# DEPOSITIONAL AND DIAGENETIC SETTING OF JURASSIC CARBONATES, THANDIANI SECTION, HAZARA BASIN, PAKISTAN: IMPLICATIONS ON RESERVOIR STUDIES

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**August, 2023**

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

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# ABSTRACT

The Thandiani Section of Abbottabad Group of Samana Suk Formation is selected for research study. The research is centered around the examination of rock characteristics, specifically through petrographical analysis involving microfacies and observed diagenetic features. The findings from the study of deposition and diagenesis indicate that the majority of the region consists of dense and compacted, fine to coarse grained dolomitic limestones. In certain areas, dolomite forms as a secondary diagenetic feature. The limestone displays a light grey color on fresh surfaces and a light brown hue on weathered surfaces. It varies in size, with some areas exhibiting large, planar, and fossil-rich deposits that range from thin to medium to thick-bedded. During our field investigation, we observed and documented various features such as stylolite fractures, calcite veins, and calcite patches. By analyzing photomicrographs, a comprehensive depositional model of the microfacies has been developed, illustrating that these microfacies were deposited within the inner portion of a homoclinal ramp, transitioning from a lagoon to shallow marine environments.

# ACKNOWLEDGEMENT

To begin with the name of Allah, Most Beneficent and the Most Merciful, we have taken the initiative to complete our research related to Depositional and Diagenetic setting of Jurassic carbonates. We would like to express our gratitude towards our Highly Respectable supervisor Dr. Maryam Saleem (Assistant Professor), Department of Earth and Environmental Sciences, Bahria University, Islamabad, our parents and friends for their efforts and guidance which helped us to steer out this research successfully.

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# CHAPTER 1

# INTRODUCTION

## 1.1 General Description

Thandiani, which translates as "very cold," is hill station situated in the Galyat region of Khyber Pakhtunkhwa Province, Pakistan. Positioned in the north-eastern part of Abbottabad District, Thandiani is approximately 37.5 kilometers (23.3 miles) away from Abbottabad, nestled in the foot hills of the Himalayas. On the eastern side, one can behold the snow-clad Pir Panjal mountain range in Kashmir, while the mountains of Kaghan and Kohistan are visible to the north and northeast. To the northwest, the snow ranges of Swat and Chitral can be seen. The Thandiani hills tower at an altitude of approximately 2,750 meters (9,020 feet) above sea level.

The Hazara Basin's Jurassic carbonates, Samana Suk Formation helps us in Analyzing and Interpreting Microfacies. This type of stratigraphic basin helps in determining the correlation of different sedimentary units in terms of chronostratigraphy and their location. Bio-stratigraphic data that is obtained from this type of basin is mostly utilized by geo-scientists to establish connections between specific rock units. This also helps in identifying stratigraphic gaps. Worldwide Facies analysis of various ages occurring in the rocks describes certain relations that allows comprehensive examination of sedimentary rocks rather than studying each rock layer separately. However, facies alone have limited utility when studied as a group, researchers prefer to rely upon microfossils and nano-fossils, as they are widespread as compared to macrofossils and microfossils as they have limited distribution due to ecological preferences. These fossils help in determining the deposition of various basin fills.

While considering Jurassic rock unit, studying the influence of paleoclimatic conditions that impact geography is equally important. During Jurassic period, various ecological circumstances affected the arrangement of carbonate grains in rock. The ooids were developed very well in Jurassic carbonate units due to these circumstances.

## 1.2 Study Area

The selected Thandiani section of the Samana Suk Formation is located along Abbottabad-Thandiani Road, eastern Hazara, north Pakistan, geographic coordinates are (34.227835N Latitude: 73.33589E Longitude) which is also shown in Figure 1.1.

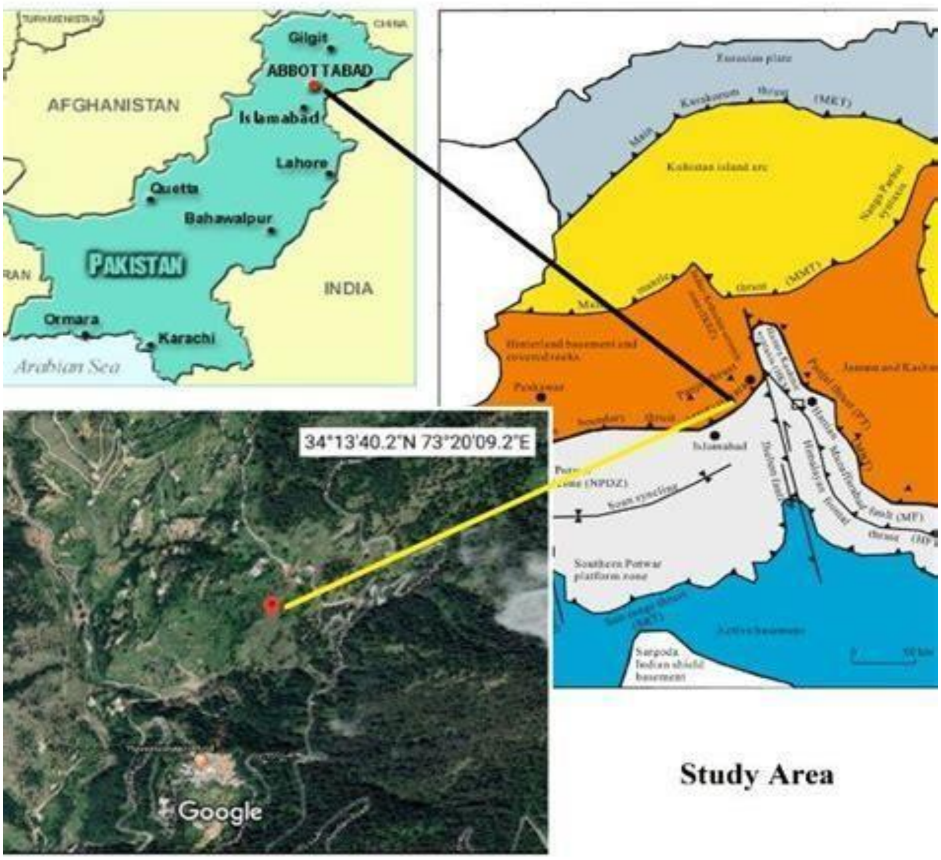


**Fig 1.1** Map showing Thandiani Section, Abbottabad.

## 1.3 Objectives

This study goals are as follows:

i. Examination of Microfacies in Thandiani Section, Hazara Basin, Pakistan.

ii. To study depositional and diagenetic settings of Jurassic Carbonates.

iii. To determine conditions under which Samana Suk Formation was deposited.

## 1.4 Methodology

The following photographs describe methodology used to achieve the goals, objectives and major concerns of this research.

### A) Sampling.

The thesis project encompasses both fieldwork and laboratory work, with sampling being recognized as a crucial initial stage. Prior to embarking on fieldwork, a thorough desk study is conducted to examine various aspects of the field, including accessibility, location, lithology, fossils, and other relevant characteristics.

### B) Field Work.

Field work was carried out to explore and examine the lithology of the area, and the variations through which depositional and diagenetic features has been developed. There was a found information of Jurassic layers. The upper and lower limits of Development were apparent with no conformable contacts. Samana Suk Development complete thickness has been estimated. The lithological qualities and sedimentary designs of rock unit were explored. The disparity in lithology leads to a collection of absolute 20 to 25 examples. Field photos are taken at different scales. Microfacies has been studied.

### C) Laboratory Work.

The thin sections were prepared in the laboratory of Pakistan Museum of National History, created standard-sized thin sections for the petrography in laboratory work. The petrographic lab of National Centre of Excellence in Geology used a polarizing microscope to identify forces established microfacies and other diagenetic characteristics in the thin sections. There are three metrics used to identify Microfacies in Samana Suk Formation: Wilson (1975), Dunham (1962) and Flugel (2004).

### D) Thin sections using polarizing microscope.

The limestone samples were classified using the Dunham (1962) and Folk (1962) classification systems, which relied on petrographic data such as the proportions of allochems, matrix, and cement (1959). To determine the specific sub-environments of deposition, further analysis was required to identify the types of allochems present. After conducting the petrographic examination, microphotographs of the microfacies were captured. The laboratory work was carried out in a systematic manner to ensure accurate interpretation. By studying thin slices of the rocks under a petrographic microscope, the diverse allochemical components were identified. These components were then utilized to establish microfacies. The thin slices were carefully examined to gain insights into the various diagenetic characteristics. To document well-preserved grains and structures such as stylolite's, a digital camera connected to a microscope and computer system was employed to capture photomicrographs.

# CHAPTER 2 GENERAL GEOLOGY

## 2.1 Tectonic Setting of Pakistan

During the early Jurassic period, the Indian Plate was part of the Gondwana supercontinent. Later, in the Cretaceous period, it moved towards Laurasia, particularly in a northern direction. Throughout the Jurassic, Cretaceous, and Eocene periods, the Indian Plate underwent rifting and fragmentation in the Tethyan Sea, possibly leading to marine sedimentation. In the Cretaceous period, the collision of the Indian Plate with the Eurasian Plate resulted in the Kohistan Ladakh Arc's formation and the division of the Tethyan Sea into Paleo-Tethys and Neo-Tethys. The Main Karakoram Thrust (MKT) and Main Mantle Thrust (MMT) developed during the late Cretaceous and late Eocene, respectively. The Tethyan Sea played a role in carbonate formation in the Eocene. The geological characteristics of northern Pakistan are shaped by the Himalayan orogeny due to the collision of the Eurasian and Indian plates in the early Eocene. This collision led to the closure of the Tethyan Sea and subduction of the Indian Plate beneath Asia. Northern Pakistan displays the Eurasian Plate, Kohistan Island Arc (KIA), and Indian Plate. The Main Karakoram Thrust (MKT) separates the Eurasian and KIA plates in the Shyok suture. The Himalayan interior zone contains Precambrian rocks from the Indian Plate and sedimentary layers south of the Main Mantle Thrust (MMT). The KIA formed when the Ceno-Tethys plate collided with the Eurasian Plate, later colliding with the Indian Plate. This collision formed the Main Mantle Thrust (MMT) and caused distortion and metamorphism of KIA's lithology. The Indian Plate's basement rocks (Gneiss) in the footwall of MMT experienced granulite facies and magnetization around 1850 million years ago. (Figure 2.1)

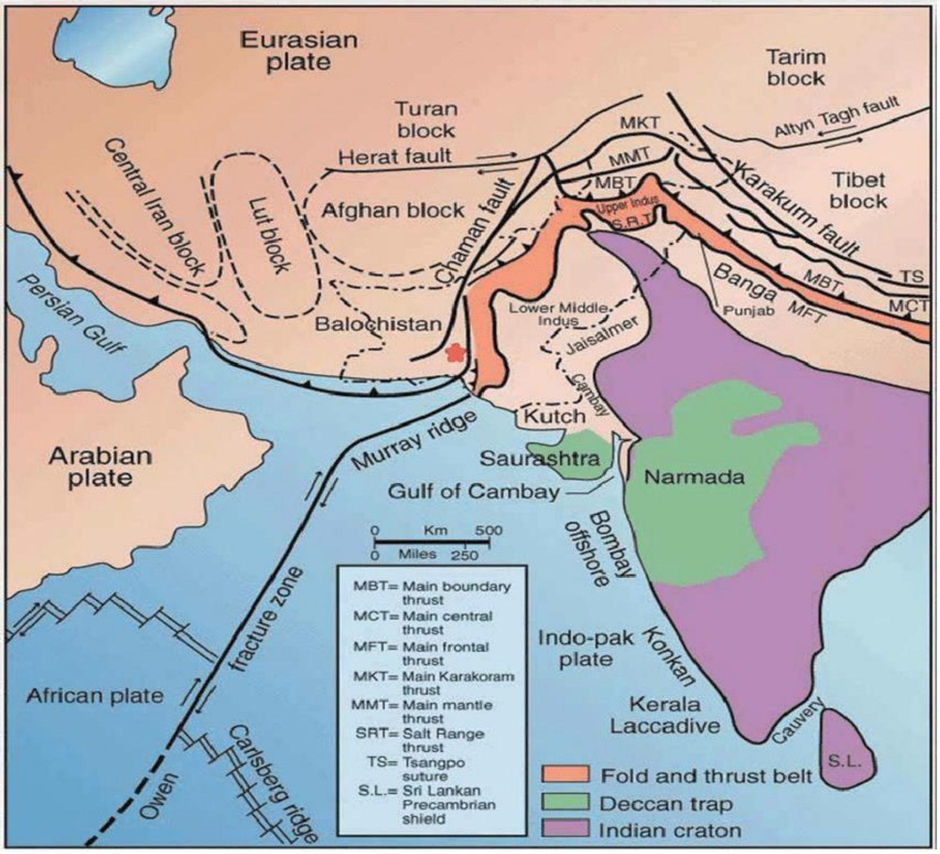


**Fig 2.1** Tectonic Setting of Pakistan.

## 2.2 Regional Geology

During the Carboniferous to early Permian period, the supercontinent Pangea start to separate, giving rise to a new ocean known as the neo-Tethys. The Indo-Pakistan continent embarked on a journey towards the southern hemisphere tropical region, crossing the Indian Ocean. The neo-Tethys Ocean experienced compression from the Pacific to the Mediterranean during the Eocene epoch, spanning approximately 45 to 55 million years ago. During the Cretaceous period, around 145 to 66 million years ago, the subduction of the Indian Oceanic Plate led to the emergence of the Kohistan Island Arc (KIA). This island arc together with the Eurasian plate during the Turonian epoch, approximately 93.9 to 89.8 million years ago. Roughly 67 million years ago, the collision between the Indo-Pakistan Plate and the Kohistan Island Arc marked a important tectonic event. While Chaudhary et al. conducted a bio-stratigraphic study offering penetration into this collision, specific discovery wasn’t detailed. The Himalayan Orogeny took structure as the Indian and Eurasian plates collided, started around 55 million years ago. This going on process led to the uplifting of the Himalayan Mountain range, creating the world's youngest mountains. Pakistan, situated on the north-western edge of the Indian plate, grip geological evidence of this Himalayan collision, shaping the region's geology to this day

Approximately 55 million years ago, the collision between the Indian and Eurasian plates activate the uplift of the Himalayas and the formation of the Tibetan Plateau. This collision creates a remarkable elevation of the Himalayan Mountain range. Thrusting, a process where rocks are pushed over each other, is accept to have happen in the later stages because of the going on settling in and collision between the Indian and Eurasian plates from the Neogene period, which extends from around 23 million years ago to the current day.

The impact between the Indian and Eurasian plates had an extreme effect on the geological features of the region, controlling to the continued rise of the Himalayas and the arrival of thrust faults. These ongoing tectonic processes have created the landscape and geological characteristics of the Himalayas.

The Himalayan region is a composite orogenic system resulting from the collision between the Indian and Eurasian plates. It consists of various geological features and divisions:

i. The Nanga Parbat and Namche Barwa syntaxes mark the boundaries of the Himalayan region, with the former on the northwest side and the latter on the northeast side.
ii. The Trans-Himalayan batholiths, extend from north to south, are large igneous intrusions formed deep within the Earth's crust. They play a significant role in the Himalayan geology and stand for the contact boundary between the Indian and Eurasian plates.
iii. The Tethyan Himalaya, composed of sedimentary rocks, represents the southernmost division of the Himalayas and corresponds to the area where the Tethys Ocean once existed.
iv. The Greater Himalaya, also known as the Higher Himalaya, forms the central and highest part of the mountain range. It is characterized by a core of metamorphic rocks such as gneisses and schists.
v. The Lesser Himalaya, or the Middle Himalaya, lies south of the Greater Himalaya. It consists of sedimentary rocks deposited during the late Paleozoic

to Cambrian era. The Lesser Himalaya is narrower and lower in elevation compared to the Greater Himalaya.

vi. The Sub-Himalaya, also referred to as the Siwalik Range or Outer Himalaya, represents the southernmost division of the Himalayas. It is composed of younger sedimentary rocks, including detrital sediments.

Within the Lesser Himalaya, also known as the Lower Himalayas, the width ranges from 32 to 80 kilometers, and elevations reach between 3,900 to 4,500 meters. It is primarily composed of debris sediments extract from the Indian continental margin during the late Paleozoic to Cambrian era. Additionally, some early Paleozoic granites and acid volcanic rocks are found interspersed within these layers. The movement along the Main Boundary Thrust has resulted in these strata being referred to as tectonic windows, representing forced displacement along the thrust fault. These various geological divisions and features contribute to the diverse landscapes and rock formations found in the Himalayan region.

The Sub-Himalayas, also known as the Lesser Himalayas or foothills of the Himalayas, are situated south of the Lesser Himalaya region. They have a width ranging from 8 to 80 kilometers and average elevations of around 900 meters. The sediments in this region are firstly composed of the Eocene and Miocene Molasse deposits familiar as the Murree and Siwalik formations. These formations are well in fossilized vertebrate remains. Over the path of the Eocene era, a series of thrusts in the Himalayas has caused the enlargement of the mountain range at the cost of approximately 5 centimetres per year. This process has resulted in about 2,500 kilometres of crustal shortening.

The Main Karakoram Thrust (MKT), formed during the Cretaceous era, replace the northernmost suture zone in the Himalayas. It starts from the collision between the Kohistan-Ladakh Arc and the Karakoram block. Construct of shale, slate, limestone, and volcanic greenstones, the MKT apart the Kohistan Island Arc from the rock units of the Karakoram block.

The Main Mantle Thrust (MMT) is a local thrust that dips northward and split the Kohistan Island Arc from the Indian plate. The subduction of the Indian plate below the Kohistan Island Arc through the Eocene led to the formation of the MMT. The MMT increase from the Khar area in the west to Narran in the east and is primarily together of gneisses and Precambrian schists.

The Main Boundary Thrust (MBT) is special feature in the Himalayan belt. It is northward-dipping thrust that has force metasedimentary rocks of the Lower Himalayas over the unmetamorphosed rocks of the Himalayan foredeep. The area where the MBT intersects the foreland basin is known as the Hazara Kashmir syntaxis. The MBT is estimated to have moved approximately 40 kilometers and is associated with a blind thrust followed by shallow back thrusting.

The Salt Range Thrust (SRT), located at the southernmost point of the Salt Range, encircles the southern border of the range and intersects the Jhelum and Indus rivers. It has pushed Paleozoic strata of the Punjab Platforms over the Quaternary alluvium. While mostly concealed by alluvium, the fault can be notice where it is exposed, particularly at the Kala-Bagh fault in the west and along the right bank of the Jhelum River.

## 2.3 Local Geology

In Figure 2.2 The Hazara region is positioned on the lesser Himalayan terrane, place in a NE-SW direction. It is pointed by significant thrust faults: the Punjab Thrust to the north and the Main Boundary Thrust (MBT) to the south. Further, lesser NE-SW-oriented thrust faults make the "Hazara Arc." This area encloses the Hazara Fold and Thrust Belt (HFTB), contain the MBT in the south and the Punjal Thrust in the north. The Hazara Basin grip a variety of rocks - metamorphic, metasedimentary, and sedimentary – cross from Precambrian to Miocene times. Structural traits like many thrusts, folds of different sizes, and a general SE-NW trend recommend compression from the northeast. The oldest geological formation here is the Precambrian Hazara Formation. (Figure 2.2)

Within the geological formation of the Hazara district, various types of rocks are present, including sedimentary, igneous, and metamorphic rocks, as well as unconsolidated materials. Geologists such as A.N. Fatmi from the Geological Survey of Pakistan and C.E. Meissner from the USGS have correlated over a dozen stratigraphic units in the Hazara region with those in the Kala-Chita Hills, located approximately 40 miles south of Abbottabad in the Kohat region. Additionally, some formations in the Hazara area bear resemblance to those found in Shimla, India, about 300 kilometers southeast, as well as in the Kashmir region of Pakistan.

In the Hazara region, the clastic rock units from the Paleozoic era, such as the Sankhla and Hazara Formations, and potentially the early Paleozoic era, represented by the Tadawul Formation, consist primarily of carbonate rocks. These carbonate deposition episodes are observed in a mostly complete succession of rock layers, reaching a thickness of up to 5,500 feet. This prolonged period of carbonate deposition occurred from the Carboniferous to the Eocene.

During the middle and late Tertiary period, the Himalayan orogeny commenced, resulting in the deformation of all rocks in the area. The geological features and mountain ranges in the eastern portion of the region, covered in this report, display a complete reversal of orientation. The term "Hazara-Kashmir syntaxis" was initially introduced by Wadia in 1931 to describe this characteristic. The primary rock formations and faults create a large westward arc that eventually loops around to the Indus River. The evolution of this syntaxis continued until the post-Miocene period, influenced by the Oligocene and Miocene-aged Murree Formation. The Tertiary Himalayan orogeny appears to have undergone two distinct phases of deformation.

Signs of pre-Tertiary igneous activity are mainly found in the volcanic greenstone and "Agglomerated Slates" of the Punjal Formation, dating back to the Carboniferous and Permian eras. The Mansehra Granite, formed during the late Cretaceous and early Tertiary periods, resulted from intrusions during the orogeny. The extensive granite intrusions in the Himalayan axial zone are believed to have originated from the southern margins of these granite rocks. These are later associated with a period of mild hydrothermal activity that contributed to the formation of soapstone’s and barite veins.

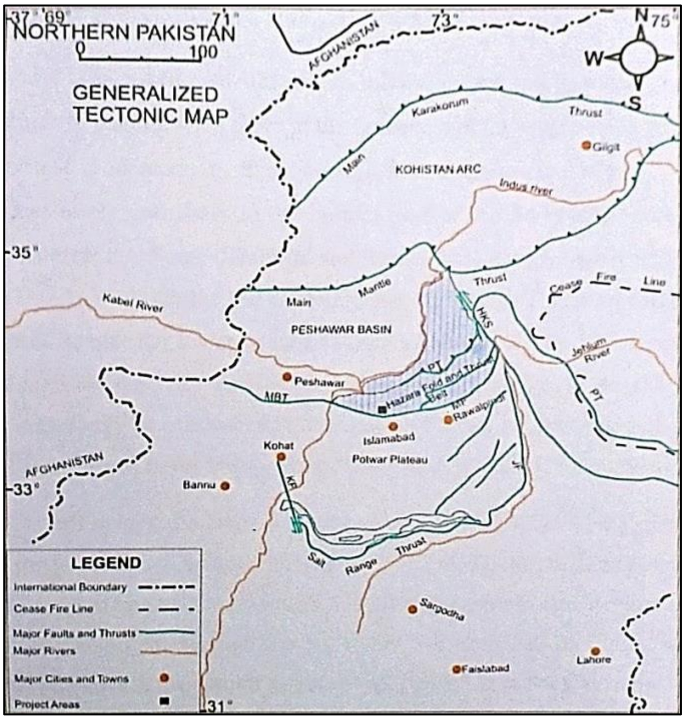


**Fig 2.2** A generalized tectonic map showing major faults and tectonic regions.

## 2.4 Stratigraphy of Study Area

### 2.4.1 Samana Suk Formation

In 1930, Davis propose the term "Samana Suk" for the Samana Range. The major peak northeast of Shinwari is commonly known as Samana Suk. In the Salt Range and Trans-Indus Range, it's referred to as "broach limestone." The Formation of Samana Suk includes shale, marl, and grey to dark grey limestone with average to thick bedding. It grips calcium-rich shale layers. The lower part of the Salt Range and Trans-Indus Range has light-coloured, thinly bedded, marly, and shaly limestone. Some deposits in Hazara, Kala Chita, and eastern Kohat exhibit traits like dolomite, iron content, sand, and oolitic texture. The formation's lower boundary meets the Shinwari Formation in some areas but not the Datta Formation in the Salt Range. The upper boundary might orient with the Chichali Formation in the Surghar Range but might not conform in the Salt Range, like with the Hungu Formation. Thickness varies from 186 to 366 meters across regions. Fossils in the Surghar Range reveal middle Callovian fauna: ammonoids, crinoids, brachiopods. The Samana Suk Formation contains bivalves, gastropods, indicating its Middle Jurassic age. Dinosaur footprints found, estimated around 160-170 million years old. The Takatu Limestone and Mazar Derik Member of the Takatu

Formation in the Lower Indus Basin and Central Belt are correlated with Samana Suk Formation. (Table 2.1)

**Table 2. 1** Generalized stratigraphic area of Hazara.

| AGE | FORMATIONS | | LITHOLOGY | ENVIRONMENT |
|---|---|---|---|---|
| | Stratigraphic Nomenclature After Latif (1970) | Stratigraphic Nomenclature After Shah (1977) | | |
| Mid-late Miocene | Kamlial formation | Kamlial formation | Massive red and sandstone, dark red clay | Fluvial environment |
| Early Miocene | Murree formation | Murree formation | Gray and reddish sandstone and shales | Fluvial environment |
| Unconformity | | | | |
| Eocene | Kuldana formation<br>Lora formation<br>Margala hill formation | Kuldana formation<br>Lora formation<br>Margala hill formation | Maroon colored shales and marl<br>Thinly bedded limestone and mar! Nodular foraminifera<br>Grey limestone | Transitional marine<br>Inner shelf<br>Carbonates shelf/reef |
| Paleocene | Kuza Gali shale<br>Mari limestone<br>Not mention | Patala formation<br>Lockhart formation<br>Hangu formation | Greenish grey shales with Limestone<br>Nodular foraminifera grey Limestone<br>Sandstone, claystone, laterite | Pelagic/hemi-pelagic shelf<br>Carbonates platform<br>Shallow marine-deltaic |
| Unconformity | | | | |
| Cretaceous | Chenali limestone<br>Giumal sandstone group<br>Spitti shale | Kawagarh formation<br>Lumshiwal formation<br>Chichali formation | Fine grained light grey limestone<br>Grey to brownish coarse Sandstone<br>Dark gray and reddish sandstone bed | Inner-outer ramp<br>Inner-shelf-deltaic<br>Mid-outer shelf |
| Jurassic | Sakhar limestone<br>Mairal limestone group<br>Not reported | Samana Suk formation<br>Shinawari formation<br>Datta formation | Limestone with dolomite patches and oolites<br>Sandstone, quartzite and miero conglomerates | Epi-continental and inter tidal. Carbonates shelf. Shallow marine, deltaic and alluvial plains |
| Unconformity | | | | |
| Cambrian | Hazira formation<br>Galdanian formation<br>Sirban formation<br>Kakul formation | Hazira formation<br>Abbottabad formation | Calcareous siltstone and slates<br>Dolomites with sandstones, shale in lower part | Pelagic/hemi-pelagic Shelf<br>sub-tidal and fluvial |
| Unconformity | | | | |
| Pre-Cambrian | Tanol formation<br>Hazara formation | Tanawal formation<br>Hazara formation | Quartzite and quartz mica schists<br>Slates, pelits sandstone quartzite with horizon of gypsum and two limestone beds | Inner-outer shelf<br>Deep marine |

# CHAPTER 3

# FIELD OBSERVATIONS

Field observations were conducted at the Thandiani Section, focusing on the Samana Suk Formation, which exhibited a thickness of 172 meters (Fig. 3.1 A). These observations are carried out by using 25 different samples. The limestone layers in this formation showed significant variability, with interbedding ranging from thin to thick and medium to thin. The primary objectives of the fieldwork included observing field features, studying diagenetic alterations, and collecting samples for later analysis. Special attention was given to rocks displaying notable diagenetic features. Notably, various colors of limestones were observed, indicating differences in mineral composition and deposition conditions. Weathering patterns were also noted, particularly the "Butcher chop" weathering style seen in calcitic veins filling fractures (Fig. 3.1 C - D), likely resulting from Mechanical Compaction associated with tectonic activity during or after limestone deposition. Additionally, calcitic cements were found filling vug (Fig. 3.3 A - B), suggesting diagenetic processes at work (Fig. 3.2 C - D). The carbonate units in the Thandiani Section showed extensive diagenetic alteration, particularly in the form of calcitic veins and patches, indicating post-depositional changes in mineral composition and texture (Fig. 3.1 B). Micro vug, believed to have formed due to meteoric influence, were evident in the limestone layers. An interesting find in the section was the presence of oolitic limestone (Fig. 3.1 E - F), characterized by small spherical grains called ooids, formed through the precipitation of calcium carbonate in shallow marine environments, providing insights into the paleoenvironment during deposition. The limestone representative a blue colored arrow, while stylolite, a pressure solution feature, was represented by a yellow colored arrow, serving as markers for distinguishing different lithological units (Fig. 3.2 A - B). Sharp contacts between dolomites of various colors were observed, suggesting significant changes in environmental conditions or sedimentation processes during the formation of the dolomite layers. Bioclastic limestone (Fig. 3.2 E - F), featuring abundant fossil fragments of marine organisms, provided valuable information about the paleobiology and paleoenvironment during deposition.


**Fig 3.1** Field outcrop picture of Samana Suk Formation in Thandiani Section, where thin to thick or medium to thin interbedded limestone is clearly visible **(A)** Calcitic Patch in Limestone and in **(B)** Sharp contact of Limestone on basis of color **(C)** Calcitic veins filling Fractures **(D)** Micro vug showing Meteoric effect clearly visible **(E)** Oolitic Limestone **(F)**.


**Fig 3. 2** Low compacted stylolite due to chemical compaction **(A)** Limestone is represented by blue colored arrow and stylolite is represented by yellow colored arrow (**B)** Calcitic Veins due to Mechanical Compaction **(C)** Different color dolomites **(D)** Both represents Bioclastic Limestone **(E** and **F)**.

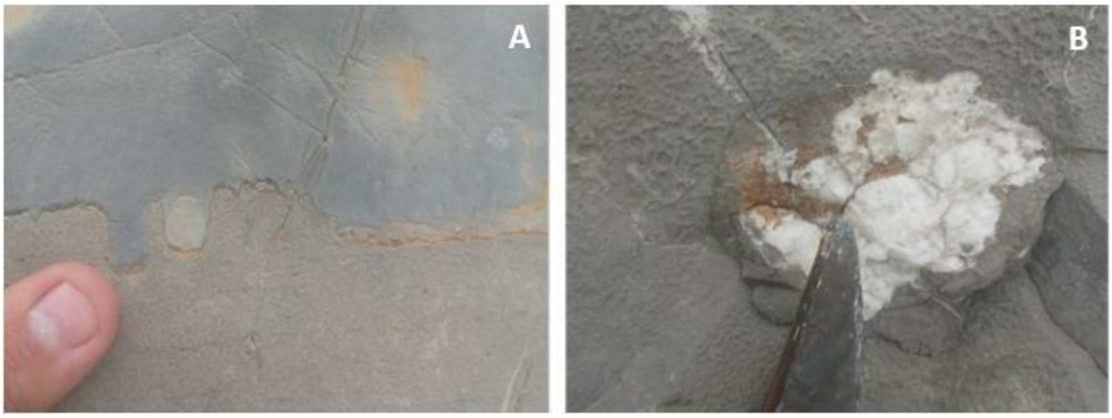


**Fig 3. 3** Sharp contact between Limestone and Dolomite separated by a stylolite **(A)** cement filling a vug**(B)**.

# CHAPTER 4

# PETROGRAPHICAL ANALYSIS

Petrographical analysis based on Dunham's classification is a technique used to examine and categorize carbonate rocks, such as limestone and dolomite, by their texture and composition. This classification system was proposed by Robert J. Dunham in 1962 and has been widely employed in geology and petrology ever since.

Dunham's classification divides carbonate rocks into four main groups, that are mudstone, packstone, grainstone and bound stone depending on the relative abundance of two primary components: allochems (grains or fragments) and the interstitial material (matrix or cement).

## 4.1 Microfacies

The Samana Suk Formation exhibits a variety of facies, each characterized by distinct features. Currently, there are five distinct microfacies identified within this formation. Here is an overview of these microfacies and guidelines for interpreting them in relation to the environment in which they were deposited. The microfacies that are observed using Dunham's classification is:

- Microfacies.
- Mudstone.
- Dolomudstone.
- Ooidal Grainstone.
- Peloidal Grainstone.
- Peloidal Packstone.

### 4.2 Mudstones (MF1)

Lime mudstones, which are muddy carbonate rocks, exhibit low grain to bulk ratios, typically less than 10%. The presence of a lot of calcite veins cutting through the lime mud is also note. Within various layers of the Formation of Samana Suk reveal in this area, fragmented and calcite-filled mudstones can be found.
(Figure 4.1)

**Interpretation**

Based on the type of allochems, the ratio of allochems to matrix, lack of faunal remains, predominance of lime mud as the mesh, and the presence of thin lamination, it is accepting that this specific microfacies was deposited in a low-energy lagoonal environment.

### 4.3 Dolomudstone (MF2)

The Dolomudstone microfacies is distinguished by the prevalence of dolomite and fine-grained mud particles in the rock. It is characterized by a substantial proportion of carbonate mud and generally lacks substantial quantities of larger grains or fossil remains. The dolomite component of the microfacies typically accounts for approximately 80 to 90% of its composition. (Figure 4.1)

**Interpretation**

The occurrence of dolomite signifies a notable diagenetic transformation in which calcium carbonate minerals have been substituted by dolomite through chemical reactions. The Dolomudstone microfacies typically indicates a calm, low-energy depositional environment, such as a confined lagoon or shallow marine setting with restricted water circulation and minimal sediment input. It is present in peridital environment.

### 4.4 Ooidal Grainstone (MF3)

The grainstone microfacies is distinguished by an abundant presence of wellsorted, coarse-grained sedimentary particles in the rock. The Figure (4.2 a) show compaction and grain have a sutured contact. It commonly consists of a significant proportion of grains, such as particles of sand size or larger, and can include various types of grains such as carbonate fragments, ooids, peloid, or skeletal remnants of organisms. The grainstone microfacies typically displays minimal to no matrix or mud component and is predominantly composed of the grains themselves. (Figure 4.2)

**Interpretation**

The grainstone microfacies implies a depositional environment characterized by high energy, where sediment is transported and modified by the action of currents or waves. It is frequently linked to settings like shoals, reefs, or energetic shallow marine environments. The presence of the grainstone microfacies often signifies the existence of distinct sedimentary structures, such as crossbedding or ripple marks, which arise from the dynamic nature of the depositional conditions.

## 4.5 Peloidal grainstone (MF4)

The MF4 microfacies primarily consists of 80-95% peloid, accompanied by infrequent microbial crusts and ooidal grains in smaller quantities. The peloidal grains exhibit good sorting and are bound together by blocky and granular calcite cement.
(Figure 4.2)

**Interpretation**

The without of micrite and the fine sorted nature of peloidal grains seen a shoal depositional environment under high-energy conditions. The shoal environment is characterized by low mud bond, tidal influence, and relatively high wave energy. In this setting, the peloid are create due to restricted circulation of warm water in shallow depths. The abundance of peloidal grains and scarcity of ooids more support a high-energy.

## 4.6 Peloidal packstone (MF5)

The MF5 microfacies predominantly consists of 80-90% peloid within a packstone matrix. Among the skeletal grains present, approximately 2-4% comprise bivalves and miliolids, while 1-3% are ooids. The peloid exhibit an elliptical, rounded, or irregular shape and are primarily fecal, with a micritic rim. Intergranular blocky calcite cement is observed as pore-fillings. Diagenetic processes include the micritization and calcitization of bioclasts within this microfacies. (Figure 4.2)

**Interpretation**

The deposition of the studied microfacies in a calm environment with a low diversity of biota clearly suggests a lagoonal setting. The limited circulation and semiarid climate contribute to the formation of a partially hypersaline environment within these lagoons (Flügel, 2010). The predominance of peloid, along with a minor presence of bioclasts and skeletal grains, points towards a restricted subtidal lagoonal environment. Furthermore, the occurrence of iron oxide staining in nearby suture zones indicates low sedimentation rates.

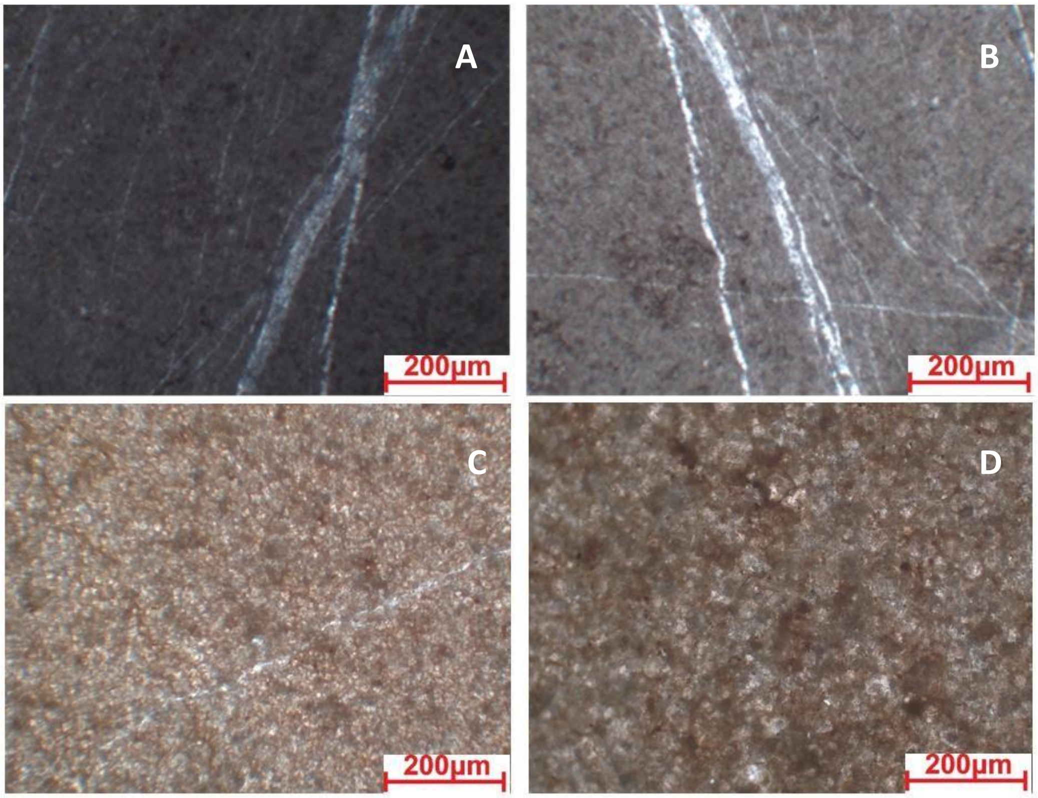


**Fig 4. 1 (A and B)** Mudstone Microfacies and **(C and D)** Dolo mudstone Microfacies

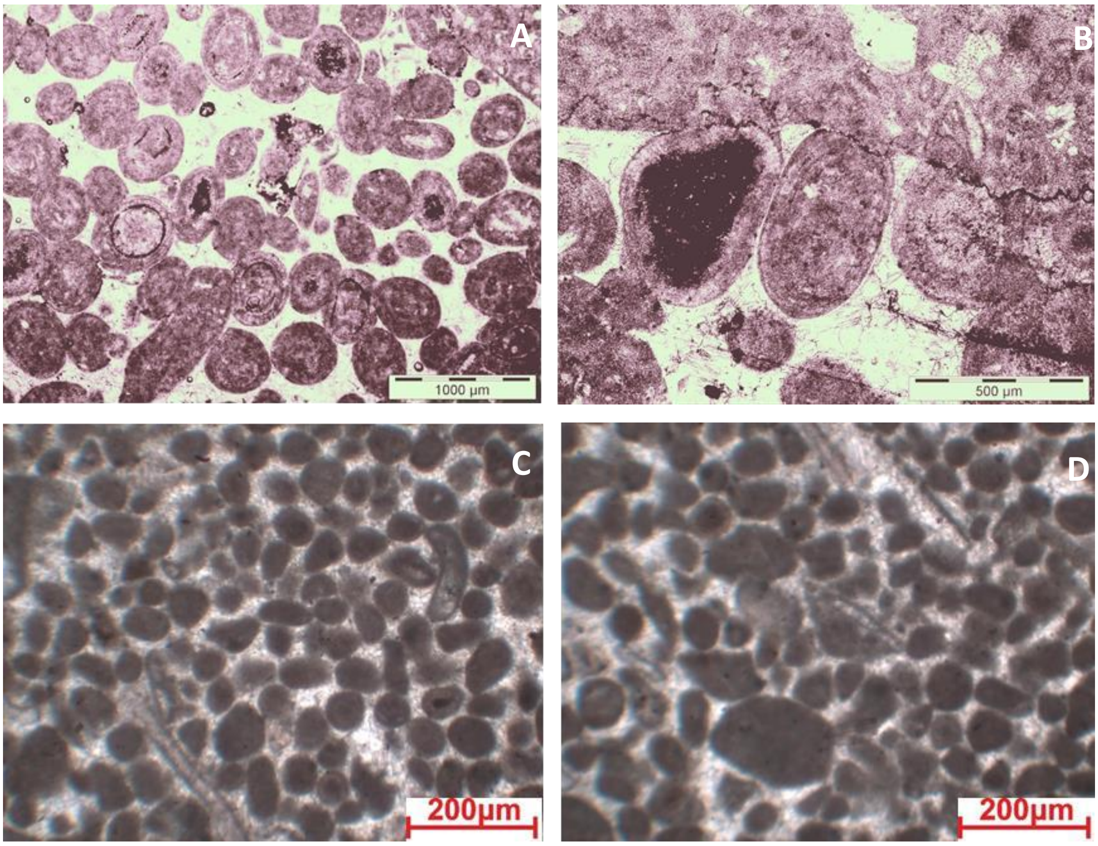


**Fig 4. 2** Ooidal Grainstone and Peloidal Grainstone **(A and B)** Peloidal packstone. **(C and D)**.

## 4.7 Depositional Model

Petrographic analysis reveals the existence of five distinct Microfacies (MF1MF5) distinguished by their skeletal and non-skeletal components, depositional textures, and other petrographic characteristics. By considering the lithology and relative abundance of non-skeletal components, these microfacies can be categorized into three facies associations: lagoons, carbonated sands, and shoal and marine conditions. Based on the established Paleozoic and Mesozoic carbonate ramp facies standards the studied microfacies can be further classified into two facies assemblages on the carbonate ramp. (Figure 4.3)

The inner ramp comprises the lagoonal facies (MF1, MF2, and MF5), the shallow marine facies (MF3), and the shoal environment facies (MF4). Lagoonal facies are characterized by low energy and limited water circulation, while the shoal environment facies represent a moderate to high energy setting. The lagoonal environment exhibits low diversity in biota, predominantly non-laminated, lacking fossils, and containing a significant amount of non-skeletal fragments. On the other hand, the shore environment features well-sorted sediment, cross-bedding, tightly packed patterns of ooids, and poorly sorted peloid embedded in sparry cement.

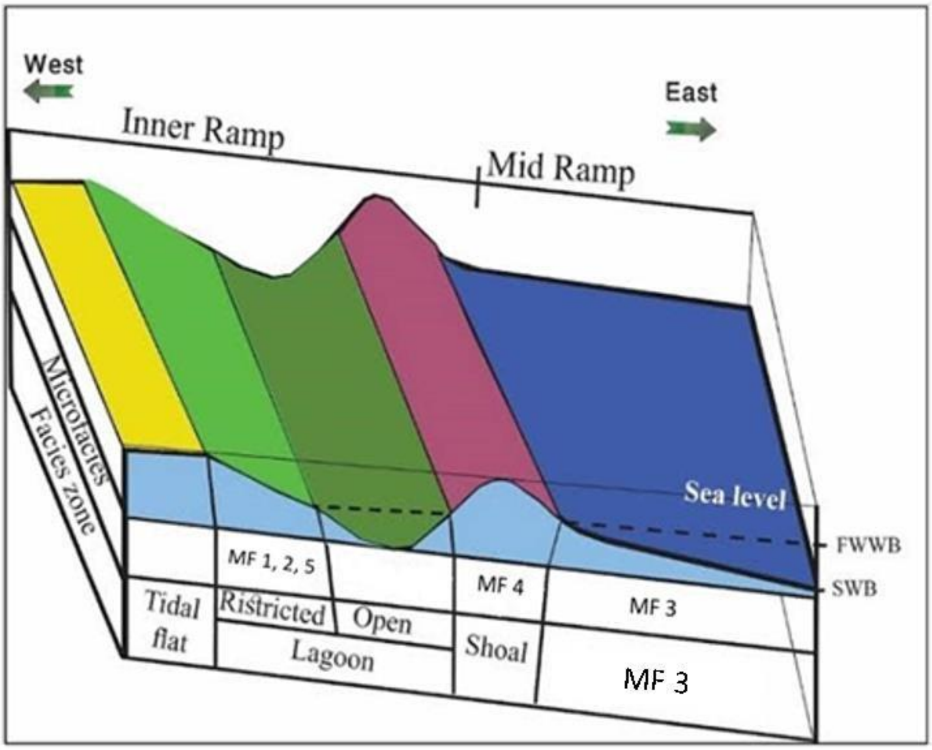


**Fig 4. 3** Depositional Model of Samana Suk Formation of Thandiani Section.

# CHAPTER 5

# DIAGENESIS

Petrographic analysis was conducted to investigate the diagenesis of the Formation of Samana Suk in Thandiani sections, when field observations were employed for macro-examination. It is the process of dolomitization, the study area exhibits alternating beds of limestone and dolomite. The following diagenetic processes have been identified in the study area.

## 5.1 Micritization

The microbial processes lead to the formation of a micrite envelope around the allochemical components. The micritization process can be divided into two stages: early-stage micritization, which is attributed to microbial activities according to Harris (1979), and late-stage micritization, primarily associated with the stabilization of mineral content without microbial involvement. The occurrence of micritization is influenced by factors such as water depth and sedimentation rate. In shallow marine environments, various microorganisms including endolithic algae and bacteria play a significant role in the process of micritization, as suggested by Kobuk and Risk (1977), Micritized Envelops can be seen in Figure (5.1).

## 5.2 Bioturbation

Bioturbation refers to the process of sediment reworking by organisms, which leads to the disruption of sediment texture and is characterized by the presence of burrowing fillings. This phenomenon is predominantly observed in low-energy marine phreatic environments, particularly in mudstone facies, as described by Flügel (2010).

## 5.3 Mechanical Compaction

Mechanical compaction, which refers to the physical compression of sediments, initiates within a few meters of burial, as indicated. The continuous deposition of sediments leads to the formation of sediment layers, resulting in the development of an overburden thickness. The process of physical compaction involves the dewatering, rearrangement, and crushing of rocks due to the load exerted by the overlying sedimentary layers. A linear relationship exists between lime mud and undeformed ooids, whereby the ooids remain preserved in an undeformed state when they are exposed to high lime mud content. In the case of the Samana Suk Formation, anomalous compaction occurs during shallow to deep burial due to the deposition of overlying sediments. (Figure 5.1) represents the mechanical compaction process, caused by strain concentration at grain contacts, leads to the deformation and breakage of grains, as well as the formation of sutured contacts between grains.

## 5.4 Chemical Compaction

Pressure solution, which is a common aspect of diagenesis contributes to chemical compaction. When combined with mechanical compaction, it leads to a significant reduction in bed thickness, taking into account the composition of the rock. Chemical compaction is frequently observed in the Samana Suk Formation, manifesting in various forms such as pressure solution contacts, sutured seams, micro-stylolite’s, and stylolite. Deep burial plays a crucial role in enhancing pressure solution processes, causing the sutured contacts to merge laterally and form continuous stylolite (Figure 5.1).

## 5.5 Dissolution

Dissolution in carbonate minerals occurs when the diagenetic pore fluids are undersaturated compared to carbonates. This process is a commonly observed secondary phenomenon that gives rise to various types of porosity in the Formation of Samana Suk, including intragranular, intergranular, moldic, oomoldic, vuggy, and fracture porosity, as mentioned in the previous sections. Petrographic analysis reveals the presence of two stages of dissolution observed in different facies of the Formation of Samana Suk. (Figure 5.2)

## 5.6 Cementation

Cementation refers to the process of minerals precipitating from fluids and filling void spaces. It takes place when diagenetic pore fluids are supersaturated relative to carbonate minerals. Cementation plays a crucial role in recording the diagenetic environment and determining the paragenetic sequence. In the Middle Jurassic Samana Suk Formation, cementation is a prevalent phenomenon, and various types of cements have been observed. These include equant mosaic, granular mosaic, isopachous, blocky, syntaxial calcite overgrowth, drusy, and saddle dolomite cement (Figure 5.2).

## 5.7 Dolomitization

Dolomitization is a geological process which involves the change of calcium (Ca) with magnesium (Mg) within the calcite mineral, resulting in the formation of dolomites. This transformation leads to changes in volume and crystalline structure compared to the precursor rock, as well as impacts the porosity of the dolomite. Due to the smaller ionic size of Mg compared to Ca, the volume of the mineral decreases while the porosity increases (Weyl, 1960). The process of dolomitization is facilitated by the presence of Mg-rich fluids, which cause the replacement of Ca by Mg. The rhombic crystalline form of dolomite exhibits greater resistance to compaction during burial compared to the precursor limestone rock (Murray, 1960). Dolomite is an important carbonate mineral, akin to calcite and aragonite, in terms of its contribution to carbonate formations. However, the origin of dolomite minerals remains uncertain. Fairbridge (1957) highlights two main challenges associated with dolomite: the limited occurrence of modern dolomite and the difficulties in synthesizing dolomite in laboratory conditions. While the presence of depositional dolomite is less, replacive dolomite is more commonly observed in the geological record (Figure 5.3).

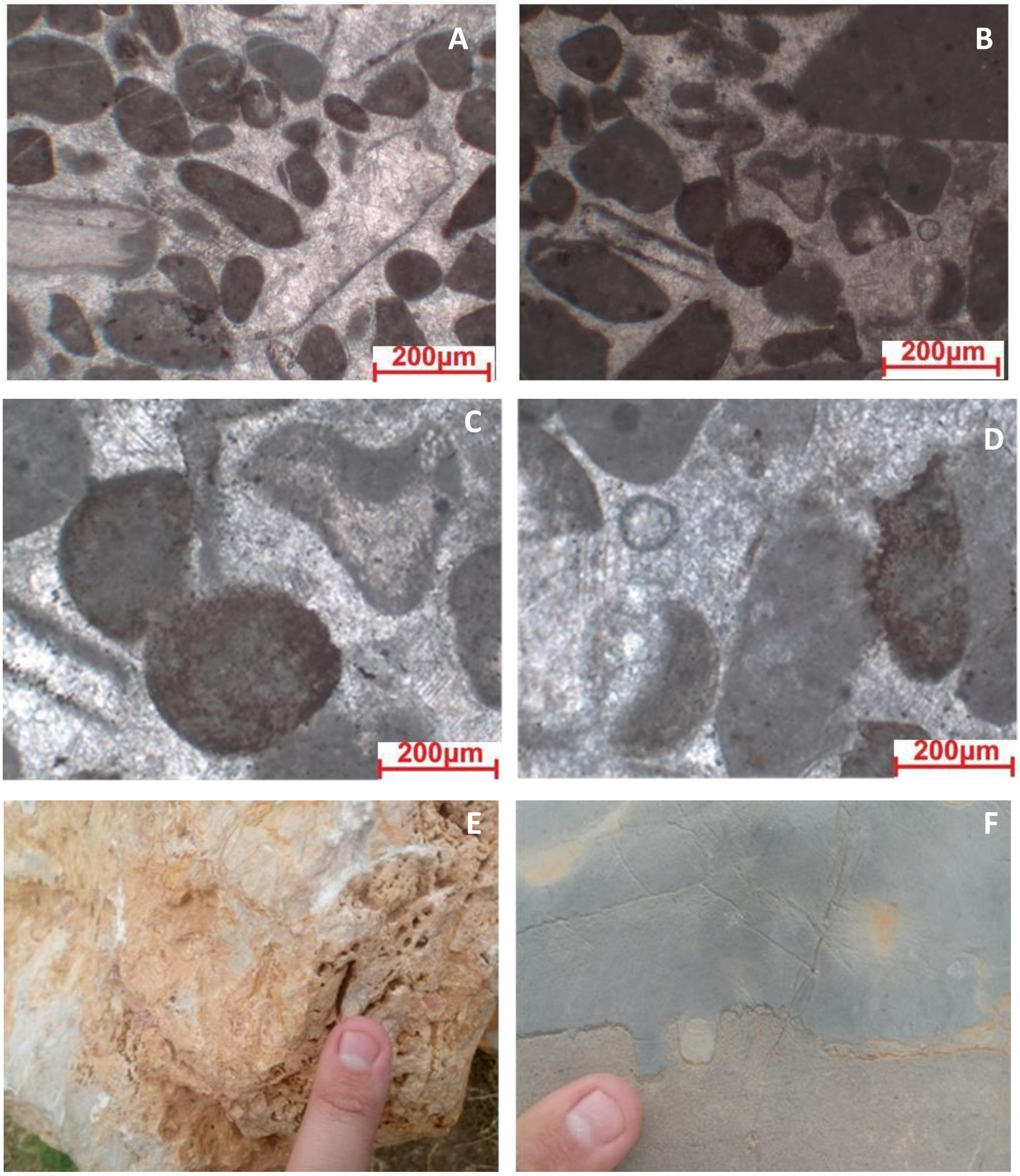


**Fig 5. 1** Mechanical Compaction **A)** shows suture and point contact between grains and **B)** mechanical compaction between various grains that are collided with each other and in **(C and D)** the Envelop around the clast. Also, a Big Black clast is a Micritized Clast. Dissolution in **(E and F)**.

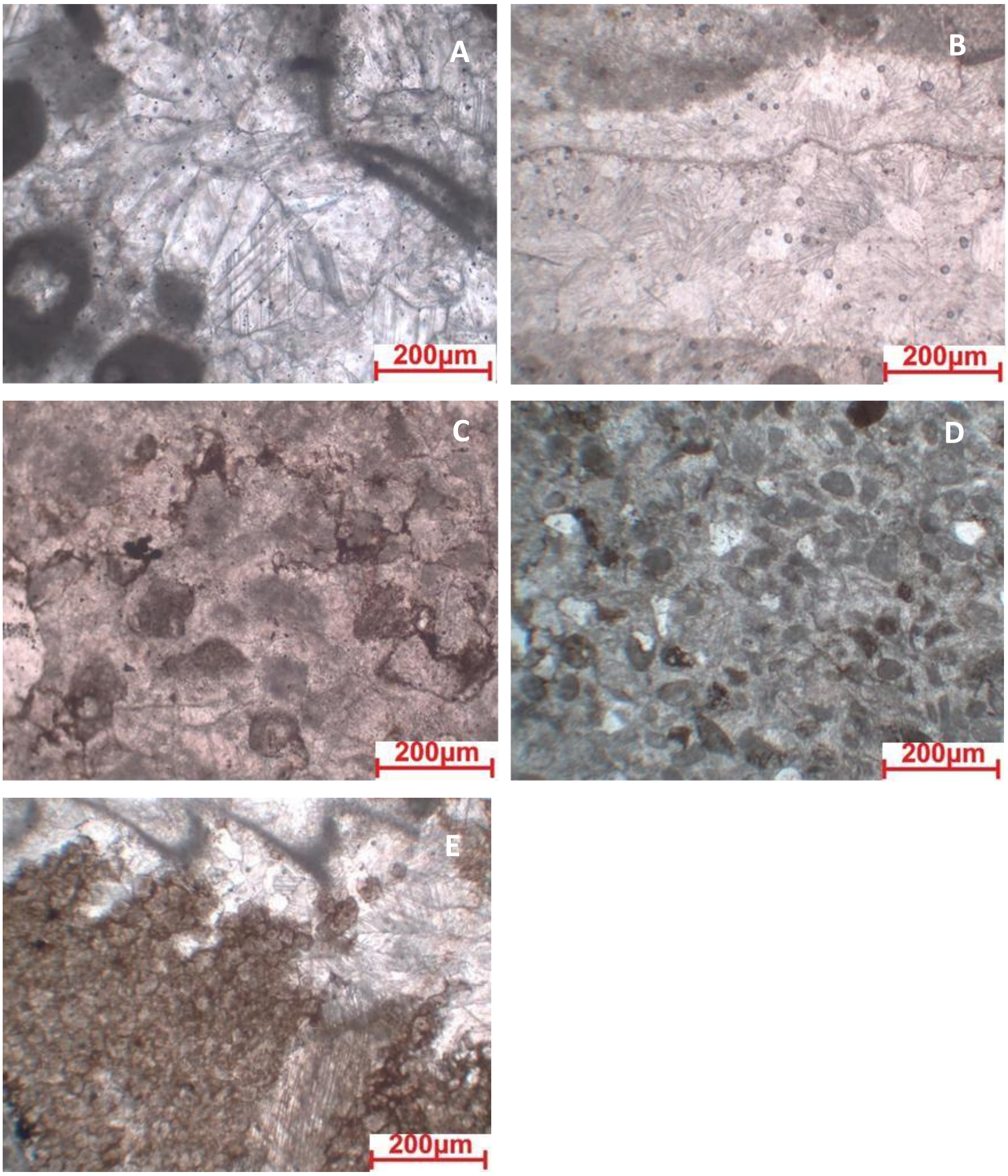


**Fig 5. 2** Blocky cementation and Twinning with calcite Dolomitization **(A and B)** Here permassive dolomization can be observed in which whole limestone becomes dolomized **(C and D)** It shows euhedral to subhedral dolomitic rhombs or crystals It represents selective dolomization (Dolomization of grain) **(E)**.

## CONCLUSION

- In Formation of Samana Suk, the detailed research on Thandiani Section concludes that this region primarily consists of dense and compacted. On exposed surfaces, the limestone appears light grey when fresh and light brown when weathered. The limestone deposits exhibit significant variation, with some areas being extensive, planar, and containing fossils. The thickness of these deposits can range from thin to medium to thick-bedded.
- During field investigations, several notable features are documented, including stylolite fractures, calcitic veins, calcite patches, and both dolomitic beds and patches. The formation comprises various microfacies, namely mudstone, Dolomudstone, ooidal grainstone, peloidal grainstone, and peloidal packstone (referred to as M1 to M5). The mudstone and Dolomudstone facies suggest deposition under low-energy conditions, particularly in calm lagoons. The ooidal grainstone facies, on the other hand, indicates a high-energy depositional environment, possibly in energetic shallow marine settings. The peloidal grainstone represents a shoal depositional model under high-energy conditions, while the peloidal packstone points to a lagoonal setting characterized by a hypersaline environment.
- Diagenetic features play a crucial role in the formation and alteration of sedimentary rocks. Diagenesis refers to physical, chemical, and biological processes that transform sediment into rock during burial and geological time. The diagenetic features that are observed in Thandiani includes Micritization, Chemical and Mechanical Compaction, Dissolution, Cementation etc.
- By analyzing microphotographs, a comprehensive depositional model of the microfacies is concluded. This model allows for the recognition of overall patterns observed in the Thandiani section, in better understanding of depositional processes within the Samana Suk Formation.

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