ORIGIN AND DEMARCATION OF THE DEPOSITIONAL ENVIRONMENT BASED ON CONCRETIONS PRESENT IN SAMANA SUK FORMATION, HAZARA BASIN, ABBOTTABAD, PAKISTAN

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

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C e r t i f i c a t e

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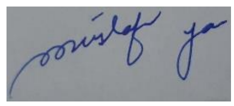
External Examiner	**Mr. Mustafa Yar**	
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DEDICATION

This thesis is dedicated to my parents, who have raised me to be the person I am today. You have been with me every step of the way, through the good times and the bad. Thank you for the unconditional love, guidance and support you have given me, which has helped me in building my confidence so that I am capable of doing anything I put my mind to. Thank you for everything.

ABSTRACT

The present study is focused on the origin and demarcation of the various types of concretion and non-skeletal grains, depositional environments and their significance. The area under study lies in the vicinity of the Abbottabad region of the Khyber Pakhtunkhwa province Pakistan. The study area being topographically close to the MBT has been under intense deformation. The study area is marked by South East moving thrust faults, and North-East Trending Anticlines. The Samana Suk Formation consists of well bedded limestone which is light brown to grey in color. The Samana Suk Formation includes brachiopods, belemnite guards, micritic beds and Oolitic limestone.

The Concretions and non-skeletal grains interpreted are; 1) *Ooids* grains have been further divided into 6 types which are Micritic Ooids, Concentric Ooids, Radial Ooids, Superficial Ooids, Broken Ooids, Deformed Ooids. These Ooids are characterized by well-rounded to sub-rounded and differ from each other on the basis of number of cortices and the structures of the Ooids, the environment of deposition for the ooids range from a lower intertidal to lagoonal shallow marine environment. 2) *Aggregates*, grains have been characterized as grapestones based on the stage of transformation. Grapestones grains are sub rounded and moderately sorted. The features indicate a platform to marginal reef marine environment. 3) *Peloids* grains have been further divided into 2 types which are Fecal Pellets and Bioerosional Peloids. These are characterized by elongated rod like to angular shaped grains formed by burrowing of micro-organisms. The present features indicate upper to middle intertidal shallow marine environment. The depositional environments for the concretions and non-skeletal grains range from inter tidal zone to marginal reef zones. The significance of these concretions and non-skeletal grains are such that they're presence of absence can indicate Sea level fluctuations, these grains can be used for correlations on a regional scale, Specific depositional settings can be interpreted on the basis of abundance and type of grains present, carbonate concretions and grains are of high economic importance and their geometries have a significant influence on the reservoir qualities of carbonate rocks.

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CONTENTS

CHAPTER 1

INTRODUCTION

1.1 General information

The Samana Suk Formation is considered as an important lithological unit in the various basins of Pakistan (Nizami and Sheikh, 2009). The areas where the Samana Suk Formation is exposed are the Trans Indus Ranges, Salt Range, Hazara Mountains, Kohat Tribal Range, Samana Range and Kala Chitta Ranges. The study area is a vital part of the Mesozoic era and extensive research is still being carried out at various localities. The pure massive limestone and fossiliferous characteristics of the Samana Suk Formation makes it an essential lithological unit of carbonates rocks in Pakistan.

The Formation under current analysis is situated along Abbottabad-Nathiagali Road; about 3 km north east of the city of Abbottabad. The field of research is situated in the northwest Himalayas and depicts a site with well-developed stratigraphic sequence and deformed tectonic features. The exposed rocks in the area vary from Precambrian to Mesozoic and Tertiary age. Extensive study has been carried out on the paleontology, economic geology, structural geology and as well on the stratigraphy of the study area.

1.2 Location and accessibility

The area of research under current study lies in the vicinity of Abbottabad area Khyber Pakhtunkhwa as shown in Figure.1.1. It is 110 kilometers north of the city of Islamabad and approximately150 kilometers northeast of the city of Peshawar. Abbottabad is in the Orash Valley lying between (34°07′0″ to 34º 09′0″ N) and (73°08′0″to 73°10′0″ E) at an altitude of 4,120 feet.

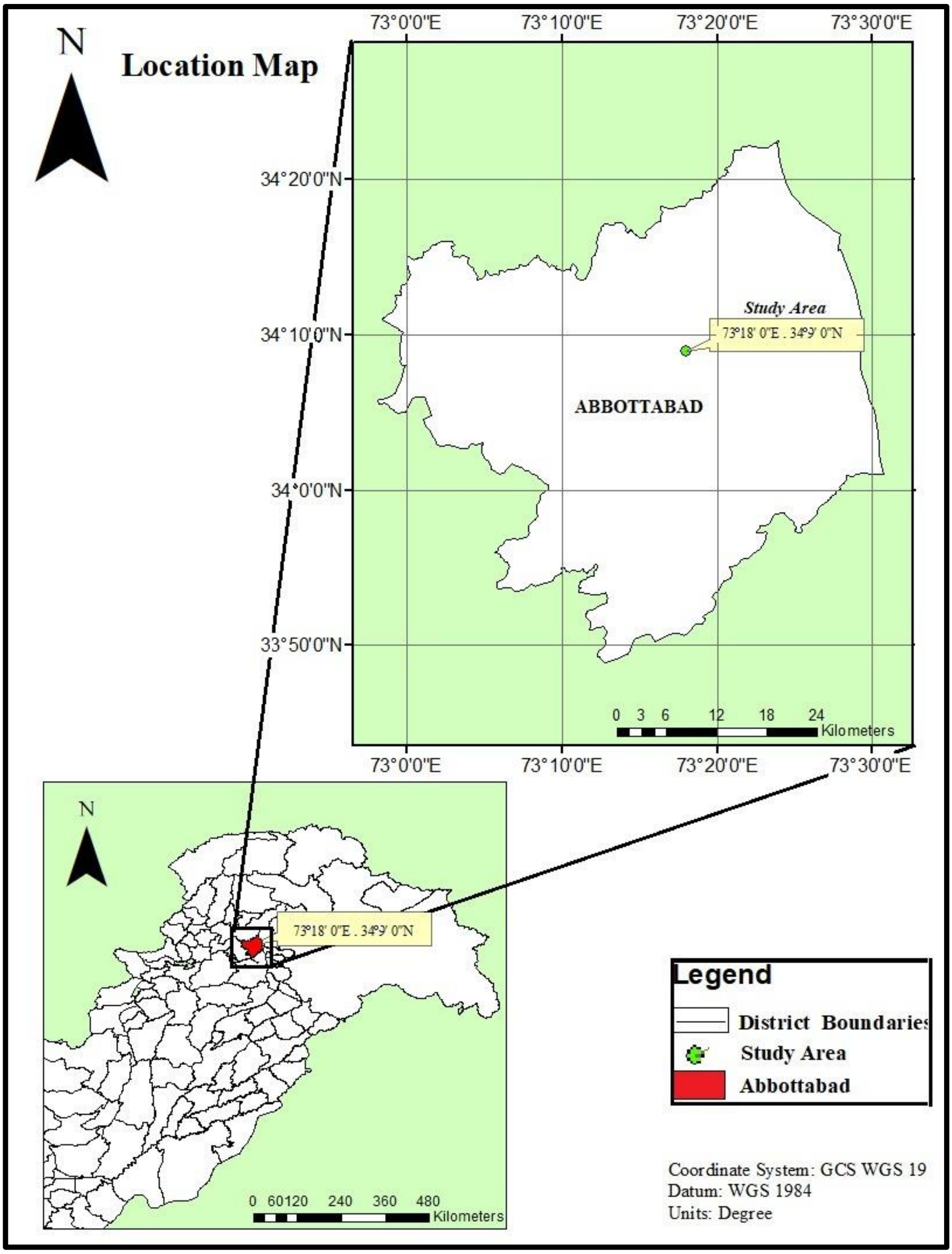


Figure 1.1 Location map of the study area (Arc GIS, 10.1).

1.3 Climate

The region has a damp subtropical weather. During summertime the temperature can climb upto 38 °C and during winter seasons the temperatures fall below 0 °C down to −5 °C. In winters, it occasionally snows in the months of December and January, whereas there is substantial amount of rain in the monsoon season which stretches from July and lasts uptill September.

1.4 Topography

The Abbottabad area is mainly surrounded by mountains and hills. These mountainous regions are a part of the Himalayan subdivisions known as Lesser Himalayas. One end of the Abbottabad mountain ranges from the North merges and comes into Abbottabad District flanking the right banks of Kunhar and Jhelum rivers. These mountain ranges run through the district and are known as Dungagali ranges, and their elevation ranges from 2,500 to 2,700 meters. From this Dungagali range many hilly areas project on either side. The hills pointing in the westward direction are longer, with valleys lying between these hills but westward, the elevation of these mountains vary between 600 to 1,500 meters (Population Census Abbottabad, 1998).

1.5 Previous work

Many people have performed detailed studies on different aspects of the southern Hazara Samana Suk Formation. In the beginning researchers had been focusing on establishing large geological and lithological relations in the field and naming the various rocks. Limited research had been carried out in the early days when it came to the area of sedimentological analysis. In recent years, facies and diagenetic study Samana Suk Formation has been carried out in the Kalachitta ranges and the Trans Indus ranges. Detailed study on the depositional environment has been carried out very widely across these mountain regions on a regional scale, although only a few people have carried out research on the deposition environment in the Hazara area by Fatmi et al. (1990), Ahmad and Mertmann (1994), Mensink et al. (1988).

1.6 Objectives

The current research study aims to achieve the following objectives;

i. To demarcate the types of concretions and non-skeletal grains present in the Samana Suk Formation.
ii. To interpret the detailed depositional environments on the basis of concretions and non-skeletal grains present.
iii. To identify the significance of concretion and non-skeletal grains in Samana Suk Formation.

1.7 Methodology

The following parameters were taken into account for this research work was (Fig.1.2):

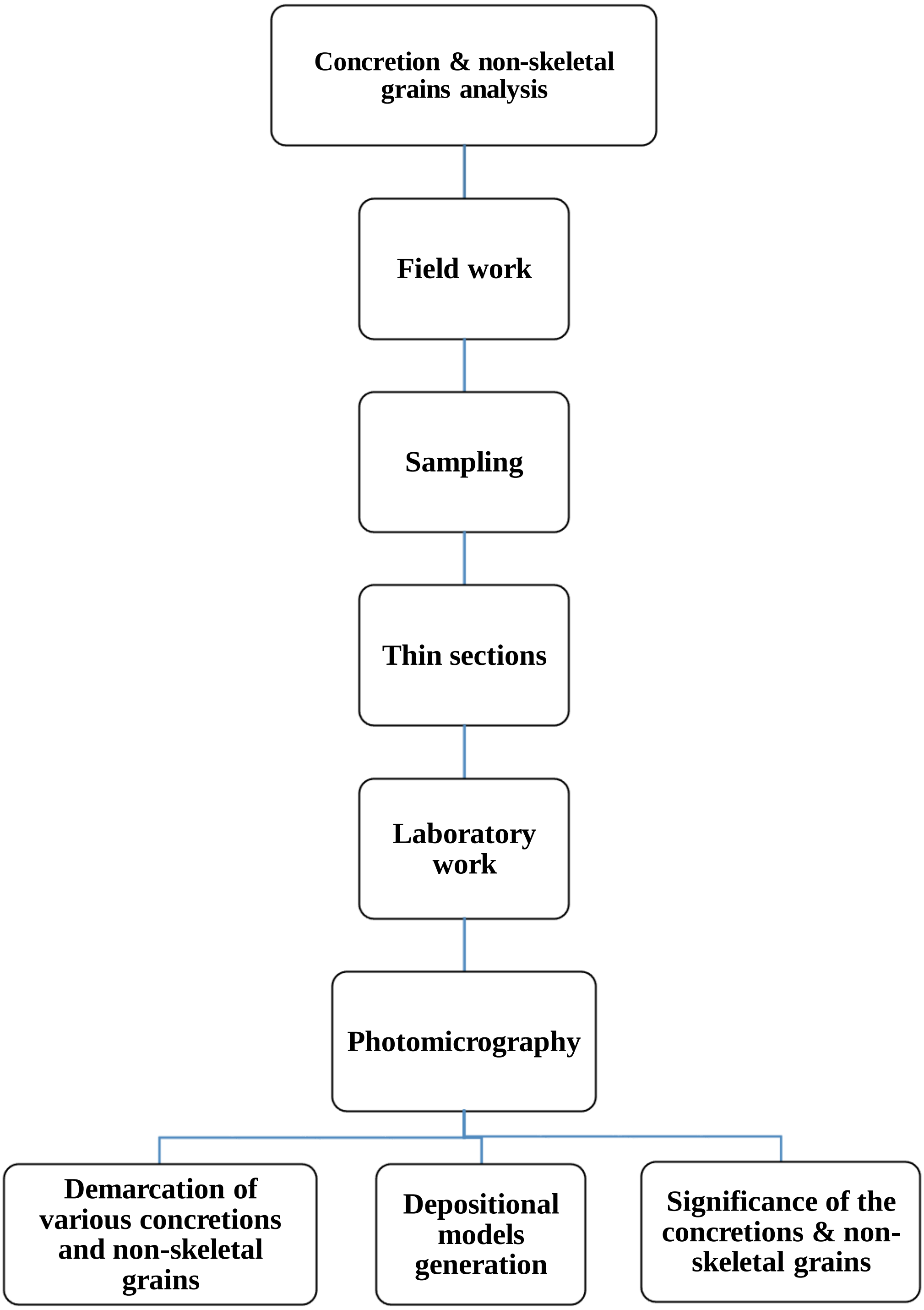


Figure 1.2. Figure showing procedures followed for the research work.

1.8 Field work

The field work involved identification of the formation and collection of fresh, unaltered and compact rock samples at 2-4 meters interval from the bed rock of the Samana Suk Formation for further preparation of the thin sections. During the field work other related data such as lithological and paleontological character, contact relationships, structural and sedimentary features were also noted (Fig.1.3).

Figure 1.3 Field photographs of the study area during sampling at the Samana Suk formation, Harnoi section, Abbottabad.

1.9 Laboratory work

The field samples collected were taken to the department of Geology, university of Peshawar for the preparation of thin sections for the microscopic study. Precautionary measures were taken into account while preparing the thin sections. After the thin sections were prepared, the study was carried out at the sedimentological lab in National Center of Excellence in Geology, University of Peshawar. Different features were identified, and photomicrographs were taken for further interpretation.

Figure 1.4 Thin section study at the National Centre of Excellence in Geology, University of Peshawar.

CHAPTER 2

REGIONAL GEOLOGY AND TECTONICS OF THE HAZARA AREA

2.1 Introduction

Geographically Pakistan sits in a peculiar region of the world with an active tectonic setting and resides on lithospheric plates Arabian, Indian and Eurasian plate. Geological features present in Pakistan are the Indus and shyok suture zones, the Chaman Fault, the Makran subduction zone and an active trench arc system. The collision of the various tectonic plates has caused the formation of the Himalayan mountain ranges of varying complexity, along with the Karakoram and Hindukush ranges. Precambrian to Recent age rocks are present and these act as a record for the region's tectonic history (Kazmi and Jan, 1997).

2.2 Geological setting of the region

According to researchers the super continent Pangea started to split during the Carboniferous period to Early Permian period (300-250 ma) which resulted in creation of many new tectonic plates, micro plates and an ocean the Neo Tethys. The Indian plate started moving in the North direction, which caused the shrinkage and closing of the Neo Tethys ocean (Farah and Dejong, 1979; Tapponier, 1986).

During the Eocene period, the Indian plate and Eurasian plate collided (Tahirkheli et al., 1979). The collision resulted in the formation various tectonic structures and features in Pakistan and surrounding regions which can be seen in (fig 2.1). These tectonic features are MainKarakorumThrust (MKT) (Coward et al., 198 6;Coward and Butler, 1985; Gansser, 1981), Main Mantle Thrust (MMT) (Tahirkh eli and Jan., 1979), Main Boundary Thrust (MBT) (Treloar et al., 1989; Yeats an d Lawerance, 1984) and Salt Range Thrust (SRT) (Gee and Gee 1989; Yeats et al. 1984) and these tectonic features have been marked as the major subdivisions of the collision zone.

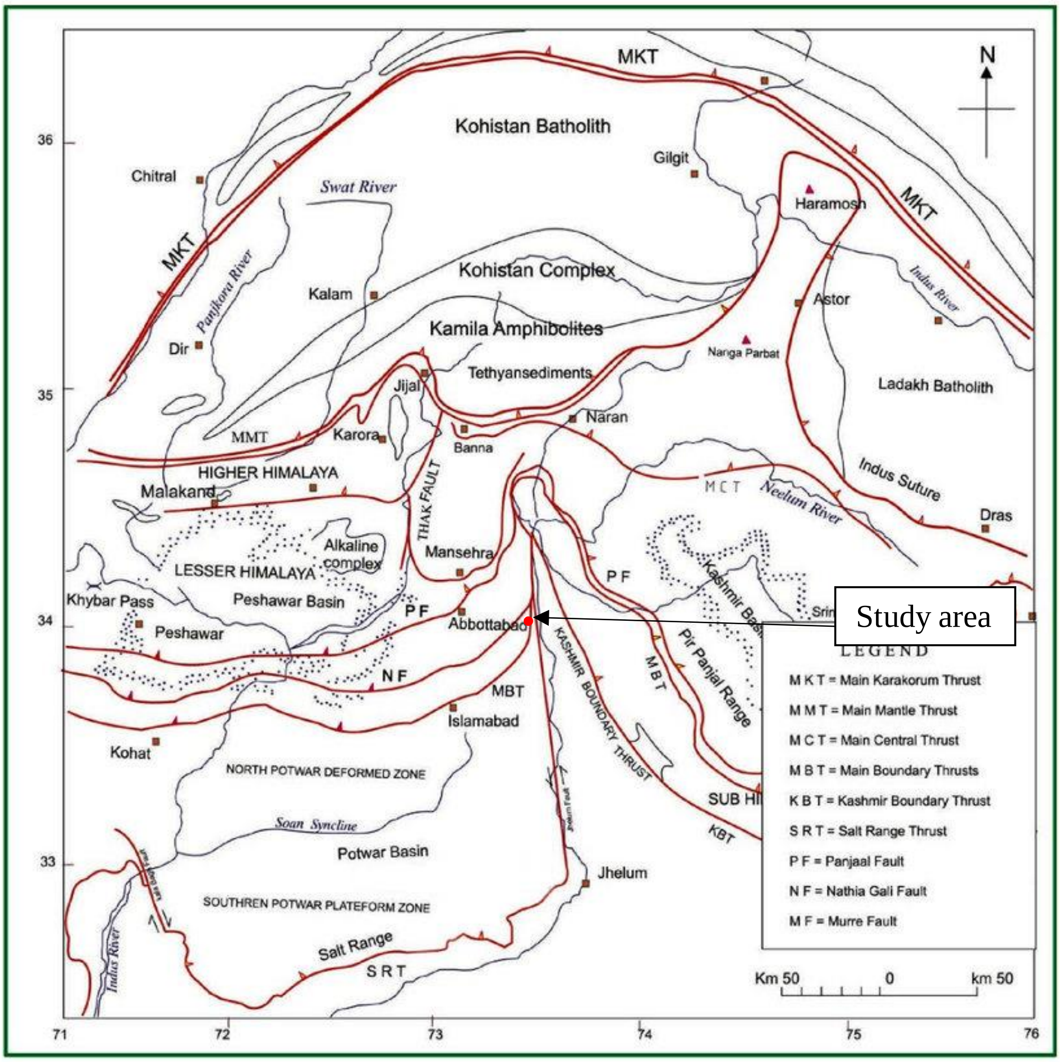


Figure 2.1 Generalized Tectonic map of Pakistan (Ghazanfar, 1993)

2.2.1 The Main Karakorum Thrust

The collision between Karakorum plate and Kohistan Island Arc (KIA) created the Main Karakorum Thrust (Tahirkheli, 1979, 1982, 1983). The MKT borders the Karakorum block in the southern region. In Pakistan the MKT is considered to be an important tectonic feature in the north. Pudsey et al. (1985) identified the MKT as a suture zone and named as the "Northern Suture."

2.2.2 The Main Mantle Thrust

In the North of the Northern Deformed Fold and Thrust Belt (NDFTB) lies the Main Mantle Thrust (MMT). The MMT marks the boundary between the platform rocks of the Indian plate and ultra-mafic rocks of the KIA. The MMT consists of Proterozoic gneisses and schists with a 15 km thick sequence in KIA (Madin, 1986). The block movement on either part of the Main Mantle Thrust stopped around 15 Ma ago (Zeitler et al., 1982). However, research shows that the MMT is continuously moving with a speed of 5mm / year ever since (Patriate & Achache, 1984).

2.2.3 The Main Boundary Thrust

The (MBT) trending in the northeast to southwest marks deformation of Himalayas in the south regions. The MBT spreads along the (NDFTB) around the Hazara-Kashmir syntaxis.

The Himalayas have been ivided into a “hinterland zone” and a “foreland zone” due to he presence of several thrust faults are present in the MBT zone. The Hazara and Murree faults are linked to the Main Boundary Thrust. These thrust faults mark the margins in the north of Hazara and Kalachitta range (Seeber and Armbuster. 1979 ; and Yeats and Lawrence. 1984). The MBT is bedded in parallel and is exposed somewhere in the molasse of northern Potwar and Kohat Plateaus by (Izzat, 1993). Following the movement on the MCT and MMT Continental shortening along the MBT detachments were moved ahead.

2.2.4 Salt Range Thrust:

The active frontal thrust zone of Pakistan is the Salt Range Thrust. It is cut by the Salt Range Frontal Thrust, which is bounded between Jhelum and Indus River. The older sequences of the Salt Range have been pushed and emplaced onto the tertiary sequences of the Punjab Plain in the south. Recent Conglomerates and Jehlum River alluvial sediments cover the thrust zone (Yeats et al. 1984). However, the thrust exposed in the vicinity of the Jalalpur and the Kalabagh areas show that the Neogene or Quaternary deposits are overlain by Palaeozoic rocks of the Punjab Plain (Yeats et al. 1984; Gee and Gee 1989). Along the Salt Range Thrust, extensive weathering of sediments from the basement along the layer of salt has led to southward transport of the.Salt Range and Potwar Plateau in the form of a large slab over the Punjab Plain(Yeats et al. 1984).

2.3 Hazara Area

2.3.1 Tectonics

The active faults and thrust belts have been divided into two belt regions the Suleiman belt and the North-Western Himalaya Fold and Thrust Belt along the Northwestern boundary of the Indo Pakistan plate. The Suleiman belt is considered as a zone of extension, while the North-Western Himalaya Fold and Thrust Belt is related with the formation of Himalayas (Jadoon, 1992). The compressional regimes in the North-Western Himalaya Fold and Thrust Belt are the result of when the Eurasian plate collided with the Indo Pakistan plate in the Eocene to Oligocene time period.

In 1981, Gansar classified Himalayas form South to North as:

1. MFT (Main Frontal Thrust) to MBT (Main Boundary Thrust) as sub Himalayas.
2. MBT (Main Boundary Thrust) to MCT (Main Central Thrust) as Lesser Himalayas.
3. MCT (Main Central Thrust) to MMT (Main Mental Thrust) as higher Himalayas.

The South East Hazara being topographically close to the MBT (to the North of MBT), has been under intense deformation. The study area, is marked by South East moving thrust faults, and North-East Trending Anticlines. The North-East positioning of the anticlines propose that the study area has been and still is undergoing North-West to South-East directed stresses (Latif, 1970). The axis of most of the fold structures in the study area are North East - South West direction which also suggests that compressive stresses act in the North-West South-East direction in the study area (Latif, 1970).

The style and deformation in the Eastern limb of the Hazara Kashmir syntaxes differs from that of the Western limb (Latif, 1970).

CHAPTER 3

STRATIGRAPHY

3.1 Stratigraphic chart of the Hazara basin

The stratigraphy of the Hazara basin as suggested by (Shah, 1977) is shown in table 3.1.

Table 3.1. Showing stratigraphy of the Hazara area (Shah, 1977)

FORMATION	AGE
MURREE FORMATION	OLIGOCENE TO MIOCENE
KALA CHITTA GROUP	PALEOCENE TO EOCENE
KAWAGARH FORMATION	UPPER CRETACEOUS
LUMSHIWAL FORMATION	UPPER JURASSIC TO LOWER CRETACEOUS
CHICHALI FORMATION	UPPER JURASSIC
SAMANA SUK FORMATION	JURASSIC
DATTA FORMATION	LOWER JURASSIC
MANSEHRA GRANITE	CAMBRIAN
ABBOTTABAD FORMATION	CAMBRIAN
TANAWAL FORMATION	CAMBRIAN
HAZARA FORMATION	PRECAMBRIAN
SALKHALA FORMATION	PRECAMBRIAN

3.2 Detailed stratigraphy of the hazara area

3.2.1 Salkhala Formation

The oldest known rocks in the Hazara region are the Precambrian age metamorphic rocks from the Salkhala Formation. The lithological components of the Salkhala formation are quartz schist, graphite, quartzo feldspathic gneisses and marble (Shah, 1977). The formation schist constitutes about 20 to 40% of chlorite and muscovite, whereas remainder is quartz along with clinozoisite, garnet, magnetite and biotite in minor amount is also present. The Formation is widely exposed in the Mahindra and Balakot region.

3.2.2 Hazara Formation

The “Hazara Slate Formation” by Marks and Ali, 1961 is one of the numerous titles given to the extensive rock sequence of slate phyllite and little metamorphosed graywacke. The Hazara Formation is said to cover a region of about 12 miles. Along with the Hazara Formation, the overlying younger stratas extends in the south direction from the "Ghari Habibullah" area through the Abbottabad district, and then west to Tarbela.

3.2.3 Tanawal Formation

The Tanawal Formation lies in the stratigraphic sequence, above the Hazara Formation and below the Abbottabad Formation. Wynne (1879) initially named this rock sequence as “Tanawal Group” and Middlemiss (1896) identified the lithology as “Tanawal Quartzites”. Middlemiss assumed that the quartzites had formed from the base of the overlying “Kingriaili Formation” between Sherwan and Indus river region. The Tanawal Formation lithology consists of a quartzose schist series that overlies the Hazara formation in the northeastern part of Tarbella district.

3.2.4 Abbottabad Formation

The name "Abbottabad Formation" was proposed by Marks & Ali, 1962 of a part containing highly deformed folded belts, which lie between the northeastern corner of Sirban Hill Abbottabad, to Ghari Habibullah region. There are several other main areas where the formation is exposed that includes the belts between Muzaffarabad and Balakot, Sherwan and the Indus river and the MandaKuchha syncline.

3.2.5 Mansehra Granite

Mansehra granite was named by Shams (1961). This Formation consisted of foliated granites which were observed in and around the town of Mansehra. The foliated granite was distinguished from the non-foliated granite and was named as Hakale granite by Shams (1961). Later in a paper Shams stated that these various types of granites were similar based on lithological characteristics but differed in their location. Later on, all the varieties of the granites were combined into one single unit named as the Mansehra granite (Shams and Rehman 1966). The Mansehra granite is considered to mark the southern border regions of the widespread granite intrusions in the axial zone of the great Himalayas, that are known as "Central Himalayas.

3.2.6 Datta Formation

The name Datta Formation was introduced by Danilchik and Shah (1967) after the Datta Nala section in the Trans Indus Salt Range. This name has also been extended to the Kala Chitta Range and adjoining areas by the Stratigraphic Committee of Pakistan (Fatmi 1973). The formation having lithology of sandstone and shale has low porosity and permeability. The Datta Formation in the Hazara region consists of a thin sequence of red and brown shale and quartzose beds which are exposed in the northeast of Abbottabad.

3.2.7 Samana Suk Formation

Davies (1930) coined the term for a lithological section which was derived from a mountain peak of same name in the Samana range. The type locality is designated by Fatmi (1968) in north east of Shinawari. The lithological components are described as a sequence of thick limestone bed Fatmi (1977). The foraminifera reported consists of ammonoids, bivavles, gastropods, barachiopods and crinoids (Fatmi, 1968,1972).

In the recent study the area consists of limestone bed which is generally grey colored on fresh surface and is medium to thick bedded. The eroded exterior region shows a yellowish-brown shade. The limestone is Oolitic at its base and contains broken bivalve fragments. The lower contact is with Shinawari Formation.

3.2.8 Chichali Formation

Danilchik (1961) named the lithological section in Surghar Range based on the type locality. The lithological components of the Formation include weathered rusty brown glaconitic sandstone and greenish grey colored fresh surface. In the lower parts grey glauconitic shale with phosphatic nodules and sand, silt intercalations have been reported. At the Chichali pass, the Formation contains enough iron to form an iron ore of low grade. In the Hazara area in many places, the thickness of the formation is not much and in many places the units are as less than 100 feet.

3.2.9 Lumshiwal Formation

This Formation was first introduced by Wynne (1880) in the Trans Indus mountains and was classified to be of Cretaceous in age. With the passage of time some of the rocks units in the Trans Indus mountains were named as Lumshiwal Formation Gee (1945). The lithological components consist of light grey colored sandstone with silty, sandy, glauconite shale towards the base. The Formation is covered by carbonaceous material in the upper portion of Samana range.

3.2.10 Kawagarh Formation

Waagen et al (1872) first observed the presence of the lithology in the Hazara region. The formation extends southward to Kakul and engulfs the core of a synclinal structure which plunges in the south direction. This rock unit has not been named or mapped separately. The limestone which occupies this part of the lithological unit consists of fine grained texture and is moderately thick bedded.

3.2.11 Kala Chitta Group

Waagen et al (1872) first named the Kala Chitta Group based on the limestone and calcareous shale on Sirban Hill near Abbottabad. In the Hazara region the formation was known as the "Nummulitic Formation" for many years. The lithological components of the Kala Chitta group are composed of dark colored calcareous shale grey along with intercalations of nodular limestone. The shale present in the formation contains limestone nodules and is abundantly fossiliferous.

3.2.12 Murree Formation

The formation was first reported by Wynne (1874) on the presence of sequence of sandstone and red shale at the base of the Himalayas. The formation was initially named as the "Mari Group" along with other terms for this sequence which were "Murree beds" (Lydker and Richard 1876). The lithological section is now known as Murree Formation by the geological survey of Pakistan. The lithological components of Murree Formation consist of red, thin bedded siltstone and shale, red mudstone and iron rich fine to medium grained greywacke. Murree formation contains sufficient carbonate material to produce effervescence with hydrochloric acid.

CHAPTER 4

CONCRETIONS, SKELETAL GRAINS AND THEIR ORIGIN

4.1 Origin

Carbonate Concretions are solid grains with concentric laminae created by solidifying material precipitated around grains and skeletal material (Ottawa: Agriculture Canada, 1976). Concretions are found in sedimentary carbonaceous strata, concretions are often of rounded shape, although deformed and irregular forms are also present in certain environments. The term ' concretion ' is of Latin origin and means ' together '. The cementing agent also solidifies the concretions and in turn makes them weathering resistant. (Davis, J.M, 1999).

There is a considerable difference between the concretions and nodules. concretions are formed around a certain type of grain or skeletal component by secretions of cementing material whereas nodules are substituted for body material.

Many geologists regard carbonate concretions as little more than natural grains, others are more aware of their importance as habitats for well-preserved megafossils. Carbonate concretions are hardly considered habitats for microfossils and have only been used as paleo-depositional and paleoenvironmental markers in recent years. Our micropaleontological studies (Pessagno and Blome, 1980, 1982; Blome, 1983, 1984) have shown that the number, size, and consistency of survival of fossil radiolarians, dinoflagellates, seeds, and spores in carbonate concretions are higher in comparison with their host. Radiolarian faunas extracted from carbonate concretions tend to be better preserved, more abundant and diverse, and more likely to retain delicate and fragile structures than those extracted from the surrounding rocks.

Geologists and paleontologists have found fossils of invertebrates and vertebrates remains within carbonate concretions for many years. Dickson and Barber (1976) deduced that the substances found in the concretions originate from the remnants of massive animals that have decayed, or from the accumulation of varying numbers of microscopic organisms.

They also suggested that microfossil concretions are scattered along or around bedding planes and are spread laterally. Those observations led to the conclusion that, under anaerobic conditions, the degradation of organic material is the controlling factor in concrete production (Berner 1968). Collection and lithification of pellet grains may be another explanation for the production of large concentrations of organic matter. Most of the remains of the planktonic microorganisms tend to dissolve quickly during which they make their way down through the water.

Throughout their descent these tests can avoid dissolution by being encased within fecal pellets of planktonic grazers (Flugel, 2010). As soon as they drop to the ocean floor the bacteria begin to work on the pellet grains, they disintegrate quickly due to bacterial activity. This bacterial decay could provide the alkaline environment and the carbon dioxide needed for the development of carbonate concretion.

The early carbonate concretions have their own significance written in different studies of the carbon-isotope ratio (Galimov et al., 1968; Tan and Hudson, 1974; Hudson, 1978). Concretions developed during or before compaction of the sediments (early diagenesis) have negative isotope values of 13C, suggesting derivation from organic matter decomposing. In other cases those concretions which were formed after compaction at a later stage of diagenesis have positive isotopic values of 13C. Carbon isotopic data show that strata layers that are in contact with seawater trigger concretion production. Many concretions are enriched with 12C isotopes, meaning carbonate derived from carbon dioxide produced from decaying organic matter (Galimov et al., 1968; Hoefs, 1970).

Carbonate concretions are known to form either from isolated nucleation in an atmosphere that is uniformly supersaturated with respect to carbonates, or from the production of specified supersaturation through the deterioration of organic matter concentrations at the concretionary site (Raiswell 1976). The concretions under debate are indicative of calm waters in which oxygen is rapidly used up, carbon dioxide accumulates, and lime is mainly retained as bicarbonate in solution. Such environments today generally have a low potential for oxidation-reduction (Eh). They contrast noticeably with the carbon dioxide-free environments of shallow, aerated bottoms, such as those of the basin shelves and more limited bottom highs, where excess calcium carbonate is most readily removed from the waters.

A reducing environment or its creation soon after burial is demonstrated by the preservation of organic material. There is no direct relationship between the accumulation of calcium carbonate and the potential to reduce oxidation; it is largely an interaction with the environment (Tarr, W. A., 1921). The potential of the calm water condition typically varies from slightly positive (only mildly oxidizing) to negative or diminishing, but it is the stagnancy that keeps lime in solution rather than the O / R potential.

Calcium carbonate deposition is regulated primarily by the concentration of hydrogen ions (pH). There are conditions such as the reduction of carbon dioxide pressure in the atomsphere, increasing temperature, agitation and aeration raises the pH and favour lime deposition. Every decrease in alkalinity helps to retain the lime in solution, on the other hand. Sea waters, with a pH ranging from around 7.5 to 8.5, are usually alkaline. pH of 7.0 is for neutral solutions and decreasingly lower values reflect rising acidity. Calcium carbonate deposition usually requires at least a pH of 7.8.On stagnant bottoms the pH would normally be well below 7.8 or even in the acid range (Tarr, W. A., 1921). There are methods in which the pH of an unfavourable environment can be raised locally to the point of deposition of carbonate. In most stagnant bottom conditions, decomposition, if only anaerobic, goes on. Ammonia or amines are concentrated locally by anaerobic decomposition. In order to determine whether the bacterial phase is progressing, bacteriologists use this method. The release of ammonia would sufficiently increase the pH to cause the bicarbonate to precipitate as carbonate. Once the initial concentration and precipitation (seeding) of calcite crystals occurs, they are expected to persist for some time. Any type of carbonate, such as a fragment of aragonite from a shell, may act as a nucleus for the development of carbonate concretions.

Non-Skeletal grains in terms of peloids are formed in carbonate lithologies. These are more or less structureless grains that lie between microns to a few millimeters in size. The origin of peloid grains is often in conflict and distinguishing them is often hard, however these peloid grains are characterized into categories on the basis of composition, shape, size and sorting to better understand their origin (Flugel, 2010). Theses sub-categories are biotic origin, alteration of grains and by in-situ formation.

The peloids originated from biotic origin are formed by either micro-organisms excreting materials or from the hard part boring and rasping by organisms. Theses grains range from 20µm-100µm in size. The peloids formed by the alteration of grains include ooids and other grains that have undergone intense micritization and have recrystallized or destroyed their internal structure. The peloids formed by in-situ include microbial and precipitated peloids which are formed by chemical precipitation triggered by microbes and organic compounds(Flugel, 2010)

When it comes to non-skeletal grains in terms of aggregates are formed by the consolidation of bioclasts, ooids and other grains together by organic films to form composite grains (Flugel, 2010). Aggregate grains tend to form in areas with some water circulation, winnowing of fines and mobilization of sediment, followed by periods of stabilization and cementation (Wanless, 1981). Aggregate grains are further sub categorized into grapestones, lumps and microbial and encrusted aggregate grains based on the shape, carbonate cements and contributing grains. The most common aggregates are grapestones which are formed when ooids mostly micritized are bound together in the presence of carbonate cement.

4.2 Concretions and Non-skeletal grains in Samana Suk Formation

On the basis of a detail study of 40 thin sections from the study area and are represented in the columnar section in figure (4.2). Following are the concretions and non-skeletal grains observed.

4.2.1 Ooids

4.2.2 Aggregates (Grapestones)

4.2.3 Peloids

4.2.1 Ooids

Ooids are spherical grains which contain a nucleus that can be a grain itself or a skeletal fragment of some sort is laminated with a single external or multiple cortex, the outer cortices of these ooids grains is considered to be smooth. Ooids in general range between 0.5 and about 1 mm in diameter but some can reach up to 2mm sizes. The composition of the ooids can be calcitic or aragonitic. There are characteristics of ooids that rely on the climatic conditions of regions lacustrine and shallow marine setting in which ooids are deposited, which indicate biological controls in ooids formation have a significant role. The ooids have been divided into various types based on structural and morphological features and are described in the figure (4.1).

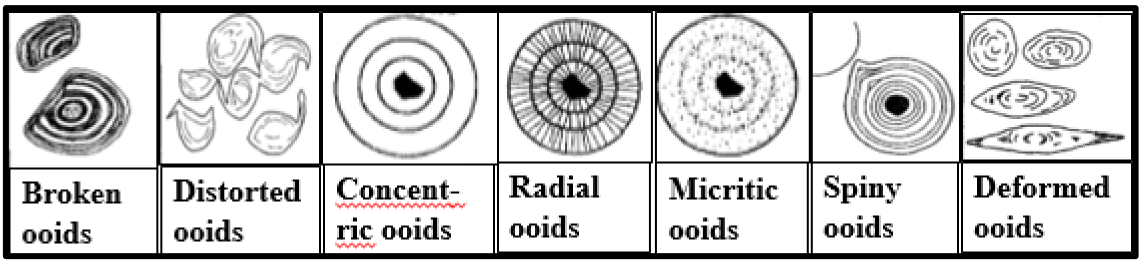


Figure 4.1 Various types of Ooids (Flugel, 2010)

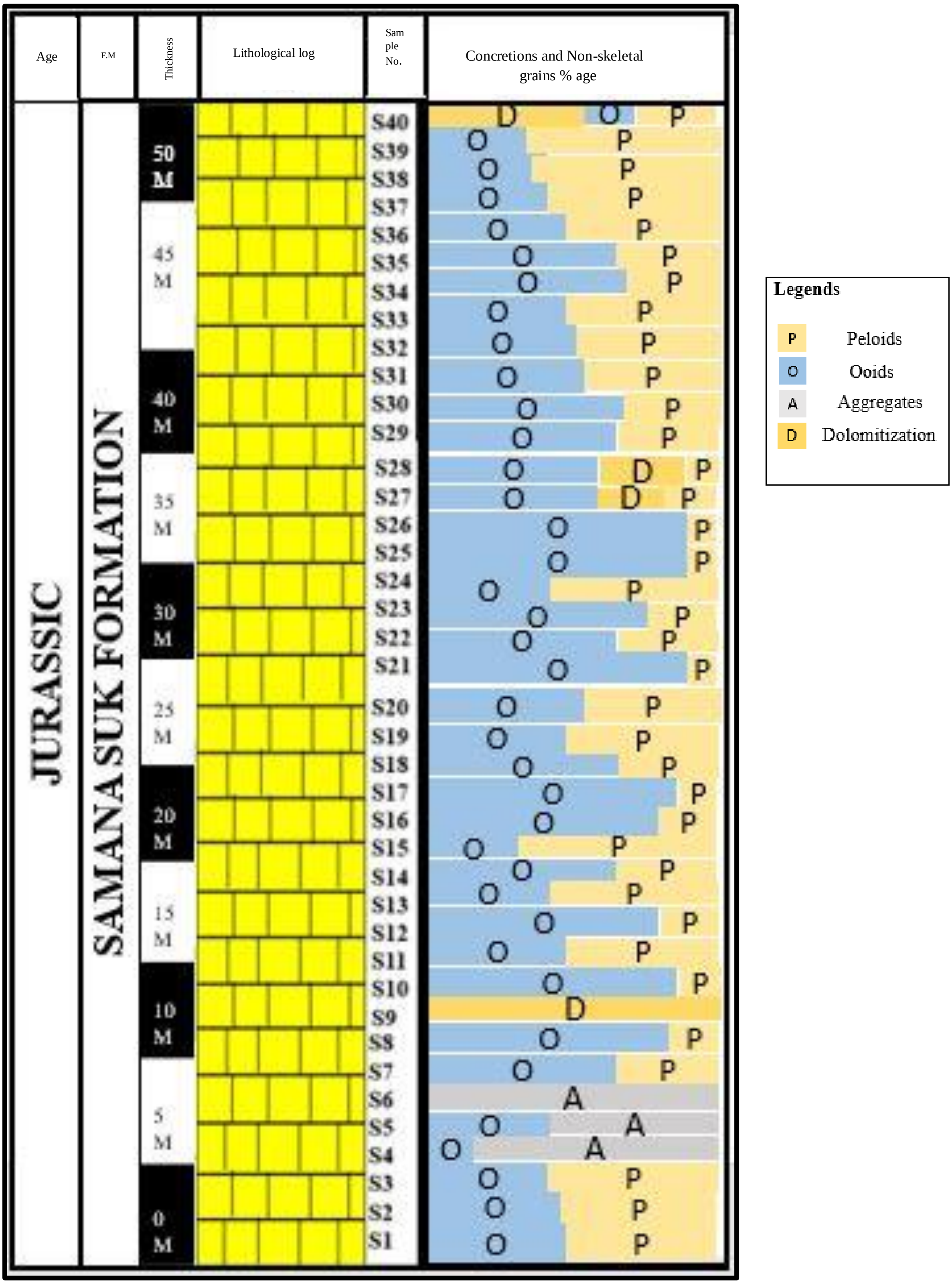


Figure 4.2 Columnar section of the Samana Suk Formation showing concretions and non-skeletal grains distribution at Harnoi section, Abbottabad.

4.2.1.1 Types of ooids present in Samana Suk Formation

The formation under study consists of mainly micritic radial and concentric type but other types like eccentric, deformed, broken, superficial ooids are also present that are based on morphology and diagenetic processes.

4.2.1.1.1. Micritic ooids

Micritic ooids are basically concentric or any other ooids type that is micritized to a certain degree. The micritic texture can be limited upto one or two cortices or it can occur in the entire cortex which can be originally calcitic or aragonitic. Microsparitic and micritic ooids can be formed with the transformation of aragonitic ooids (Popp and Wilkinson 1983, Friedel, 1995). In this study the sections reveal micrite ooids displaying cortices of micrite together with radial structures and microcrystals embedded in their cortices. The micritic fabric results from the activity of microborers or from recrystallization, the sizes of the ooids range from 150-400 µm as shown in plate (4.2.1.1.1). The laminations within the ooids range from 10-15µm in thickness. The proportion of micritic ooids concentration in the Samana Suk Formation is about 20-25%.

4.2.1.1.2 Concentric ooids

Concentric ooids include several repeated laminations around a nucleus. The lamina includes crystals arranged in tangential pattern whose vertical sections are parallel to the exterior of the laminas. In the study the thin sections reveal that the ooids include several cortices and these cortices are thin to medium in thickness. The c ooids are well to sub-rounded as shown in plate (4.2.1.1.2). These concentric ooids contain calcite crystals embedded in their cortices which are large and clearly visible. Concentric ooids are of 20-25% in proportion in the Samana Suk Formation.

4.2.1.1.3 Radial ooids

Radial ooids are represented by crystals present in the laminas of ooids. Concentric banding can also be observed in most of the cortices in radial ooids (radial-concentric, banded radial), however these band cannot be observed in small ooids. In this Formation the ooids consist of radial structures appearing perpendicular to the cortices, radial structures are well preserved and concentric banding can also be been seen as shown in plate (4.2.1.1.3). The cortices are 8-10µm thick, but their proportion is about 13-15% in the Samana Suk Formation.

4.2.1.1.4 Superficial Ooids

Superficial ooids are the type of ooids, where the cortex is extremely thin, and its thickness is less than that of half of the diameter of the entire ooid. In the studied thin sections, the cortices of these ooids is very thin of 5-10μm. Most of these cortices contain micrite in their fabric. The ooids are sub rounded to well rounded and some contain crystals present in their nucleus which are clearly visible in the plate (4.2.1.1.4). The superficial ooids constitute to about 25-30% of the total ooids in the Samana Suk Formation.

4.2.1.1.5 Broken Ooids

These are Fragments of radial concentric ooids. The ooids are represented by alternating concentric banding or by radial structures in the cortical fabric. In this study the thin sections reveal that several broken ooids are formed which are both radial and concentric with moderate to well preserved structures as shown in plate (4.2.1.1.5). These have thin to medium thick cortices 5-15μm. Broken ooids also act as nucleus for new ooids to form cortices around the previously broken ooid. The broken ooids constitute to 5-8% of the total ooids in the Formation.

4.2.1.1.6 Deformed Ooids:

These ooids types were Originally of spherical shape but after deposition such ooids are distinctly elongated, flattened and stretched. The structures of the ooids are less recognizable or at times destroyed due to deformation. These Indicate tectonic style and timing of plastic deformations. In this Formation the thin sections reveal that several deformed or stretched ooids are present which can be assumed to be originally spherical. These deformed ooids are mostly concentric and contain thin cortices. Tectonic stresses are considered to be an important factor for their formation. The deformed ooids constitute to 15-20% of the ooids present in the Samanasuk Formation.

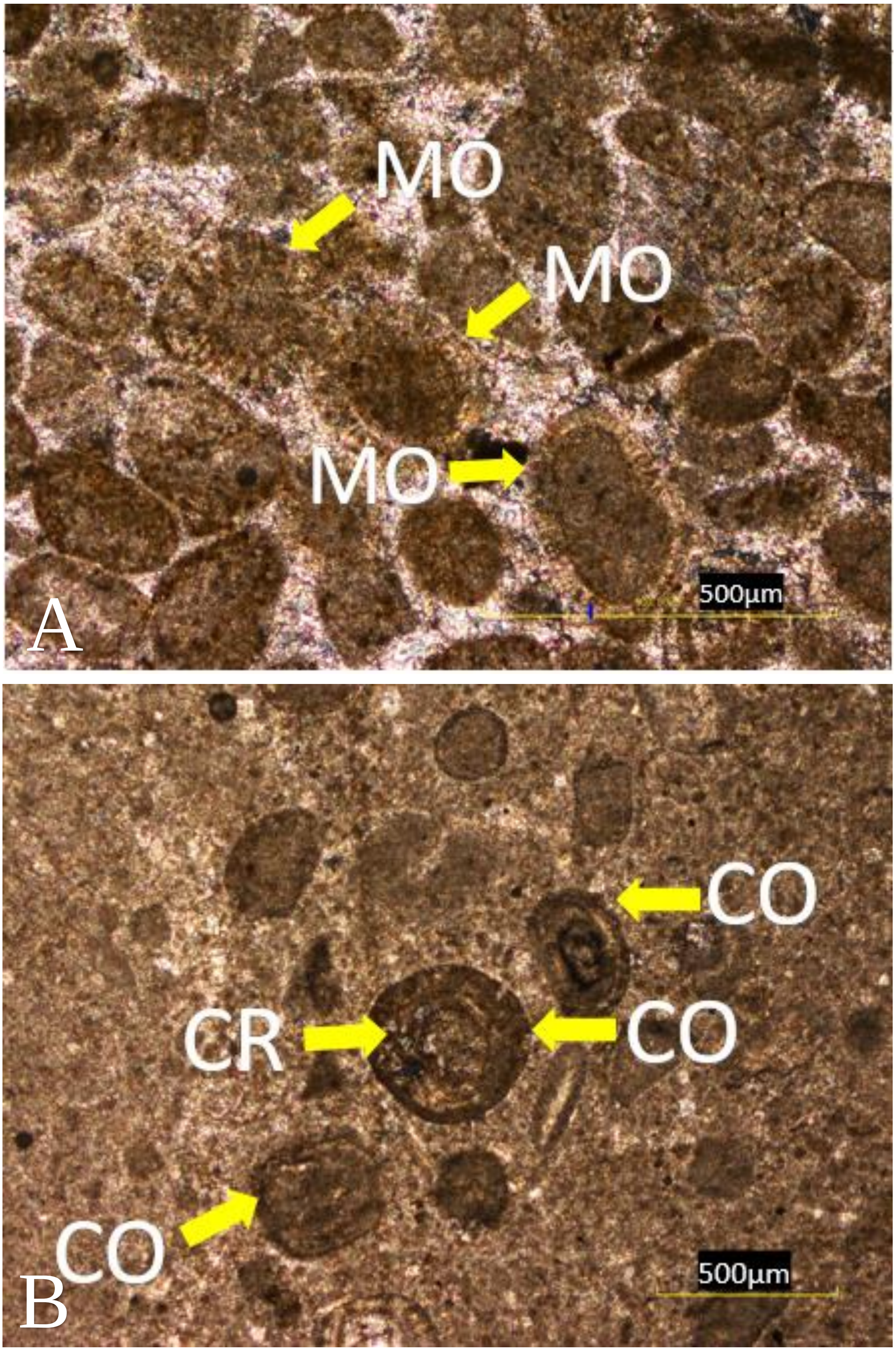


Plate 4.2.1.1.1 Photomicrograph (A) displaying high concentration of Micritic Ooids (MO) having very thin lamina 5-10µm along with some ooids having thick lamina of 15-20µm. Photomicrograph displaying Micritic Ooids (MO) having dolomite crystal grown (CR) in the lamina. There are multiple concentric laminations with 5-10µm thickness.

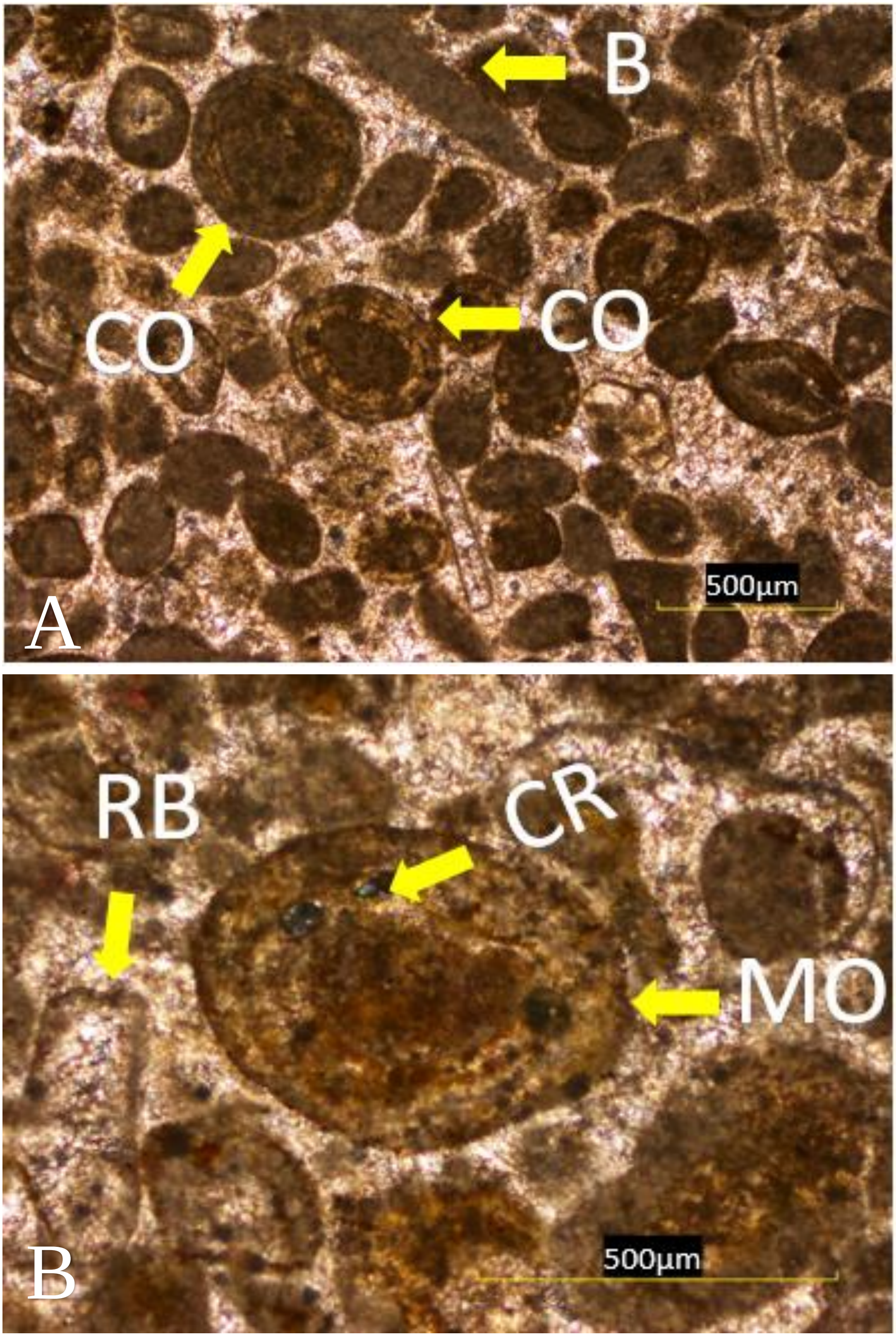


Plate 4.2.1.1.2 Photomicrograph A displaying Concentric ooids (CO) with thin laminas of 5-10µm and some bioclasts. Photomicrograph B displaying Concentric ooids (CO) with laminas of 10-12µm along with crystals (CR) grown within the cortices.

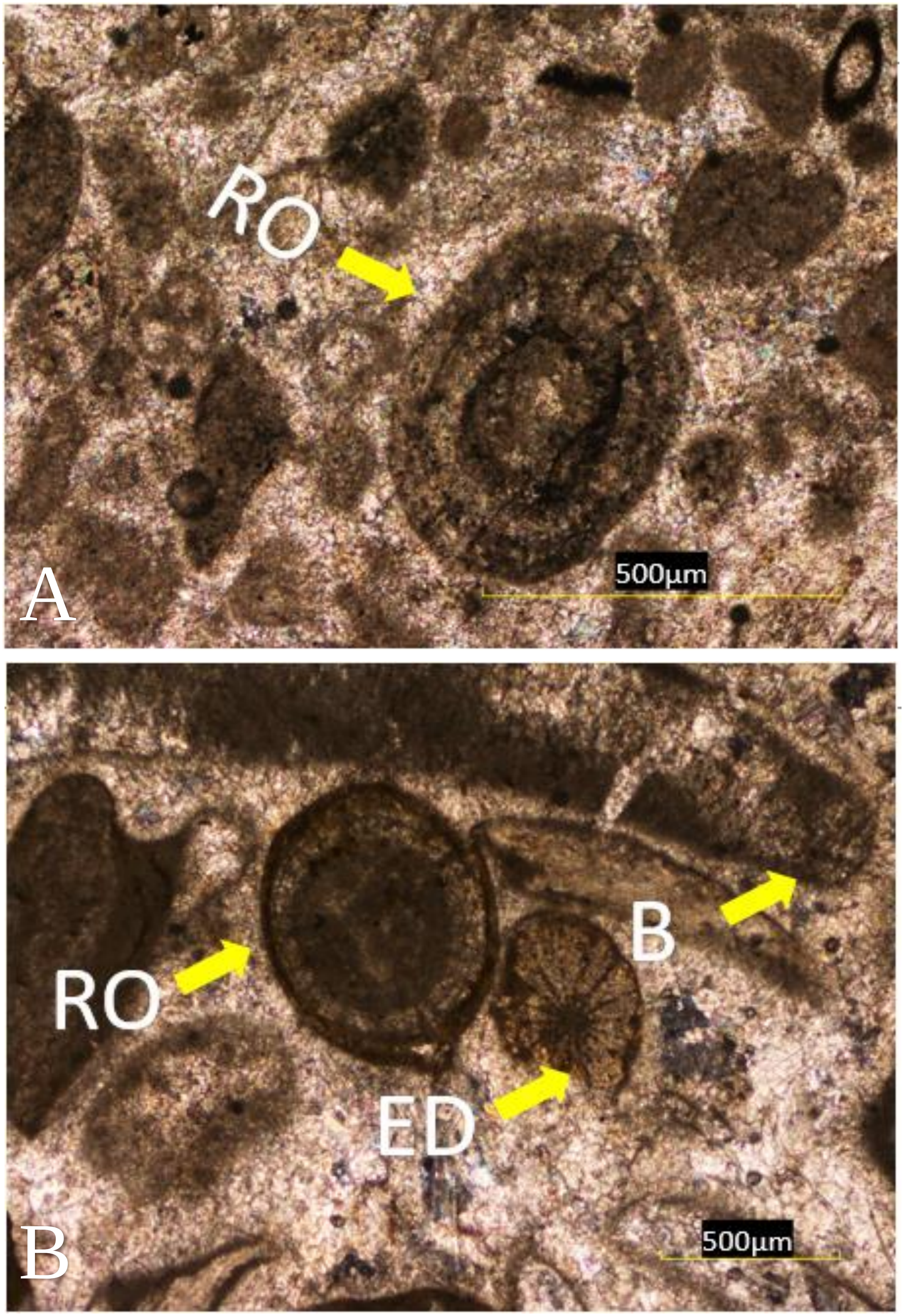


Plate 4.2.1.1.3 Photomicrograph (A) displaying Radial ooids (RO) with laminas of 10-15µm with moderate to well preserved radial structures. Photomicrograph (B) displaying Radial ooids (RO) with laminas of 8-10µm partially to moderately preserved radial structures along with an echinoderm (ED) and bioclast.

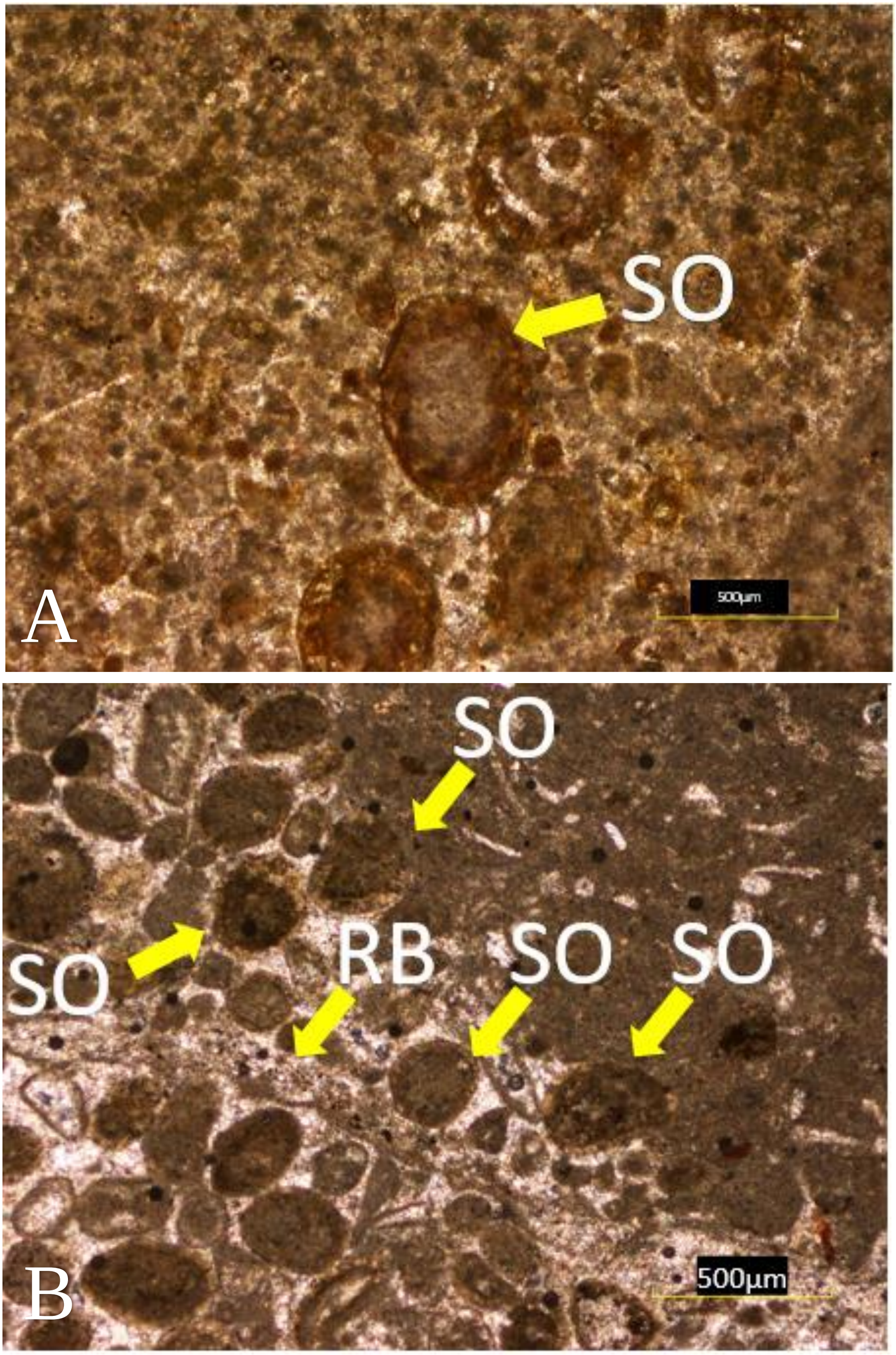


Plate 4.2.1.1.4 Photomicrograph (A) displaying superficial ooids (SO) with very thin cortices. Photomicrograph (B) displaying superficial ooids (SO) and recrystallized bioclast (RB).

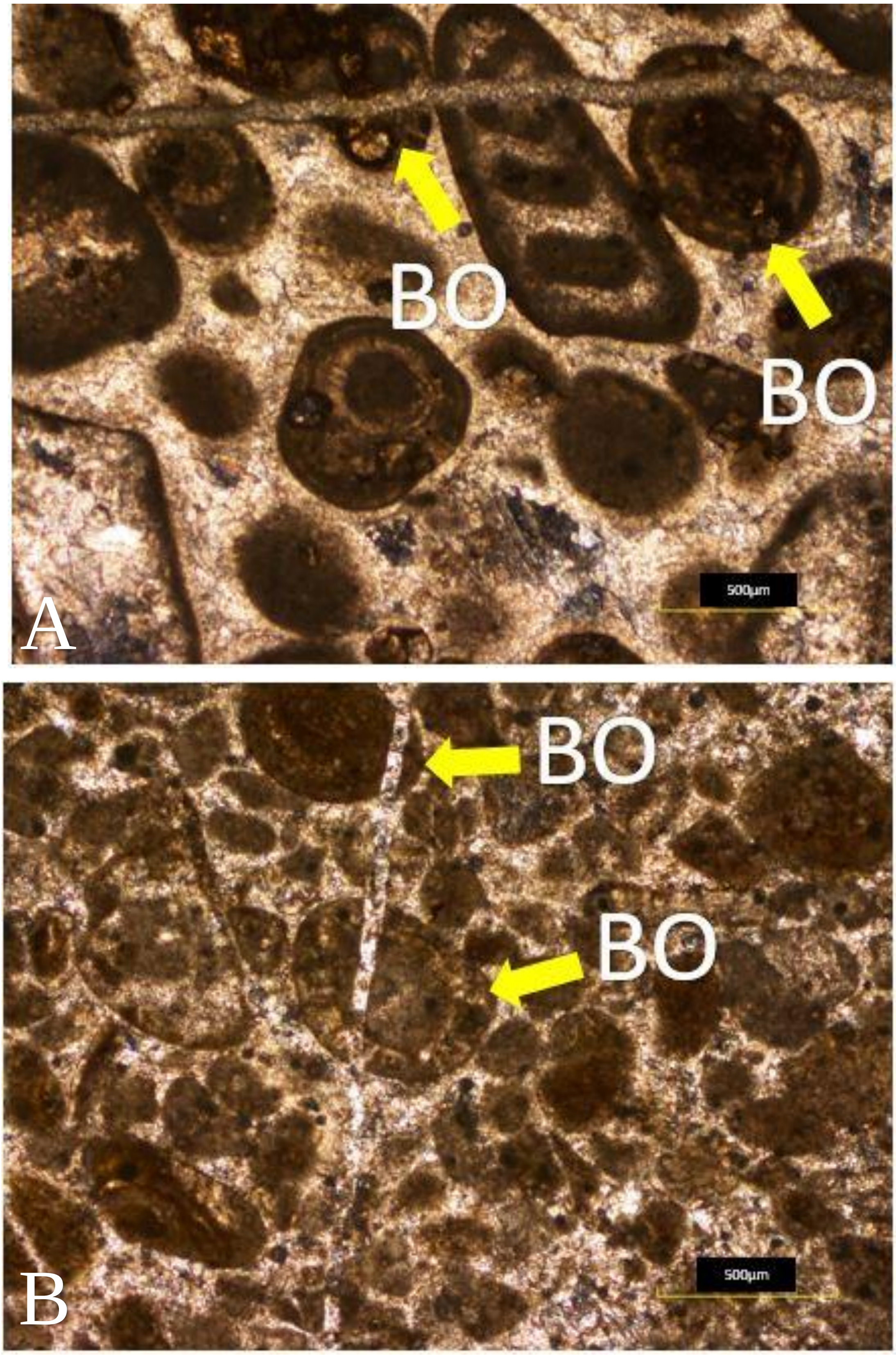


Plate 4.2.1.1.5 Photomicrograph (A) displaying Broken ooids of radial type (BO) with lamina of 10-15µm. Photomicrograph (B) displaying Broken ooids of concentric type (BO).

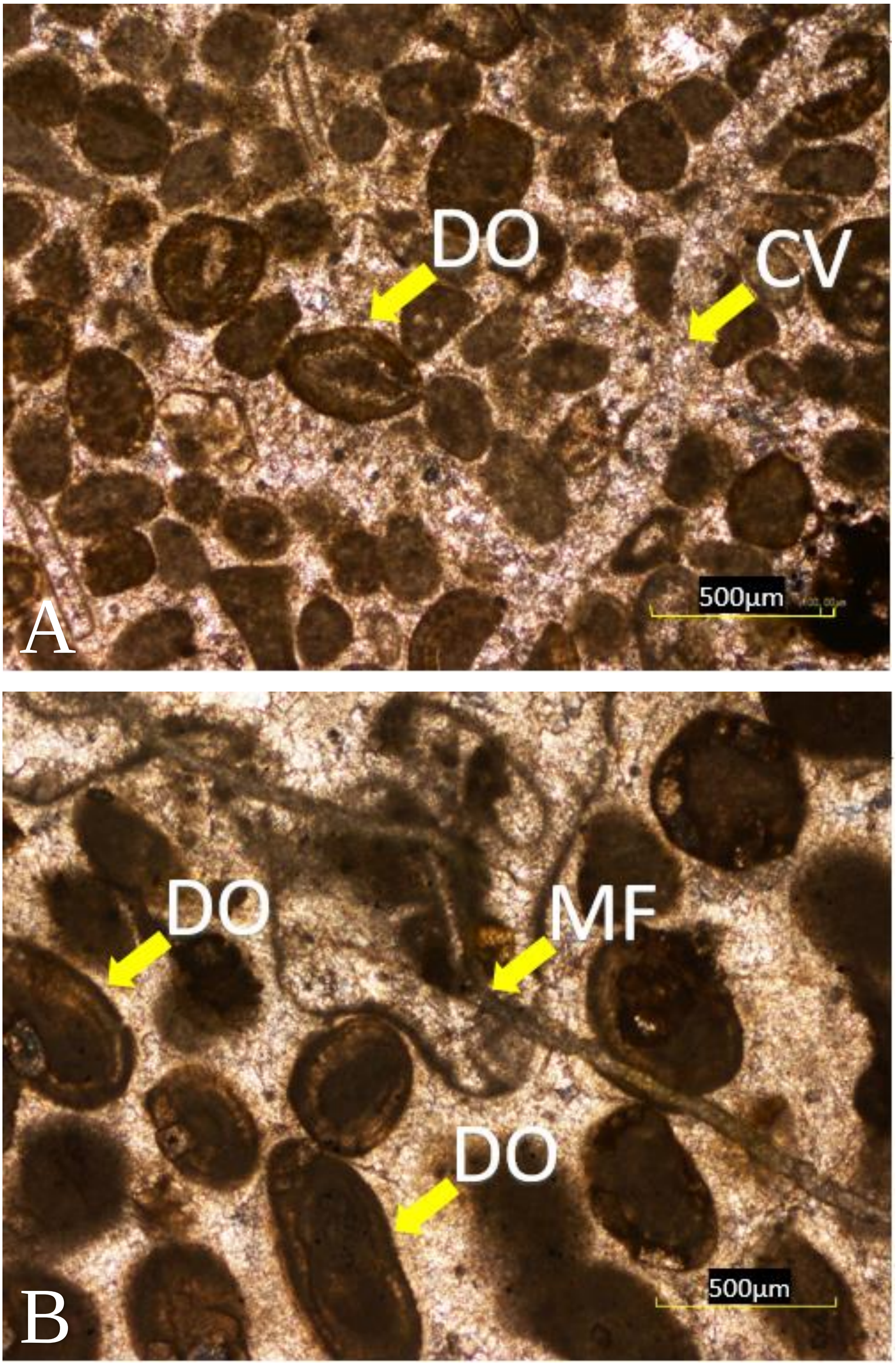


Plate 4.2.1.1.6 Photomicrograph (A) displaying Deformed ooids of concentric type (DO) with lamina of 5-10µm along with a calcite vein (CV) cutting across the thin section. Photomicrograph (B) displaying Deformed ooids of concentric type (DO) with lamina of 10-15µm along with a microfracture (MF) cutting across the thin section.

4.2.2 Aggregates

Aggregate grains are formed when individual grains and carbonate cements are encrusted together by thin organic films. There are various examples of aggregate grains out of which the Bahama Bank grapestones are the most suitable example in which there are aggregate grains in high abundance and their depositional environment varies between agitated ooid shoals to marginal reefs. At times it is hard to distinguish between aggregate grain and recrystallized sediments due highly intense micritization of the sediment grains constituents. The depositional environments for aggregate grains are shallow marine.

There are number of parameters that must be kept in mind while identifying aggregate grains. 1. Aggregate grains have irregular shapes as these aggregates have multiple grains bound together so their shape is irregular. 2. They are 0.5 to several millimeters size is the range for aggregate grains. Many different types of aggregates exist based on the stage of transformation and on the differences in current energy levels. Although many other types exist only those types are identified that can be meaningfully differentiated between each other (Flugel, 2010).

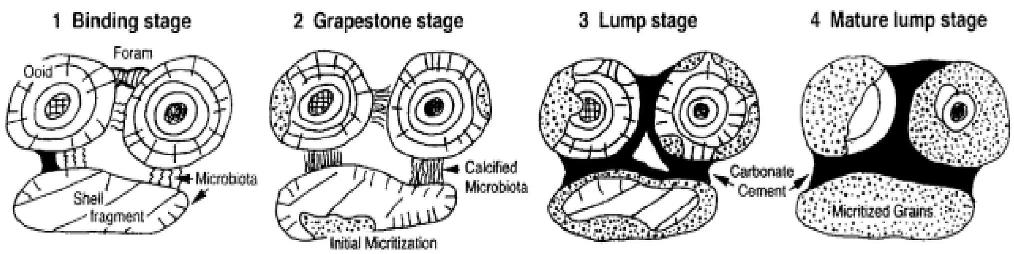


Figure 4.3 Stages of transformation of aggregate grains (Flugel, 2010)

4.2.2.1 Types of aggregates present in Samana Suk Formation

There are several varieties of aggregates out of which only grapestones are observed.

4.2.2.1.1 Grapestones

These carbonate sediments are known as a cluster of rounded grains whose outer shape appears as a microscopic bunch of grapes. Most of the grapestones show presence of microcrystalline carbonate in very minute quantities, whereas carbonate cements between particle is observed. Micritization can result these grains to transform into lump grains. In the present study the aggregate grains are of grapestone type in which various types of grains are bound together in which ooids, peloids and bioclasts are present. The sizes of these range from 400 to 850 µm. Several grapestones contain calcitic cement between the bounded grains which may indicate previously present hollow spaces present between the bounded grains which have now been filled with calcitic cement which are clearly shown in plate(4.2.2.1.1). The aggregate grains constitute about 5-8 % of the concretions present in Samana Suk Formation.

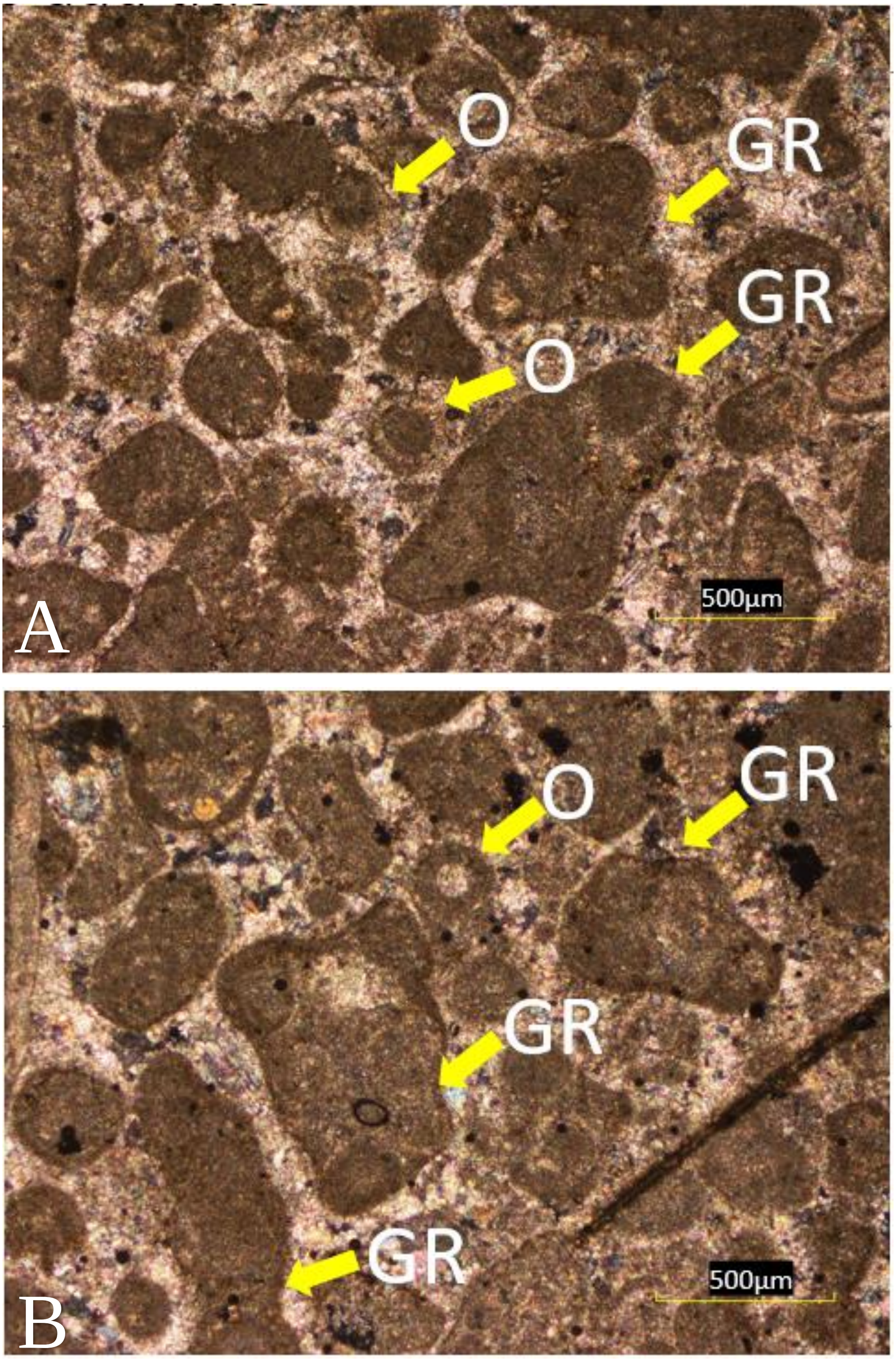


Plate 4.2.2.1.1 Photomicrograph (A) displaying aggregates of grapestone type (GR) with calcite cement present between the bounded grains. Photomicrograph (B) displaying aggregates of grapestone type (GR) along with ooids separately present as well.

4.2.3 Peloids

Many carbonate lithologies contain micrometer to millimeter sized structureless sub rounded to angular opaque grains, these grains are named as peloids or pellets. Though peloid is sometimes used as a term of ignorance, these grains's genetic distinction provides important knowledge on the environments in which these grains are deposited, paleoenvironmental factors, and diagenetic properties.

The term peloid is a systematic descriptive term used micro and cryptocrystalline material which are a part of polygenetic grains (McKee and Gutschick 1969). Peloids grains are considered to be opaque ad structureless, however these grains may contain bioclasts and other material. The word pellet was first used but when it became an alternative expression for fecal pellets, the term peloid was introduced.

Peloids occur as either carbonate rock constituents with other types of grains or as peloid limestones formed by rock building abundances. Peloids are sediment formed from mud and other grains which can seen as combined or separated and are present in layered and clotted textures (McKee and Gutschick 1969). These grains are abundantly present in tropical shallow marine carbonate and are rare or are scarce in areas where carbonates rocks are formed in cool waters (Flugel, 2010).

The shapes of peloid grains vary as some appear to be rounded to sub-rounded whereas others appear as elongated and rodlike. The sizes of these grains range between micrometers to millimeters, however many of the calcitic peloids range between 200-500 µm, and their diameters range between 100-150 µm (Flugel, 2010).

The difference between peloids and other grains that peloids does not contain any internal structures whereas grains like ooids and pisoids macroids do exhibit internal structures. Peloids differ from these on the basis of size aswell as peloid grains are smaller than the ooids, macroids and pisoid grains (Flugel, 2010).

4.2.3.1 Types of peloids present in Samana Suk Formation

There are a number of peloids out of which fecal pellets and bioerosional peloids are observed.

4.2.3.1.1 Fecal Pellets

These are termed as rounded and elongated grains which are formed by organisms which consume mud and excrete non-digested mud material. The term 'pellet' is still assumed to be used by many researchers for peloids that are created by organisms excreting carbonate mud. Fecal pellets are usually shaped in the form long cylindrical rods. Many of the fecal peloids are similar in size, whereas silt sized pellets have also been reported. These grains appear to be opaque under transmitted light due to high organic content in these peloid grains. In this study the pellets appear to be elongated along with other varieties of peloids and all the grains appear to be opaque. The internal structure appears to be absent in these grains as shown in plate (4.2.3.1.1). The sizes range from 300 µm to 1mm in the Formation. The fecal pellets constitute about 25-30% of the peloids in the Samana Suk Formation.

4.2.3.1.2 Bio erosional peloids

These grains are formed by burrowing through rock and hard parts biological organisms. These occur in tropical and temperate oceans, in which these demosponges penetrate the subsurface by means of cellular etching (Hatch, 1980). These demosponges excrete scoop-shaped material. These scoop-shaped materials become part of the peloid fractions (Acker and Risk, 1985; Edinger and Risk, 1996; Fiitterer, 1974; Torunski, 1979). Endolithic sponges started appearing during the Cambrian time period and were in abundance in the Mesozoic peroid (Perry and Bertling, 2000). The angularity of peloids is attributed to the burrowing and abrasion by microorganisms which results in the erosion of small limestone that vary in size. They range in size from 50µm to 300µm. In the present study the thin sections show the presence of several angular shaped grains that have been formed due to burrowing and erosion by organisms. These grains observed range in size from 100µm to 250µm as represented in plate (4.2.3.1.2). These constitute to about 15-20 % of the peloids in the Samana Suk Formation.

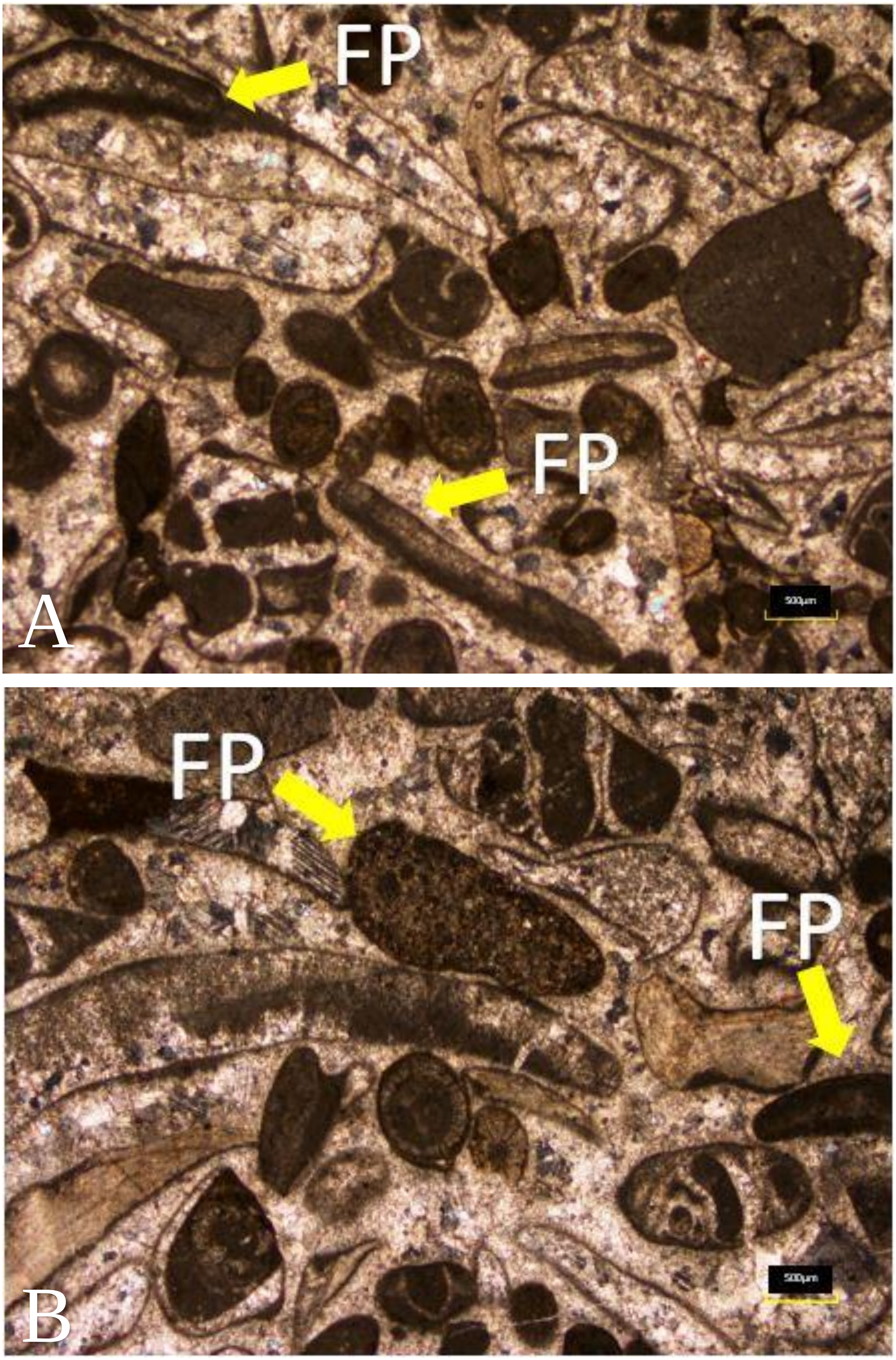


Plate 4.2.3.1.1 Photomicrograph (A) displaying elongated grains of fecal pellets (FP). Photomicrograph (B) displaying elongated grains of fecal pellets (FP) with some calcite cement present in their structure along with some ooids present aswell.

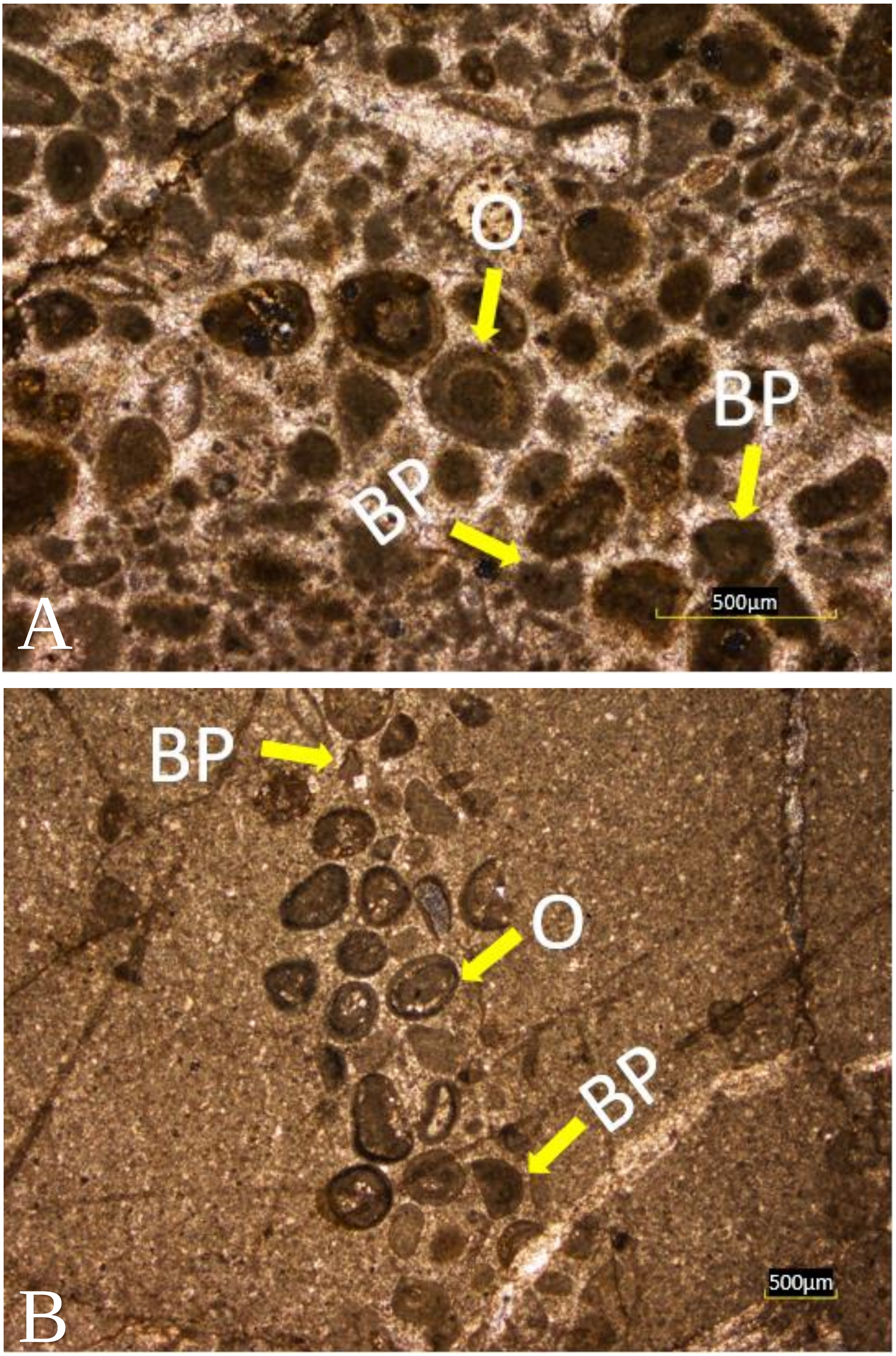


Plate 4.2.3.1.2 Photomicrograph (A) displaying angular grains of bio erosional peloids in a calcite cement (BP) along with some ooids present. Photomicrograph (B) displaying scope shaped sub angular grains of Bio erosional peloids (BP) along with some ooids present aswell.

CHAPTER 5

ENVIRONMENT OF DEPOSITION

5.1 Introduction

Depositional environment is a geographic location on the surface of the earth where a limited number of processes occur and cause various types sedimentary deposits to form. The preserved characteristics of each such deposit define its facies. Sediments accumulation is a time-consuming process and takes millions of years. Firstly, various tectonic processes form sedimentary basins in which sediments are deposited and accumulated in a basin over a prolonged period of time (Reineck HE, Singh IB, 1973).

There are certain characteristics of sediment grains which if properly identified can provide a means to interpret the ancient depositional environments. These characteristics can be used as important parameters for the mapping of the subsurface petroleum reservoirs and their identification. Depositional environments have a significant influence on the porosity-permeability characteristics and the subsurface architecture of sedimentary deposits and orientation are, in the first instance. However various tectonic and diagenetic processes can alter the behavior of these grains. There are three main terms in every sedimentary basin which require characterization include facies, depositional system and depositional environment (Walker, RG,. 1976). On a regional scale, many small depositional environments are linked together to create depositional systems. For example, the coast of Texas has various linked environments which include the tidal flats, barrier-lagoon systems deltas and estuaries forming depositional systems. A key component of stratigraphic research, described as "the analysis of layered rocks," is the regional study of these depositional structures as preserved in the rock record. Stratas are grouped into series, which are strata packages bounded by regional non-conformity surfaces.

Sedimentary rocks are classified into two broad categories clastic and chemical sedimentary rocks. Clastic sediments form by the weathering, erosion and transportation of lithified material by several means; whereas chemical sediments are formed by chemical and biochemical processes. The study of the origin of sedimentary rocks is based on the principle of uniformitarianism, which states, all those mechanisms that operate today have operated the same way in the past. Often this principle is used in the aphorism “the present is the key to the past” whereas its opposite is “past is the key to the present” (Miall AD, 2015)

5.2 Environment of deposition of the concretions and non-skeletal grains present in the Samana Suk Formation

The formation under study consists of pure limestone beds with wackestone, packstone and grainstone packing which includes a wide range of foraminifera along with their broken fragments, coated grains (ooids) and non-skeletal grains. The Samana Suk Formation has already been assigned “Inter-Tidal” zone of deposition based on the bioclasts and grains present in the Formation. In this research our purpose is to identify the various kinds of concretions and non-skeletal grains and generate a detailed depositional environment map based on the various kinds present in the Formation. The environment of deposition for the concretions and non-skeletal grains range from inter tidal to reef zone, and all have been interpreted individually in detail;

5.2.1 Ooids

In carbonate rocks ooid grains form mostly in tropical shallow marine environments, however deep marine ooids have also been reported. In the recent study the ooids are of micritic, concentric, radial and superficial type mainly. These ooids range from inter tidal to lagoon in terms of deposition. The micritic spherical ooids (1) with thinly tangential cortices have formed in the inter tidal zone in agitated waters. The concentric ooids (2) with tangential cortices representing the traditional ooid structure are formed in calm regions of inter tidal zone where tidal actions are not severe. The radial Ooids (3) with radial structures in the cortices are formed in lagoonal environment with frequent stirring up of sediments. The superficial oids (4) with very thin cortices are formed in brakish lagoon environments.

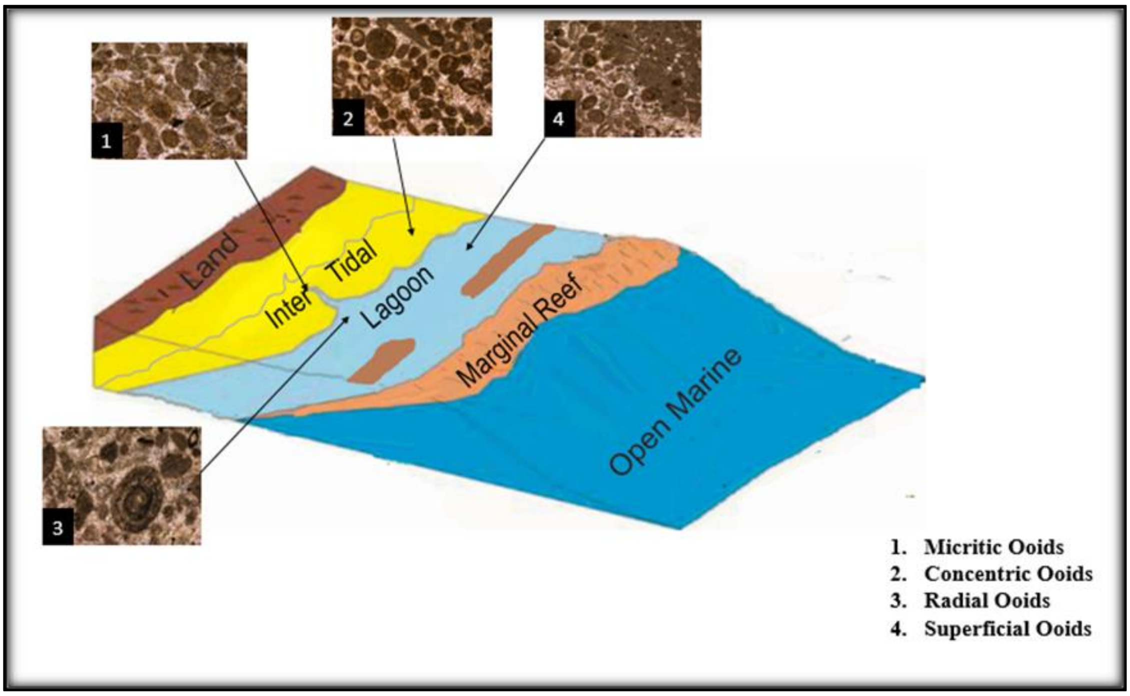


Figure 5.1 Depositional model for the various ooid types present in the Samana Suk Formation, Harnoi section Abbottabad.

5.2.2 Aggregate Grains

Aggregate grains are composite grains formed by the cementation of concretions and other grains by organic films around various kinds of grains. The Aggregate grains present in the Formation have been assigned a platform to marginal reef environment of deposition. In the recent study the aggregate grains are of grapestone type and are formed in marginal reef zone of deposition.

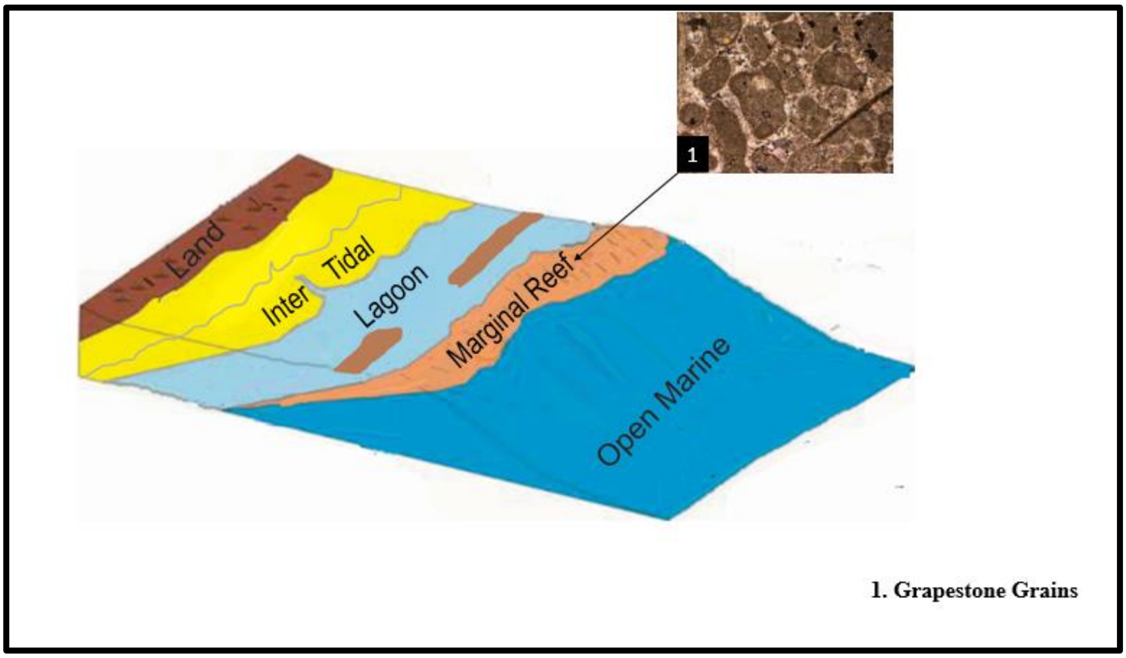


Figure 5.2 Depositional model for the various aggregate grains present in the Samana Suk Formation, Harnoi section Abbottabad

5.2.3 Peloids

Carbonate fecal pellets and bio erosional peloids form in tropical shallow marine environments, with low water energy. The fossilization of the initially soft particles involves a bacterial decomposition of organic secretions and intra-granular cementation by Mg-calcite or aragonite. Lithification occurs preferentially in warm, shallow waters that are supersaturated with respect to calcium carbonate, i.e., the inner portion of the Bahama base (Kornicker and Purdy 1957; Land and Moore 1980). In the recent study the fecal pellets represent lower inter tidal zone of deposition whereas the bioerosional peloids represent an upper inter tidal zone of deposition.

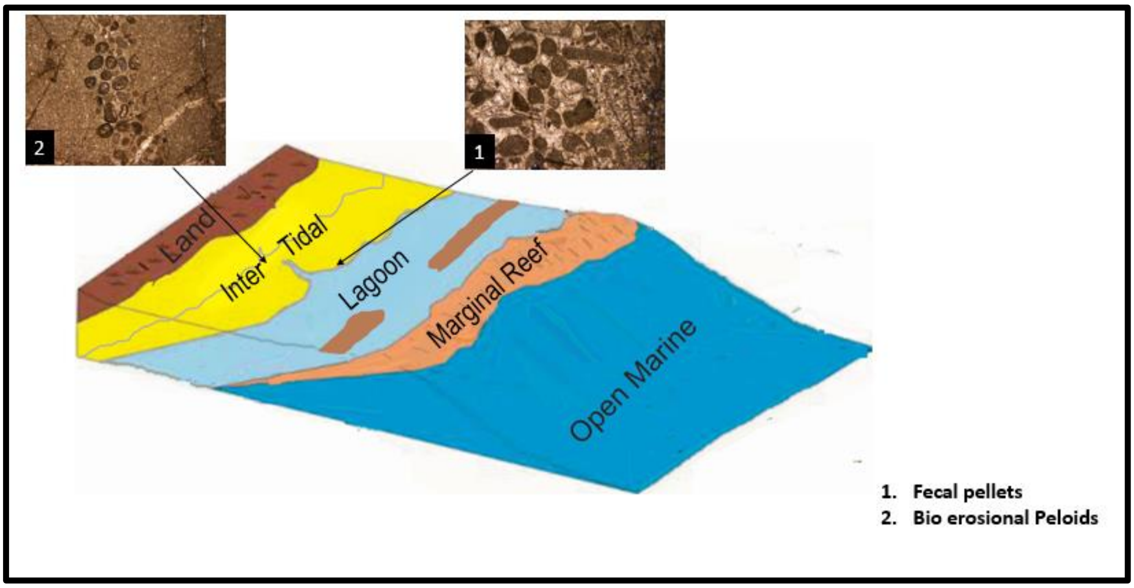


Figure 5.3 Depositional model for the various peloid types present in the Samana Suk Formation, Harnoi section Abbottabad

CHAPTER 6

DIAGENESIS

6.1 Introduction

The process of diagenesis is defined as a phenomenoa which encompasses all the processes that are taking place after the sediment grains have been deposited and up to the point the metamorphic processes start (Flugel, 2004). There are certain parameters which control the diagenetic processes which include sediment mineralogy and composition, the characteristics of fluids present, environment and sea level fluctuations (Tucker and Wright, 1990). Various changes can be noted within a single lithological unit under the influence of such processes. The sediments in carbonate rocks are composed of aragonite and High-Mg calcite. However, in ancient carbonates, due to the passage of time the concentration of Mg in Mg-calcite is reduced (Flugel, 2004).

The diagenetic processes play a vital role in altering the porosity and permeability of carbonate rocks. Processes like compaction and cementation tend to reduce porosity and permeability whereas dissolution and microfractures tend to increase the porosity and permeability of the Formation. The role of the diagenesis is significant in studying the petrophysical properties of carbonate reservoirs, thus studying these processes is necessary for carbonate reservoirs (Tucker and Wright, 1990).

The diagenetic processes are active in the marine, near surface meteoric and burial settings. Such environmental settings contain certain cement types and other textural lateral and vertical differences which can be observed (Tucker and Wright, 1990).

6.2 Diagenetic Features

The studied concretions and non-skeletal grains of Samana Suk Formation have experienced various diagenetic changes which include neomorphism compaction, micritization and cementation. Compaction micritization are the diagenetic features of high importance observed in the Formation. The diagenetic features are discussed in detail as follows;

6.2.1 Tectonism

As sediments are deposited layer by layer the pressure of the overlying sediment layers results in the lithification of sediments which causes the reduction in porosity .At the same during compaction due to the increasing pressure of the overlying sediments microfractures are created which enhance the porosity (Wright and Tucker, 1990). In the present study the abundance of flattened, deformed and interpenetrating grains which are closely packed with very little cement present between them indicate high degree of compaction. The overall shape volume and inter particle porosity between the ooid grains are reduced significantly in the presence of intense temperatures and pressures deep burial temperatures and pressure during the burial processes. Ooid grains that are deformed show concave convex and longitudinal contacts (Bhattacharyya and Friedman, 1984).

The peloids in the study appear to have suffered moderate to high compaction at various point in the section. The preservation of fecal pellets is only possible if the process of consolidation takes place quickly.

6.2.2 Micritization

Micritization is characterized as a process of altering the original skeletal grain fabric by repeated algal microborings and subsequent filling of the microborings by micritic precipitates to a cryptocrystalline texture. Grain micritization is common in c arbonate rocks. In the present study few of the concretions (ooids) are micritized to a high degree whereas most of the ooids show micritization up to the level of 2 or 3 cortices. Micritization is considered as an early diagenetic process. However, micritization is also formed by the recrystallization of the skeletal material during deposition (Reid et al., 1992; Macintyre and Reid, 1995, 1998). The evidence suggests that micrite is formed by the precipitation of inorganic material in shallow marine environments where the water energy is low and in some cases by disintegration of green algae (Folk, 1959). The indication of little transportation of sediments, presence of selective micritization of concretions (ooids) and partial cementation reflects shallow marine phreatic environments.

6.2.3 Cementation

The carbonate rock precipitation is considered to be an important diagenetic process and this process starts when pore-fluids are super saturated with the cementing material. Common cements present in carbonate rocks are Aragonite, high-Mg calcite, low-Mg calcite and dolomite, and they consist of a variety of arrangements. The actual mineralogical structure highly depends on the composition of the fluids present in the pores, the supply rate of the carbonate material and the precipitation rate. In the present study cementation is limited and is of micricte, calcite and dolomite cements. Micritic and calcitic Cementation is observed present between grains in the Formation. Dolomitric cementation is also observed at some points in the Formation.

Peloidal cement plays an important role during precipitation of Mg-calcite in the cementation process of shallow marine sediments. Micritc and calcitic cements is observed present between the peloid grains and at various points in the formation calcite overgrowth has also been observed which has caused crystallization of the peloid grains.

6.2.4 Neomorphism

Its a procedure during which the carbonate grains are replaced or recrystallized. During such a process the minerology of the parent material can possibly change (Folk, 1965). There lies a difference in the recrystallization and replacement of the material. During recrystallization the size of the crystal changes but the mineralogy remains the same, whereas on the other hand during the replacement process the parent material is replaced with a new element that does not relate with the parent material (Tucker and Wright, 1990). Dolomite, hematite, anhydrite, quartz and pyrite. The common replacement material of calcite includes (Boggs, 1995). In the present study neomorphism has been observed in the form of replacement mostly as the calcite material has been replaced by dolomite in most of the thin sections. In Samana Suk Formation neomorphism is of aggrading type in which porphyroid neomorphism has also been observed. Burial diagenetic and meteoric environments are most common and ideal for neomorphism (Tucker and Wright, 1990).

Plate description

A&B. Photomicrograph showing deformed ooids (DO) formed due to close packing and compaction along with a microfracture (MF) (PPl.Mag.X5).

C&D. Photomicrograph showing micritic cement (MC) present between grains and micritization around the ooids formed after diagenesis (MO) (PPl.Mag.X10).

E&F. Photomicrograph depicting overgrowth of calcite cement (C) present between grains and micrite cement (M) between grains (PPl.Mag.X2,X5).

G&H. Photomicrograph showing neomorphic crystals (NE) present in the cortices of the ooids (O) with calcite cement between the grains (PPl.Mag.X5).

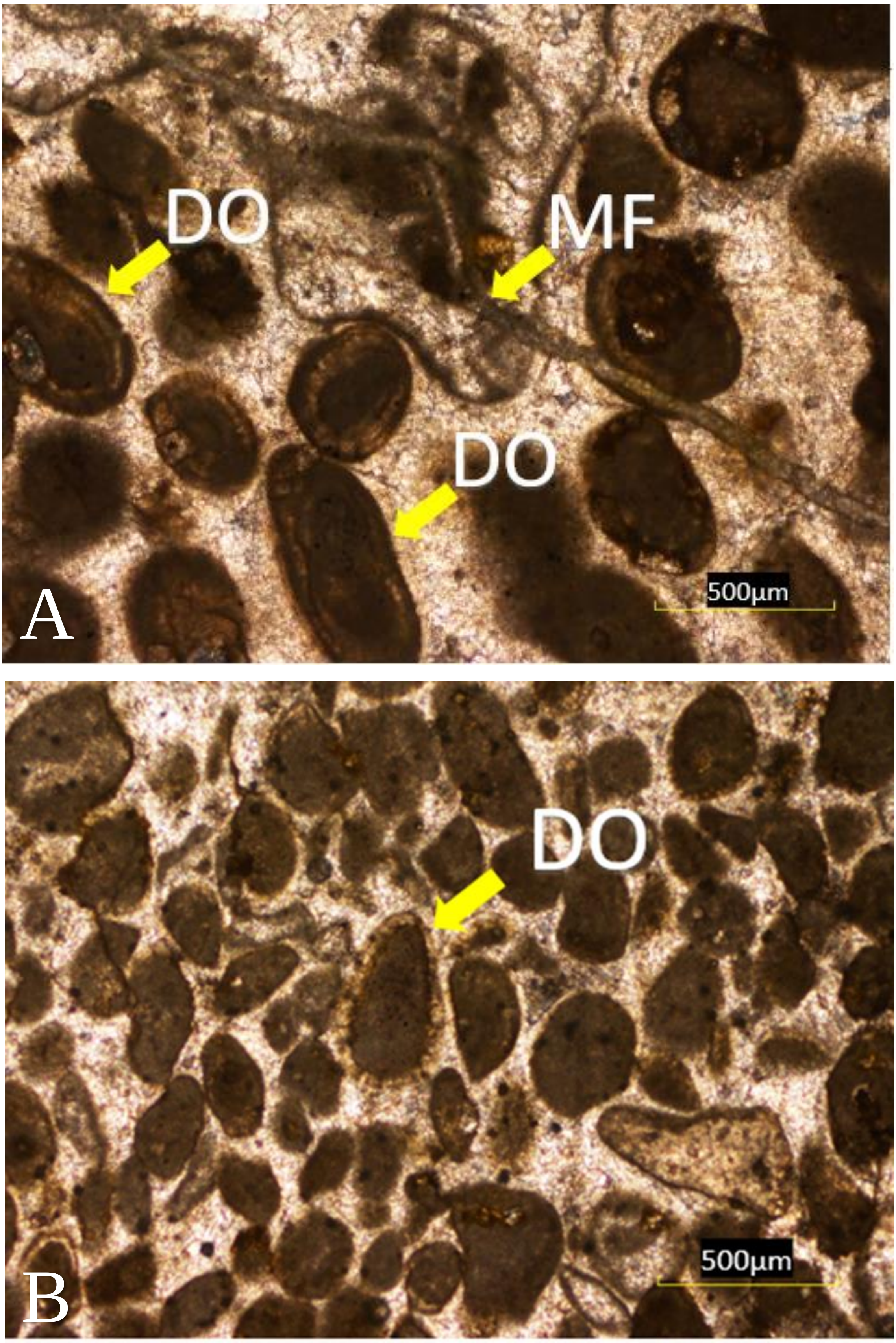
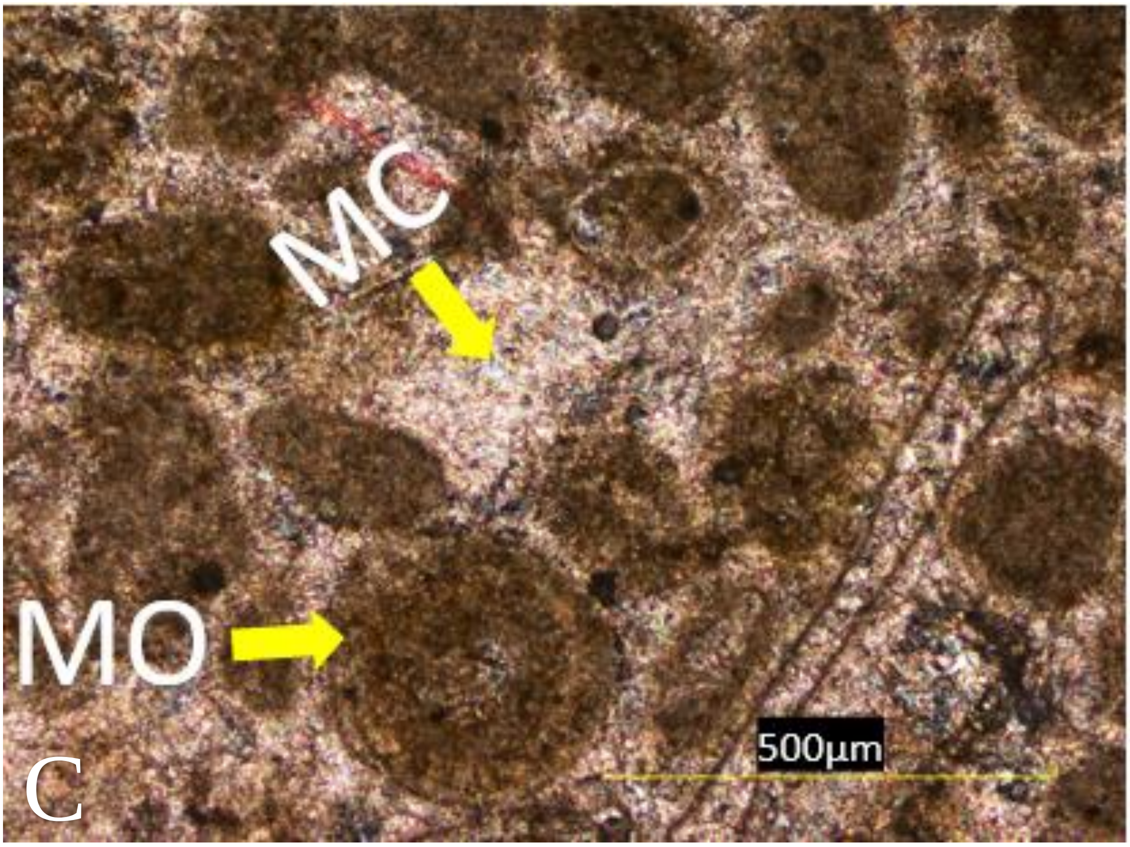


Plate (A&B) Photomicrographs showing deformed ooids (DO) formed due to close packing and compaction along with a microfracture (MF).



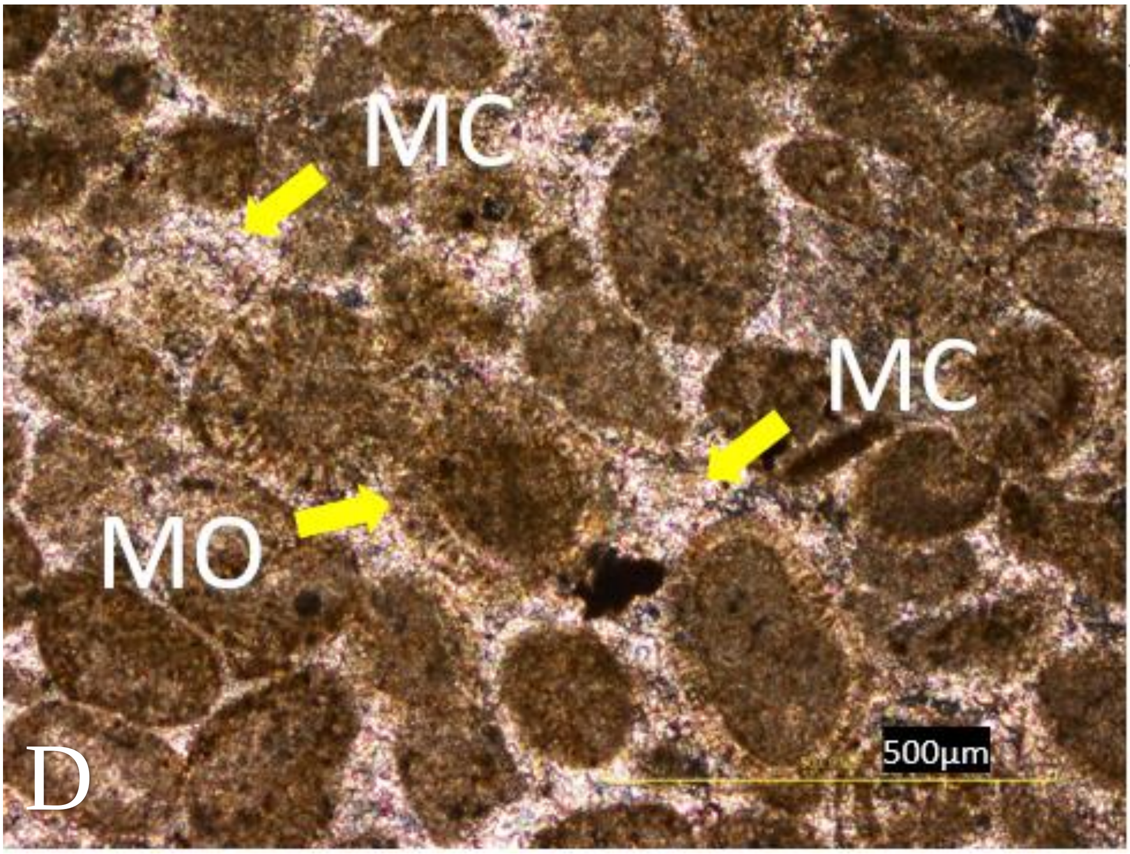


Plate (C&D) Photomicrographs showing micritic cement (MC) present between grains and micritization around the ooids formed after diagenesis (MO).

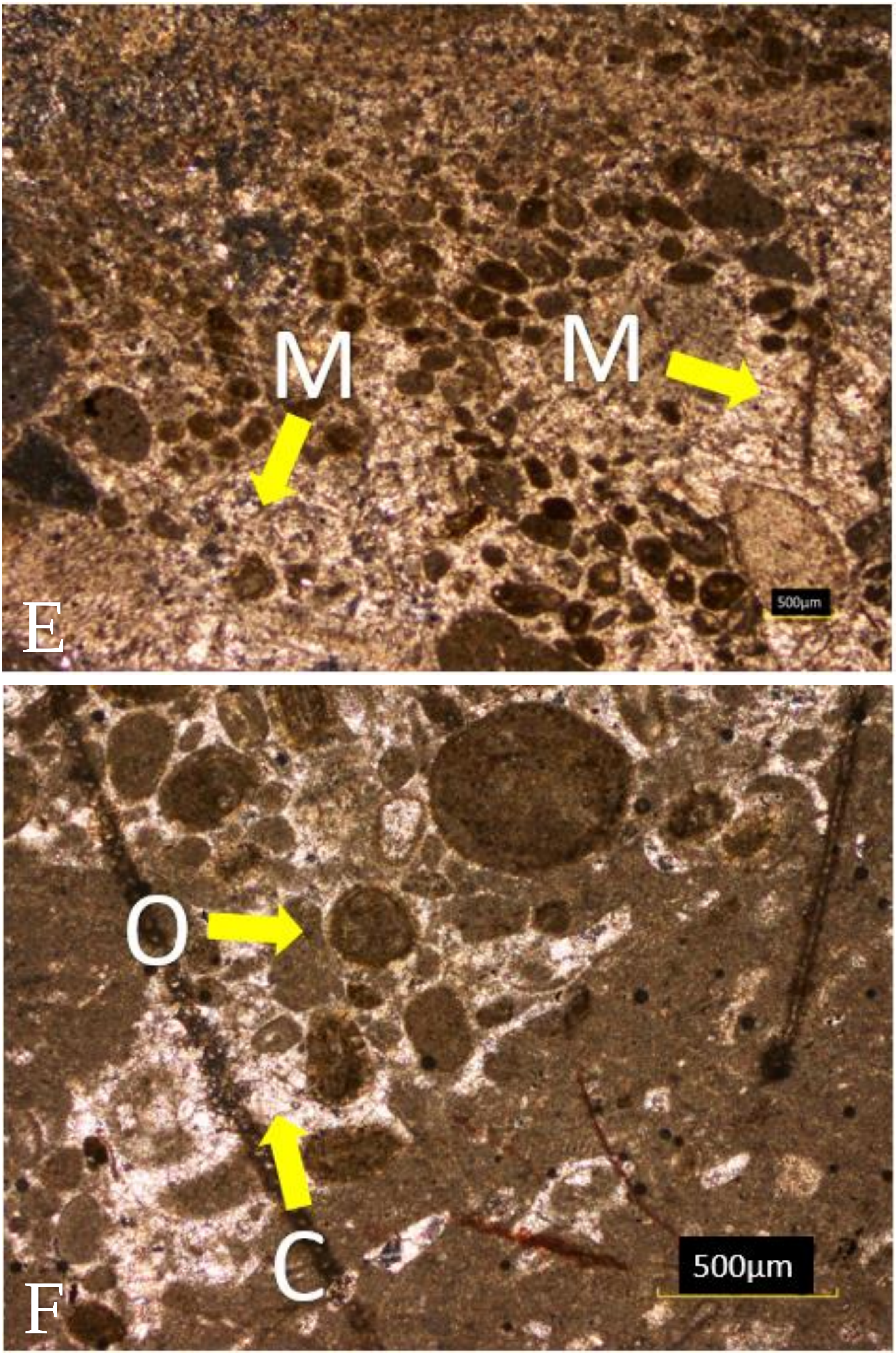


Plate (E&F) Photomicrographs depicting overgrowth of calcite cement (C) present between grains and micrite cement (M) between grains.

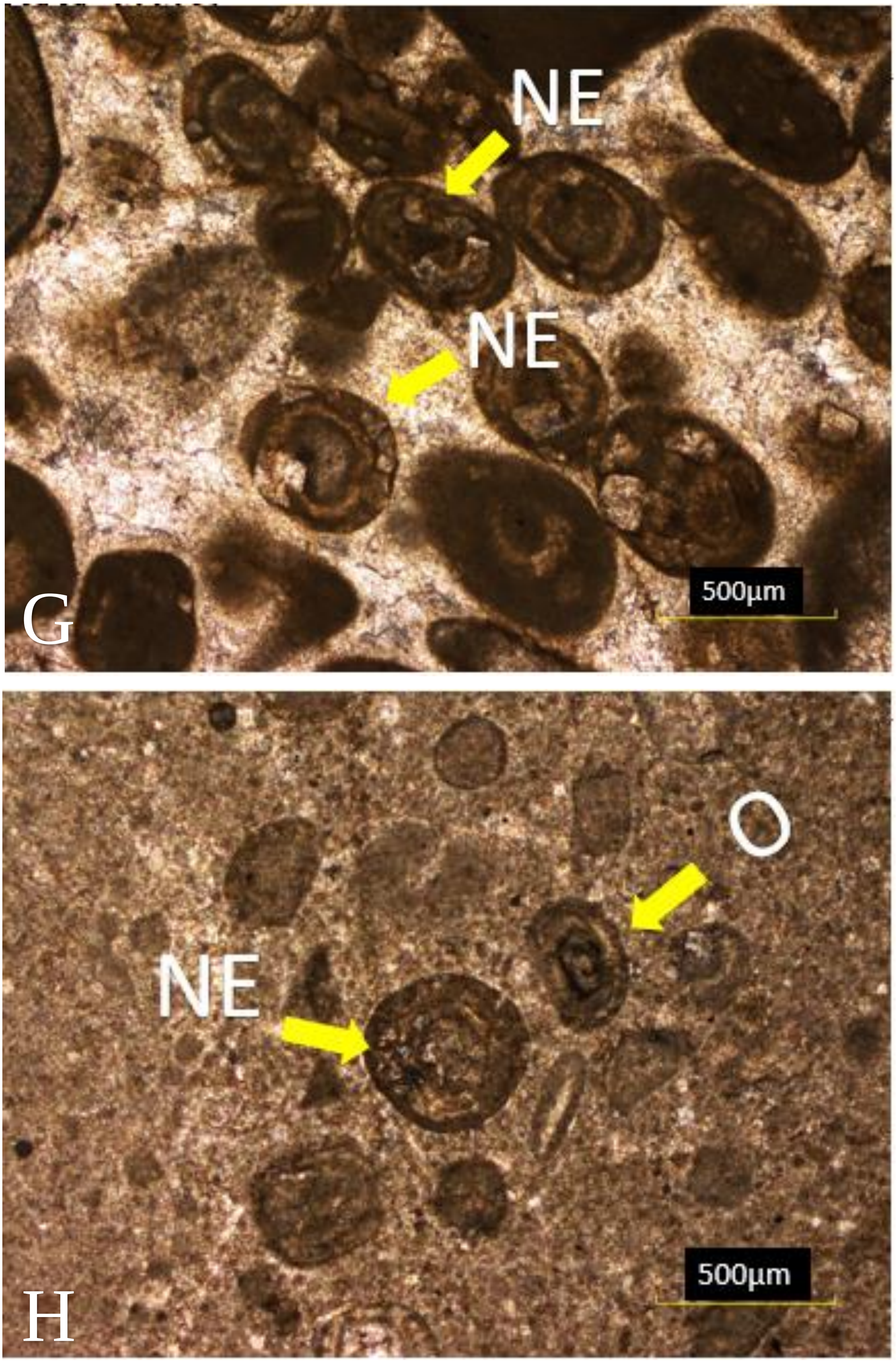


Plate (G&H) Photomicrograph showing neomorphic crystals (NE) present in the cortices of the ooids (O) with calcite cement between the grains.

CHAPTER 7

SIGNIFICANCE

7.1 Introduction

Formation of the concretions starts after the sediment grains have been deposited within the sedimentary strata. The concretions are formed in the early diagenetic stage after the sediment grains buried, before the lithification and compaction of the sedimentary strata. Concretions are formed by minerals precipitating around nucleus which can be either a grain, skeletal fragment or a mineral itself. Concretions are an important component of the sedimentary unit and have their own significance in various aspects of study (Flugel, 2010). Carbonate concretions have the potential to reflect seawater chemistry indirectly and can provide unique records of ancient biogeochemical processes in marine sediments. Carbonate concretions provide information about sea level changes in the past, ancient climates, provide means of reconstructing paleo-environments and many of other concretions hold economic value aswell.

7.2 Significance of Concretions and Non skeletal grains

. Several types of concretion have been identified and their significance is illustrated in detail below;

7.2.1 Ooids

Ooids are grains, which consist of a nucleus which can be a clast, fossil or even a mineral coated with layers of concentric laminas. Information about the depositional environments can be deduced from the varieties of ooid, these grains can provide information about possible ancient fluctuations in sea level. Concretions also give an idea about the economic importance along with the diagenesis of a particular sedimentary deposit.

7.2.1.1 Changes in sea level

Rise and fall of sea level have a high impact on the flow patterns and underwater depositional settings. These changes act as the influential parameters required for the ooid development. This may be indicated by specific compositional variations from skeletal to Ooids grainstone. Changes in the sea-level and exposure of the sediment layers containing can cause cementations processes to accelerate and cause the destruction of Ooids in the exposed layers (Bosellini et al. 1981). In the recent study Samana Suk Formation shows absence of ooids at various levels throughout the thin section column indicating sea level fluctuations at various levels. From these indications we can assume that the ooids had been exposed and destroyed due to rapid cementation processes acting on the exposed areas.

7.2.1.2 Regional correlations

As being a useful stratigraphic markers ooid beds can be used to correlate formations on a regional scale. Such correlation can be made between the same formation or different formations. Oolitic limestone is the diagnostic feature of the Formation under study and the ooids can be used to compare formations of the same age in various basins. The ooids can be used to note the similarities and differences in the various types of ooids and other concretions in the Samana Suk Formation present in same or other basins.

7.2.1.3 Depositional settings

The depositional settings for ooids ranges between several environments depending on the area and features of the ooid grains. Marine ooids are allochthonous grains accumulated as sediments on the slope and on the outer platform margins in proximal or distal basin areas in dock shore environments, on inland platforms. The quantity, texture and ooid varieties may be helpful in determining the exact deposition settings (Kolckmann 1992; Erba & Zempolich 1999; Bosellini et al. 1981). In the recent study of Samana Suk Formation, several ooid categories were identified on the basis of texture and each of the ooid types are given their place in the specific depositional setting based on their differences in their features.

7.2.1.4 Salinity

There are main categories of ooids Freshwater and marine ooids. These differ from each other on the basis of structure and sizes as freshwater ooids consist of peripheral or micro-sparitic cortices. Radial ooids are formed in environments of hypersalinity comparison with the other types. Researchers have suggested that ooids can be used to measure depths of water based on their quantites (Fabricius 1967). In the recent study the Samana Suk Formation contains various types based on the differences of textures and salinity. Some ooids are formed in environments of low salinity whereas others formed in moderate salinity environments.

7.2.1.5 Paleoclimate and paleoceanography

The principal theory is that ooids prefer warm waters with high salinities for their generation and growth (Lees, 1975). Ooids were usually distributed in the warm, humid tropical regions in the Phanerozoic time period but not areas which were close to the equator, that is the reason Ooids are considered as good indicators of the paleoclimatic conditions. However there exist some diagenetic variations in ancient ooids and are due to the conditions prevailing at the time. Climates have a significant impact of the concentration of meteoric cements as ooids present in dry regions show absence of meteoric cements, whereas tropical areas show the presence of meteoric cements in high abundance (Hird and Tucker, 1988). The recent study shows that there is presence of calcite cement through out the formation which has been deposited by dissolution during diagenesis which gives us the indication that meteoric waters were perculating during diagenesis and that the climate was arid and humid in the past.

7.2.1.6 Economic importance of Ooids

On the basis of composition ooids are characterized into aragonitic and calcitic ooids. Both act differently when it comes to the diagenetic processes which include dissolution and cementation. The reservoir qualities are greatly affected by the distribution, morphology and mineralogy of ooid bearing sequences (Swirydczuk, 1988). Reservoir rocks which consist of autochthonous and allochthonous ooids grains behave differently on the basis of reservoir characteristics which include porosity, permeability and mineralogy (Carozzi, 1983; Handford, 1988). The present ooid grains can used as ornaments in the form of polished sections and can fetch substantial amounts in the markets.

7.2.2 Peloids

Peloids are opaque structureless grains which form due to burrowing of microscopic organisms. They are often found in association with other grains. Peloid grains are important in predicting paleo-environmental conditions and these have been discussed in detail below:

7.2.2.1 Paleo-environmental proxies

Many peloid grainstones in marine environments either show absence in organic material or comprise of limited organic matter which represent environments that were not suitable for organisms with respect to salinity and substrate. On the other hand, wackestone and packstone facies with high concentrations of pellet grains represent environments with high oxygen and nutrient content. In this study Samana Suk Formation contains abundant packstone and wackestone facies by which with their high abundance we can infer that in the past there were nutrients in abundance and with such information more accurate past settings can be predicted.

7.2.2.2 Depositional proxies

Shallow, restricted and low energy environments are ideal for peloid grains formation. This idea is supported by many evidences; however the evidences should be thoroughly assessed due to : 1. Peloids can record exact sites of preservation rather than environments of depositional, 2. The deposition of peloids can be near their source, but can also be transported to different depositional environments by various means, 3. The high abundance of fecal grains can be allochthones or autochthonous, so the intensity of wave energy does not influence sorting and size of the peloids. To explain the origin of peloidal carbonates, understanding of the hydrodynamic action of carbonate fecal pellets is important. (Wanless et al, 1981).

7.2.3 Aggregates

Aggregate grains can indicate the energy of currents at the time of deposition, changes in the water depths, can give indications of the depositional environments, can give information of areas where sedimentation and nutrient input is low(Flugel, E,. 2010). Platforms environments are assigned to carbonate lithologies containing aggregate grains. The Grainstone facies consisting of aggregate grains formed during sea level high stand indicate parts of platforms.

7.2.3.1 Economic potential

Carbonate rocks containing aggregate grains that appear in connotation with ooid grains are typically river rocks (e.g. in the Near East Cretaceous). Due to the fact that most grapestones form in settings with very little to negligibly poor land supply, the non-carbonaceous remains of many calcareous rocks that are rich in aggregate grains are obviously low. limestones are important chemically high-quality carbonate rock tools and function as strong reservoir rocks in the excess of ooids in the calcareous (Flugel and Haditsch, 1977). In the recent study grapestone aggregates have been observed at various parts of the formation with ooids and peloid grains combined. The ooid grains can create porosity and permeability within the grain itself. This property gives aggregate grains significant importance in reservoir rocks.

CONCLUSIONS

i. The concretions and non-skeletal grains identified include ***Ooids*** grains which have been further divided into 6 including; which are Micritic Ooids, Concentric Ooids, Radial Ooids, Superficial Ooids, Broken Ooids, Deformed Ooids, ***Aggregates***, grains have been characterized as grapestones based on the stage of transformation, ***Peloids*** grains have been further divided into 2 types i.e; Fecal Pellets and Bioerosional Peloids.

ii. The present features and characteristics of the concretions and non-skeletal grains indicate inter tidal zone to marginal reef zones of environment of deposition for these grains.

iii. The diagenetic processes that are involved in the creation or have taken part in altering the grains structurally or mineralogically are compaction, neomorphism, cementation and micritization.

iv. The significance of these concretions and non-skeletal grains are paleo-environmental proxies, Sea level fluctuations, regional correlations, depositional proxies and their economic importance.

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