peripheries, Su: suture line, S: septa. The spiral arrangements of the shell and overall morphology are the identifying features of the given fossil (Fig.4.29).

4.16 *Lockhartia retiata Sander*

4.16.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom

- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Rotalioidea = Superfamily
- Rotaliidae = Family
- Lockhartiinai = Subfamily
- Lockhartia = Genus
- *Lockhartia retiata* = Species

Plate 4.30

1

2

Fig. 4.30 Represent curved to rounded peripheries. The chamber in 1 is spherical to semispherical in shape, while in 2, there is irregular.

4.16.2 Description

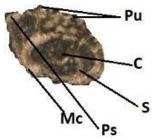
This species belongs to the genus *Lockhartia*, which is dominantly found in the Lockhat limestone of Nammal Gorge, Western Salt Range

The marginal cord is perforated, granulated, and relatively thin in 1, while it is thick and bulging in the second. The pustules are present on the margins of 1, while in 2, they are not visible.

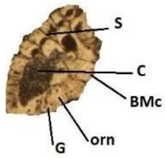
The chambers and septa are observed in both fossils, while granules are prominently seen in 2, forming punctate ornamentation. The thick, buldging marginal cord in 2 and the spherical chamber in 1 are the morphological characters that are helping in identifying the fossil in thespecimen (Fig.4.30).

4.16.3 Morphology

Plate 4.31



1



2

Fig. 4.31 Indicate the morpological attributes of Lockhartia retalia. Septa, Chamber, and marginal cord are present (1 and 2)

Abbreviations: S: septa, c: chamber, pu: pustules, c: chamber, Mc: marginal cord, Bmc: buldging marginal cord, orn: ornamentation, G: granules, Ps: sharp peripheries. These are the attributes that guide the diagnosis of the given fossil in the specimen (Fig.4.31).

4.17 *Elazigina harabekayisensis*

4.17.1 Classification

Plate 4.32

Fig. 4.32 *Elazigina harabekayisensis* have sharp peripheries on one side, while the other sides have curved or rounded peripheries. The marginal cord is thick and granulated.

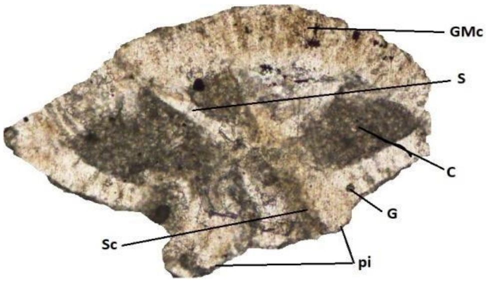
4.17.2 Description

Elazigina harabekayisensis also belongs to the phylum foraminifera. The species is found in sample no. 40 of the Lockhart limestone of Nammal Gorge, Western Salt Range. Its taxonomic status is accepted by the Global Biodiversity Information Facility ID (GBIF).

The inner chambers are partially divided by seta. True septa are lacking. Spiral canals and thick pillers are also visible, which give the fossil a unique morphology. The ornamentation shown by the species is punctate. The presence of thick pillars at the base, spiral canal, and chamber morphology are the attributes that guide the recognition of the given fossil in the specimen (Fig.4.32).

4.17.3 Morphology

Plate 4.33



1

Fig. 4.33 Depict the morphological features of *Elazigina harabekayisensis*. Spiral canal, septa, chambers, granulated marginal cord and pillars are visible.

Abbreviations: Sc: spiral canal, s: septa, c: chamber, G: granules, GMc: granulated marginal cord, pi: pillars. These are the important attributes that are helpful in identifying the species (Fig.4.33).

4.18 *Rotalia trichidiformis*

4.18.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Rotalioidea = Superfamily
- Rotaliidae = Family
- Rotaliinae = Subfamily
- Rotalia = Genus
- Rotalia trochidiformis = Species

Plate 4.34

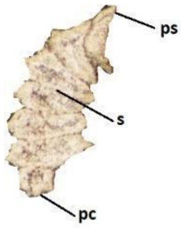
Fig. 4.34 Rotalia trochidiformis exhibits sharp and curved peripheries.

4.18.2 Description

Genus of foraminiferans having a finely perforated test with the segments in a turbinoid spiral. The most abundant and diverse order corresponded to *Rotaliida* (79%); their high diversity of trochoid forms gives them the advantageous ability to adhere to various types of substrates, inhabiting most marine environments and especially coastal areas. They can therefore be foundin neritic areas, both on the coastline and at the end of the photic zone (Haynes, 1981; Boix- Martínez, 2007).

4.18.2 Morphology

Plate 4.35



1

Fig. 4.35 Represent the morphology of *Rotalia trochidiformis*.

Abbreviations: ps: sharp peripheries; pc: curved peripheries; s: septa. The general morphology of the fossil can help in its identification (Fig.4.35).

4.19 *Quinqueloculina lamarckiana*

4.19.1 Cassification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Tubothalamea = Class
- Foraminifera = Order
- Miliolina = Suborder
- Milioloidea = Superfamily
- Hauerinidae = Family
- Hauerininae = Subfamily
- *Quinqueloculina* = Genus
- *Quinqueloculina lamarckiana* = Species

Plate 4.36

1 2

Fig. 4.36 Show *Quinqueloculina* lamarcki. The overall appearance is globose to ovate. Miliolid coiling is also visible.

4.19.2 Description

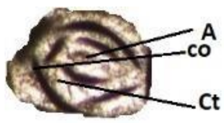
Quinqueloculina lamarckiana is a fossil found in samples L43 and L47 of the Lockhart Limestone of Nammal Gorge, Western Salt Range. It belongs to the Milioloidea superfamily.

The taxonomic status of the species is also accepted. The wall material of the species is porcelaneous. The overall appearance is globose to ovate. It depicts miliolid coiling while the sutures are depressed and curved.

The chamber form is tubular. The aperture of the species is terminal with a round, oval form. Globose-to-ovate appearance, chamber form, and coiling pattern are the identifying features of the species (Fig.4.36).

4.19.3 Morphology

Plate 4.37



1

Fig. 4.37 Indicates *Quinqueloculina lamarckiana* morphological features.

Abbreviations; A: apercture; co: coiling; and ct: tubular chamber. These are important attributes that can be used to recognize the species in the specimen (Fig.4.37).

4.20 *Quinqueloculina vulgaris*

4.20.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Tubothalamea = Class
- Foraminifera = Order

- Miliolina = Suborder
- Milioloidea = Superfamily
- Hauerinidae = Family
- Haueririnae = Subfamily
- *Quinqueloculina* = Genus
- *Quinqueloculina vulgaris* = Species

Plate 4.38

1

Fig. 4.38 *Quinqueloculina* vulgaris exhibits the aperture which is present on dorsal side.

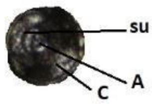
4.20.2 Description

Quinqueloculina vulgaris d'Orbigny, 1826, was found at the beach of Langkawi. *Quinqueloculina* is a genus of foraminifera and belongs to the superfamily Miliolidae. As with all miliolids, the shell of Quinqueloculina is comprised of imperforate, porcelaneous calcite.

Like all Miliolidae, the chambers are arranged in different planes, with two chambers per whorl. All chambers are, however, not comprehensively visible in the fossils observed in this research; however, the aperture is recognized on the dorsal side (Fig.4.38).

4.20.3 Morphology

Plate 4.39



1

Fig. 4.39 Represent the morphological features of Quinqueloculina vulgaris.

Abbreviations: Su:future, A: aperture, C: chamber. These features are helpful in recognizing the fossil in thespecimen (Fig.4.39).

4.21 *Triloculina sp*

4.21.1 Classification

- Biota
- Chromista = Kingdom

- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Tubothalamea = Class
- Foraminifera = Order
- Miliolina = Suborder
- Milioloidea = Superfamily
- Hauerinidae = Family
- Miliolinellinae = Subfamily
- *Triloculina* = Genus

Plate 4.40

1

Fig. 4.40 *Tricoculina* has chambers in the form of coiling. The shape is semispherical to spherical.

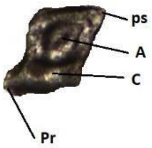
4.21.2 Description

Tricoculina is also a genus of the phylum foraminifera and is included in the Milioloidea superfamily. The shells are three, and the chambers are in the form of coiling. The shape of the species is semispherical to spherical. The test is comprised of imperforate and porcelaneous calcite.

The aperture is terminal at the end of the last chamber. Only three final chambers are observed from an external view. The generation is in microspheric form, as the proloculus is small in size. The test morphology in triloculina species, arrangement of the chambers in coils, and aperture position are helpful for identification of the fossil in the specimen (Fig.4.40).

4.21.3 Morphology

Plate 4.41



1

Fig. 4.41 Show the morphological features of *triloculina sp*. Peripheries and aperture is visible.

Above figure depicts the attributes of the *triloculina* sp. of the *Milioloidea* superfamily. Abbreviations: Pr: rounded peripheries; ps: sharp peripheries; c: chamber; A: aperture. These are the diagnostic characteristics that are helpful in recognizing the species in the specimen (Fig.4.41).

4.22 *Milliolids*

4.22.1 Classification

- Phylum = Protozoa
- Sub phylum = foraminifera
- Class = Tubothalamea
- Order = Foraminifera

Plate 4.42

1

2

Fig. 4.42 Indicate *miliolids* having tests that are calcareous and porcelacous.

4.22.1 Description

Miliolids are included in foraminifera and have been observed in samples L39 and L40 of the Lockhart limestone of Nammal Gorge, Western Salt Range. These are benthic foraminifera and are abundant in shallow waters (estuaries and coastlines).

The *miliolids* are classified based on the overall morphology of their shells. Their tests are calcareous and porcelacous, which are imperforate in nature. Pseudochitinous lining is also present in them.

The tests have a high amount of magnesium in them, along with organic matter. They lack pores and have multiple chambers. The shape of the test is spherical to semispherical in nature. The miliolids have a wide range of occurrences from the Carboniferous to the recent era (Fig.4.42).

4.22.2 Morphology

Plate.4.43

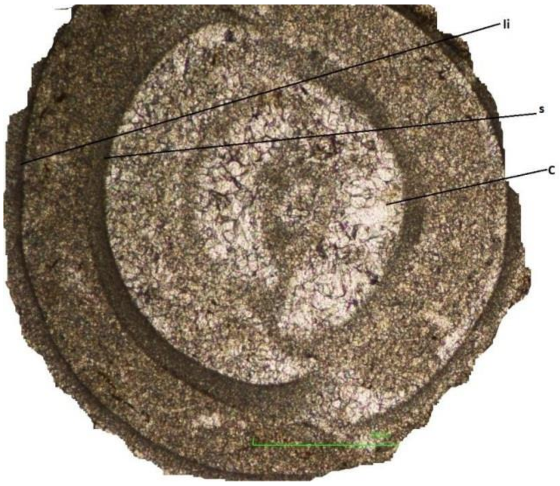


Fig 1

Fig. 4.43 Represent the morphology of the *milliolids*.

Abbreviation: C, chamber; li: pseudochitinous lining; s: suture. These morphological attributes are very helpful in recognizing the species in the samples (Fig.4.43).

4.23 *Bigenerina* sp.

4.23.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Textulariana = Subclass
- Foraminifera = Order
- Textulariina = Suborder
- Textularioidea = Superfamily
- Textulariidae = Family
- Textulariinae = Subfamily
- *Bigenerina* = Genus

Plate 4.44

1 2 3

Fig. 4.44 Depict morphology of the shell having irregular arrangement of the chambers tightly bound by cement.

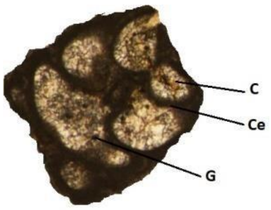
4.23.2 Description

Bigenerina species is found in samples L37, L45, and L47 of the Lockhart limestone of Nammal Gorge, Western Salt Range. The shape of the test is irregular. The chambers are not arranged in a uniform pattern. The size, shape, and chamber arrangement are quite unique and irregular.

The overall morphology of the shell and the irregular arrangement of the chambers are the characteristic features of the species to be recognized. The chambers are, however, bound to eachother by cement that holds the shell morphology (Fig.4.44).

4.23.3 Morphology

Plate 4.45



1

Fig. 4.45 Indicate the attributes of the *bigenerina* species.

Abbreviations: C, chamber, Ce: cement, G: granules. The shell chambers are bounded by cement that holds the structure of the species (Fig.4.45).

4.24 *Textularia.sp*

4.24.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum

- Globothalamea = Class
- Textulariana = Subclass
- Foraminifera = Order
- Textulariina = Suborder
- Textularioidea = Superfamily
- Textulariidae = Family
- Textulariinae = Subfamily
- *Textularia* = Genus

Plate 4.46

1

2

Fig. 4.46 In *textularia* sp, sutures are observed to be dintinct and depressed. The peripheries are conical to curve.

4.24.2 Description

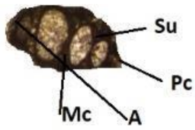
The *textularia* species is found in sample no L39 and L41 of Lockhart Limestone in Nammal Gorge, Western Salt Range. Generally it is found barkish marine. The species has conical rounded and compressed sides.

Aperture is elongate and slightly curved and is found at the last chamber of the structure. The shell is generally increasing in size and towards the aperture end, where it is widest. The walls of the test are smooth and are composed of finely arenaceous material, with mud cement.

Sutures are observed to be dintinct and depressed. The peripheries are conical to curve. The test chambers are bounded by the mud cement that helps the structure of the species to be held in place (Fig.4.46).

4.24.3 Morphology

Plate 4.47



1

Fig. 4.47 Represent the morphology of the *textularia* species.

Abbreviations: Su; suture, Pc: conical peripheries, A: aperture, Mc: mud cement. The connical shape and the gradual increase in size of the shell are important attributes of textularia species to be recognized (Fig.4.47).

4.25 *Globogerina linaperta*

4.25.1 Classification

- Biota
- Chromista = Kingdom
- Harosa = Subkingdom
- Rhizaria = Infrakingdom
- Protozoa = Phylum
- Globothalamea = Class
- Rotaliana = Subclass
- Foraminifera = Order
- Globigerinina = Suborder
- Globigerinoidea = Superfamily
- Globigerinidae = Family
- Globigerininae = Subfamil
- *Globigerina* = Genus
- *Globigerina linaperta* = Species

Plate 4.48

1 **2**

Fig. 4.48 Show *Globigerina* ooze coiled

4.25.2 Description

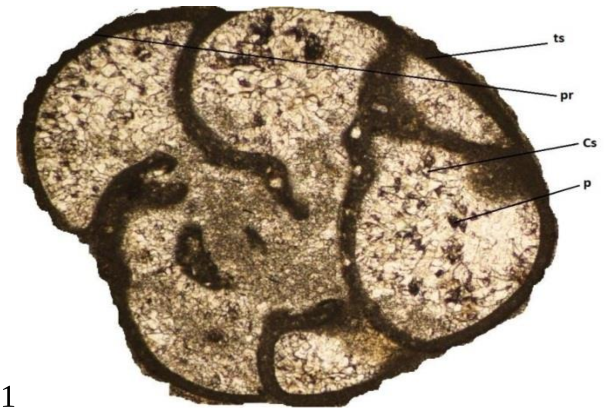
Globigerina ooze has been found in the floor of the western Indian Ocean, the mid-Atlantic Ocean, and the equatorial and South Pacific. Species are used to establish the temperature and climatic condition.

Globigerina linaperta is is a marine species generally characterized by its spherical and coiled shell or test. The test is comprised of chambers which are rounded and trochospiral. The chambers are elongated like the other species explained earlier. When the organisms grow, the size of thechambers also increases.

The shell is calcareous and perforate. There are pores present on the surface of the shell that can be cylindrical or irregular in shape. The aperture is interiomarginal, umbilical (Fig.4.48).

4.25.3 Morphology

Plate 4.49



1

Fig. 4.49 Diagonastic features of *Globigerina linaperta*. The shell is calcareous and porous.

Above figure indicates the attributes of the Bigenerina species. Abbreviations: C, chamber; Ce: cement; G: granules. The shell chambers are bounded by cement that holds the structure of the species (Fig.4.49).

CHAPTER 5
DIAGENETIC ALTERATION IN LOCKHART LIMESTONE

5.1 Introduction

Limestone in general is sensitive to diagenetic alteration because it is more soluble in acidic water than other kinds of natural minerals. Various physical and chemical processes are involved in diagenetic alterations that occur during and after the deposition of certain rock units. These processes are carried out in certain sequences, like deposition, compaction, cementation, dissolution, fracturing, etc. These phenomena are significant in the heterogeneity of the rock unit and hence play a vital role in controlling important factors like porosity and permeability of the rocks.

5.2 Importance

Diagenesis can increase or decrease the porosity and permeability. In general, it means that it tends to progressive loss of porosity or permeability, or it can increase them with increased depthand time, and this shift is quite substantial. Understanding the diagenetic processes that can inhabit the porosity loss, the porosity evolution, and the time of oil migration are critical factors in the hydrocarbon exploration industry.

5.2.1 Diagenetic overprint

The following are the processes that are common in the diagenetic alteration of limestone:-

- Cementation
- Dissolution
- Replacement
- Recrystallization
- Physical compaction
- Chemical compaction
- Fracturing

The microfacies of Lockhart limestone that were processed by diagenetic alteration are summarized below in the given processes.

5.2.2 The compaction

It is a process of rearrangement of the grain due to the overburden pressure of rocks. It can be physical or chemical in nature. This leads to change in the original fabric of the rocks.

5.2.3 Physical compaction

It is also known as mechanical compaction. It is usually associated with larger foraminifera and bioclasts. The localized fracturing without much displacement or dislocation is seen in the following microphotographs (Fig. 5.1, indicated by arrows) from samples L37, L25, and L40 of Lockhart Limestone.

Plate 5.1

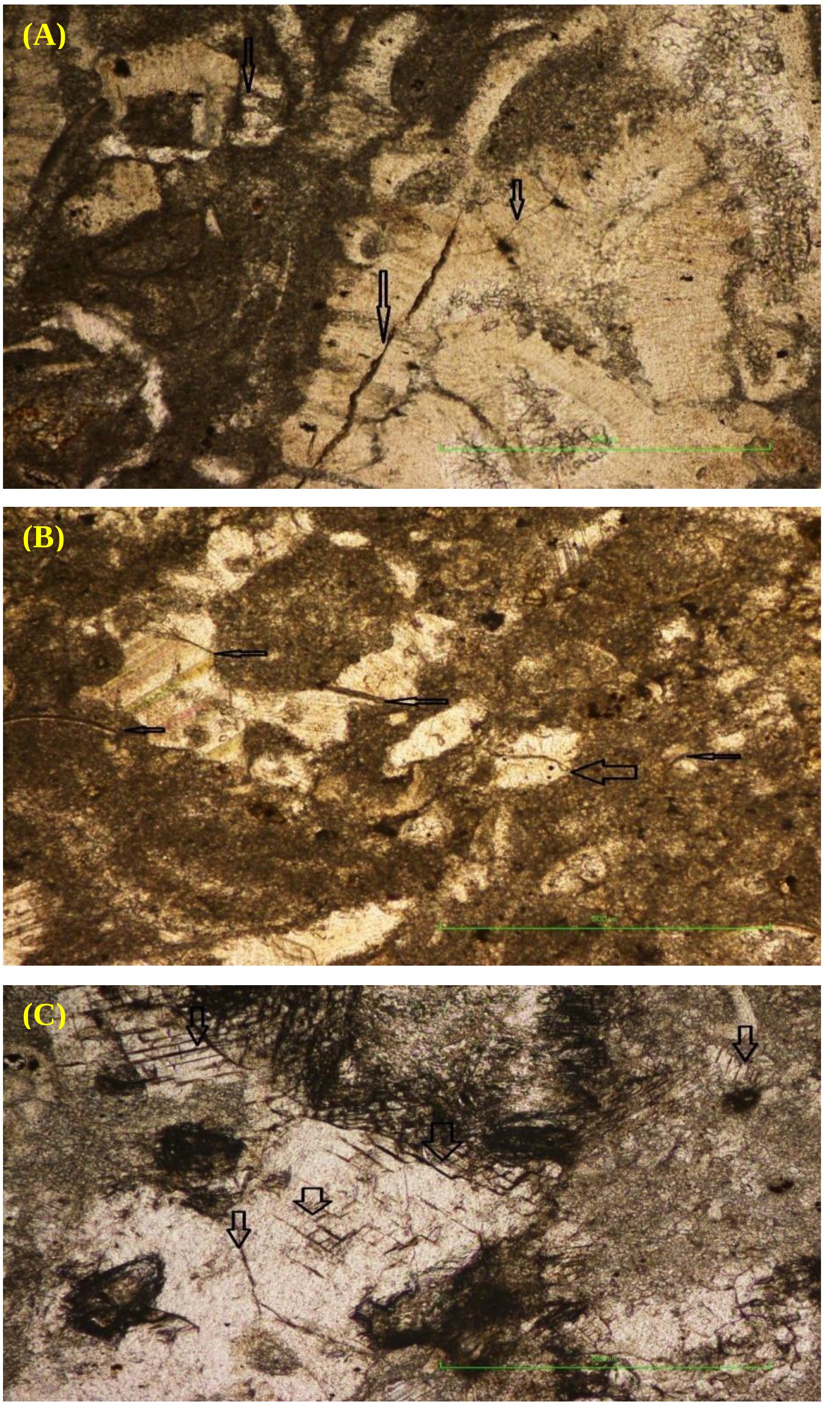


Fig. 5.1 Show the localized fracturing without much displacement (physical compaction).

5.2.4 Chemical Compaction

The compaction that results due to the precipitation of certain chemical solutions is referred to as chemical compaction. It can be of various types and can be seen in different microfacies of the given research. In Lockhart Limestone, many stylolitic characteristics have been recognized. They are believed to have been developed in the last stage of diagenesis. In stylolites, the compacted grains at pressure zones are dissolved (dissolution) at suture zones or contact planes.

Stylolites are pressure-solution-sensitive rocks (Ramsay and Huber 1987). They commonly occur in limestone and dolomite (Hassan, 2007). They have irregular planes of discontinuity (Fig.5.2).

Plate 5.2

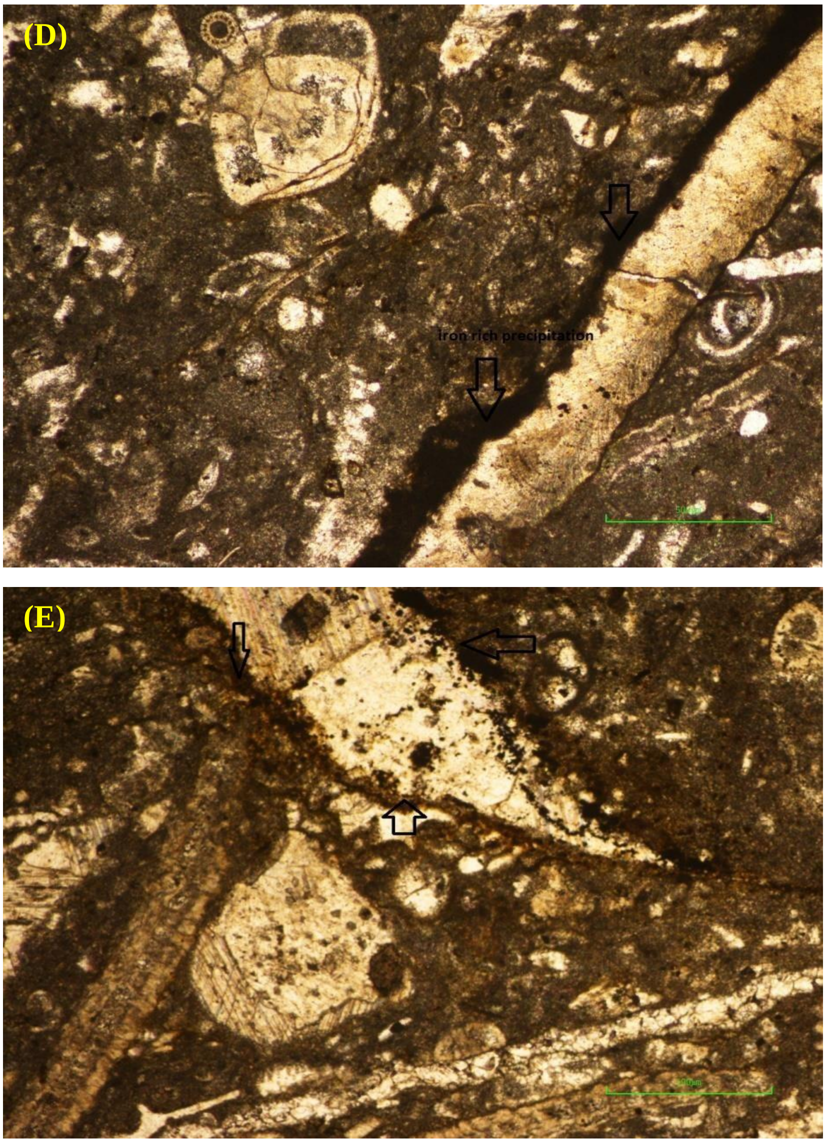


Fig. 5.2 Show the chemical compaction due to the precipitation of chemical solution (iron rich) in fractures and sutures.

5.3 Sutured seams

These are seams of irregular stylolities or stylolitic swarms. These are isolated or swarm-like lines or partings characterized as thin seams of insoluble accumulated residue (Logan and Semeniuk, 1976). They usually contain fine material, and the presence of such material can reduce the permeability of the reservoir rock.

During the process of stylolitization, the suture seams are developed due to the pressure solution that is being developed at the stylolitic planes. These solutions contain fine minerals like clay or iron oxide. The orientation of these seams is perpendicular to the pessure direction (Fig.5.3).

Plate 5.3

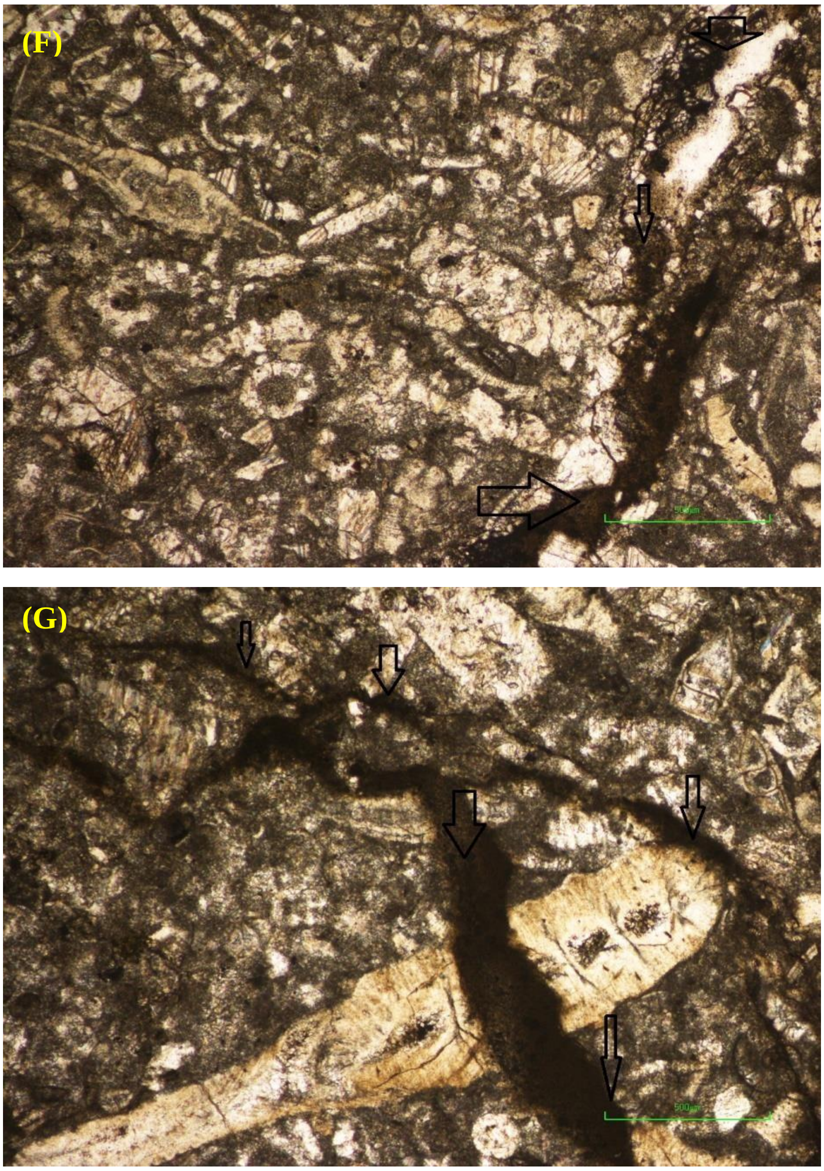


Fig. 5.3 Indicate stylolitic swarms (swarm-like lines). The orientation of these seams is perpendicular to the pessure direction.

5.4 Stylolamination

These are the laminated sutured seams that run parallel to each other. These are found in sample no. L40. The material in these seams is iron oxide precipitation. It is formed when the clay content is more than 10% (Logan and Semeniuk, 1976). This type of stylolitic feature is visiblein the limestone, which is in continuous dissolution. Parallel seams are indications that chemical compaction occurred during the same phase of precipitation of pressure solution.

This depicts the late phase of diagenetic alteration, as this kind of stylolitic characteristic is developed in a post-depositional environment. The reddish brown color indicates the presence of iron solution (Fig.5.4).

Plate 5.4

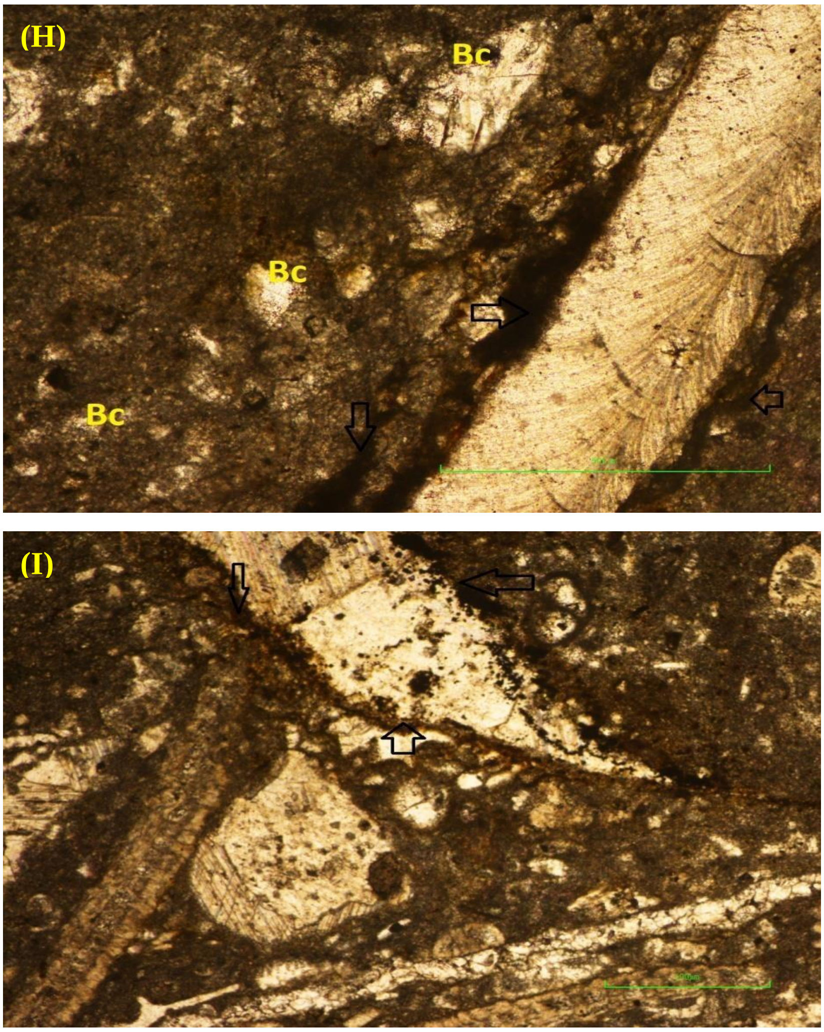


Fig. 5.4 Show stylolamination, the lamination of sutures seams that run parallel.

5.5 Brecciated stylolitic fabric

This is a type of stylolitization that contains a condensed fabric (Logan and Semeniuk, 1976) andis found in sample no. L39. The three-dimensional framework of stylolites intersecting and enclosing a rigid grain is a characteristic feature of these stylolites. The resulting character is referred to as an iden that is densely packed by irregular stylolites (Logan and Semeniuk, 1976).

These microstylolites indicated in Fig.5.5 (J and K) are the result of the chemical compaction of grains. The fossil fragments are brecciated, and the stylolites have irregular geometry.

Plate 5.5

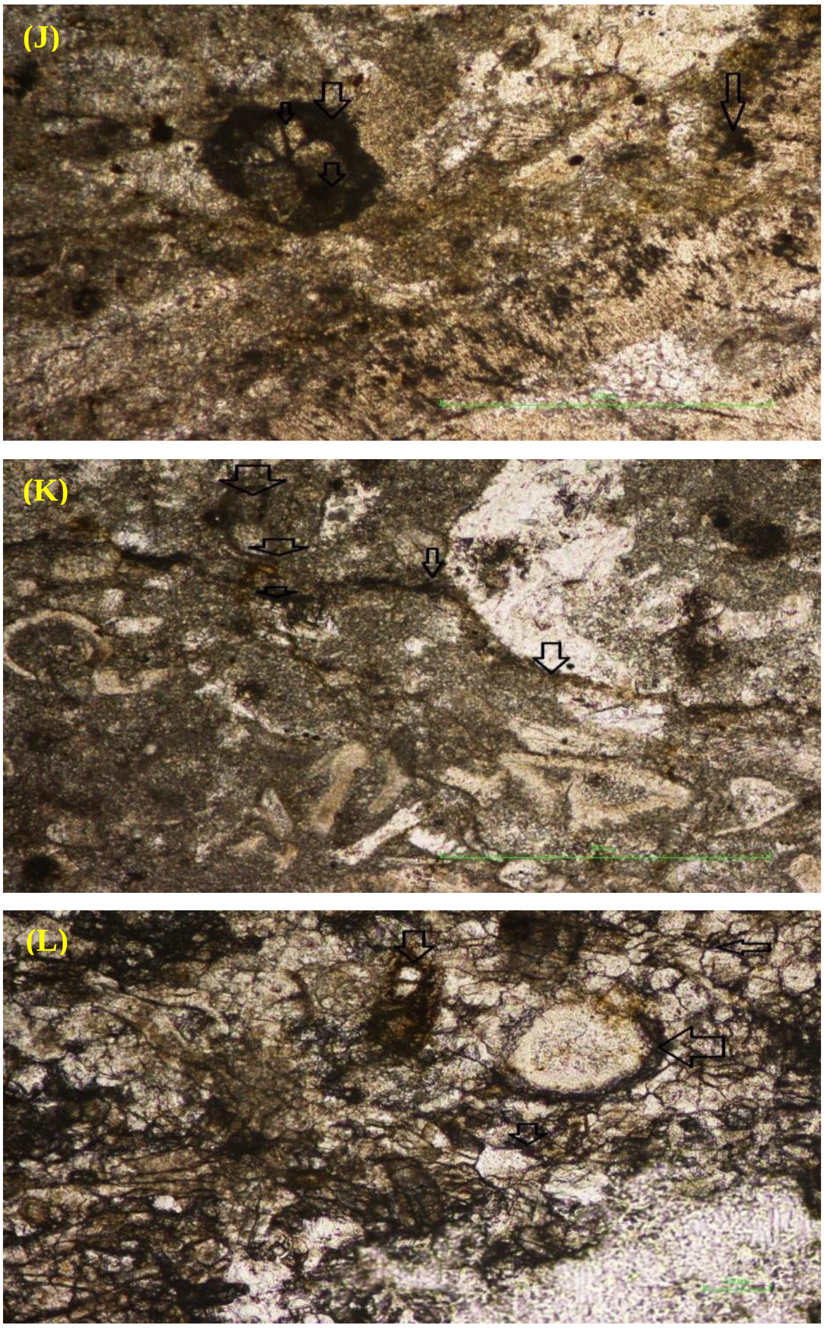


Fig. 5.5 Three-dimensional framework of stylolites due to chemical precipitation in sutures followed by intense pressure from all directions.

5.6 Nodular stylolitic fabric

It is actually swarms of stylolites that enclose the residual idens (Logan and Semeniuk, 1976). This type of stylolitic pattern is available in the inner ramp facies environment. The stylolites are variable in size, and they have irregular shapes as well. The shapes can be spherical or rounded; however, size varies from millimeters to centimeters (Fig.5.6).

Plate 5.6

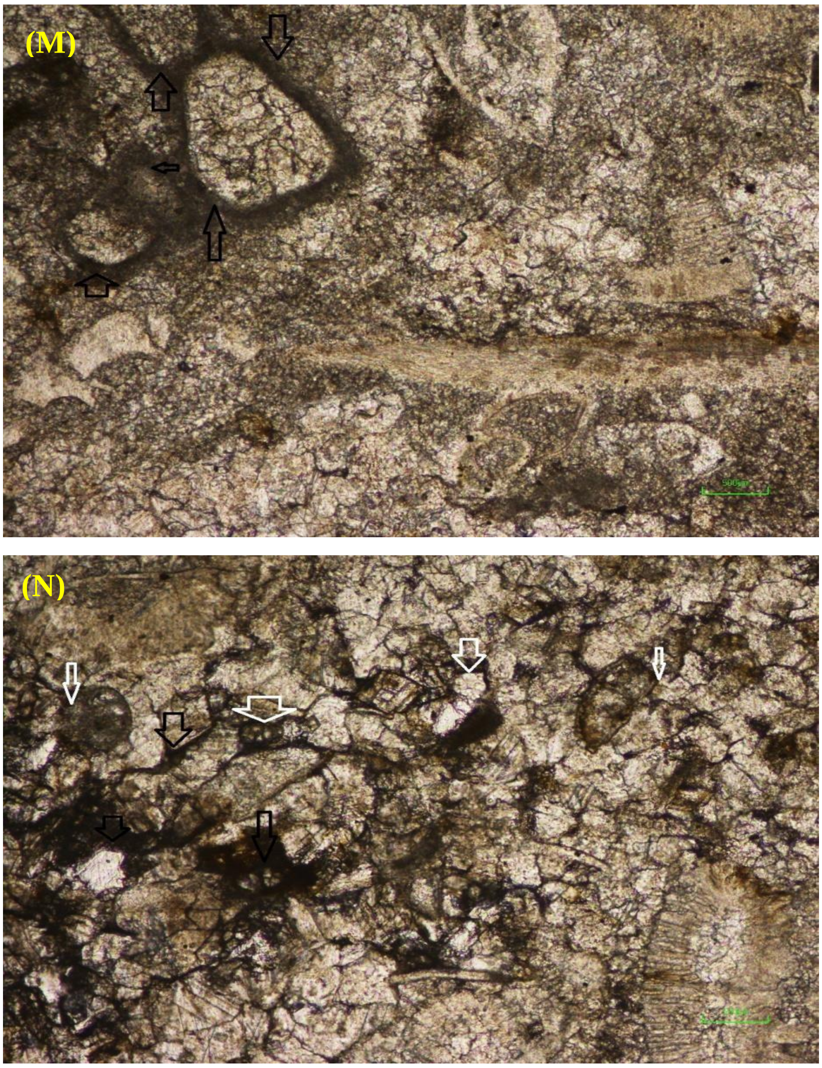


Fig. 5.6 Show the swarms of stylolites that enclose the residual idens, an indication of Inner Ramp microfacies.

5.7 Stylolitization

Pressure solutions are the main causes of stylolitic features that are tectonically developed. This happens due to physical factors, while chemical factors are rather uncommon (Park and Schot, 1968).

Stylolites in these microfacies are thin seams at suture planes. These are more obvious in the following microphotographs (Fig 5.7) of sample no.L44 of Lockhart Limestone from the Western Salt Range. They demonstrate late diagenetic events and can cause a reduction in the permeability of the fluid.

Plate 5.7

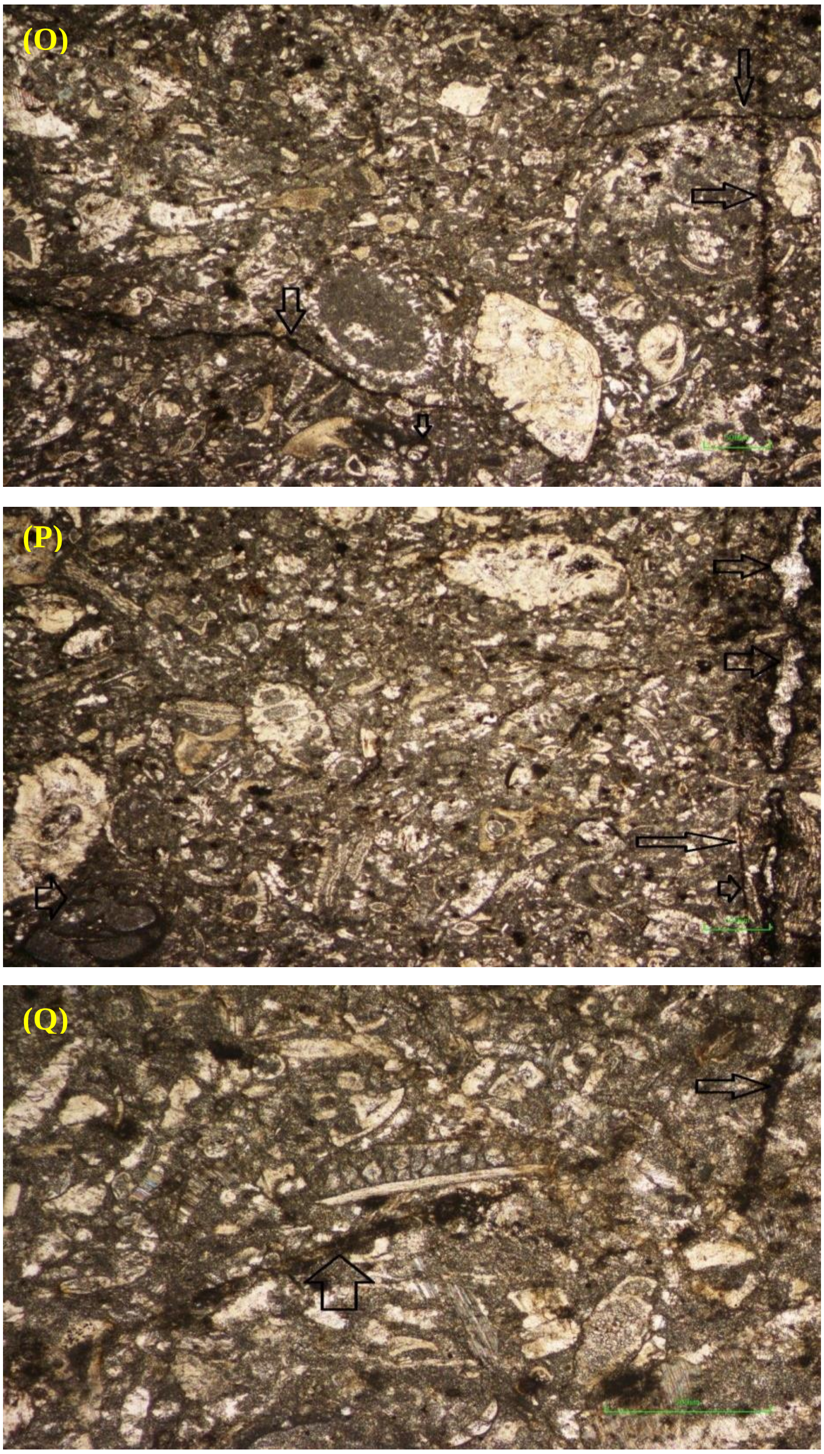


Fig. 5.7 Stylolitic features developed due to pressure solutions caused by tectonic activity and they are late diagenetic events.

5.8 Micritization

The conversion of allochemical content into micrite or lime mud in carbonate rocks occurs through the activity of endolithic algae (Bathurst, 1966). This is the first phase of diagenesis and occurs in the marine diagenesis of limestone.

This process develops inside the chambers of the foraminifera or other biolasts, gastropods, etc.; it replaces the original mineral composition of certain species. The process of micritization is quite obvious in the microphotographs of samples L37 and L40, indicating an early phase of diagenetic alteration (Fig.5.8).

Plate 5.8

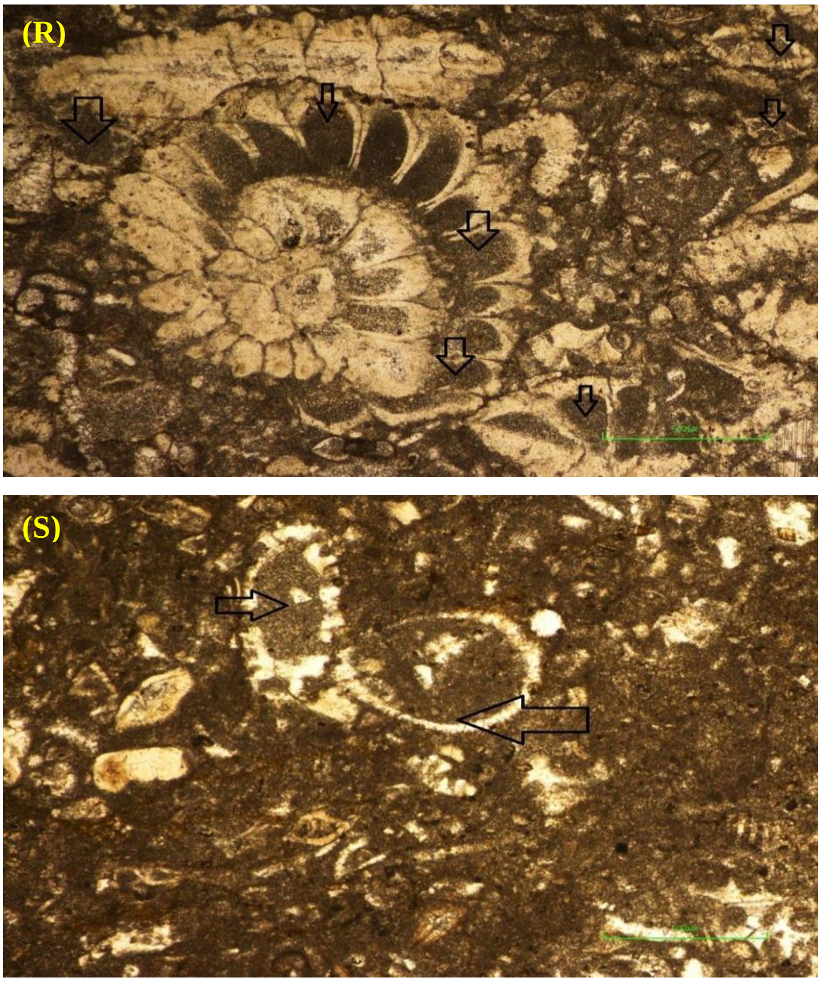


Fig. 5.8 Conversion of allochemical content into the lime mud is shown by arrows in microphotographs.

5.9 Microspar fabric

In the Lockhart Limestone of Nammal Gorge, Western Salt Range, the transformation of micrite to microspar is commonly observed. In this phenomenon, isolated patches of microspars were seen where they converted high Mg-calcite to low Mg-calcite. This has been observed in sample no. L25.

The particular term "microspar" is used for fine-grained calcite matrix, which has characteristic features like uniform size or subhedral or euhedral calcite crystals (ranging from 5 to 20 micrometer), in diameter (Folk, 1959). The formation and development of microspar are considered aggrading neomorphisms (Folk 1965). Spar and microspars are indicated by arrows in the microphotographs given below (Fig.5.9).

Plate 5.9

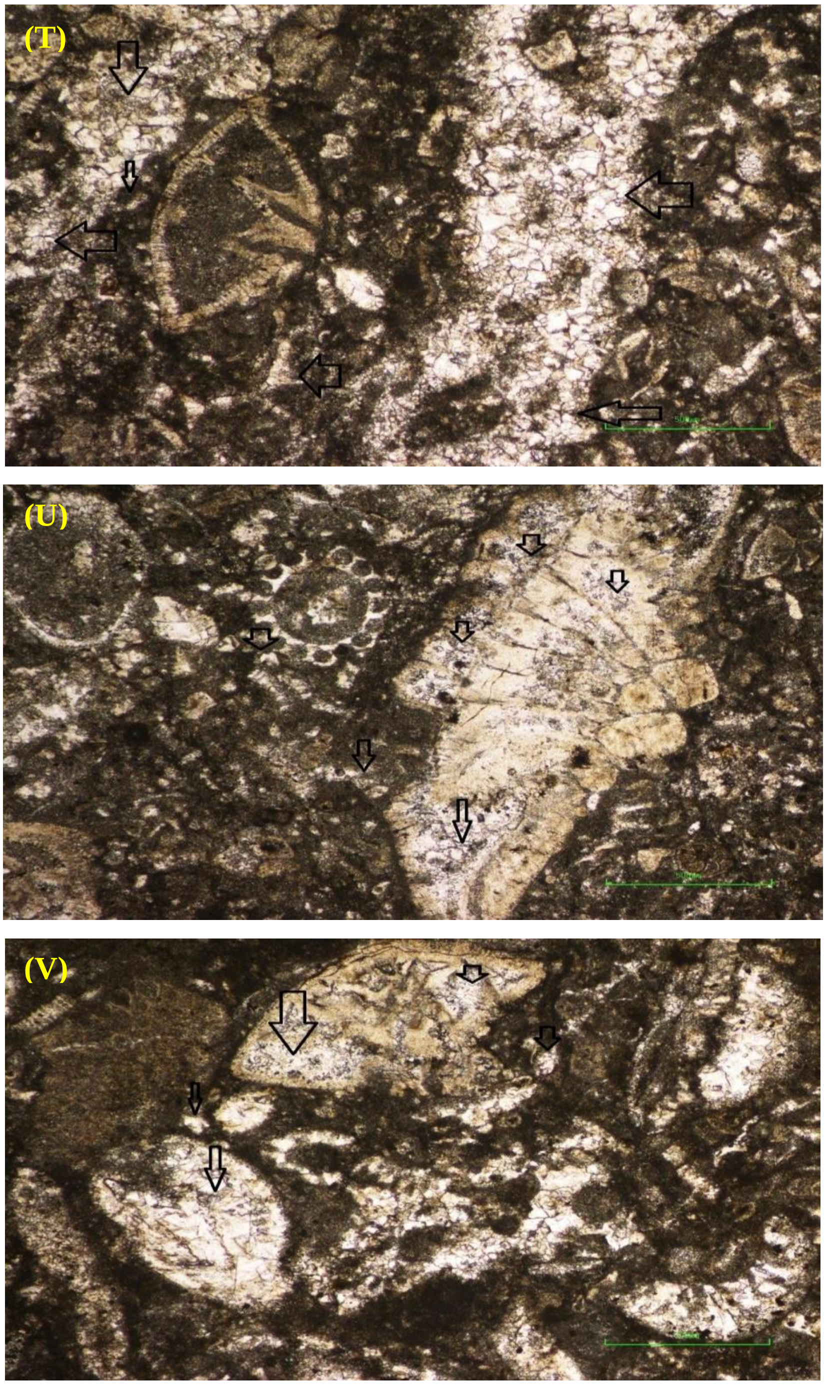


Fig. 5.9 Show the transformation of micrite to microspar. Isolated patches of microspars were seen where they converted high Mg-calcite to low Mg-calcite.

5.10 Aragonite to calcite conversion

The aragonite mineral is highly unstable in nature; hence, it is replaced by low-Mg calcite, which somehow preserves the morphological attributes of the dissolved content. This phemonimon is also seen in inner ramp facies, where species like Dasycladacean algae, Foraminifera, Foraminiferal bioclasts, etc. contain chlorophyta (with mineral oragonite). As explained earlier, aragonite content is unstable in nature, so it can easily undergo deformation and be converted to another mineral.

Aragonite-to-calcite transformation is well established in the following microphotographs, where the constituents of algae and foraminiferal bioclasts undergo transformation. This is clearly depicted by the arrows (Fig.5.10) given below.

Plate 5.10

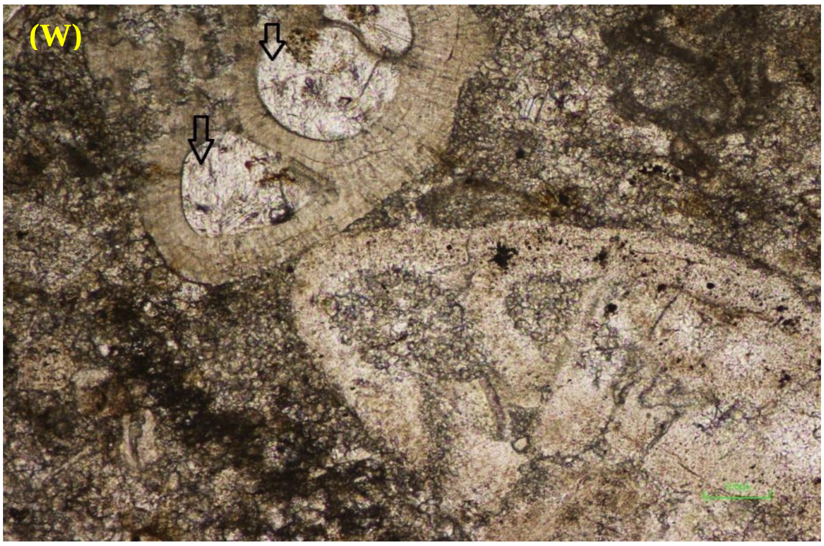


Fig. 5.10 Aragonite-to-calcite transformation is well developed in the above microphotographs, where the constituents of *algae and foraminiferal bioclasts* undergo transformation.

5.11 Calcite-filled fractures

The calcite-filled fractures are developed as veins by certain precipitations of minerals in circulating fluid that are filled in the fractures or joints by secondary deformation. This is usuallyreferred to as the healing of joints or fractures.

Fractures are secondary features that are usually formed due to regional tectonic forces. Physical and chemical compactions are the other main characteristics that cause them. These play asignificant role in the permeability of the reservoir rocks. In the case of the given Lockhart limestone, these fractures are commonly observed in field studies and thin sections as well (samples L25, L37, L41, L44, etc.), (Fig.5.11).

Plate 5.11

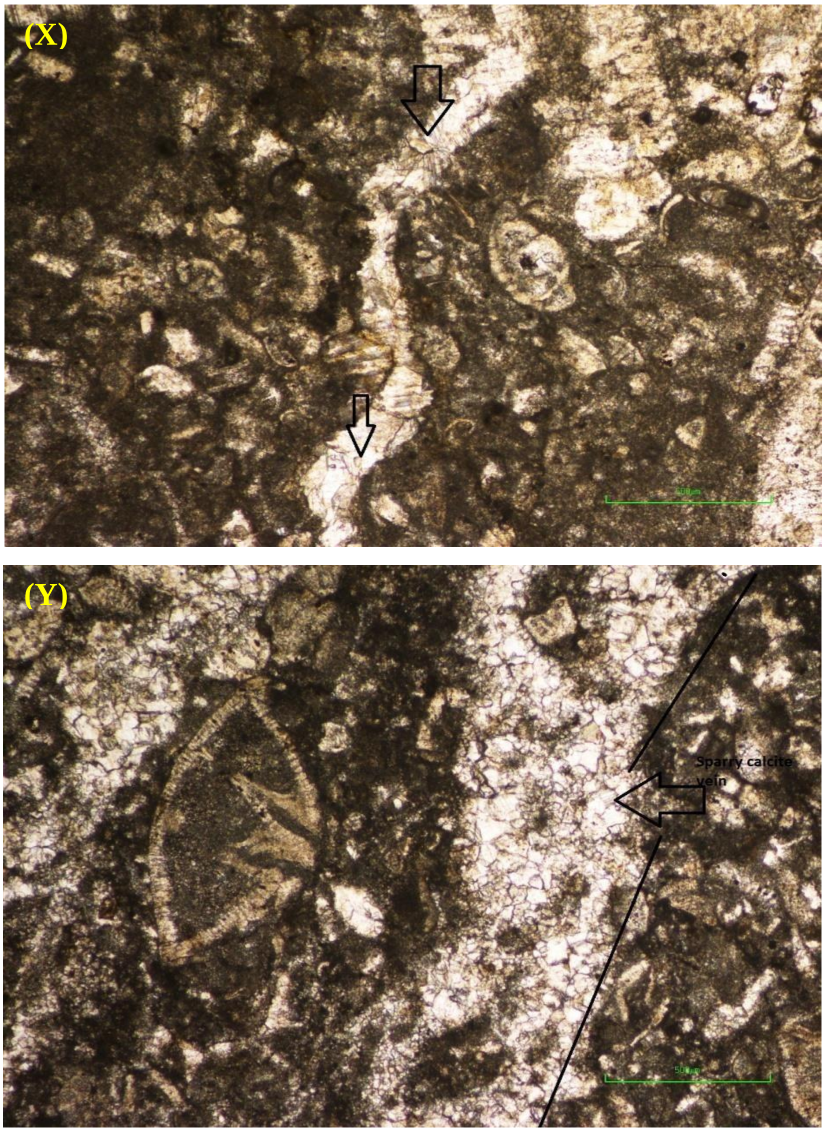


Fig. 5.11 Sparry calcite vein is indicated by arrows in Z, while a fracture filled by a calcite vein is shown in Y. These pholograhs contain the precipitated calcite mineral in veins.

CHAPTER 6
DEPOSITIONAL ENVIRONMENT

6.1 Depositional environment of Lockhart Limestone

The presence of certain microfacies and fossils content like *foraminifera, foraminiferal bioclasts*, and different *Algae* types are the characteristic features that are helpful in recognizing the depositional environment of Lockhart Limestone.

The microfacies of Lockhart Limestone were compared with the standard chart of Dunham Classification. The mcirofacies recognized in the thin sections of the given research were apparently compared with the standard microfacies of the Limestone (Dunham Classification). The recognition of microfacies and different species of fossils helped in finding the environment in which the particular Limestone was deposited.

This sedimentological approach depicts that there are four main microfacies; packstone microfacies, wackestone microfacies, grainstone microfacies and boundstone microfacies, alongwith thirteen (13) sub-microfacies present in the Lockhart Limestone of Nammal Gorge area, Western Salt Range Pakistan. However, the grainstone microfacies and packstone microrfacies are relatively more dominant over the wackestone microfacies and boundstone microfacies in the thin sections observed for petrographic analysis. There is good amount of boundstone whereas the wackestone is very less common in the studied thin sections.

The dominance of grainstone and packstone microfacies in the research area suggests that the Lockhart Limestone was deposited in moderate to high energy environment as both are grains-supported but differ in carbonate cement. There are six different sub-microfacies of Lockhart Limestone (grainstone microfacies) and three different sub-microfacies of packstone was found in the investigation that are helpful to recognize logoon, reef-talus and shallow marine environment of deposition of these rocks.

Moreover the presence of (three sub-microfacies of boundstone) boundstone also indicate very high energy environment of deposition. These investigations are helpful to interpret Inner Ramp Lagoonal environment of deposition to the Lockhart Limestone of Nammal Gorge area.

Biostratigraphy of these rocks also helps in this regard. The presence of *Foraminifera; Lockhartia sp, Miscellanea sp, Assilina sp, operculina sp, Ranikothalia sp, Millliods, Textularia sp, and Globogerina linaperta* etc has helped to determine the shallow marine environment of deposition.

Diagenetic alterations in the form of physical compaction, chemical compaction, suture seams, stylolamination, brecciated stylolitic fabric, Nodular stylolitic fabric, stylolitization, aragonite to calcite conversion etc, was seen in the studied thin sections.

The presence of nodular stylolitic fabric and aragonite to calcite conversion is considered to be found in Inner Ramp facies. This altogether strongly suggests that the Lockhart Limestone was deposited in Inner Ramp depositional environment. The pattern of deposition of these rocks is shown below (Fig.6.1, Fig.6.1a, Fig.6.1b and Fig.6.1c).

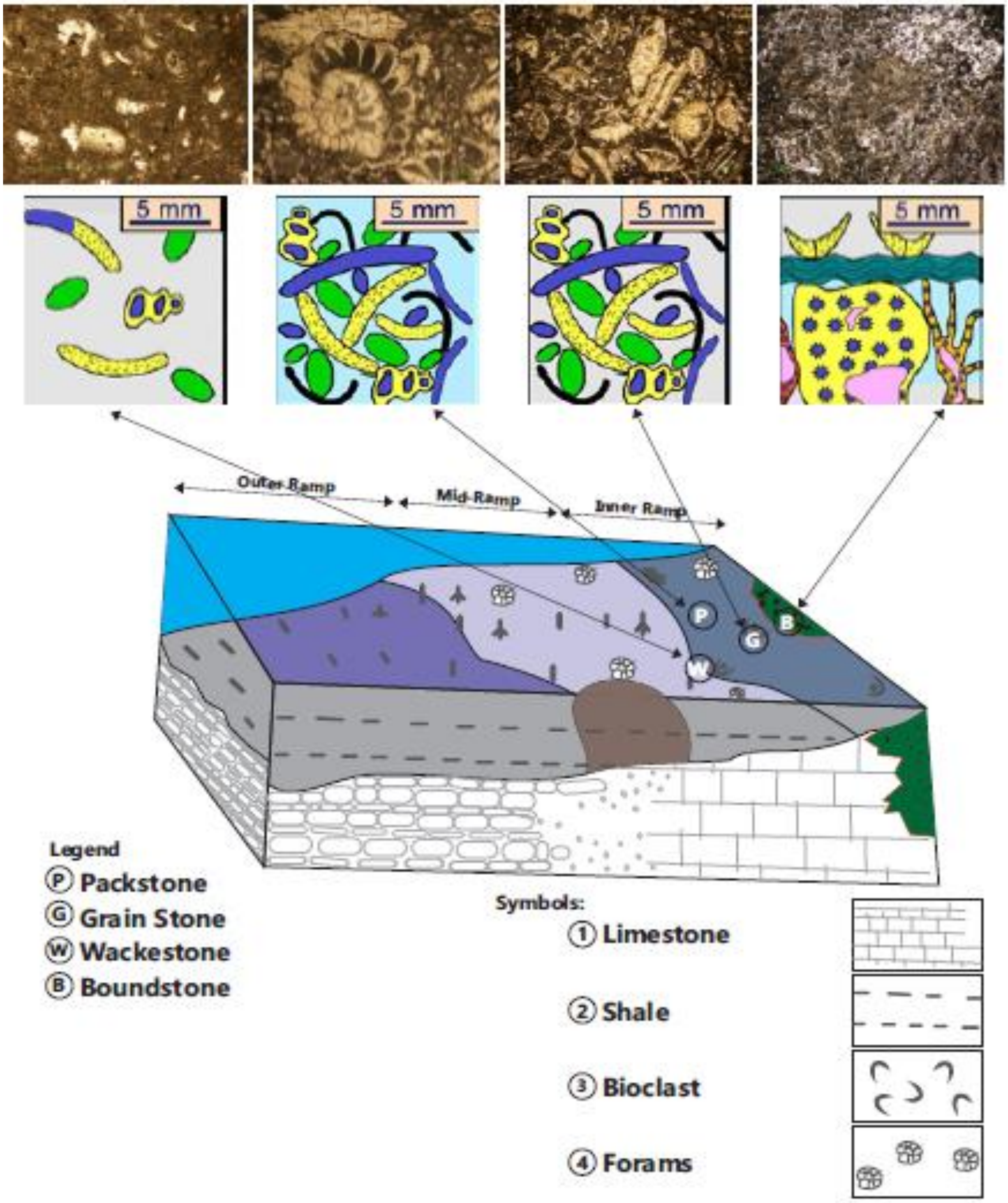


Fig. 6.1 Depositional Environment of Lockhart Limestone

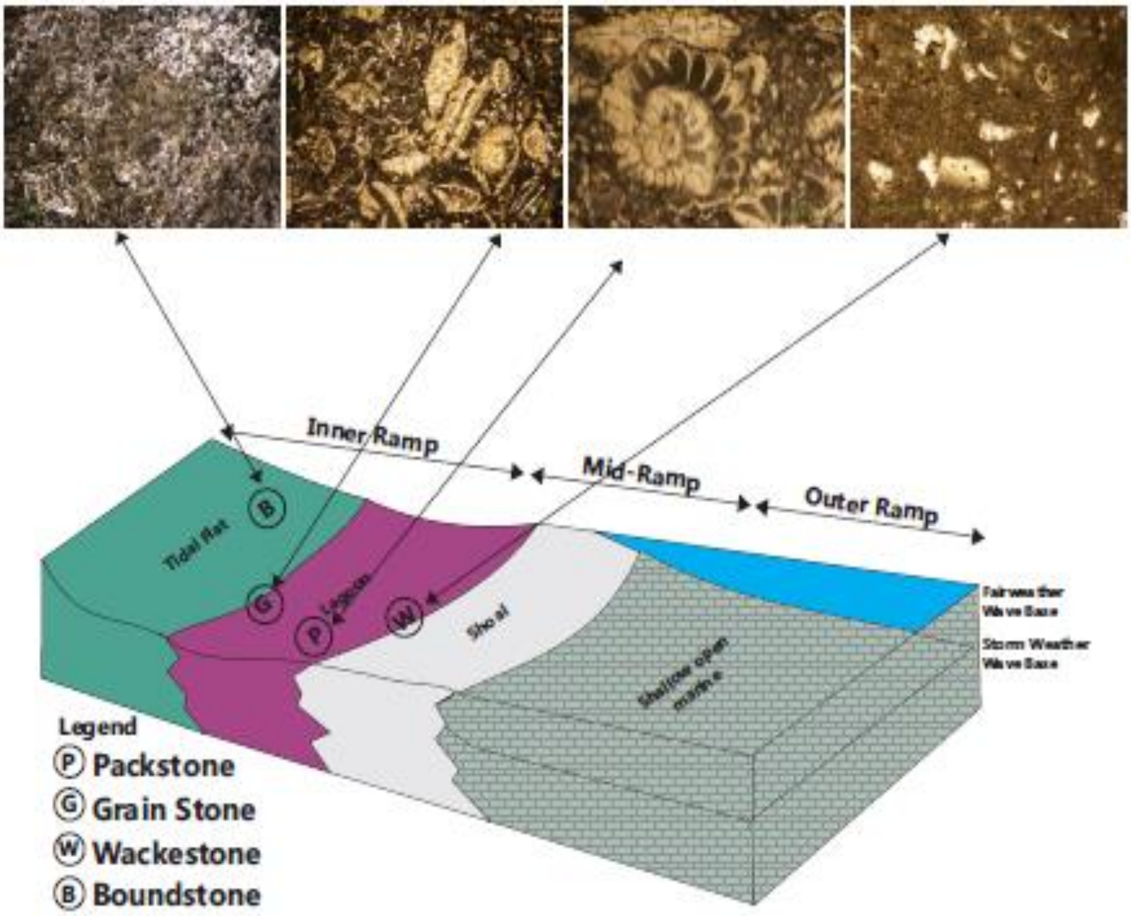


Fig 6.1a Depositional Environment of Lockhart Limestone

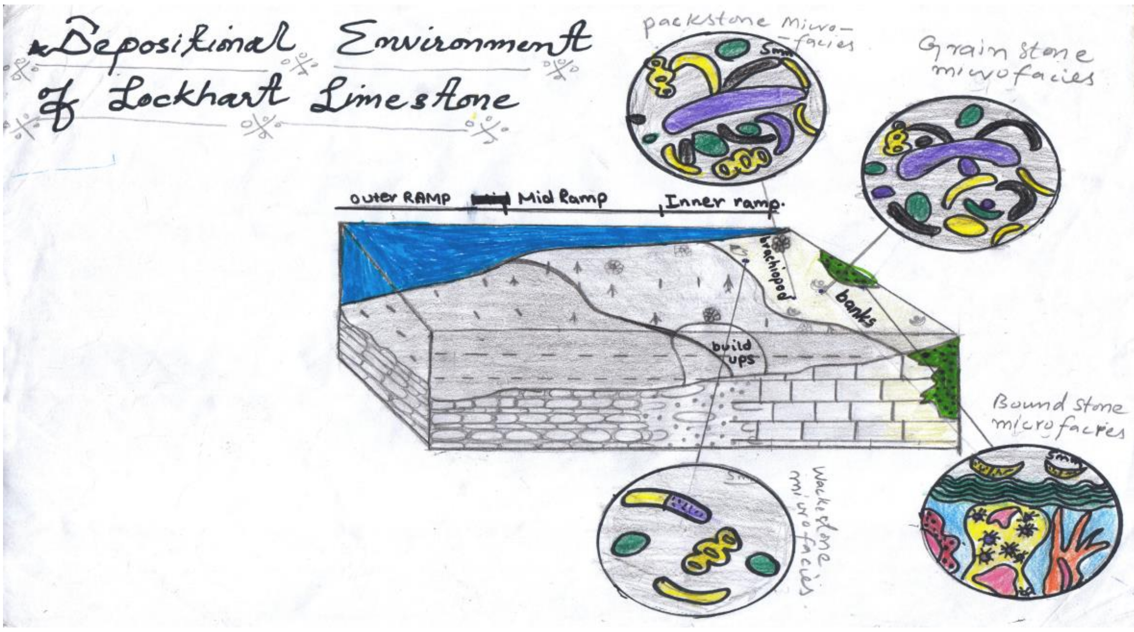


Fig 6.1b Depositional Environment of Lockhart Limestone

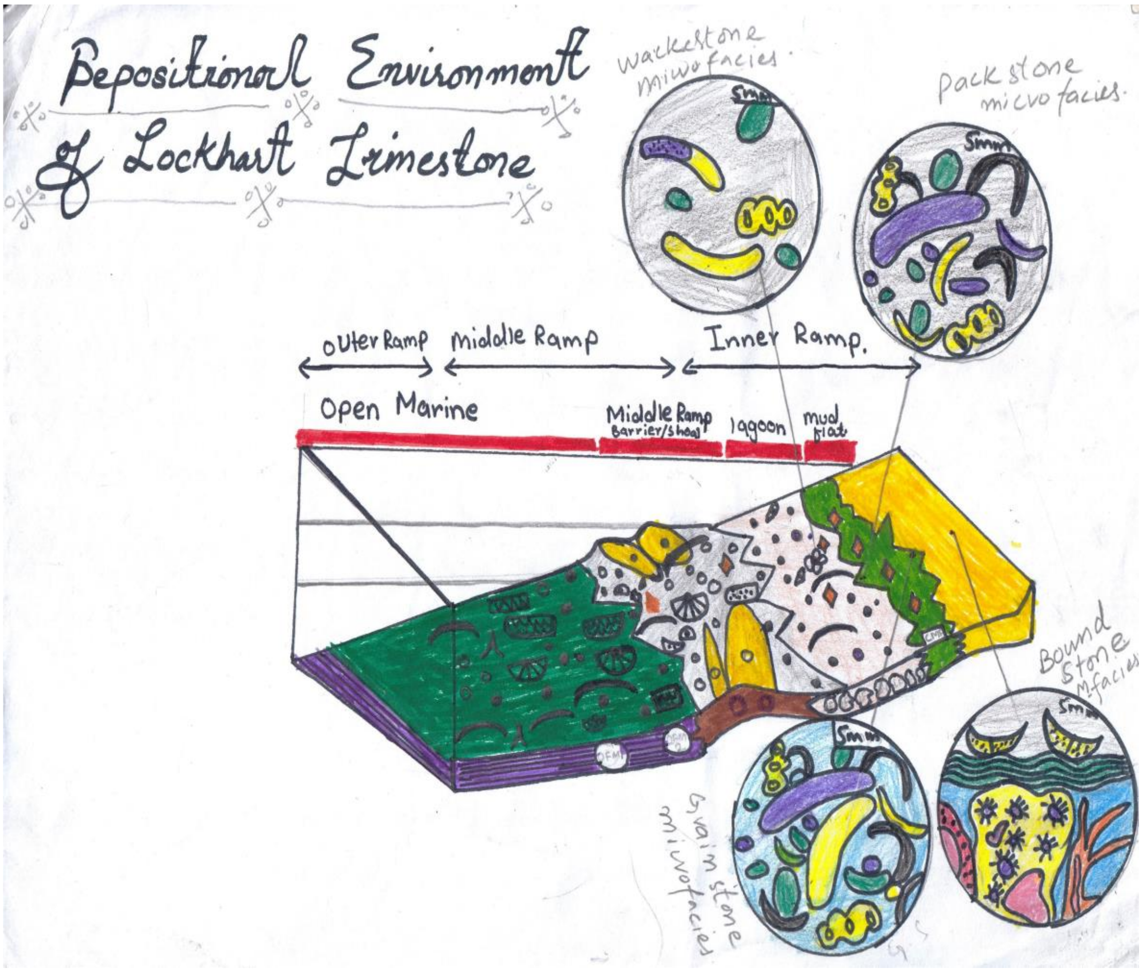


Fig 6.1c Depositional Environment of Lockhart Limestone

6.2 Conclusion

This research suggests that there are 4 main microfacies and 13 sub-microfacies of Lockhart Limestone present in the study area. The grainstone and packstone are relatively abundant microfacies than wackestone and boundstone. Major portion of the studied thin section is grain-supported so it can be concluded that Lockhart Limestone of given area is deposited in moderate to high energy environment (Inner Ramp environment).

Biostratigraphy (fossil identification) of these rocks also exhabits the presence of *Foraminifera*; like *Lockhartia sp, Miscellanea sp, Assilina sp, operculina sp, Millliods, Textularia sp, and Globogerina linaperta* etc. This has helped to determine the shallow marine environment of deposition.

The diagenetic alteration patterns like aragonite to calcite conversion and nodular stylolitic fabric also confirm the Inner Ramp depositional environment for the Lockhart Limstone of the study area.

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