



**ADDIS ABABA UNIVERSITY**  
**SCHOOL OF GRADUATE STUDIES**  
**SCHOOL OF EARTH SCIENCES**

**MICROFACIES ANALYSIS AND PALEONTOLOGY OF CARBONATE ROCKS  
IN SHANAN SECTION; SOUTH EASTERN ETHIOPIA**

**A thesis submitted to the School of Graduate Studies of Addis Ababa University in  
Partial fulfillment of the requirements for the degree of Master of Science in Earth  
Sciences (Paleontology and Paleoenvironment)**

**By: - Beksa Amente Kumsa**

**Advisor:-Balemwal Atnafu (Dr.)**



**June, 2017**

**Addis Ababa, Ethiopia**

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**Approved by the Examining Committee**

Dr. Balemwal Atnafu	_____	_____
Head, School of Earth Sciences	Signature	Date
Dr. Balemwal Atnafu	_____	_____
Advisor	Signature	Date
Dr. Mulgeta Fesseha	_____	_____
Examiner	Signature	Date
Prof. Asfawossen Asrat	_____	_____
Examiner	Signature	Date

**Declaration**

I hereby declare that this thesis is my original work and has not been presented for a degree in any other university, and all sources and materials used for the thesis have been duly acknowledged.

Beksa Amente \_\_\_\_\_ Date \_\_\_\_\_

(Student)

**Approved by**

Dr Balemwal Atnafu \_\_\_\_\_ Date \_\_\_\_\_

(Advisor)

## **Abstract**

*Shanan section is situated in Southeastern Ethiopian plateau has a thick succession of carbonate rocks. These studies generally considered the stratigraphy, paleontology, microfacies analysis, biostratigraphy and determine depositional environments of Shanan section carbonates. Based on thin section analysis of 40 samples collected the compositional and textural types of rocks were studied and grouped into six microfacies associations which are characteristic for lagoon, platform margin, foreshoal and offshore environments. The presences of micritic, bioclastic wackestone and peloidal grainstone microfacies at lower Shanan indicate lagoon deposits. The Bioclastic peloidal grainstone and oolitic grainstone facies present following the lagoon facies carbonates are indicators of carbonate shoal/barrier deposits of shallow marine setting. The middle Shanan layers conformably overlies the lower Shanan and consists of the foreshoal microfacies of thick, allochemical rich wackestone-grainstone limestone's, mainly dominated by reworked intraclastic grains. A low energy deposit of offshore environment is characterized by fine grained dark gray blackish micritic limestones with some cherts present at upper Shanan section. The overall microfacies and facies successions throughout the unit show that the environments ranges from lagoon, high energy platform margin carbonate sand bodies, foreshoal deposits and offshore deposits successively from bottom to top. Based on the presence of index fossils of *Pfenderina cf. salernitana* and *Kurnubia palastiniensis* the age of this carbonate rocks determined to be Callovian to Oxfordian time. Paleontological study of Shanan section shows that the carbonates are rich in macro and microfossils that supply additional data for stratigraphic and paleoenvironmental interpretations. *Eoguttulina polygona*, *Lenticulina subalata*, *Lenticulina quenstedti*, *Verneuilinoides minuata*, *Haplophragmoides bartensteini* and *Choffatella.sp.*, are species of foraminifera collected also 5 genera of ostracods such as, *Cytherelloidea.sp.*, *Progonocythere.sp.*, *Procytheridea.sp.*, *Bairdia.sp.*, and *Paracypris.sp.* are identified. From macrofossils different species of bivalves, gastropods and brachiopods are also identified. The carbonate deposits of the section are correlated with some of equivalent deposits in Southeastern plateau and major regional sedimentary basins of Ethiopia.*

**Key words:**-*Depositional Environment, Fossil, Microfacies, Paleontology, Shanan section, Southeastern Ethiopia.*

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## **Acronomy**

ASS	Antalo super sequence
cf.	Compare with
FB	Facies belts
sp.	Species
MFT	Microfacies type
SMFT	Standard Microfacies Types
UTM	Universal Transverse Mercator

# CHAPTER ONE

## 1. INTRODUCTION

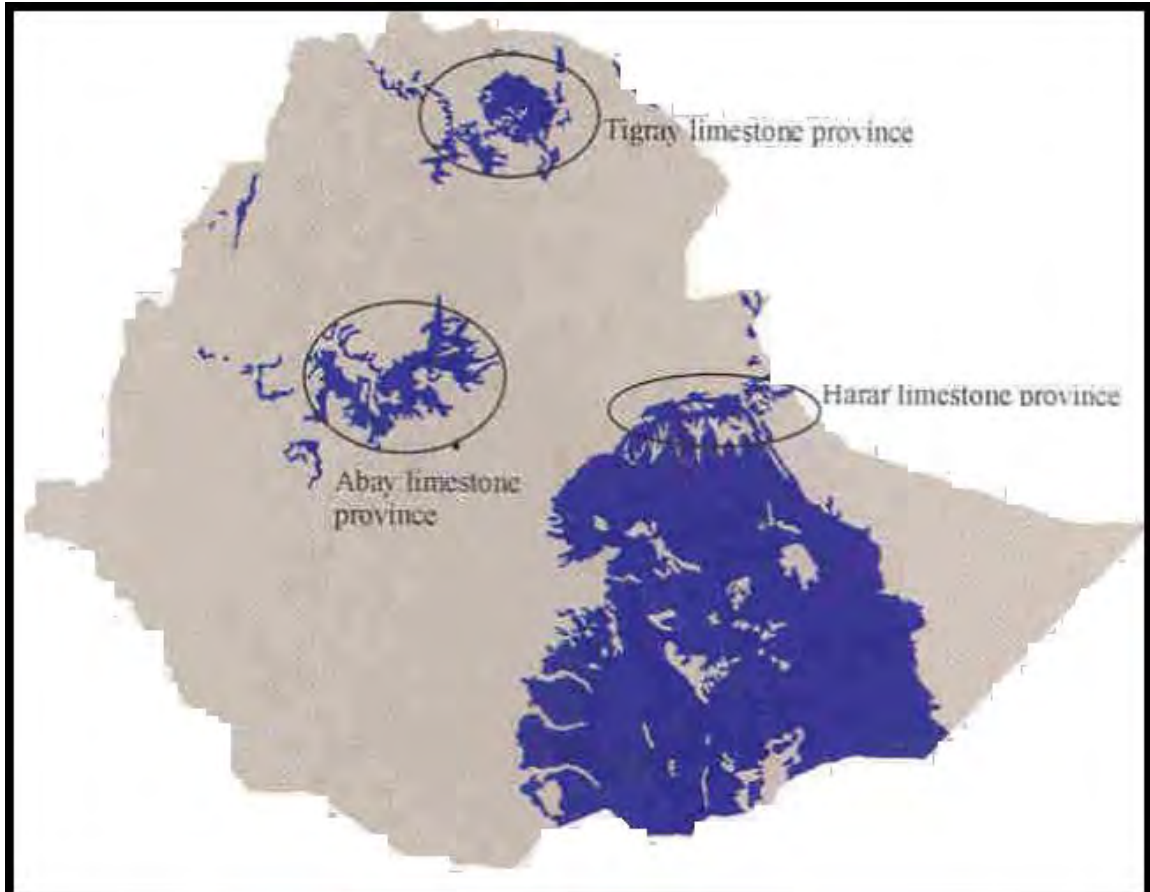
### 1.1. Background

In Ethiopia rocks of different origin, age and evolution are present. Precambrian basement complexes, late Paleozoic to early tertiary sediments and Cenozoic volcanics are the main rocks in the country. Paleozoic and Mesozoic sedimentary successions are widespread in Ethiopia they are exposed in the North (in Tigray and the Danakil Alps) (Beyth,1972a;1972b; Kazmin,1973), in central Ethiopia in the Blue Nile basin Russo et al., (1994) and in Ogaden basin and Harrarghe, in Southeastern (Kazmin, 1973; Merla et al., 1979; Bosellini et al., 2001;Asfawossen Asrat, 2015). The development of most of these basins is related to the extensional tectonic events that have taken place since the Late Paleozoic time (Merla et al., 1979). Mesozoic deposits of Carbonate rocks in Ethiopia are highly exposed in, Mekelle Outlier, in the Blue Nile Basin, and Ogaden Basin (including Western Harrarghe region, Fig 1.1).

From various types of sedimentary rocks Carbonate rocks, such as limestone are characterized by containing important and varied textures, sedimentary structures and fossils that yield important information about ancient marine environments, paleoecological conditions and the evolution of life forms, particularly marine organisms, through time.

Compositional and textural constituents of carbonate rocks are highly interpreted based on microfacies analysis that examined in thin sections to reflect the depositional and diagenetic history. Microfacies studies aim for the recognition of overall patterns that reflect the history of carbonate rocks thorough examination of their sedimentological and paleontological characteristics (Walker, 1992).Petrographic analysis is primary method for microfacies study but also various other analytical techniques and paleontological techniques can be used (Flugel, 2004). Facies can be defined as‘a particular combination of lithology, structure, palaeontology and textural attributes that characterizes features different from other rock bodies’ (Walker, 1992; Selley, 2000). One of easy method of studying limestone and their depositional environment is to compare them with the most widely used Standard Microfacies Types (SMFT) and assign these microfacies types with standard facies belts (FB) which are developed by (Wilson, 1975). Each facies has a distinctive composition which should be diagnostic for a particular environment, Wilson (1975) recognize 24 standard microfacies and assign them to

nine standard facies belts (FB) (see Appendix 1). Microfacies type of Shanan section carbonate and their related depositional environment is compared with SMFT and FB of Wilson (1975) as given in Chapter 4 of this paper.



*Fig. 1.1. Locations of Mesozoic sediments of Ethiopia (Ethiopian Ministry of Mines, 2009)*

Most limestones are ultimately biogenic in origin and understanding of biological and palaeobiological factors is essential in knowing their formation. The remains of animals or plants preserved as a fossil in carbonate rock are used for the interpretation of depositional environment, the geological record dating, and chrono correlation of strata.

The concept of a facies analysis, stratigraphic column, and paleontology provide the recognition of periods in the history of the earth (in terms of geological record, paleoenvironmental changes, basis of correlation of strata and fossil identification).

## 1.2. Geographic Setting of the Area

### 1.2.1. Location and Accessibility

This research project is conducted in the Southeastern Ethiopian plateau. The area is located about 600km from capital Addis Ababa and can be accessed via the main road that joins Addis Ababa and Mechara through, Addis Ababa-Adama-Asebeteferi-Bedessa-Gelemso- Mechara-Shanan. The section is located at about 72 Km from Mechara town in south and the road is totally all weather gravel from the town. In UTM (Universal Transverse Mercator) the area is bounded by a grid of Easting from 882870E to 885655E m and Northing of 659400 to 661336 m (Fig.1.2). The study area has coverage of approximately 16 km<sup>2</sup>. The study is undertaken on one locally selected stratigraphic section in Shanan section throughout the area which is located in Daro Lebbu Woreda

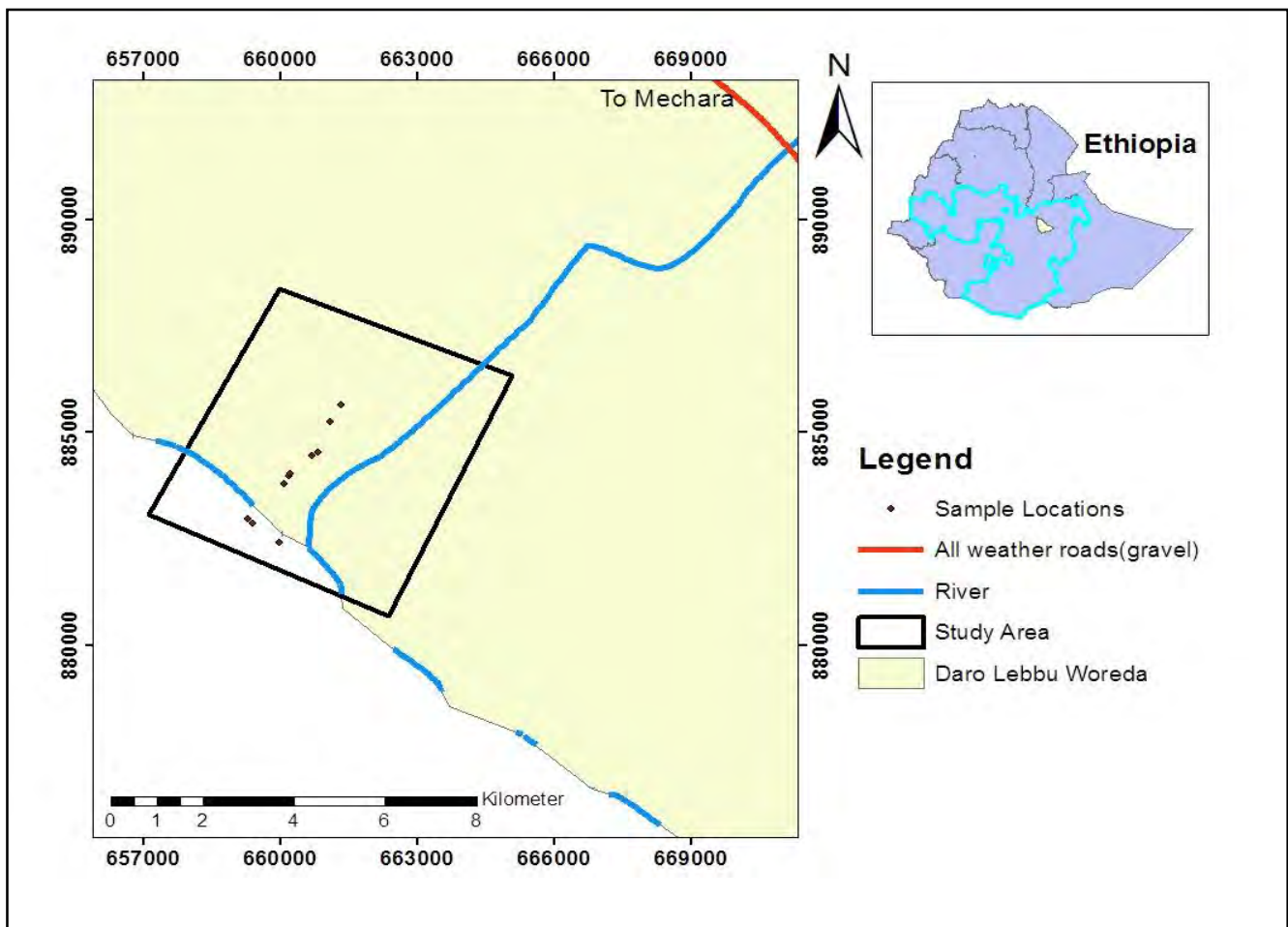
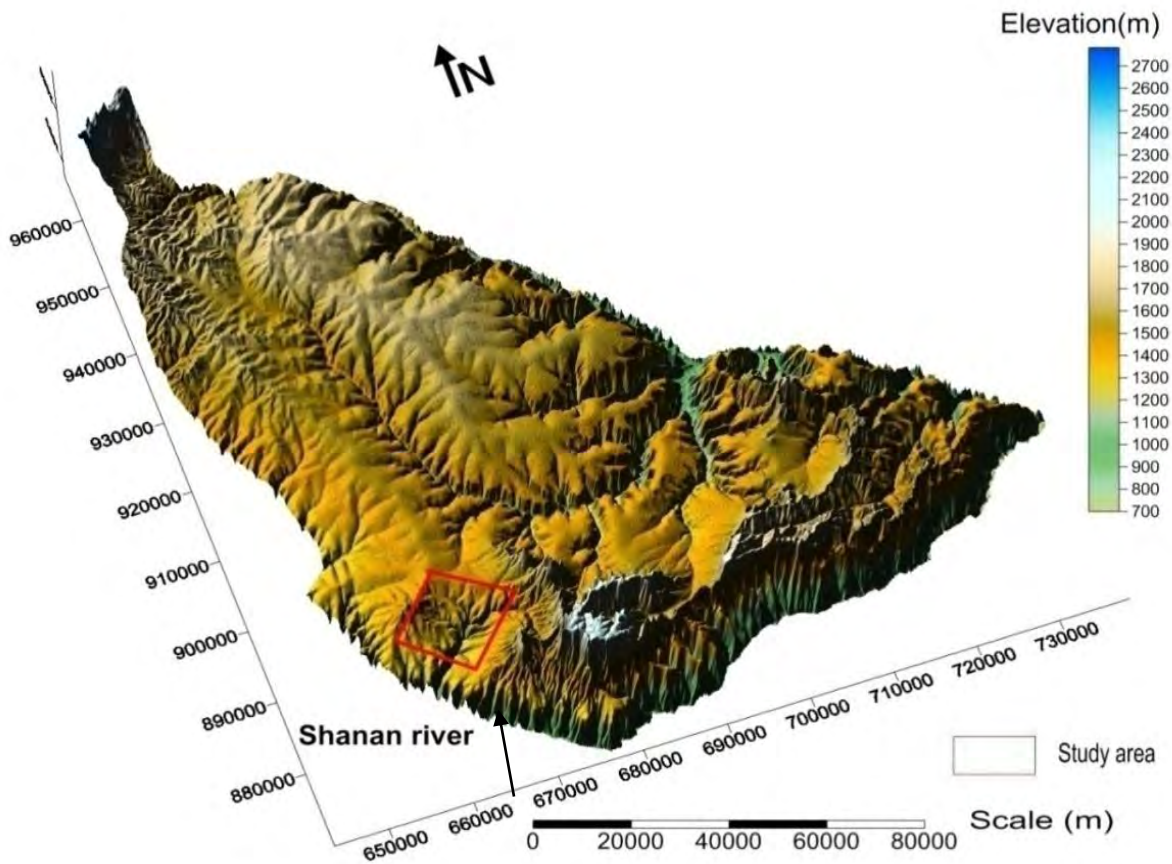


Fig. 1.2. Location map of study area.

### 1.2.2. Physiographic and Drainage

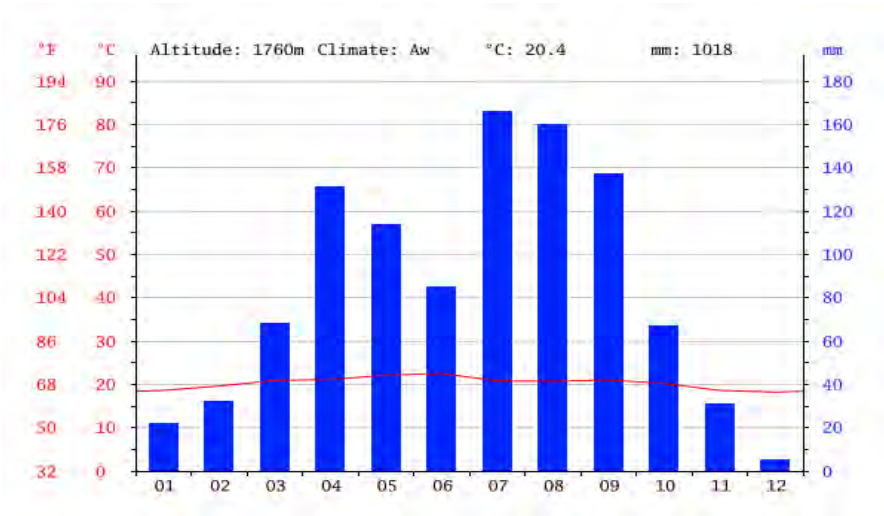
The study area is located in Daro Labbu woreda, which is one of the districts of West Hararghe Zone, Oromia regional state of Ethiopia and the area encompasses varied topography ranging from lowland to rocky mountainous terrains. The area characterized by highland area, mid-high land and lowland areas (Fig 1.3). Shanana river is the biggest river near the study area and it drain to Wabe shebele river which is biggest river in the woreda.



*Fig 1.3. Physiographic map of the Daro labbu woreda.*

### 1.2.3. Climatic Condition and Vegetation

According to Climate-Data.org in <https://en.climate-data.org/location/762997/>, at an average temperature of 22.5 °C, June is the hottest month of the year. The lowest average temperatures in the year occur in December, when it is around 18.2 °C .The summers are much rainier than the winters in Mechara. The greatest amount of precipitation occurs in July, with an average of 163 mm and lowest in December, with an average of 5 mm. In terms of vegetation, it is covered by grasses and moderately vegetated by scattered patches of trees and scrubs.



*Fig 1.4.: A bar chart that show climatic condition of area around mechara. Sourced from Climate-Data.org in <https://en.climate-data.org/location/762997/>*

### 1.2.4. Population and Settlement

The population density in the area is low. The closest big town to the study area is Mechara and there are small villages that are found within the study area. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), Daro lebbu Wereda rural and urban area has a total population of 198,095. The three largest ethnic groups in the area were the Oromo, Amhara and somalie respectively. Oromic is spoken as a first language Amharic was spoken secondly. The majority of the inhabitant beliefs are Muslim and Orthodox with 186,620 and 10,263 members respectively.

### **1.3. Previous works**

Different studies have been conducted in the region from different perspectives. The earlier studies conducted in the area include (Kazmin, 1973; Merla et al., 1979; Greitzer 1970; Jaboli 1959). The limestone units of Southeastern Ethiopian plateau are mainly fossiliferous neritic limestones with marly, shaly units ranging in age from Dogger to upper most Jurassic (Merla et al., 1979). Greitzer (1970) also state that the carbonate formation is widely exposed in Harrar area and consists predominantly of limestone and dolomite. Most of works on carbonate deposits of Ethiopia was mainly depended on the facies at out crop level, rather than microfacies study and are not detail they focus on regional level.

Paleontology of Harrar is also studied by different authors and organization in different ways such as by authors from (American museum of natural history in the Dudley expedition in, 1943; Kazmin,1973; Jaboli, 1959; Greitzer, 1970).The study of paleontology on Mesozoic carbonate is very rare which mostly focus on invertebrate fossils and microfossils are just mentioned neither described in detail nor figured.

This work is detail microfacies analysis and Paleontology of Shanan section. For this particular area this will be the first work and will need to interpret depositional environment of carbonate unit of the section, for identification of fossils, to know age of units of the section and for correlation with other sedimentary basins of the country.

### **1.4. Problem statement**

Microfacies analysis and the fossil record suggest a long-term view to understand depositional environment. Sedimentary basins are crucial place for the study of fossils, depositional environment, stratigraphy etc and most of this information is obtained through detail study of facies analysis, paleontology and stratigraphy. This will guide us to identify fossils, to predict the age of rock, to interpret environments of depositions and rock correlation. In Ethiopia there are many sedimentary basins and their sedimentology, stratigraphy and paleontology of the country is roughly studied in regional level but there are limited number of local detail studies under taken especially on microfacies analysis and paleontology. In particular this work is detail local study

on the microfacies analysis for interpreting depositional environment of carbonate unit and fossil identifications found in the studied section.

## **1.5. Objectives**

### **1.5.1. General objective**

The main objective of this research is detail microfacies analysis, paleontology and depositional environment interpretation of carbonate units found in Shanan section.

### **1.5.2. Specific objective**

- To produce detail stratigraphic log of the area.
- To identify and describe fossils found in the section.
- To describe detail petrographic properties of carbonate units.
- To determine age of sedimentary rock units of the section.
- To interpret depositional environment of the unit and
- To correlate the rock units of the area with regional sedimentary rock units of the country.

## **1.6. Methods and Materials**

In order to accomplish this thesis, different materials have been used and different methods have been applied, detailed field studies following exposures on road-cuts, lithofacies analyses, microfossil collection and identification were carried out in the field.

Over 44 rock samples and 6 marl samples were collected. The microfacies analysis was carried out from 40 hard limestone samples and thin sections were studied with petrographic plane polarizing microscope. Photographs of outcrops, thin section and fossils were taken using digital camera. The classification scheme of Dunham (1962) and Folk (1962) have been applied for the carbonate rock naming. Recognition of facies belts and microfacies types are based on standard microfacies types (SMFT) and Facies belt (FB) of Wilson(1975). The overall works of the research are mainly divided into three phases; pre-field work, field work and post-field work. In the pre-field work assessment, it began with reviewing literatures and followed by identification of the problem, setting objectives, methods etc are done. Field and post-field works generally

involved sample collection, stratigraphic logging, sample preparations, sample analyses, fossil description and interpretations of field and laboratory data were used. In the following sections the main methods that applied in the research work is presented.

### **1.6.1. Field work**

Field work were complemented with the collection of approximately 44 rock samples, 6 marl samples and macro invertebrate fossils. The sedimentological data such as lithology, texture and sedimentary structures were described and lithologic log of compositional and textural data was produced. Detail description for each of field activity is given as follows:-

#### **A. Rock Sample collection**

A collection of rock samples in the selected stratigraphical section was done in July 2016. Representative samples of the unit in the study area were collected from surface following the roads which cut and expose the units. Both fossilized and non-fossilized rock samples were collected for petrographical analyses and marl samples for microfossil extraction.

During the field work the following materials were used: Topographic map (1: 50,000 scale), regional geological map (1:250,000 scale), GPS, compass, hammer, hand lenses etc.

#### **B. Lithostratigraphic log of section**

In this study stratigraphic logs of section and bed-bed scale description of rock exposures based on lithology, texture, rock color, bedding, sedimentary structures, fossils and biogenic structures were made and composite stratigraphy of ~161m total thick carbonate succession were produced, as their stratigraphic logs are given in (Fig 3.9).

#### **C. Macro-Invertebrate fossil collection**

Collections of invertebrate macrofossil were conducted in the selected stratigraphical section. Fossil samples of the unit in the study area were mostly found as a mold or a cast and collected from the exposed units. Some of the fossils collected in the field have already been removed from the rock those can be easily collected and some fossils remain embedded in the rock. Description and identification of macro fossils based on shape and size was made in the field.

### **1.6.2. Laboratory and Data analysis**

Detailed microfacies analysis of carbonate units through thin section study, fossil description and microfossil sample preparation were made in laboratory. Attempts made in laboratory are discussed below:

#### **A. Petrographic analysis**

Forty thin-sections (40) were used to investigate the compositional variation of limestones in section. Each sample was viewed under a petrographic plane polarizing microscope. Thin sections are prepared for study of the relative abundance of the main constituents grains (shapes, sizes, sorting), matrix, sparite and cements) fossils and diagenetic features.

The standard microfacies types of Wilson (1975) based on Dunham's (1962) and Folk's (1962) classification of carbonate rocks were used in description and analysis of the observed carbonate microfacies. Depositional settings and palaeoenvironmental reconstructions of most carbonates were interpreted based on compositional, textural and sedimentary data by comparison with Standard microfacies types (SMFT) and Facies belts (FB) of (Wilson, 1975). From these stratigraphic log of the area is produced and correlation with other basins made.

#### **A. Macrofossil identification**

Fossil Observation, detailed description of observed external morphology of invertebrate fossils based on size, shape etc is made for identification and classification of macrofossils and comparison with Jaboli (1959) and Keissling (2011) has been applied.

#### **B. Micro fossil preparation and Description**

Six unconsolidated marl samples are collected in order to isolate microfossils. Samples are prepared in Addis Ababa university stratigraphy and sedimentology lab. In order to observe and study microfossils 50 grams of dry marl samples were placed in beaker, soaked in 50 to 75 ml of 30% concentrated H<sub>2</sub>O<sub>2</sub> solution and 100 to 200 ml of distilled water. Samples are then gently agitated and low boiled. After minimum of 24hr the samples are then washed over USA Standard sieve No. 35,45,60,120 and 450 which have 0.5mm 0.375mm, 0.25mm, 0.123 mm and 0.032mm sieves sizes respectively. Air drying method was used to dry samples over 12 hr. The dried

samples were then sparingly scattered on the black picking tray and scanned under binocular reflecting microscope (x35 magnifications) for picking and analysis of the recovered microfossils. Recognizable microfossils were picked with a fine artists paint brush and dropped into cavity slide microfossil card. All the representative microfossil specimens were mounted on micro slides for identification and selected microfossil were photographed for further morphological description.

### **1.7. Significance of the Research**

In Ethiopia there are many sedimentary basins known but only few of them detail local studies has been taken in terms of paleontology and microfacies analysis. The study area (Shanan section) has not been studied in aspect of microfacies analysis, paleontology and stratigraphy in detail and this will be a first detail study. This study has dealt with stratigraphy, microfacies analyses, correlation and description of fossils.

An attempt is made in this paper to describe and discuss:-

- Microfacies analysis and stratigraphy of the area is needed to interpret the history of the rock, depositional environment and age of units of the section and for correlation with other sedimentary basins of the country.
- Study of fossil is needed to identify taxa from other also to determine the age of the units.

### **1.8. Thesis Overview**

The thesis is structured in seven chapters. Chapter one gives general information about the area of study, the purpose and methods followed in the research. Second chapter provide a regional scale overview. Chapter three gives a detail description about the lithology, structure and fossils of the study area observed in the field. In Chapter four Petrographic description and microfacies analysis is presented and the depositional environment of carbonate unit of Shanan section is interpreted. In chapter five the description for macro and microfossils were presented. In chapter six discussions on depositional environments of carbonate units of the section, their age and the correlation with other section was made. Finally in chapter seven the main conclusion and recommendation for the future study is dealt. It has also relevance to the scientific community by providing wealth information.

## CHAPTER TWO

### 2. LITERATURE REVIEW

#### 2.1. Regional Geology

Sedimentary basins are regions of earth of long-term subsidence creating accommodation space for infilling by sediments, the subsidence can result from a variety of causes that include: the thinning of underlying crust, sedimentary, volcanic, and tectonic loading and changes in the thickness or density of adjacent lithosphere. Sedimentary basins occur in diverse geological settings usually associated with plate tectonic activity.

The nature of the sediments that accumulate in a sedimentary basin is related to the environments of the physiographic basin from which the sediments were derived and in which they were deposited. Sedimentary basins typically begin with a transgressive sequence and end with a regressive sequence but they may have a long and complicated history. Transgressive sequences record a general deepening of the sea, with reduction of the land area and migration of the facies towards the land. Regressive sequences record a general shallowing of the sea, with extension of the land and migration of the facies seaward (Selley, 2000).

Geology of Ethiopia is characterized by the occurrence of a very wide variety of rocks, differing in their age, origin and evolution. The rocks in the country mainly fall into three broad categories; Tertiary volcanic rocks which occupy large parts of the country along the rift valley, marine sediments of late Paleozoic and Mesozoic era and Precambrian basement complexes.

The East African region has been affected by two major phases of rifting. The first phase was the widespread rifting in Karoo times (Late Carboniferous to Early Jurassic) which stretches from Ethiopia to South Africa corresponds to the initiation of the break-up of Gondwanaland (Norton and Sclater, 1979; Bosellini, 1989) in that further subsidence took place. This subsidence combined with sea-level fluctuations and produced cyclic patterns of shallow-marine carbonates, shales, evaporites and minor clastic deposits. The second rifting relates to the formation of the East African rift system (Cenozoic to Recent).

Tectonic evolutions throughout NE-Africa and sea level fluctuations through geologic time in general have the great roles for the formation of Ethiopian sedimentary basins and thick sedimentary deposits within them. The development of most of these basins is related to the extensional tectonic events that have taken place since the late Paleozoic and continued up to Tertiary (Merla et al., 1979; Blanford, 1970). The beginning of the breakup of Gondwana gave rise to the Jurassic flooding of the Horn of Africa with a marine transgression from the Paleotethys and the Indian/Madagascar nascent ocean (Abbate et al., 2015)

Sedimentary regions of Ethiopia cover a significant portion of the country. They are widespread and occur in five distinct basins, namely: Ogaden, Abbay, Gambela, Southern rift and Mekele. Paleozoic and Mesozoic sedimentary successions of Ethiopia lie over Precambrian basements. Most of sedimentary succession of the country is part of the vast sedimentary succession of East Africa which was deposited during the Mesozoic transgression. But also there are some late Paleozoic to early Mesozoic sedimentary rocks mainly sandstones and minor tillite, shale, siltstone and conglomerate present in some parts of the country (Beyth 1972a; 1972b; Bosellini, 1989).

An alternate sinking and uplifting of the landmass of the whole horn of Africa triggering transgression of the Indian Ocean from the southeast to the northwest characterized the early Mesozoic (Getaneh Assefa, 1991; Bosellini, 1989). The Jurassic transgression came from the southeast reaching its maximum limit in western Ethiopia and Eritrea during the Kimmeridgian and deposited a sandy formation (Adigrat Sandstone) followed by neritic sediments composed mainly of limestone (Antalo limestone), a regression toward the southeast began at the end of limestone deposition and a nearshore upper sandstone facies (Amba aradam formation) accumulated above the Adigrat and Antalo Formations (Kazmin, 1973; Getaneh Assefa 1991; Mengesha Tefera et al., 1996; Bosellini et al., 2001).

The Mesozoic succession of Ethiopia is present in the Mekele outlier in the Blue Nile basin and in Southeastern Ethiopia with adjacent Ogaden Basin (Kazmin, 1973; Merla et al., 1979; Bosellini et al., 2001; Beyth 1972a; 1972b; Getaneh Assefa; 1991; Russo et al., 1994).

The Blue Nile basin part of Northwestern Ethiopian Plateau contains thick Mesozoic sedimentary section. It is underlain by Neoproterozoic basement rocks and overlain by Early-late

Oligocene and Quaternary volcanic rocks (Russo et al., 1994; Gani et al., 2008). In northern Ethiopia the sedimentary succession un-conformably overlies the Precambrian basement in a nearly circular outlier called (Mekele Outlier) and covering an area of about 800 km (Beyth 1972a; 1972b; Worash, G. and Valera, 2002). The succession of Mekele Outlier consists of Adigrat Sandstone, Antalo Super sequence (ASS) and Amba Aradam Formation which is unconformably overlies by Tertiary flood basalts. The Hararghe and Ogaden basins which occupy the South east Ethiopian plateau are one of the three major areas in which Mesozoic sedimentary rocks occur (Kazmin, 1973; Mengesha Tefera et al., 1996; Balemwal Atnafu and Tesfaye Kidane, 2012; Asfawossen Asrat et al., 2008; Asfawossen Asrat, 2015).

According to Getaneh Assefa (1988) Ogaden basin was initiated in Paleozoic time as part of the regional trough and is dominated by non-compressional tectonic. The basin covers one-third of the country and has succession ranges in age from late Paleozoic to early Tertiary (Abiyuu Hunegnaw et al., 1998). Three formations (Calub Sandstone, Bokh Shale and Gumburo Sandstone) are the lithologic subdivisions distinguished in Ogaden basin which characterized by the continental Karroo deposition that lasted from early Paleozoic to late Triassic or earliest Jurassic times. Paleontological evidence suggests that they are of Ordovician age (Getaneh Assefa, 1988; Saxena and Getaneh Assefa, 1983). The regression of the sea from the Ethiopian region began in late Jurassic as the result of arching and doming of the Arabian- Somalian massif and sediments of varying facies (restricted marine, lagoonal and supratidal to intertidal) were deposited in structurally controlled domains. By late Cretaceous the sea completely withdrew leaving regressive continental clastics deposits (Reynolds et al., 1997). Later on the formation several basins related to east Africa rift systems took place such as the Gambela Basin which is part of the central African rift system and it's the southeast extension of the Melut Basin (White Nile rift) of South Sudan rifting along with volcanism was responsible for formation of the N-S trending extensional rift basins in southern, central and northern Ethiopia. Rift basins/grabens of significantly large size have also been formed at Neogene in relation with or as a consequence of tectonic events that contributed to the development of the east African rift system. Prominent among the Southern rift basins of Ethiopia are the Omo and Chew Bahir basins (Tilahun Mammo, 2012).

## **2.2. Jurassic Limestone formation in Ethiopian Sedimentary Basins**

Carbonate rocks make up about one-fifth to one-quarter of all sedimentary rocks in the stratigraphic record of the world. They occur in many Precambrian assemblages and in all geologic systems from the Cambrian to the Quaternary. Both limestone and dolomite are well represented in the stratigraphic record. Dolomite is the dominant carbonate rock in Precambrian and Paleozoic sequences, whereas limestone is dominant in carbonate units of Mesozoic and Cenozoic age (Ronov, 1983). On the basis of their abundance they are important group of rocks for other reasons they contain much of the fossil record of past life forms. In addition most of the time they are complete with structures and textures that provide invaluable insight into environmental conditions of the past. Aside from their basic value as indicators of earth history they also have considerable economic significance.

Carbonate sediments are commonly formed in shallow oceans either by precipitation from solution or by accumulation and lithification of fragments of preexisting rocks or remains of organisms. These form a sediment composed of particles with a wide range of sizes and shapes mixed together to form a multitude of depositional textures. The sediment may be bound together by encrusting organisms or more commonly deposited as loose sediment subject to transport by ocean currents (Flügel, 2004).

In Ethiopia largest volumes of limestone are located in the eastern part of the country also thick limestone sequences is present in the Blue Nile basin in central and Mekele area in northern Ethiopia. They are the results of the wide spread transgressions and extensional deformation, which is related to the breakup of Gondwanaland that has taken place on the horn of Africa starting from early Mesozoic time (Bosellini, 1989).

In Ethiopia the typical facies of the Jurassic transgression is represented by shallow-water carbonates referred to as the Antalo Limestones and the Hammanlei Formation. They conformably overlie the Adigrat Sandstones and their earliest occurrences (Pliensbachian/Aalenian) are found in the Ogaden (Beyth, 1971; 1972a; 1972b; Kazmin, 1973; Bosellini, 1999; Bosellini et al., 2001; Russo et al., 1994; Mengesha Tefera et al., 1996; Abiyuu Hunegnaw et al., 1998; Abbate et al., 2015). But In the Blue Nile basin the Adigrat Sandstones are followed by the Gohatsion marls and evaporites of Liassic to Callovian age (Russo et al.,

1994). In the Dire Dawa-Harrar and in the Tigray area a younger widespread marine flooding is recorded since the Bathonian and in the Callovian/Oxfordian respectively. These carbonate succession are characterized by several depositional sequences the maximum flooding surface is marked by organic-rich marls and shales and is time-transgressive from Oxfordian (Ogaden area) to Tithonian (Tigray) (Beyth, 1971;1972a;1972b, Kazmin, 1973; Bosellini, 1999; Bosellini et al., 2001; Russo et al., 1994; Mengesha Tefera et al., 1996; Abiyyu Hunegnaw et al., 1998; Abbate et al., 2015). Carbonate deposits in Ethiopia were terminating during latest Jurassic (Tithonian) and Berriasian times due to overall regression Getaneh Assefa (1991) then afterclastic deposits overlies carbonate units throughout most part of Ethiopia starting from this time.

According to Asfawossen Asrat (2015) more than 100,000 sq km of carbonate rocks are exposed in Ethiopia. These are widely exposed in the Mekelle, in the Blue Nile basin and in the Ogaden Basin (including the Bale and Western Harrarghe areas). Jurassic limestones in Ethiopia have various names according to its type locality throughout the country, example: Antalo Limestone Formation (in Abbay, Mekele and Dire Dawa area), Hammanlei Formation, Urandab and Gabredarre Formation (in Ogaden basin and Harrar) (Kazmin, 1973; Blanford, 1869; Beyth 1972a;1972b; Bosellini et al,1997; Getaneh Assefa 1991; Russo et al, 1994).

Jurassic limestone outcrops found in Southeastern has a total thickness of about 800m (Asfawossen Asrat, 2015). This unit is conformably overlain by Jurassic shale and consists of mudstone to bioclastic limestones intercalated with marl and sandy limestone (Kazmin, 1973; Greitzer, 1970; Bosellini et al., 2001).

### **2.3. General Stratigraphic Succession of Southeastern Ethiopia Plateau**

Different studies (Blanford, 1869; Currie, 1943; Kazmin 1973; Merla et al., 1979; Greitzer, 1970; Bosellini et al., 2001; Bosellini, 1999; Shigut Geleta, 1998; Mengesha Tefera et al., 1996; Abiyyu Hunegnaw et al.,1998; Balemwal Atnafu and Tesfaye Kidane, 2012; Asfawossen Asrat 2015; Abbate et al, 2015; Asfawossen Asrat et al., 2008; Gebreyohannes Habtezeghi, 1984;Kibrie Tadesse and Yirga Tura 2008; Workineh Haro, 2010) have confirmed that stratigraphically wide rock units were present in Southeastern Ethiopia which ranges from older Precambrian up to recent.

Precambrian rocks are the oldest rocks in the area up on them younger rocks possibly upper Paleozoic and lower to upper Mesozoic sedimentary rocks were laid down. Mesozoic sedimentary rocks are followed by Cenozoic volcanics and Quaternary sediment.

These wide range rocks in Southeastern Ethiopia have been categorized in to different groups (E.g. Kazmin 1973; Greitzer 1970; Bosellini et al., 2001; Bosellini 1999; Mengesha Tefera et al., 1996; Abiyyu Hunegnaw et al., 1998; Gebreyohannes Habtezeghi, 1984; Asfawossen Asrat 2015; Kibrie Tadesse and Yirga Tura 2008; Workineh Haro 2010; Balemwal Atnafu and Tesfaye Kidane, 2011). They broadly fall into exposures of major stratigraphic units: Precambrian rocks, Mesozoic sedimentary rocks, Cenozoic volcanic and quaternary deposits. According to these authors Precambrian rocks encompasses Archean to Proterozoic rocks of low grade rocks and gneisses which are underlain Mesozoic sedimentary rocks unconformably. Mesozoic successions are highly exposed in these area and they occurred between Late Triassic to end of Jurassic.

Mesozoic succession of Harrar area is generally divided into the following units from old to young they include: lower sandstone, lower and upper limestone and upper sandstone (Kazmin 1973; Greitzer, 1970; Workineh Haro, 2010; Balemwal Atnafu and Tesfaye Kidane, 2011). The Cenozoic volcanics above these sediments are thick and covering the plateau with maximum thickness development in the northwestern part. The rift plain and parts of major eroded valleys on the plateau contain Quaternary sediments of alluvial, possibly lacustrine origin, and alluvial fans related to fluvial activity.

The classification made by most of authors put the general stratigraphic units of area as follows based on their age: Precambrian crystalline basement, Mesozoic sedimentary rocks, Cenozoic volcanic and quaternary sediments. Based on this classification the rocks discussed sequentially from older to younger as the following:-

### **2.3.1. Precambrian crystalline basement Rocks**

Precambrian crystalline basement rocks are the oldest rock (Archean to Proterozoic rocks) in Harrar area and overlain Mesozoic sedimentary rocks. The basement rock units are mostly built of granite, gneiss and schist (Greitzer, 1970; Mengesha Tefera et al., 1996; Merla et al., 1979).

### **2.3.2. Mesozoic sedimentary rocks**

Mesozoic sedimentary successions are widely exposed in Harrar area and overlain by the volcanic rocks and Quaternary deposits. The known transgression responsible for their deposition is from SE to NW direction (Kazmin, 1973; Greitzer, 1970). Mesozoic Sedimentary succession of the Harrar area comprises 1) Adigrat Sandstone 2) Hammanlei Formation 3) Urandab Formation 4) Gabredare Formation and 5) Ambaradam formation from bottom to top. Each of them is described below separately:-

#### **A. Adigrat Sandstone (Lower sandstone)**

The Adigrat Sandstones are widespread in Ethiopia and with correlative units in the whole of east Africa and Arabia deposits (Kazmin 1973; Blanford 1869; Abbate, et al., 2015). In Ethiopia, they commonly rest unconformably on the Paleozoic and basement rocks except in some part of Ogaden basin where they are probably conformable with the Permo-Triassic Karro deposits (Abiyyu Hunegnawet al., 1998).

In Harrar areas Adigrat sandstone is the older sedimentary rock and it unconformably overlies the Precambrian basement rocks and it is exposed in many areas extending from western part to the eastern part. It always lies below the lower limestone and shows reddish, whitish, pinkish and grey in color (Greitzer, 1970; Mengesha Tefera et al., 1996). The contact with the overlying lower limestone is sharp and at places it grades to calcareous sandstone and also grades to limestone. The sandstone is coarse grained cross-bedded and shows general up ward fining. Lithologically the sandstone can be subdivided into two sub-units that is lower red sandstone which is argillaceous with medium beds and angular grains while the upper portion of sandstone is clean massive thickly bedded, hard and homogenous. Adigrat clastic is fluvial continental sediments origin and is fossil free accumulated from late Triassic to early Jurassic (Kazmin 1973; Gebreyohannes Habtezeghi; 1984; Bosellini et al., 2001).

#### **B. Limestone units**

Jurassic limestone of Harrar area is found overlying the lower sandstone (Adigrat sandstone) and consists of distinct members or parasequence sets.

Many authors classify the carbonate units of Harrar into different groups based on different criteria. E.g, Kazmin (1973) group Hammanlei series of marine succession into three units from bottom to top as: - oolitic, dolomitic limestone with intercalation of marl and sandstone (unit one), unit two contains grey oolitic limestone with subordinate beds of red and yellow limestone and finally limestone with concretions of chert and druses of quartz as (unit three).

In Ethiopia Jurassic limestones have various names according to its type locality throughout the country example: Antalo Limestone formation (in Abbay, Mekele and Dire Dawa area) and Hammanlei, Urandab and Gabredarre formation (in Ogaden basin and Harrar when listed from bottom to top. Each these formations of Harrar limestones are discussed below as follows:

**a. Hammanlei Formation**

Hammanlei formation or lower limestone consist predominantly limestone and dolomite which has a gradational contact with Adigrat sandstone (Kazmin, 1973). This unit consist of macro and microfossils and mostly intercalated with marl, dolomite and some sand in its lower part. It is widely exposed in many areas extending from western to eastern part in Harrar areas and covers an area of about 2704 sq. km (Workineh Haro, 2010). It is commonly exposed along the valleys of streams in the area and presents the first marine sediments formed by the flooding of the sea. In many of its exposure the limestone forms mountain chains and isolated hills.

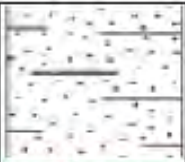

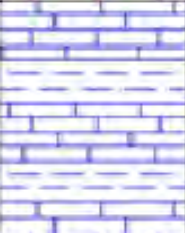
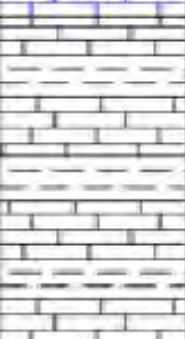
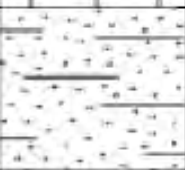

Bottom section of the limestone succession is marked by sandy limestone, marl and dolomites and grading upward to complete carbonate rocks (Greitzer, 1970; Kazmin, 1973; Kibrie Tadesse and Yirga Tura, 2008). This units was deposited in shallow marine condition.

According to Greitzer (1970) most of the lower parts of these units are composed of oolitic dolomitic limestone, marl, some sand, oosparite, intraclastic with bioclasts. The upper part of this unit is mainly oolitic with various colors of reddish, yellowish and grayish. Based on the macro and micro fauna present Bathonian to Callovian age is assigned.

**b. Urandab Formation**

Urandab comparable with Antalo formation occurs in the eastern and southern parts of the country. The formation generally shows light grey to grey colored mudstone-wackestone succession with very minor grainstone beds development (Mengesha Tefera et al., 1996; Kibrie

Tadesse and Yirga Tura, 2008). From the index microfossils present age of the unit was assigned to be Callovian to Oxfordian (Greitzer, 1970).

Age	Thickness	Lithology	Formation
Aptian-Albian	758		Upper sandstone
Kimmerdigian	408		Gerbadare formation
Callovian-Oxfordian	398		Urandab formation
Bathonian-Callovian	348		Hammanlei formation
late Triassic-Bajocian	120		Adigrat sandstone
?	33		Basement
	0		

*Fig 2.1. Stratigraphy of Harrar area geologic unit's .With their age and formation (after Greitzer, 1970).*

### **c. Gabredare Formation**

Gabredare Formation also known as upper limestone rests on the Urandab formation comprises fossiliferous limestone, black limestone, sandy and silty limestone and includes faunas such as: bivalves, brachiopods, gastropods, echinoderms, corals, sponges, foraminifera and ammonites. The maximum thickness of this formation is about 200m and covers an area of about 390 km<sup>2</sup>. The age of Gabredare formation is assigned to be lower Kimmerdgian- Tithonian (Greitzer, 1970; Workineh Haro, 2010; Kibrie Tadesse and Yirga Tura, 2008).

### **C. Ambaradam Sandstone (Upper Sandstone)**

Ambaradam sandstone is the name given for the regressive upper parts of the sandstone unit. It presents coastal clastic unit and considered as part of Cretaceous clastic sediments (Mengesha Tefera, et al., 1996; Kazmin, 1972). In Harrar area the upper most sandstone unit above the Jurassic carbonates marks the last phase of sedimentation and has a gradational contact with the underlying Gabredare formation. This succession records many sea-level oscillations and represents the final stages of the Mesozoic flooding in the Ogaden basin. Based on the Paleomagnetic investigation of intercalated marine limestone beds within the Upper Sandstone unit done in south-eastern Ethiopia around Hirna area by Balemwal Atnafu and Tesfaye Kidane (2012) it is estimated to be Aptian-Albian age.

#### **2.3.3. Cenozoic volcanic**

The top most of the stratigraphic section in Harrar is thick volcanic rock capping the upper sandstone. Cenozoic volcanic rocks covering the plateau areas are basalts. But younger fissural volcanic and pyroclastics possibly after the main Miocene rifting of east Africa are also present. These are exposed within the rift plain and at the foot slope of the rift escarpment (Gebreyohannes Habtezeghi, 1984, Mengesha Tefera et al., 1996).

#### **2.3.4. Quaternary sediments**

The rift plain and parts of major eroded valleys south eastern plateau contain also Quaternary sediments of alluvial possibly lacustrine origin and alluvial fans related to fluvial activity exist (Workineh Haro, 2010).

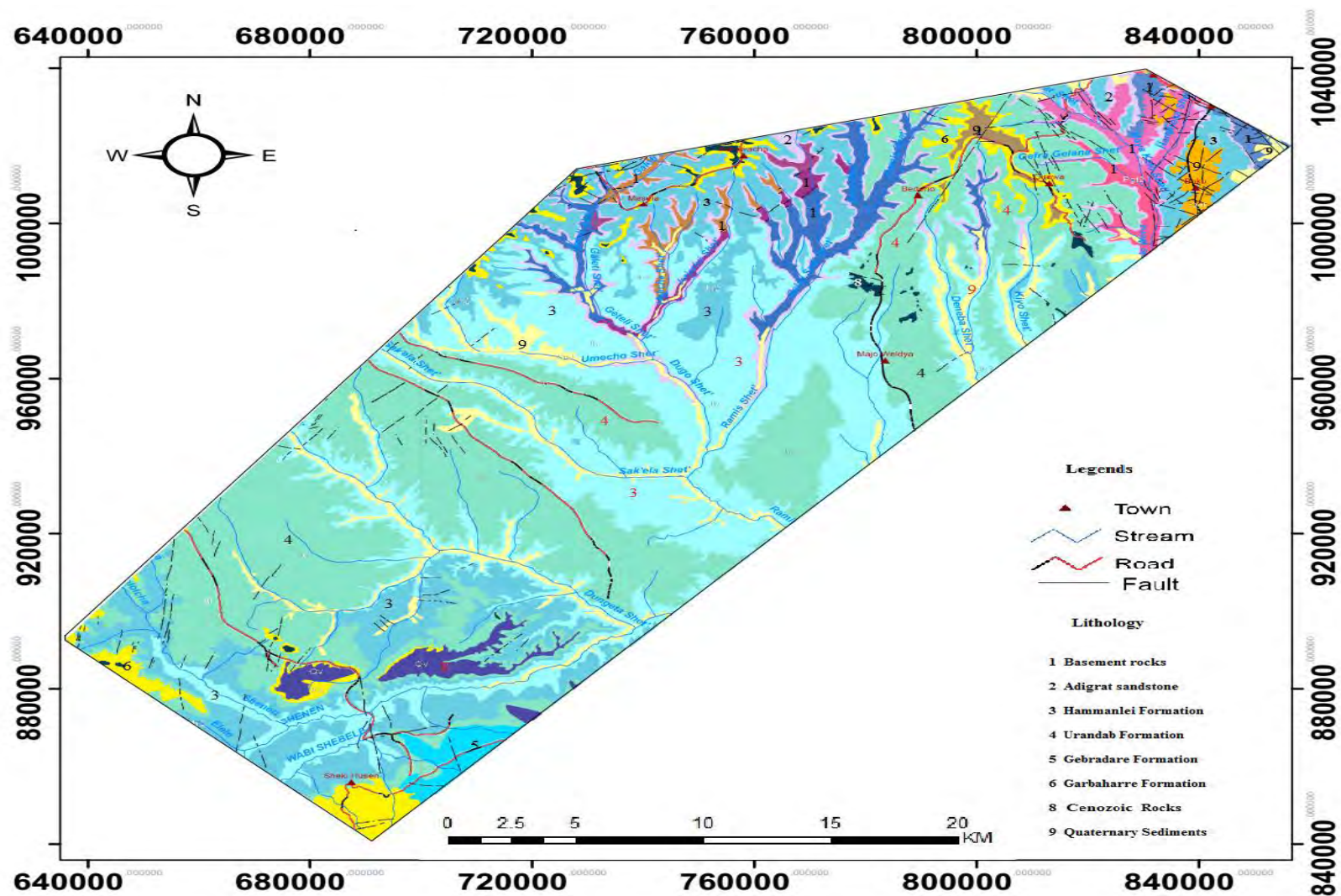


Fig 2.2. Existing geologic map of Harrar area, cropped from the regional geological map of south eastern Ethiopia (after Assaminew Gebeyehu and Seifu Kebede, 2012)

#### **2.4. Jurassic fossils in Carbonate units of South Eastern Ethiopia Plateau**

Previous works, (e.g., Blanford 1869; Jaboli, 1959; Currie, 1943; Kazmin, 1973; Gortani, 1942, Greitzer 1970) report on many collections of both micro and macro fossils in Southeastern Ethiopia. Most of this works just mentioned fossils of this area in a geological context, neither described in detail nor figured except some of the works done by Jaboli (1959) Gortani(1942) and Greitzer (1970) which describe and figure most of invertebrate macrofossil present in the area. Specifically fossils of Harrar province which are upper Jurassic and cretaceous in age were also studied by authors from American museum of Natural history in the Dudley expedition in (1943) also Kazmin (1973) list the fossils found in Hammanlei succession of Harrar area after he subdivides the formation into three different units as follows:-

Unit one and two of Hammanlei which are oolitic, dolomitic limestone with intercalation of marl and sandstone and oolitic limestone with subordinate beds of red and yellow limestone contain Microfauna's such as: *trocholina*, *palastiniensis* Henson gr., *paleonorbodyes* sp., *nautiloculina circularis*, void and baraket, *pfenderina* sp., *kilinina blanchet.*, *pfender* (25 m below the top of the unit 2) *Hurania* sp., *kurnubia palastiniensis* Henson gr, (at the top of the unit). Macrofossils include: *milleporidium zuffardae* wells, *septirhynchia azaisi cottreu*, *eocallista krenkeli coxlima(plagiostoma)* Harronis dacque and Corals: *actinostroma paraesalevensis zuffardi commerce*, *miliopordium zuffardiae wells* and the age is considered to be Bathonian-Callovian presumably Bajocian for the lower most part. Unit three which has concretions of chert and druses of quartz has micro fossils of; *ammobaculites* sp., *pseudocyclamina litus yokayama*, *chrysalidina (dukhani)* sp. and macrofossils include Ammonite *planites anabreviceps dacque*, and Mollusks: *amphiastrea gibberosa* Gregory, *isastroconia lobata* Gregory, *somlirynohia Africana* var, *jordanica noetlopha* of *gregarea* Sow. Echinoid; *Hemicidaris (hypodiadema)*, *macfadyenia crria*. Corals: *actinostroma darroensis zuffardi, comerci*, *stylina macfadyeni* Thomas, *thamnasteria aetiopia* well's in lower part the following. The age of unit three is Callovian-Oxfordian.

Kazmin, (1973) and Greitzer, (1970) just list fossils present within the formation however other studies carried out by Jaboli (1959) and Gortani (1943) describe Jurassic macrofossils of the area in species level with figures, however they didn't work on microfossils.

## CHAPTER THREE

### 3. STRATIGRAPHY OF SHANAN SECTION

#### 3.1. Introduction

Shanan section is found in western Harrarghe of Southeastern Ethiopian Plateau. In Shanan section thick Jurassic carbonates particularly Callovian to Oxfordian in age was deposited. In order to explain the depositional facies and sedimentary environment, detailed microfacies analysis of carbonate rocks of section was investigated. The rock units are described according to their stratigraphic succession as composite stratigraphy is given on (Fig.3.9), according to their vertical contact relationship in the field.

In this section carbonate rocks are highly exposed in road and following Shanan River. The detailed local stratigraphy for carbonate successions of the area are described based on the field observations and petrographic studies. The thickness of carbonate unit of the area is varying from bottom to top throughout the section which most probably shows the sea level fluctuation during their depositions.

Lithologically limestone in this section range from mudstone to grainstone and common lithologic and facies changes were vertically observed. The sequence consists of thin-thick bedded grayish micritic, bioclastic, peloidal and ooid limestone rocks with some marl intercalations in the lower most part and grayish bioclastic, intra and peloidal packstone to grainstone at middle part of the section and top part of Shanan section is dominated by dark gray blackish, grayish and reddish mudstone and bioclastic wackestone with some intercalations of marls and rare cherts. The upper most part of the section is intruded by a dike.

Based on their age, compositional and paleontological assemblage differences the carbonate sequence of Southeastern Ethiopian plateau are known by names like 'Hammanlei, Urandab and Gebredare formation by different workers. The name 'Hammanlei Formation' is used for Shanan section carbonate unit based on the age and lithologic property observed in this section is somewhat similar to that of Hammanlei as given by (Kazmin, 1973; Greitzer, 1979; Mengesha Tefera et al., 1996; Kibrie Tadesse and Yirga Tura 2008; Workineh Haro, 2010 and Assaminew

Gebeyehu and Seifu Kebede, 2012). Based on the dominant facies observed in the section the local section divided as lower Shanan for layers from bottom up to 56 m thickness, middle Shanan with around 45m thickness found overlying the lower Shanan and upper Shanan represent a thickness of around 60m. This classification is based on the lithological characteristics, dominant facies present within them and their association to indicate depositional environment.

The detailed local stratigraphy for carbonate successions of the area is described based on the field observations and petro graphic studies as follows:-.

### **3.2. Lithostratigraphy of Shanan Area**

The Hammanlei sequence is well preserved carbonate deposits present in Shanan section (Fig 1.2). In the field carbonate deposits of the area were logged and measured to give detail bed to bed descriptions based on their lithology, colors, sedimentary structures, textures, fossil contents, stratigraphic relationships and their geometries.

The carbonate sediments in Shanan section are well exposed and characterized by forming a continuous cliff forming escarp (steep slope).Carbonate unit in this area has a succession of around 161m thickness and have various rare invertebrate fossils of gastropods, brachiopods, echinoids, bivalves, crinoids, etc. Carbonate unit of this section is affected by the basaltic dike (Fig 3.6) at its upper part which is represented by cutting the formation.

Thick micrite dominate the studied facies (Fig 3.1) which varies in color from (grayish, dark-gray blackish and reddish) while grainstone, packstones and wackestone elements are the sub-lithofacies showing a fair representation. Micrite varieties of the limestone are seen to include silica lenses cherts at upper Shanan section (Fig 3.5). The underlying and overlying units with this carbonate rocks are not outcropped in this local Shanan section.

At about the start of the section (lower Shanan) the limestones are generally micritic to allochemical (skeletal, peloid and ooid grains) in some cases some sparry calcite crystals are observable. Light grayish color and well consolidated thin to thick bedded hard rock's are common characteristics of lower Shanan carbonates. Middle part of the Shanan section (middle Shanan) carbonates lithologically become rich in allochems of intra also skeletal with some

peloids showing deepening up succession. Allochemical grains are mostly embedded within sparry calcite cements in dominant and/ or in micrite at some place. Most top part of Shanan section (upper Shanan) is dominated by bioclastic and micrite limestones. The micrites on upper Shanan section are grayish, dark gray-blackish and reddish in color.

Throughout the section mode of preservation for most of fossil is mainly in forms of mold (Fig 3.8, B) but some casts and very rare skeletal fossils are also observed. Macrofossils are rare and not well preserved. The common observed macro invertebrate fossils are brachiopods, bivalves, gastropods, echinoderms and crinoids. Bioturbation is commonly observed at different place in the section (Fig 3.8, A).

Thin-thick bedding, planar lamination and cross bedding (Fig 3.7, A) are the common sedimentary structures observed in the section. Although secondary structures such as dike, joint and stylolites (Fig 3.7, B) are present.

Detail description of carbonate layers of Shanan section differentiated in the field will be discussed as follows from bottom to top based on their lithology, colors, sedimentary structures, textures, fossil contents, stratigraphic relationships and their geometries:-

At the bottom of lower Shanan from base to around 17 m (samples Shan 1-5) consists of grayish; thin to thick bedded micritic limestone with rare fossils of bivalves also bioturbation is present. The contact between lower Shanan with underlying unit is not outcropped. Above this 3-m thick bioclastic grainstone layer was deposited and followed by 14m- thick interval of carbonate layer which consist micrite to grainstone alternation. Grainstone at the bottom and micrite in the top part dominate this interval (Samples Shan 6-Shan15). Bioturbation is very commonly observed on these layers.

Samples Shan 16-Shan 20 (8 m) are micritic to grainstone limestones in some cases some sparry calcite crystals, bioclasts and peloids grains are observed. The overlying around 15-m thick unit is interval of mudstone–grainstone alternation with oolitic limestone dominance on the top (Shan 21-Shan 27). Ooid grains are mostly embedded in sparite (Shan 26 and 27) and in some rare case in micrite (Shan 25) when observed under thin section. Cross bedding structure is clearly observed on this oolitic layer.

Carbonate rocks of Shanan section which grouped in middle Shanan are seen following the above discussed oolitic layer. 9 m thick mudstone to grainstone rocks with abundant bioclast and intra grains is the base for middle Shanan facies layers. Overlying this thick (11m) bioclastic and intra grainstones within micrite matrix and in rare case with in sparry calcite (Shan 33 and 34) is observed. Following this a 25m thin-thick bedded mudstone - grainstone layer (Shan 35-Shan 39) with grainstones layer dominance is deposited. Grains of intra, bioclast and peloids are dominant also very rare ooids in their lower is seen.

Upper Shanan section is dominated by micritic and bioclastic wackestone layers. Rare grainstone layer with grains of bioclast and some ooid is also observed on the top end of these units (Fig 3.9). Samples of Shan 40-50 except 41 and 49 which are marl sample are representatives of upper Shanan and have 60m thickness. These upper part layers vary in color from grayish, dark gray blackish and reddish in color. Sedimentary structures such as thin to massive bedding and rare cross bedding on the top end part are observed. Many stylolite and thin chert layers are also observed within this units those indicate their depositions in deep low energy environments.

Upper Shanan has dark gray blackish units at its base which has most dominantly fine grained dark micrite materials with very rare amounts of bioclasts. This unit is conformably overly the bottom grainstone layers of the middle Shanan and has a thickness of around 4 m. Dark gray blackish unit is followed by massive beds of grayish micritic limestone which has very rare intercalation of marl. It has the total thickness of 35m. Between massive grayish micrite unit and the top end reddish limestone layer of upper Shanan there is around 8 m where there is no observable outcrop because of the vegetation cover. Following the vegetation cover the reddish limestone layers which varies from mudstone to grainstone is present. At their bottom around 10m these reddish layers are mudstone with marl intercalation. Top part of these layers becomes rich in allochems of bioclast and rare ooid with cross bedding structure on it.

All of the above mentioned units are logged at Shanan section according to their ascending order, as given in (Fig.3.9) and described according to their dominant facies in detail as follows:-

### **3.2.1. Micritic limestone layers**

Micritic limestones of Shanan section are found as red, dark gray blackish and dominantly grayish in color and when found most of the time intercalated with marl. Within these micrite layers there are very rare amounts of other allochems like skeletal grains. Some of the micritic limestones are bioturbated (Fig 3.8, A) but at some place they are free from any bioturbation and highly intercalated with marl.

At the bottom of the section about 17 m thick beds of fine grained, light gray micritic limestone are exposed and rare quartz grains are also observed. In upper section micritic limestone layers are thin to Massive bedded and fine grained with rare amounts of bioclasts and intercalated with rare marl and lenses of chert also observed between them (Fig.3.5). Secondary structures such as stylolite and dike are seen.



Fig. 3.1. *Thick beds of micrite layer exposure at upper Shanan section.*

### **3.2.2. Bioclastic limestone layers**

The bioclastic carbonate layers in Shanan section are found in different places through the section. In lower Shanan they are found overlaying the micritic limestone unit discussed

above. They are characterized by mostly grayish color and thin to medium bedded with some shell fragments. Most of the time these layers present intercalated with marl also bioturbation is very commonly seen on these layers.



Fig 3.2. *Thin-thick bedded dark-gray blackish micritic limestone layers. Photo taken at upper part of Shanan section.*

### **3.2.3. Bioclastic peloidal packstone to grainstone layers**

The bioclastic wackestone layers found in the lower Shanan section discussed above are overlain by bioclastic peloidal packstone to grainstone layers. They have dominant peloid grain with rare amounts of skeletal grains such as gastropod, algae and foraminifera imbedded within sparry and/or micrite calcite. Micrite layers are also seen within these layers.

### **3.2.4. Ooid limestone layers**

These carbonate layers have a thickness of around 24m. They are dominated by packstone to grainstone layers rich in ooids at top and bioclasts. All of these components are ranging in size from finer to sand-sized carbonate grains. Rare beds of micritic layers also exist. Cross bedding

and thin-thick massive bedding is common sedimentary structures observed. These grainstone layers are lithified forming horizontal beds of grainstone which is the result of reworking by wave and tidal currents at these margins. Ooid and other grains decrease upward and matrix materials increase upwards.



Fig 3.3- *Thin-thick bedded dark-gray blackish micritic limestone layers with marl intercalation. Photo taken from upper Shanan.*

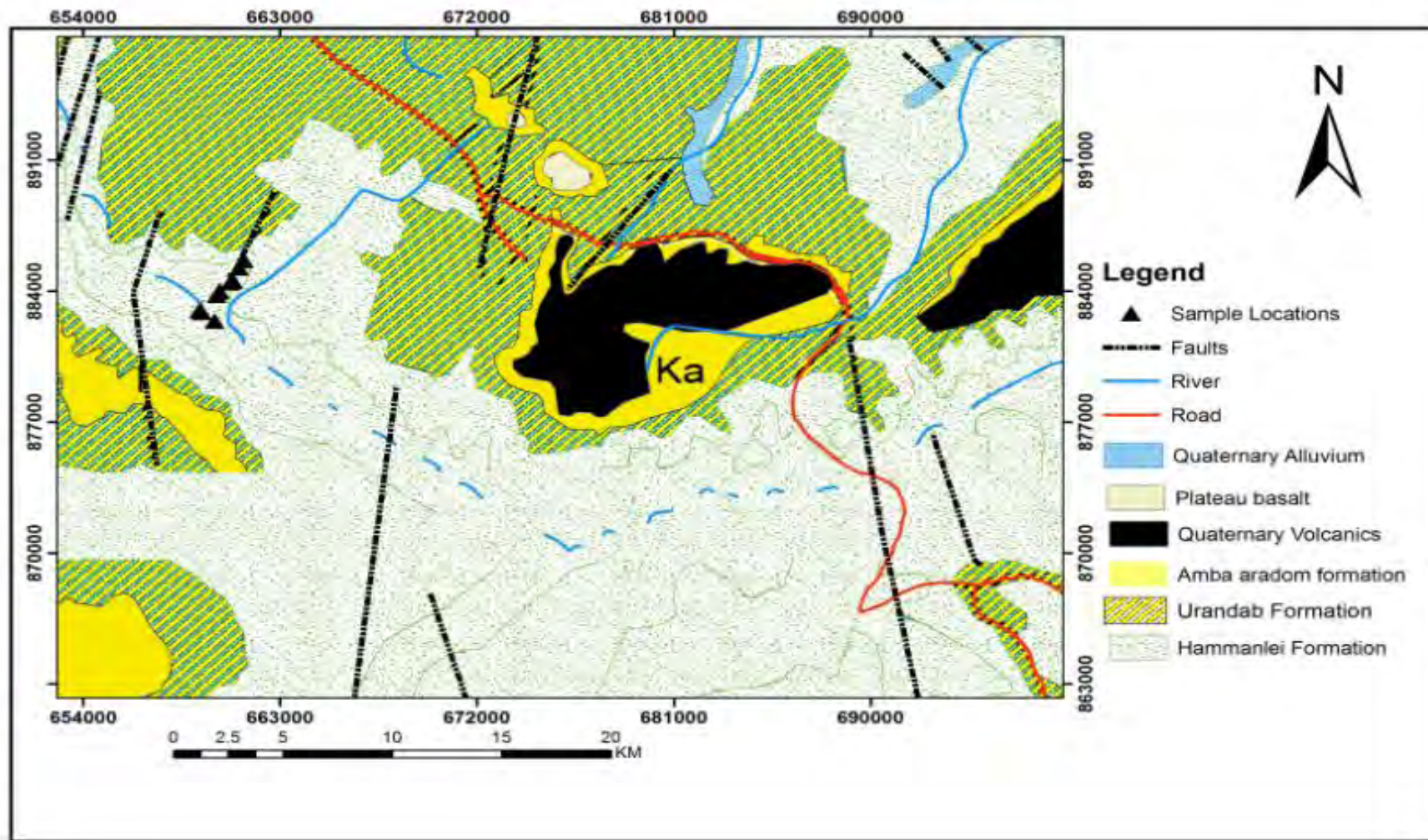


Fig 3.4. Existing geological map of Shanan section area cropped and modified from the regional geological map of south eastern Ethiopia (after Assaminew Gebeyehu and Seifu Kebede, 2012).



Fig.3.5. *Chert lenses (silica lenses) imbedded within massive micritic limestone. Photo taken at upper Shanan section.*



Fig 3.6:-*Dike which cut dark gray-blackish carbonate layers found in upper Shanan section.*

### **3.2.5. Packstone-Grainstone limestone layers**

These units are characterized by various dominant grains of intraclast and bioclast with some peloids thin to thick mudstone layers are also present. They are dominant in the middle Shanan section. The grains are embedded within the sparite dominantly with rare amounts of micrites at places. They are grayish in color and have the total thickness of about 45m. This layer can be subdivided again into two sub-layers, the bottom and top peloidal and bioclastic rich part and middle intraclast rich part. From the bottom to the top the intraclast grains are decreasing and the layers become dominated with the peloids and bioclastic grains. The repeating components in this thick grainstone layer are showing upward deepening throughout this layer in that the lower wackestone-packstone topped by packstone to grainstone above it those in turn overlain by next mudstone to wackestone layers above it.

Micritic layers found on the upper Shanan section are mostly massively bedded. The dark-gray blackish layer which has a total thickness of about 3m is the base for the upper Shanan section micritic carbonates and these layers conformably overlying the packstone-grainstone layers at the bottom. 38 m thick to massive bedded grayish limestone overlies the dark-gray blackish limestone. This layer is dominantly micritic and in between a lens of chert is observed. At some place Stylolites are also seen on these layers.

### **3.2.6. Reddish limestone layers**

Following thick to massive grayish micritic limestone layers found in the upper Shanan section there is around 8 m of non visible outcrop due to vegetation cover. The vegetation covers are followed by reddish limestone layers and range from mudstone to grainstone. They are found on the top end of upper Shanan and have a thickness of about 14 m. At its lower part with around 10m this reddish layers are pure micrite and highly intercalated with marl. The top around 4m they become completely grainstone with grains of bioclast and ooid. Cross bedding sedimentary structures is seen on the grainstone layers.

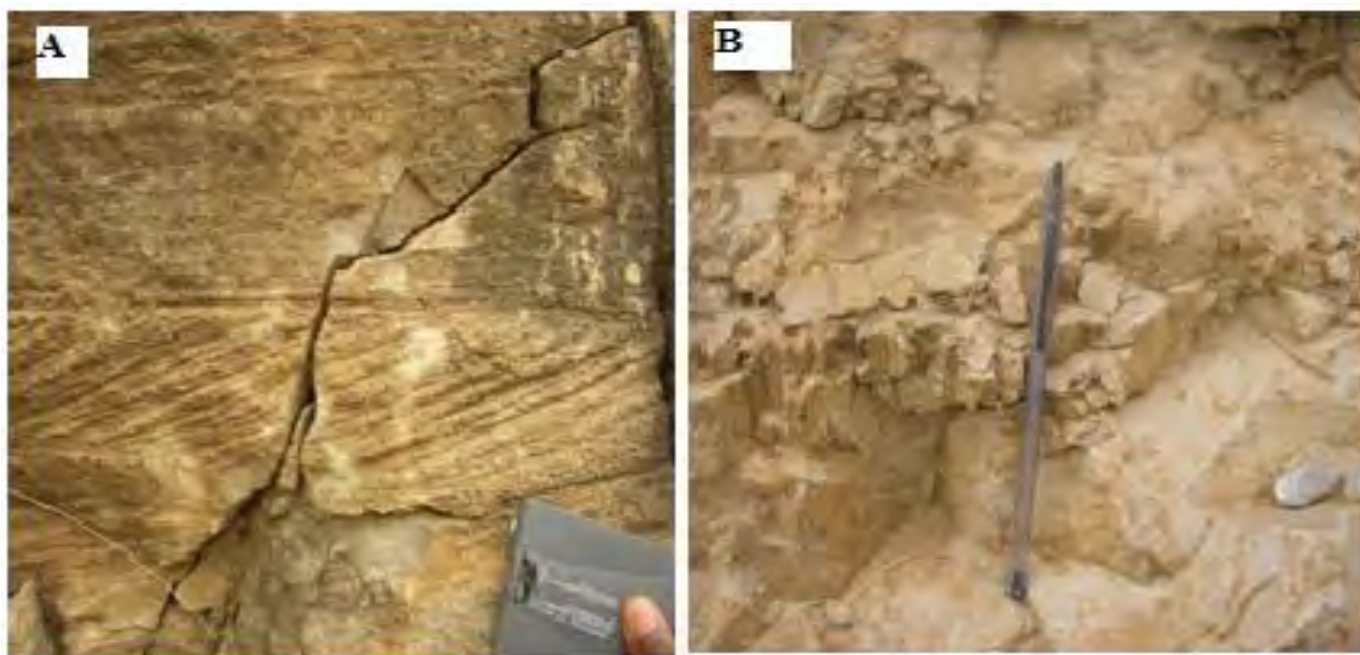


Figure 3.7:- A) Cross bedding structures on massively bedded oolitic limestone layers at Lower part of the section. B) Field photo showing stylolites on massively bedded micritic layers at upper Shanan.

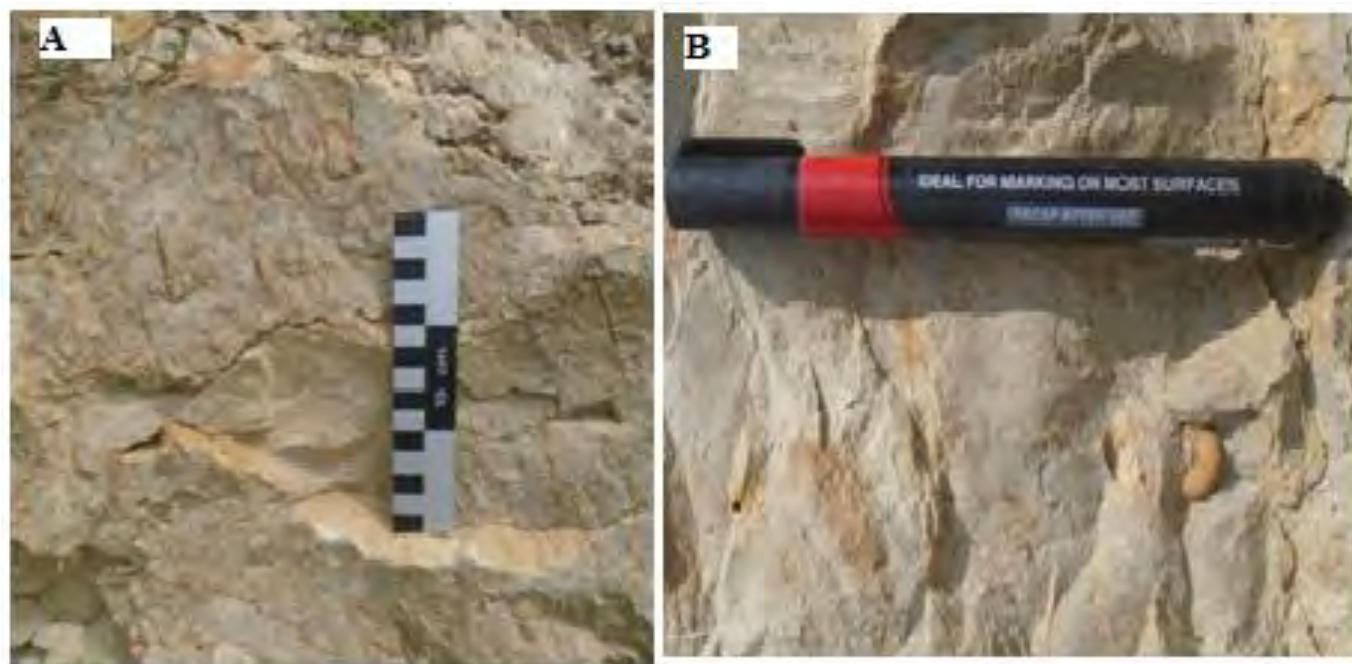
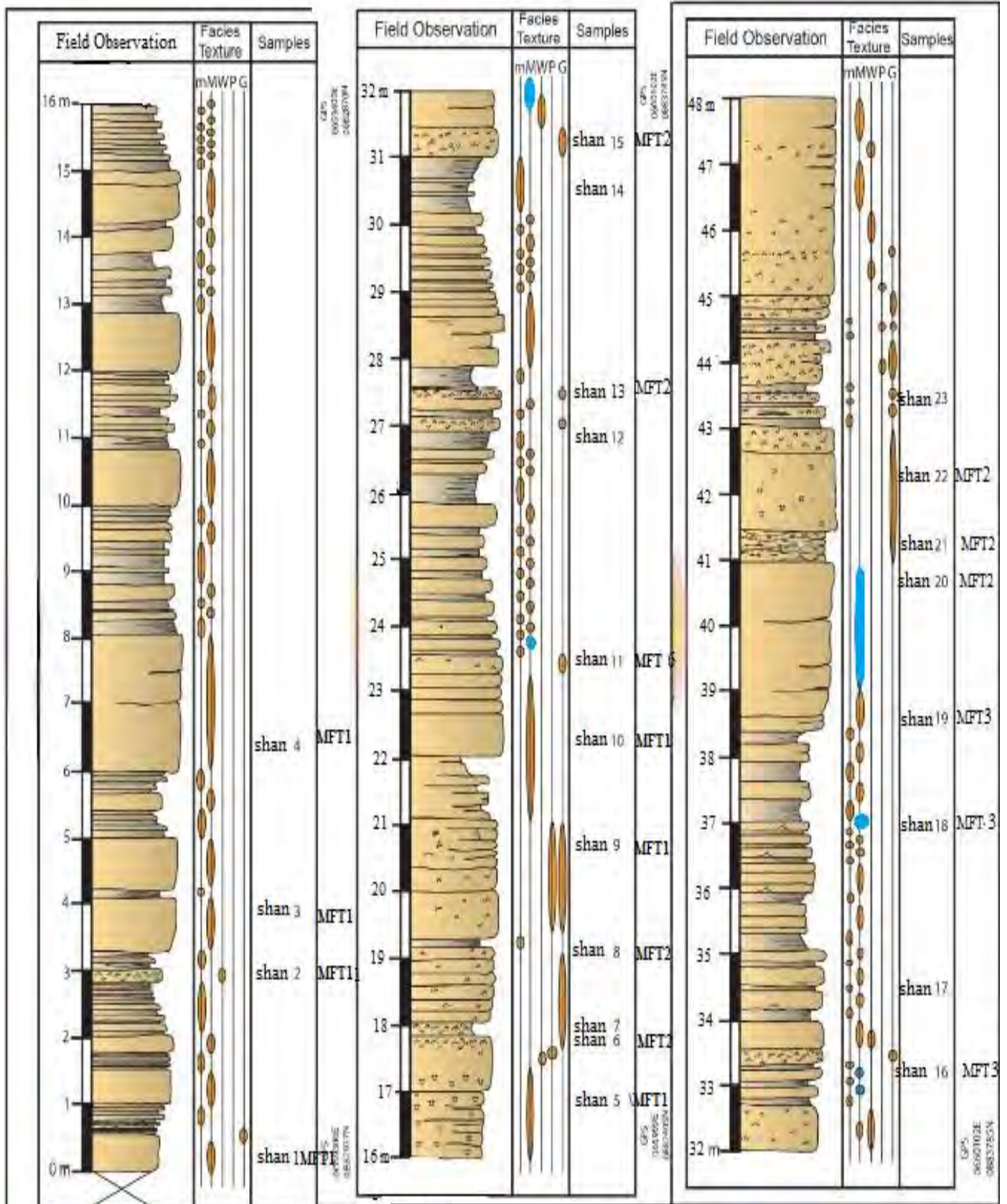
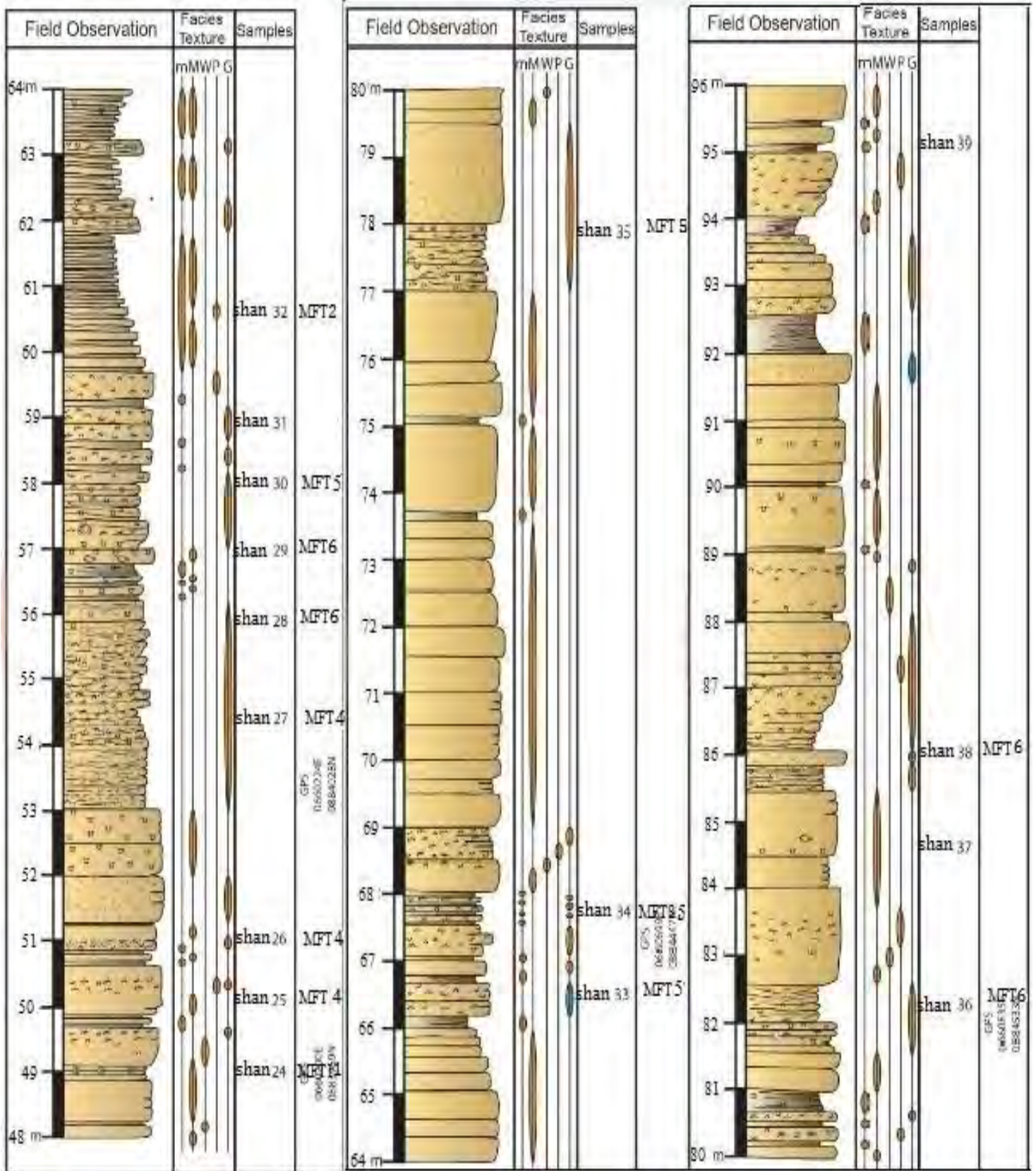
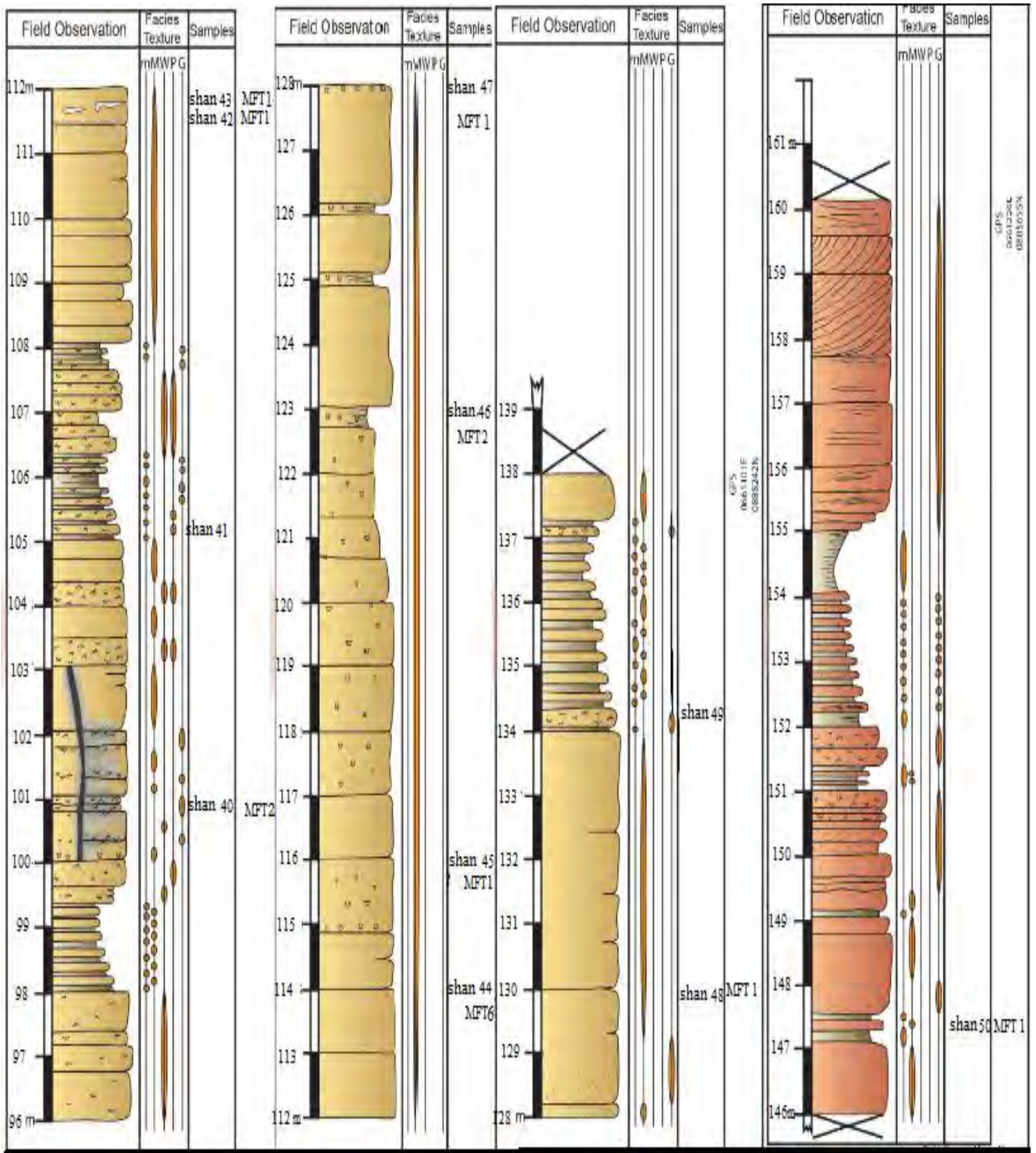


Fig 3.8:- A) Highly bioturbated limestone photo taken from bioclastic layers of lower Shanan B) Gastropod fossil preserved as mold.







**Legend**

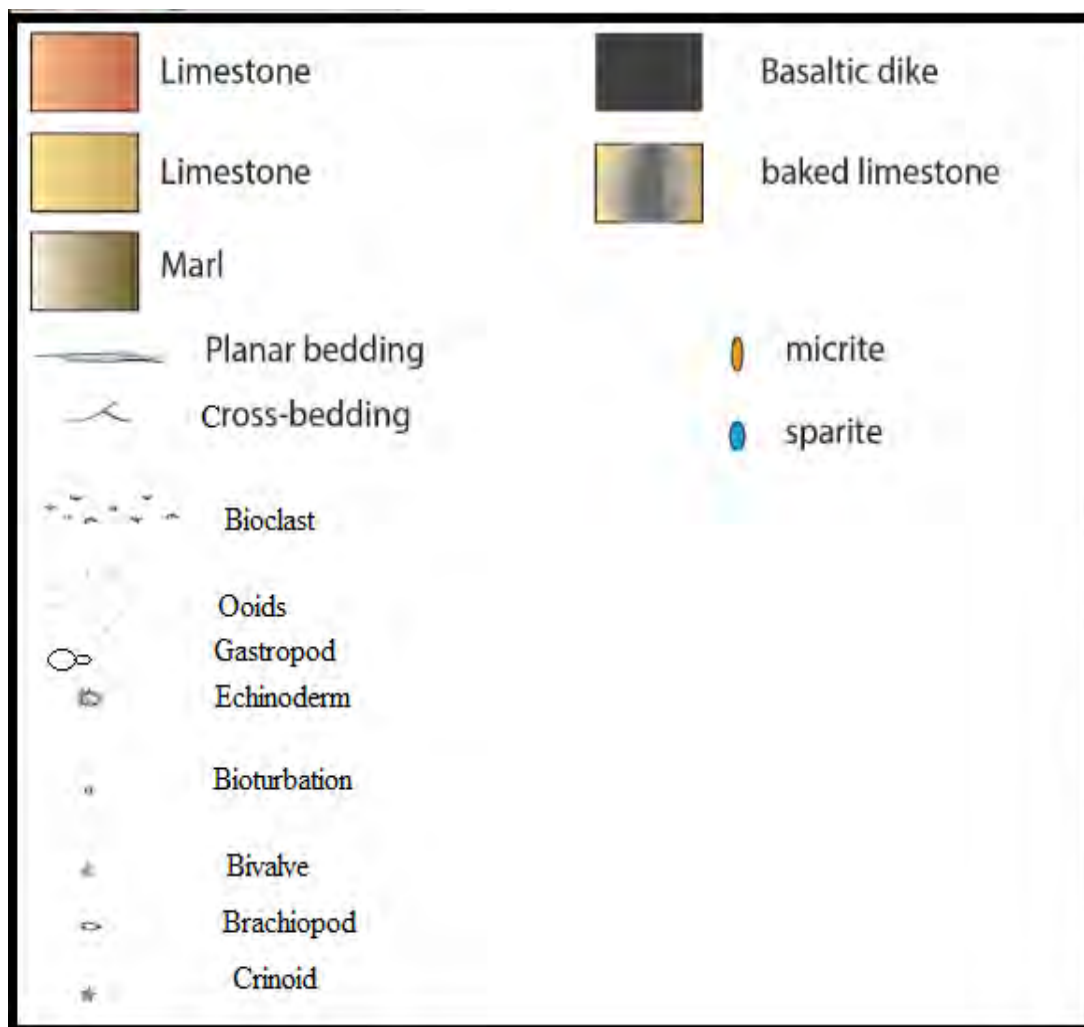


Fig 3.9:- *Detail Stratigraphic column of carbonate exposures of Shanan section. Show the description for each lithologic units, collected samples, fossils, structures and microfacies type.*

## CHAPTER FOUR

### 4. PETROGRAPHIC DESCRIPTION AND MICROFACIES ANALYSIS

#### 4.1. Petrographic Descriptions

Carbonate rocks can be classified based upon the criteria characterizable either in thin-sections or hand specimens such as matrix, cement and particles. There are different systems of carbonate rock classification based on different criteria's. Among these the most commonly used classifications are those of (Folk, 1962 and Dunham, 1962). Both classifications are based on the particle fabric and on the kind of particle binding during sedimentation.

In addition to field observations made in Shanan section detail explanations of 40 representative carbonate samples were made under petrographic microscope. According to the petrographic analysis various major carbonate components like allochems of skeletal grains, ooids, peloids and intraclasts and interstitial materials (microcrystalline calcite ooze/micrites and sparites) are identified.

All of the analyzed samples are a limestone but they are varying in abundances and sizes of components and allochems from place to place throughout the studied section. The proportions among various carbonate components in all collected samples were identified and the rocks are classified according to Dunham (1962) and Folk (1962) carbonate classification schemes as shown in (Table 4.1). Texturally the collected samples shows various carbonate textures ranging from Mudstone (14 of total sample), Wackestone (10 of total), Packstone (7 of total) to Grainstones (10 of total), and grain sorting is poorly sorted to well-sorted.

From this petrographic description the carbonate unit of section contains: - Mudstone, Wackestone-Grainstone of peloids, skeletal grains, ooid and/or intra. All these petrographic properties with their depositional environment interpretation are discussed. Also the photomicrographs of some of the collected samples with their petrographic descriptions are given.

Table 4.1: Petrographic descriptions of carbonate rocks samples collected from Shanan section.

Petrographic description of carbonate rocks in shanan section										
S. No.	Major Rocks Component							Rock Name		
								Dunham	Folk	MFTs
	Allochems				Interstitial materials		Other			
Sample Code	Fossil	Ooid	Peloid	Intra	Micrite	Sparite				
Shan 1	4				58	22	15	Mudstone	Micritic	MFT1
Shan 2	5				83		12	Mudstone	Micritic	MFT1
Shan 3	2			3	88		7	Mudstone	Micritic	MFT1
Shan 4	3	2			65	15	15	Mudstone	Micritic	MFT1
Shan 5	4				85		11	Mudstone	Micritic	MFT1
Shan 6	35		2	2	45	11	5	Wackestone	Biomicrite	MFT2
Shan 8	25			5	53	10	7	Wackestone	Biomicrite	MFT2
Shan 9	3				57	15	25	Mudstone	Micritic	MFT1
Shan 10					77	18	5	Mudstone	Micritic	MFT1
Shan 11	26		30	7	7	25	5	Packstone	Biopelsparite	MFT6
Shan 13	27			4	49	11	9	Wackestone	Biomicrite	MFT2
Shan 15	21	5	3	11	50		10	Wackestone	Biomicrite	MFT2
Shan 16	25		45		4	19	7	Grainstone	Biopelsparite	MFT3
Shan 18	20		47		5	24	4	Grainstone	Biopelsprite	MFT3
Shan 19	17		40	8	5	25	5	Grainstone	Biopelsparite	MFT3
Shan 20	20		3		64	5	8	Wackestone	Biomicrite	MFT2
Shan 21	21				54	15	10	Wackestone	Biomicrite	MFT2
Shan 22	35	8	15		23	10	3	Wackestone	Pelbiomicrite	MFT2
Shan 24	5				91	4		Mudstone	Micritic	MFT1

Shan 25	15	29		4	23	16	13	Oolitic Packstone	Bioomicrite	MFT4
Shan 26	10	36	3	8	5	30	8	Oolitic Grainstone	OoSparite	MFT4
Shan 27	16	31		3	4	35	11	Oolitic Grainstone	OoSparite	MFT4
Shan 28	22	2	28	7	3	27	11	Grainstone	Biopelsparite	MFT6
Shan 29	31	4	29	6	5	23	3	Grainstone	Biopelsparite	MFT6
Shan 30	18		5	39	3	25	10	Grainstone	Intrasparite	MFT5
Shan 32	23			5	49	16	7	Wackestone	Biomicrite	MFT2
Shan 33	25		5	34	3	27	6	Grainstone	Biointrasparite	MFT5
Shan 34	20		7	29	9	25	10	Packstone	Biointrasparite	MFT5
Shan 35	27			33	3	30	7	Grainstone	Biointrasparite	MFT5
Shan 36	31	5	27		5	27	5	Packstone	Pelbiosparite	MFT6
Shan 38	25		31	8	4	29	3	Grainstone	Biopelsparite	MFT6
Shan 40	21				48	20	9	Wackestone	Biomicrite	MFT2
Shan 42	4				81	10	5	Mudstone	Micritic	MFT1
Shan 43	6			5	74	11	4	Mudstone	Micrite	MFT1
Shan 44	24		26	4	27	13	6	Packstone	Biopelmicrite	MFT6
Shan 45				2	93	3	2	Mudstone	Micritic	MFT1
Shan 46	24				57	9	10	Wackestone	Biomicrite	MFT2
Shan 47	7				85		8	Mudstone	Micritic	MFT1
Shan 48	8			4	81	2	5	Mudstone	Micritic	MFT1
Shan 50	4				86	8	2	Mudstone	Micritic	MFT1

## **4.2. Microfacies Analysis**

Microfacies refer to the total of all the paleontological and sedimentological criteria appearing in petrography. Microfacies analysis from thin sections of carbonate rocks exhibit depositional criteria reflecting environmental constraints acting during sedimentation. Every facies of one depositional environment has its own distinct petrographical, geographical and paleontological properties which can be clearly differentiated from other facies (Flugel, 2004).

The interpretation of depositional environment from microfacies data requires detail characteristic of the rock. MFT's can be distinguished based on a depositional texture, fabric, as well as qualitative and quantitative compositional data of rock. Generalization of microfacies types leads to categorization of common microfacies data into 'Standard Microfacies Types' (SMFT).

Thin-section criteria used in establishing microfacies types of carbonates are texture of the rock (mudstone, wackestone, packstone, grainstone ), grain size, sorting and packing, qualitative composition (fine-grained matrix, carbonate cement (sparite), Grain categories (skeletal grains, peloids, intraclast and ooids) and their relative proportions with fine-grained matrix and sparite will also be identified. Other criteria's such as depositional fabrics (biofabrics; bedding and lamination; burrowing and bioturbation) are also important (Flugel, 1982).

Grains categories are a primary descriptive approach to microfacies type categorization. E.g oolitic limestones reflect particular paleoenvironmental conditions such as (water energy and transport processes) and depositional settings.

Skeletal grains are of prime importance in defining microfacies types of carbonate rocks since limestones are predominantly formed by biologically controlled processes. They are also significant proxies for paleoenvironmental conditions because they are highly sensitive to processes characterizing specific depositional environments. The composition of bioclastic carbonates depends on many factors including skeletal mineralogy and the path of taphonomic and diagenetic processes examined. The type and association patterns as well as the abundance of grains are the basic criteria for the discrimination of significant microfacies types. MFTs based on textural and compositional criteria should be examined with respect to variations caused by differences in

depositional fabrics. Specific bio fabric features including grain orientation and sedimentary structures such as cross-bedding are useful MFT criteria.

Different depositional environments of carbonate are described by different numbers of microfacies types. The number of MFT's is highly variable by its environment because of the differences in the frequency of deposited material, energy and depth of basin (Flügel, 1982).

Generally the quantitative differences of rock constituents, differences and abundance of biotas, the relationship of one biota with other and sedimentary structures help in making microfacies types.

On the basis indicative microfacies and lithofacies criteria observed from field and thin sections for carbonate unit of Shanan section 6 microfacies types (MFT1- MFT6) were identified. All these major microfacies types are described based on their components, supported with photomicrograph, interpreted with respect to their depositional environments and compared with standard microfacies types (SMFT) and facies belts (FB) of (Wilson, 1975 Appendix 1). The detail description for each of them is given as follows:-

#### **4.1.1 Microfacies Type 1**

This microfacies represent for the dominant micritic limestones found in Shanan section. It is characterized by numerous numbers of micritic limestone layers. Sometimes rare grains of skeletal and non skeletal grains less than 10% are present.

It is obtained from sample number (Shan 1, 2, 3, 4, 5, 9, 10, 24, 42, 43,45, 47, 48 and 50) those are collected from the section. Some of these micritic limestones are seen with sparry calcite cements (Shan 4, Fig 4.1: A). At some places like at upper section (Shan 42, Fig 4.1: C) the micritic are dark-gray blackish in color and associated with rare amounts of skeletal grains. In the lower Shanan these facies have a thickness of around 17m and consists of thin-thick bedded micritic limestones with rare bioturbation. Sometimes they are seen with thin marl intercalation and small quartz grains are also seen (Fig 4.1: D). Micritic limestones in the upper Shanan are medium to massively bedded and have rare amounts of bioclasts with some lenses of cherts within it. The upper and middle Shanan micritic carbonates vary from grayish, dark-gray blackish and reddish in color.

For this the upper micrite facies is compared with facies belt 3 of Wilson (1975) which is deposited in deep shelf margin or basin margin.

#### **4.1.2 Microfacies type 2**

Microfacies type 2 stands for microfacies of bioclastic wackestone. These microfacies were characterized by mostly grayish color, thin to medium bedded, hard and fine-grained limestones with some shell fragments imbedded within micrite (Fig 4.2). Mostly it is found intercalated with marl. Under thin section this microfacies is composed mainly of micrite with bioclast grains of >10%. Samples No Shan 6,8,13,15,20,21, 22, 32, 40 and 46 are common representatives of these microfacies. Fossils of brachiopod, bivalves, echinoids, foraminiferas (*kurnubia palastinensis*) and gastropod are very commonly seen imbedded within micrite materials sometimes with very rare amounts of sparite. In field observation these layers are mostly seen intercalated with marl. Some examples for this microfacies are given in (Fig 4.2: A-D).

This facies is compared with SMF type 9 of Wilson (1975) which belongs to facies belt 7 or 2, which deposited in open platform or shelf lagoon, or open sea shelf.

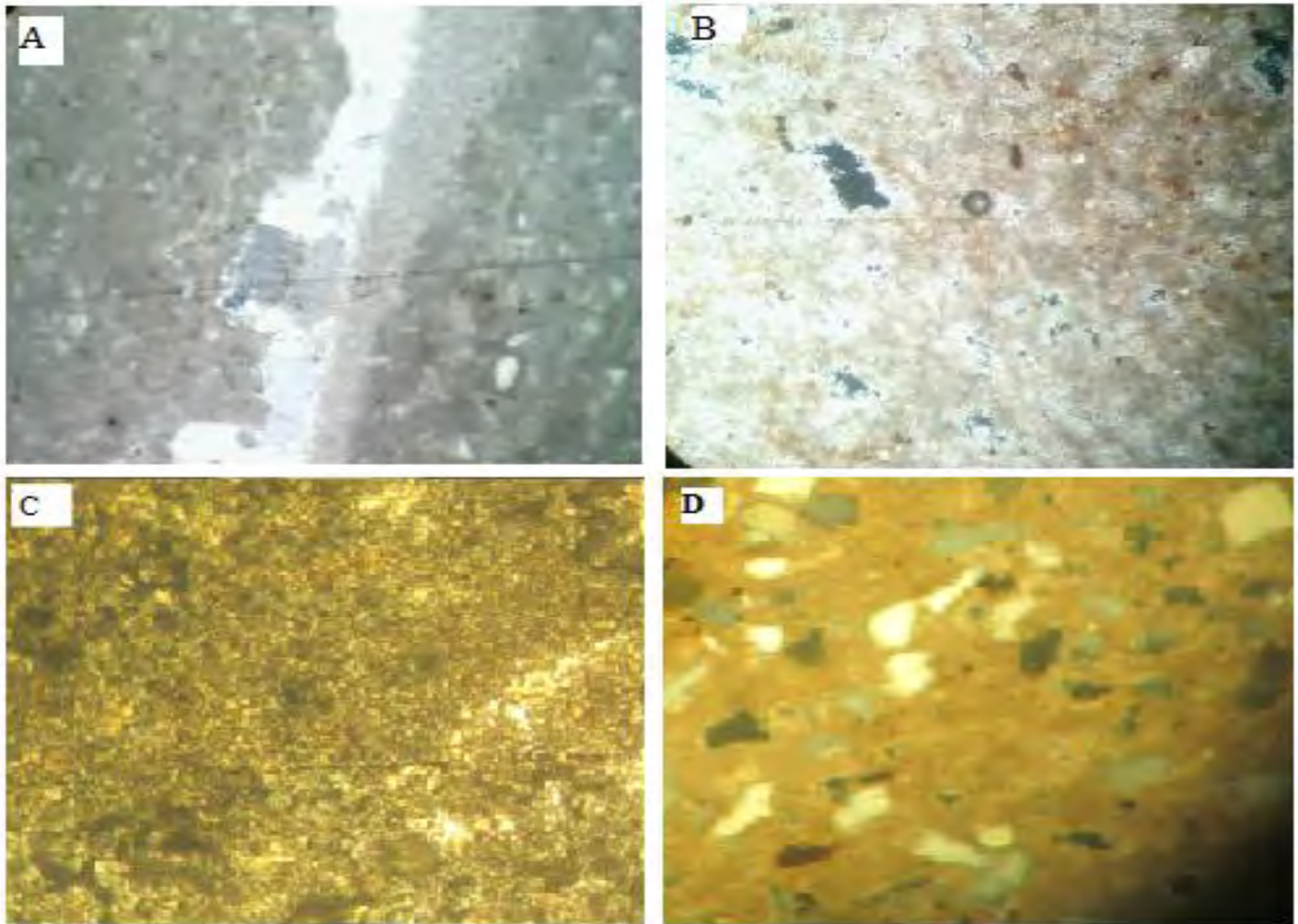


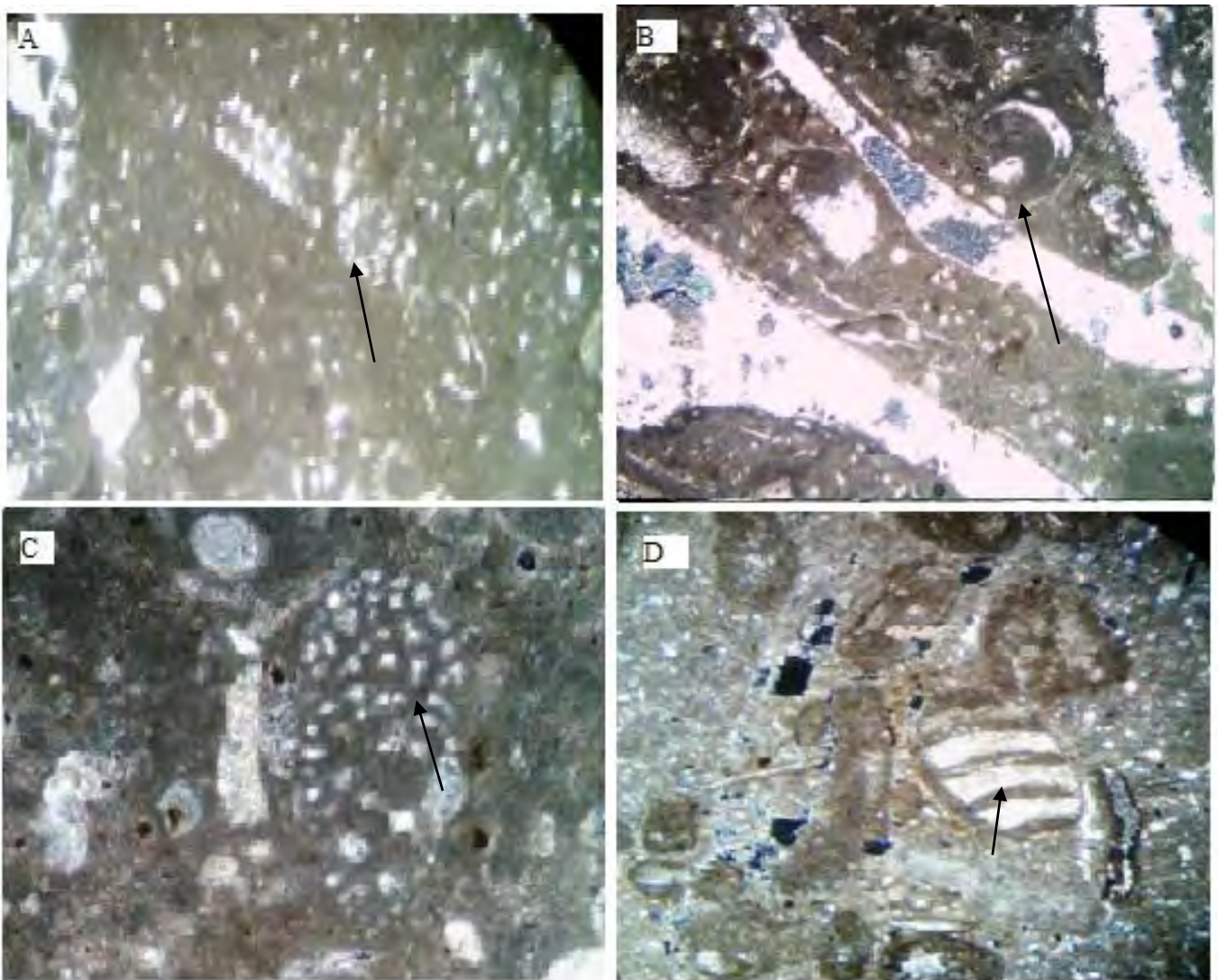
Fig 4.1. *A) Micritic limestone photomicrography showing the fractured micrite layers filled by the secondary calcite cements (Fracture filled partially with calcite cements, which are the results of burial compaction processes. microphoto of sample Shan 10, x40) B) Micritic layers, it shows bioturbated, dissolved and the boring of micritic layers by organisms the micrite matrix are replaced by sparry calcite cement. (Pore spaces (black spaces) formed by the dissolutions of micrite crystalline ooze, Sample Shan 4, under PPL, x40) C) Black-dark grayish micritic layers pore spaces (black spaces) formed by the dissolutions of micrite, Sample Shan 4, underPPL Photo taken from sample no Shan 42, x4 D) Micritic microfacies with quartz grains sample Shan 1, x40.*

#### **4.1.3 Microfacies type 3**

Microfacies type 3 stands for peloidal grainstone microfacies found in Shanan section. This facies is characterized by abundant number of peloids with rare skeletal grains such as foraminifera and

algae imbedded within the sparry calcite cements (Fig 4.3: A-C). This peloidal grainstone microfacies is mostly obtained at the top of lower Shanan from sample Shan 16, 18 and 19. The peloids grains in this microfacies are smaller in sizes and a grain size distribution is moderate to poorly sorted.

This peloidal microfacies is compared to SMFT 16 of Wilson (1975) and belongs to facies belt 7 or 8 which deposited in open platforms (shelf lagoon) or in restricted platform.



*Fig 4.2: A- D) Bioclastic wackestone microfacies bearing various shell fragments within the micrite fine materials. A) Bioclastic wackestone microfacies containing algae (arrow) dispersed in micrite x4 under XPL. Sample Shan 20 B) Bioclastic wackestone containing Gastropod (arrow) and other*

shell fragments x10 under PPL Sample Shan 13. C) Bioclastic wackestone containing *Kurnubia palastiensis* (arrow) x40 under XPL Sample Shan 6. D) Bioclastic wackestone containing *Siphovalvulina .sp* (arrow) and others Sampel Shan 32 under PPL with x40 magnification.

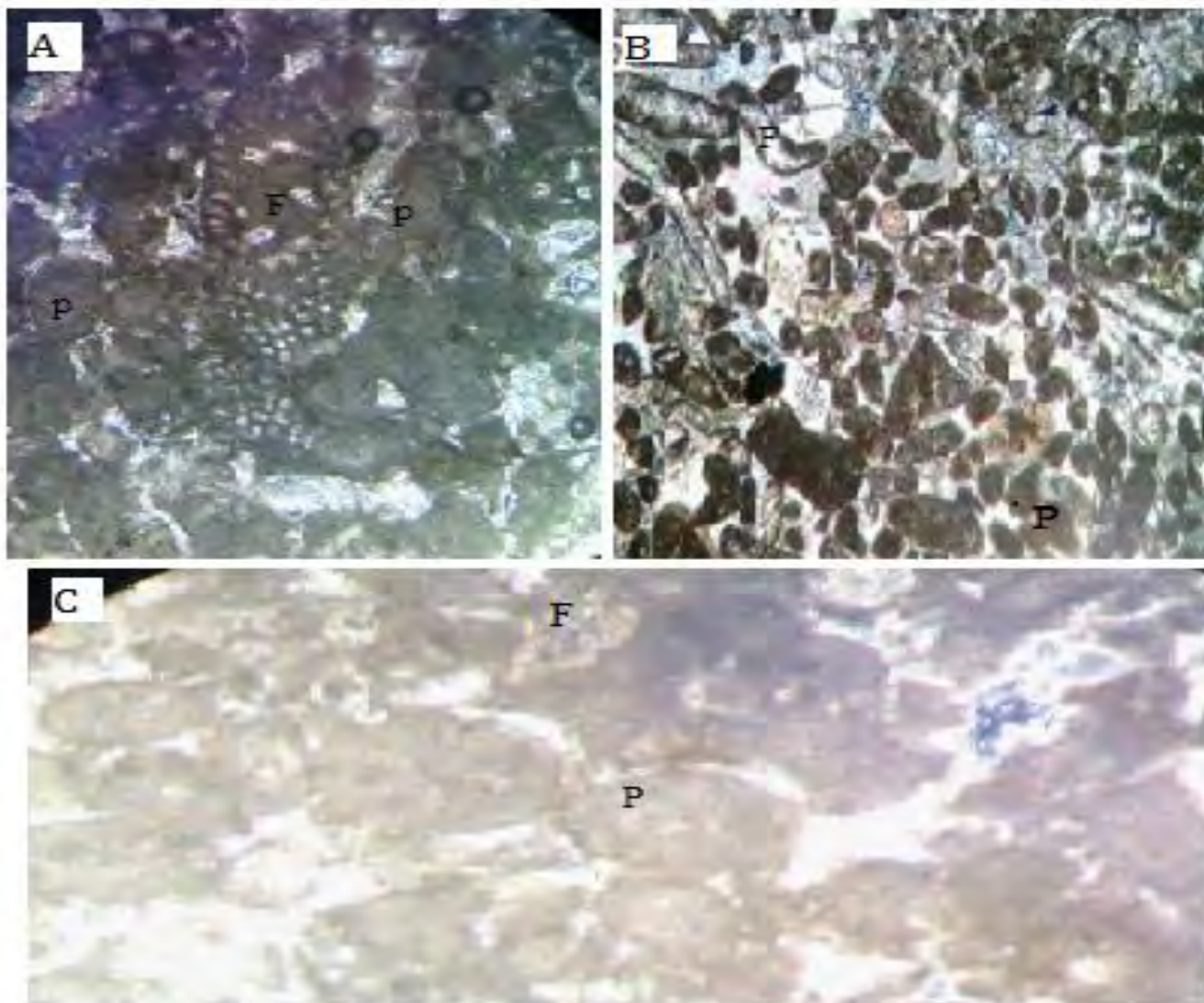


Fig 4.3: A-C) Micrographs of peloidal grainstone facies in which the smaller sized peloidal grains (P) and rare amounts of smaller skeletal grains (F) are imbedded by microcrystalline marine cements (whitish materials filling the space between the grains). Grains are moderate to poorly sorted. Microphoto which is taken with magnification A; x40, Shan 16; B x10, Shan 19 and C is x40 Shan 18 respectively. All photos are taken under PPL.

#### **4.1.4 Microfacies type 4**

This facies represent the oolitic packstone to grainstone rocks of the section and they present in the top end of lower Shanan. In the field observation on these layers cross bedding structure is clearly observed. It is obtained from sample Shan 25, 26 and 27.

The tangentially structured ooid grains >30% are imbedded in the sparite cements (Shan 26) (Fig 4.4: A and D) and sometimes in micrite. Some of the ooid grains have rare amounts of micritized skeletal fragments (Fig 4.4: E) and non-skeletal grains such as intraclast. A quartz grain on nucleus of ooid grain is also seen (Fig 4.4: C). The ooid and skeletal grains are calcified also dissolved at places and larger crystal cements are observed between grains (Fig 4.4: E, arrow). There are also some micritic envelopes on some skeletal and ooids grains mainly preserving their shape (Fig4.4: E).Accordingly this microfacies is compared with SMF Type 15 of Wilson and belongs to facies belt 6, which is deposited in winnowed platform edges.

#### **4.1.5 Microfacies type 5**

This microfacies type stands for intraclastic packstone to grainstone microfacies. They are mostly obtained from top of middle Shanan section from samples (Shan 30, 33, 34 and 35). It contains dominant amounts of intraclastic grains and bioclasts with rare peloid grains imbedded within sparry calcite cements and in rare amounts of micrite (see Fig 4.5: A-D).The intraclast grains are mostly poorly sorted and irregular shape indicate the instability of the depositional surface during the deposition. The main skeletal grains in this microfacies are benthic foraminifera and gastropods within the sparry calcite cement. Most grains are coarse grained (forming rudestone) (Fig 4.5: D) altered and compacted, mud-free, cemented, reworked and poorly sorted. Skeletal and intraclast grains are the main constituents of this microfacies and other minor constituent is peloid.

This microfacies is compared with SMF Type 4, which belongs to Facies belt 4 of Wilson (1975), those are fore slope and deep shelf margins.

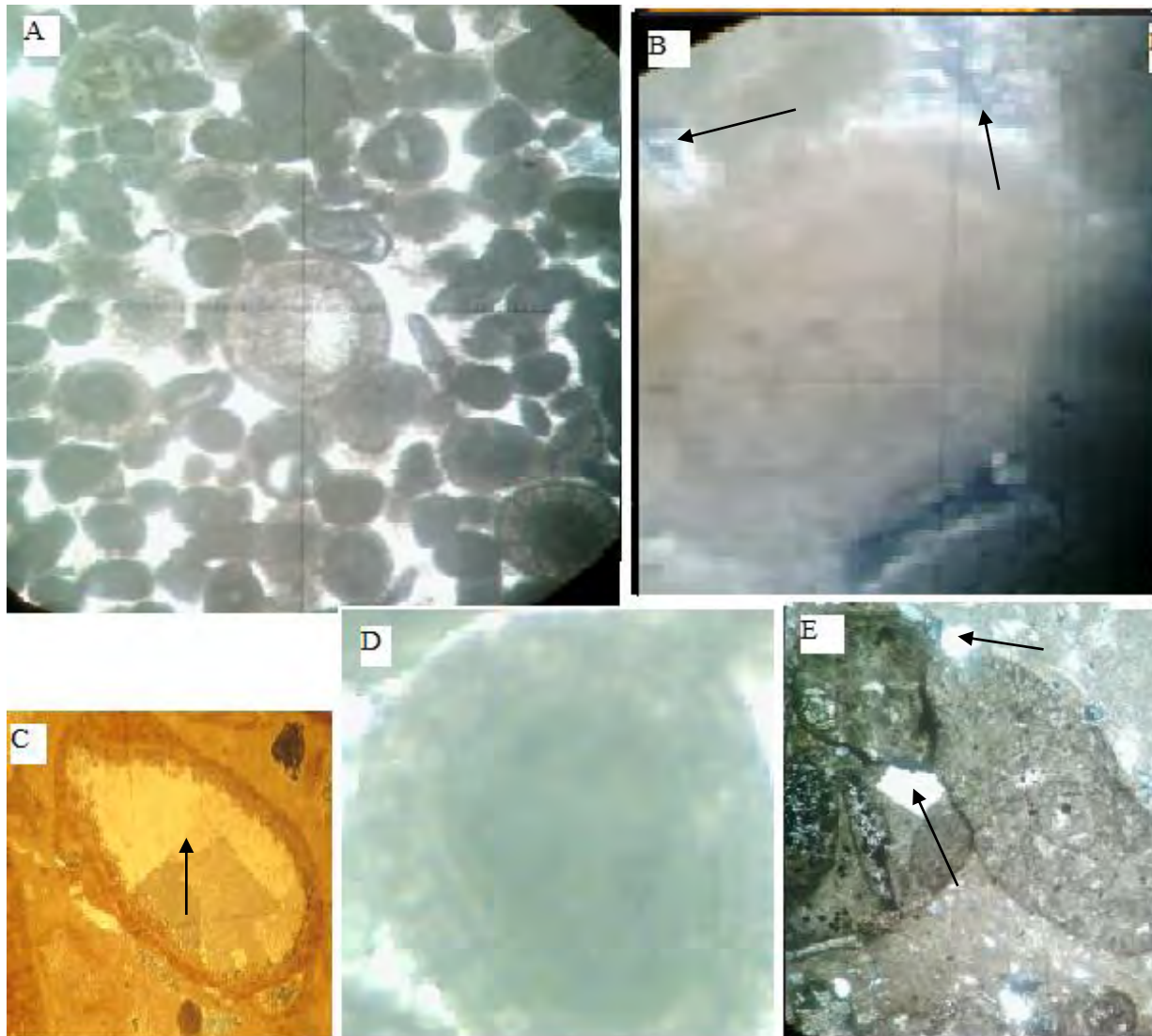


Fig4.4) **A& D)** Showing the larger tangential ooid (high energy environment product) surrounded by calcite cements. Sample Shan 26, PPL, with 4X and 40X respectively. Ooid grains are coarser in size and moderately sorted. **B)** Ooid grains (arrowed) in oolitic microfacies; those are mainly dissolved (The dissolved boundary (black color, arrow) of large ooid grain), forming secondary pores (black colors) and fitted together due to compactions. Sample Shan 25, XPL, 40X. **C)** Photomicrography showing ooid grains (spherical shaped with internal nucleus, arrowed) with quartz grains are imbedded within the sparite and micrite cements, the oolitic Packstone microfacies of Sample (Shan 25) PPL, 40X. **E)** Micritized skeletal fragments cemented together forming carbonate sands; most of the grains are compacted and broken. Sample Shan 27, PPL, X40.

#### 4.1.6 Microfacies type 6

Microfacies type 6 stands for biopel packstone-grainstone carbonate rocks of Shanan section. Dominantly they are found in the middle part of the section (middle Shanan) but also rarely they are found in lower and upper part of the section. Skeletal grains of gastropods, foraminifera, algae, echinoderms also other shell fragments and peloids of various sizes and shapes are dominant components of this facies. Foraminifera and algae are abundant skeletal grains found in this microfacies. The grains are imbedded within the sparry calcite cements with rare amounts of micrite at some places. Sometimes there are also rare amounts of carbonate clasts and ooids in this facies. The grains are moderate to well sorted and compacted. This microfacies is obtained from sample no Shan 11, 28, 29, 33, 36, 38 and 44 (as given in Fig 4.6: A-D). This facies compared to SMFT 12 of Wilson (1975) and belongs to facies belt 6 which deposited in winnowed platform edges.

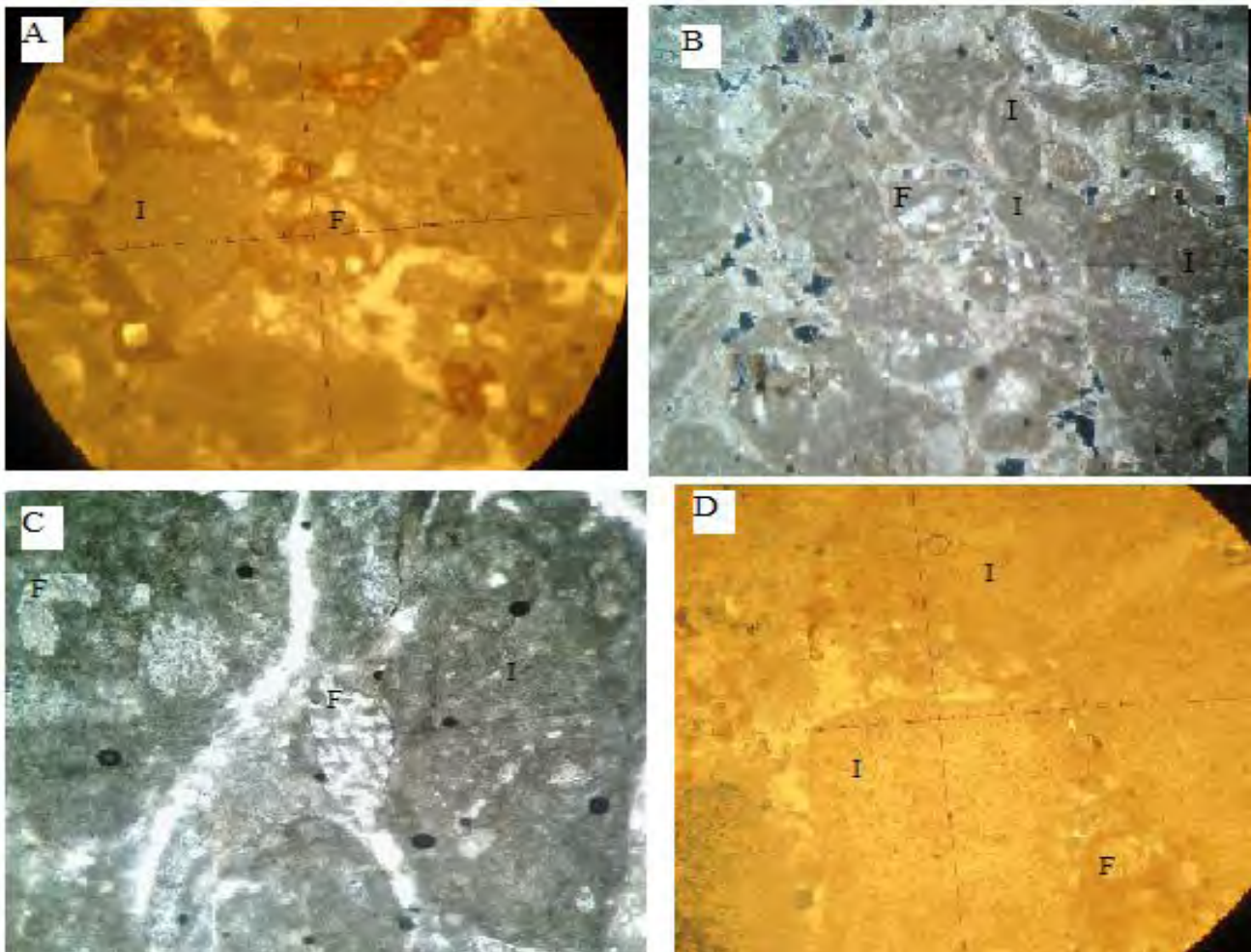


Fig 4.5: **A)** Microphoto of sample Shan 30 showing the Grainstone in which the some gastropod (F) and various shaped carbonate clasts (I) are imbedded in the sparry calcite cements **B)**Microphoto of sample Shan 34 showing the packstone in which the some fossils (F) and various shaped carbonate clasts (I) are imbedded in the sparry calcite cements and some micrite. The grains are poorly sorted and irregular in shape. (A, PPL and B, XPL, both 4X). **C)** Microphoto of sample No Shan 33 under XPL, with 4x magnification, showing the larger carbonate clasts (I) and foraminifera fossils (F) imbedded in the sparry calcite cements (whitish space between grains cemented **D)** Bioclastic intraclast rudstone, in which the fossil (F) and larger intraclastic grains (I) are cemented together by sparry calcite cements, Sample Shan 35 under XPL by 10X magnification.

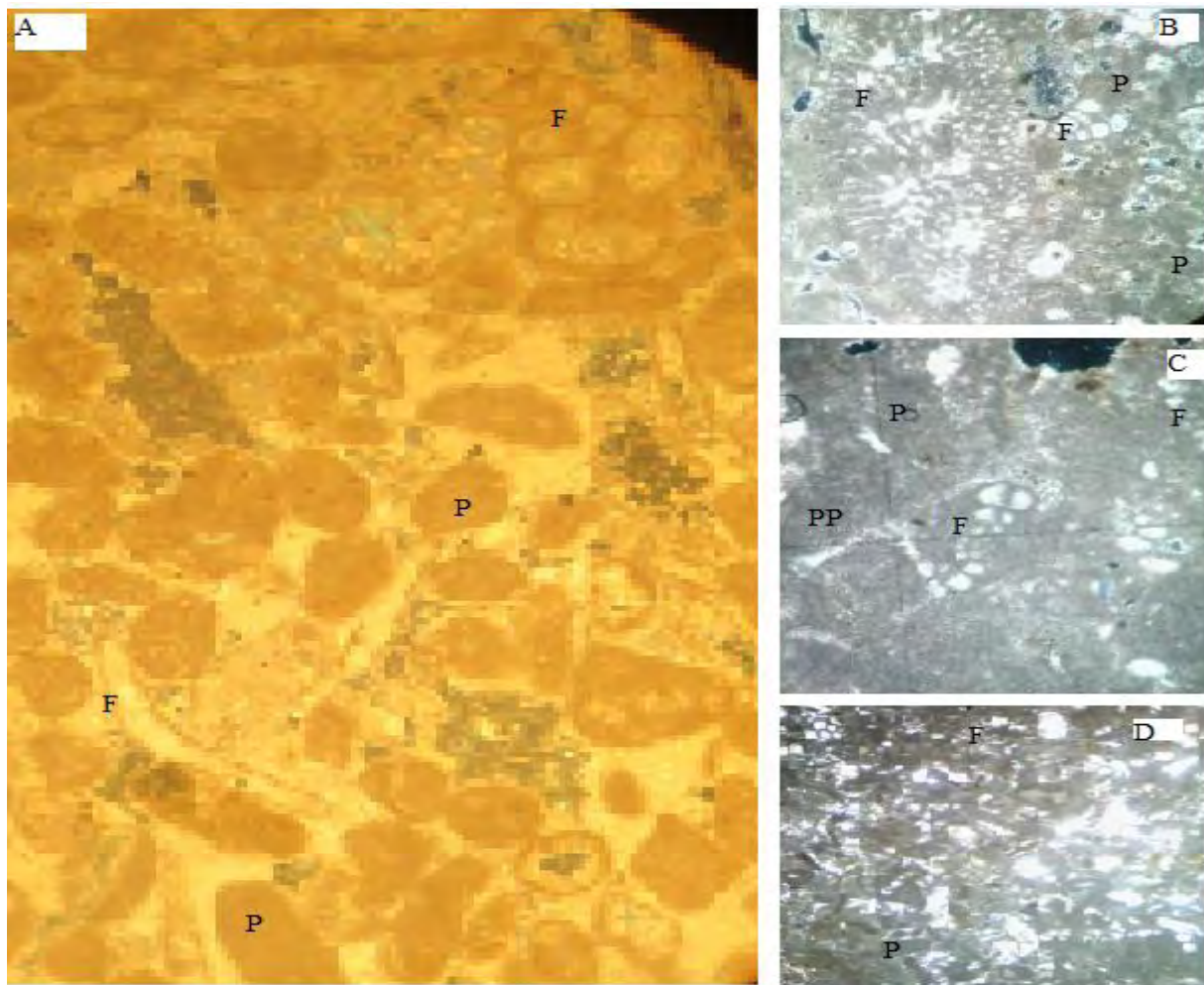


Fig 4.6: **A and C)**Photomicrographs of Bioclastic Peloidal grainstone facies in which the various sized Peloidal grains (P) and rare amounts of smaller skeletal grains (F) such as Forams and other

fragmented skeletal grains are imbedded in the sparite, from sample No Shan 38 and Shan 29, under PPL, 40x and 4x respectively **B**) Photo showing larger fossils (F) and irregular shaped peloid under PPL with 10x magnification. Sample Shan 28. D) Packstone microfacies in which the Small Algae fossils (F) and peloid (P) grains are cemented together by sparry calcite cements. Sample Shan 36, under XPL, 4x.

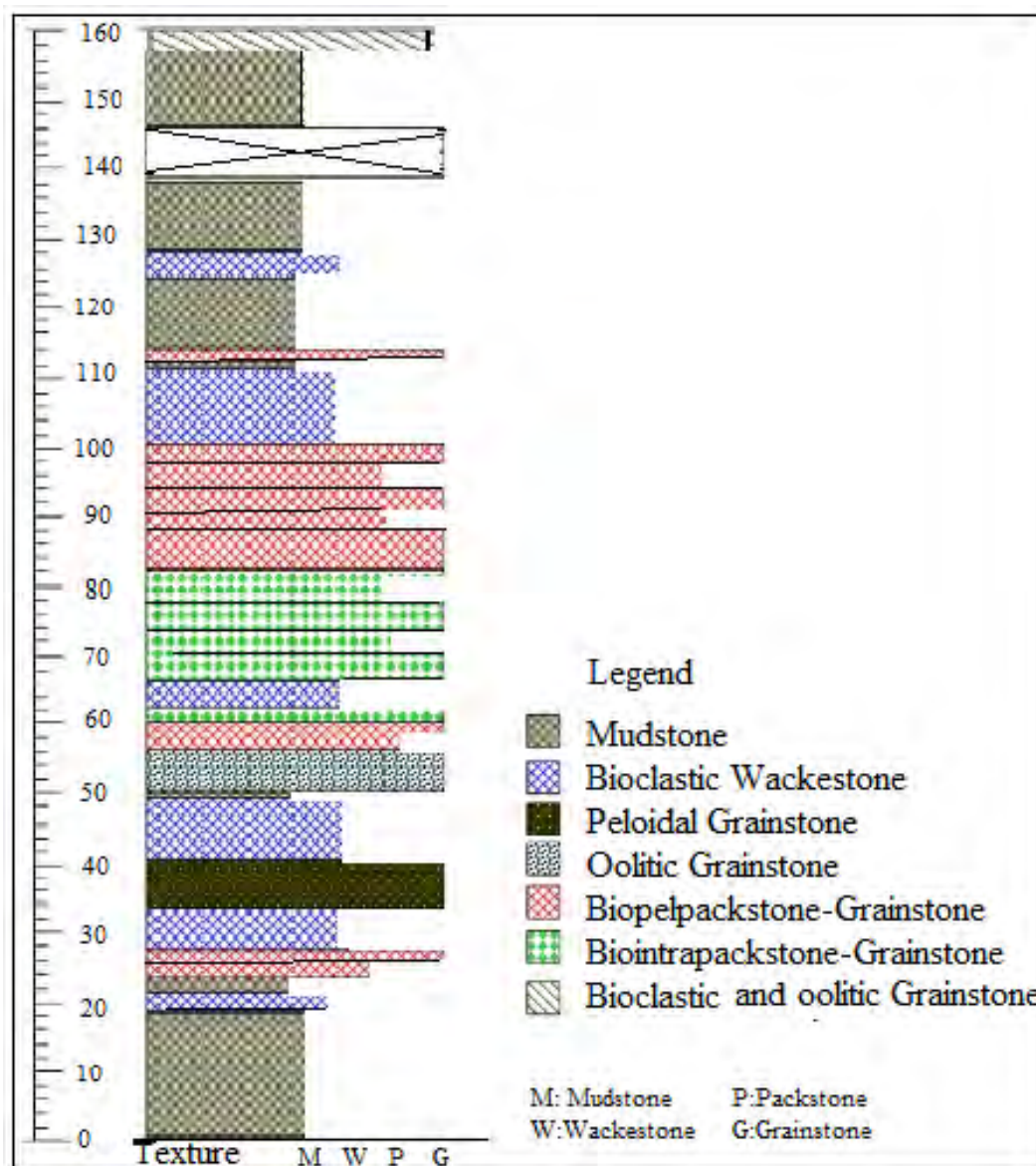


Fig. 4.7. Stratigraphic columns of carbonate exposures of Shanan section based on Microfacies type. Showing the description for each lithologic units, their thickness and microfacies type obtained from their samples.

### 4.3. Diagenesis

Diagenesis is the term used to define all the changes which occur in sediments during the interval between deposition and lithification. These diagenetic changes may take place in the submarine, subaerial fresh water and subsurface environments. The various diagenetic processes usually produce mineralogical changes, dissolution, precipitation and textural modification of carbonate rocks (Al-Dabbagh, 2006).

It includes processes such as compactions, cementation, mineral recrystallization, replacement etc. Diagenesis occurs more readily in limestones than in terrigenous siliciclastic rocks because calcium carbonate is easily soluble.

The field and petrographic observations of Shanan section carbonates indicate as they undergo several diagenetic processes. Compaction, fractures, stylolization cementation, micritization, dissolution and silicification are common diagenetic phenomena observed. The following is investigation of diagenetic features of these carbonates units:-

**Cementation:** - Cementation occurs when carbonate is precipitated into a pre-existing void space. It is one of the most common diagenetic processes, because limestones are easily dissolved and reprecipitated (Prothero and Schwab, 2014). It's the process in which chemical precipitates (in the form of new crystals) form in the pores of a sediment or rock, binding the grains together (McIlreath and Morrow, 1990). In the Shanan sections cementation are found in different places and some example is given (Fig.4.3).

**Compaction:** - Compaction of carbonate sediments occurs through pressure due to overburdens and deep burial. Compactions may be physical or chemical. Physical compaction is the diagenetic process under which the inter-grain space reduces and results in the overall reduction of porosity of the rock (Adams and Mackenzie, 1998). Stylolite (Fig 3.7:B) which found in upper Shanan is indicator of chemical compaction of carbonate sediments in the area. Chemical compaction is result due to increasing overburden, which cause the grain to grain contacts take place first and then simple grain contacts developed into sutured grain contacts. Later on dissolution of grains starts at these contacts (Adams and Mackenzie, 1998).

**Stylolitization:** - Stylolites are serrated surfaces within a rock mass at which mineral material has been removed by pressure dissolution, in this process total volume of rock decreases. Insoluble minerals, such as clays, pyrite and oxides, remain within the stylolites and make them visible (Adams and Mackenzie, 1998). Stylolite formation is associated with thin water films that allow solutes to move away from sites of dissolution. In Shanan section as discussed above macro-stylolite on lithologic units at out crop scales are observed in the upper Shanan section (Fig.3.7:B).

**Micritization:** -Micritization is a process of alteration of original skeletal grain fabric to a cryptocrystalline texture by repeated algal microborings and subsequent filling of the microborings by micritic precipitate (Bathurst, 1966). In Shanan section micritization is abundantly seen in lower Shanan, the micrite envelopes are mainly around skeletal grains (Fig 4.4; E), rarely around some ooids.

**Dissolution:** - Dissolution occurs when the rock -water system is out of equilibrium (McIlreath and Morrow, 1990). Dissolution produces pore space by dissolving pre-existing minerals. Most of the time dissolution produces voids where aragonitic or high-Mg calcitic fossils were dissolved (Prothero and Schwab, 2014). Dissolutions of carbonates grains are present on some skeletal and non skeletal components of Shanan section carbonates. Mostly it forms different pore spaces also at places these pore spaces are in turn infilled by the late stage sparry calcite cements. (Fig 4.1; B).

**Silicification:** - Chert which seen in (Fig 3.5) is a result of silicification which is formed when silica originally deposited in one place dissolves, migrates, and reprecipitates else-where and replacing older material (Prothero and Schwab,2014). Silicification is the diagenetic process in which the carbonate minerals are replaced by silica ( $\text{SiO}_2$ ) (McIlreath and Morrow, 1990). The silica which replaces carbonate minerals is mostly derived from biogenic; therefore, it is especially prevalent in deep-marine sediments from active upwelling zones and shallower-water carbonates from nutrient-rich carbonate shelves. But also detrital quartz grains that are transported by the wind to carbonate banks can be a source (Prothero and Schwab,2014).

## CHAPTER FIVE

### 5. PALEONTOLOGY OF SHANAN SECTION

#### 5.1. Introduction

Paleontology concerns the evolution, morphology, and taxonomy of fossils. Fossils can be used in different ways in geology. In biostratigraphic zones they are the main tool to study the relationship with rocks. Also study of fossil help to deducing their behavior when they were alive, their habitats, and mutual relationships. Depositional environment analysis of a rock is highly depends on biostratigraphy which is determined based on identification and interpretation of fossils it contains (Selley, 1996). Since fossils are rock builders as in limestones study of them help to know relationship between facies analysis, stratigraphy and fossil. Age of sedimentary rock is also established through study of stratigraphy and fossil.

In the carbonate rocks of the Shanan section different macro invertebrate fossil and microfossils are present. Invertebrate fossils are preserved predominantly as mold and cast. These micro and macrofauna was prepared in the laboratory and identified down to the species and genus level wherever possible. As the macrofossils are poorly preserved taxonomic identification has provided some problems. So the classification applied follows the identification and description of observable fossil morphology and comparison of previous works done in the country is done for invertebrate macrofossils. Microfossils are washed and collected from marl samples and the description of their morphology was done using binocular reflecting microscope and comparison of published micropaleontological data done in Egypt, Saudi Arabia, India, Israel, South Africa etc is done. Identification of fossils under thin section has been also carried out. Generally more than 160 micro and macrofossils have been studied from in which at least 17 Genus and 6 species have been recognized. The macrofossils are: - **Bivalve** (*Pholadomya*.sp, *Lucina*.sp, *Modiolu modiolus*.sp, *Nanogyra* sp and *Astarte* sp.), **Brachiopod**: - (*Terebratulla* .sp), **Gastropods**:- (*Ampullina*.sp and *Nerinea*.sp). Microfossils of **Foraminifers**: - (*Eoguttulina polygona* (Terquem, 1864)., *Lenticulina subalata* (Reuss, 1854), *Lenticulina quenstedti* (Gümbel, 1862), *Verneuilioides minuta* (Said and Barakat, 1958), *Haplophragmoides bartensteini* (Kalantari, 1969) and *Choffatella*.sp) and **Ostracods**:- (*Cytherelloidea*.sp., *Progonocythere*. sp., *Procytheridea*.sp., *Bairdia* sp, and *Paracypris* .sp) are identified.

Group of micro and macro fossils collected from Shanan section those listed above are described and discussed as follows:-

## **5.2. Foraminifera**

Foraminifera are small, predominantly marine protists that construct chambered shells (tests). The group belongs to the phylum Sarcodina and the class Rhizopoda. They usually develop some sort of test, of chitin, agglutinated material, calcareous or rarely siliceous material secreted.

Foraminifera provide time markers for biozonations of shallow and deep marine carbonates. They are excellent environmental proxies and help in reconstruction of ancient depositional environment. There are two major groups of foraminifera, benthic living in or on sediments of sea floor, and planktonic, living in the upper of the oceans. Most foraminiferal shells typically range from 0.1 to 1 mm in size, but some groups developed rather large tests.

The cell of foraminifera is enclosed by a test consisting of a single chamber or several chambers each connected by one or several openings. Most foraminifera are multi chambered. The chambers are arranged in whorls. They may be uniserial (forming a single linear series), or multi-serial (two or more chambers per whorl). If the test of forams coils in a single plane around the growth axis, it is called planispiral. Trochospiral if the chambers are arranged in a spiral coil. Chambers of foraminifera are divided by suture. Aperture is an opening which found in the foraminifera mostly in the final chamber of wall. The external surface of their tests is smooth or variously ornamented (e.g. spines and keels). Calcareous foraminifera especially are often highly ornamented, in many cases this is due to an excessive amount of calcareous material (Cushman, 1928).

Foraminifera are identified from one other by their wall composition, microstructure, chamber arrangement, depression or elevation of sutures, apertural characters, chamber form and ornamentation. Wall composition and microstructures are the most important features used in the classification and taxonomic differentiation of foraminifers on a generic level (Cushman, 1928). organic (protinaceous), agglutinated and secreted calcium carbonate or more rarely silica are the basic wall compositions of foraminifera .

The 6 investigated marl samples collected from Shanan section yielded more than 100 foraminiferal taxa: all of the taxa were calcareous benthic forams.

The brief description and characterization of each foraminiferal fauna is done and the synonymy lists for taxa are relatively complete. In the “Remarks” important references to the respective taxa are cited, and their geographic distribution with referenced materials is described. The image for all described species is given in plate 1.

The systematic classifications of foraminifera taxa follow (Cushman 1928; 1933; 1950; Alhussein, 2014; Said and Barakat, 2014; McMillan; 2010 and Youssef and El-Sorogy; 2015). The taxonomy is taken up to species level.

The Shanan section carbonate rock is dominated by benthic forams, consisting around six species. The taxa recovered include; *Eoguttulina polygona* (Terquem, 1864), *Lenticulina subalata* (Reuss, 1854), *Lenticulina quenstedti* (Gümbel, 1862), *Verneuilinoides minuta* (Said and Barakat, 1958), *Haplophragmoides bartensteini* (Kalantari, 1969) and *Choffatella*. sp. Description for each is given as follows:-

**Kingdom** Protista, Hogg, 1861

**Phylum** Sarcodina, Schmarda, 1871

**Class** Rhizopoda Siebold, 1848

**Order** Foraminiferida, d'Orbigny, 1826

**Family** Polymorphinidae d'Orbigny, 1839

**Subfamily** Polymorphininae d'Orbigny, 1839

**Genus** *Eoguttulina*, Cushman and Ozawa, 1930

**Type species: - *Eoguttulina polygona* (Terquem, 1864)**

*Eoguttulina polygona* (Terquem, 1864) (Plate 1, A and B)

1864 *Polymorphina polygonan*. sp. – Terquem: 305, pl. 14, figs. 16-41.

1969 *Eoguttulina polygona* (Terquem) – Kalantari: 95, pl. 6, figs. 19-20.

1991 *Eoguttulina polygona* (Terquem) – Bhalla & Talib: 102, pl. 4, fig. 9

**Material:** Four tests

**Description:** Test ovate or somewhat elongate, with chambers arranged in spiral series pointed to ends. Chambers distinct elongated and added in planes. Sutures weakly depressed (oblique) and have surface with very fine pores; aperture terminal; wall calcareous, chambers removed farther from the base.

**Remark :** *Eoguttulina polygona* (Terquem, 1864) species is also reported from middle Jurassic of western India Alhussein (2014), from late Jurassic of Cape (South Africa), McMillan (2010), from Jurassic of France (Terquem, 1864), Bajocian of Iran (Kalantari, 1969) and Callovian to Oxfordian of India (Bhalla and Talib, 1991).

**Family** Lenticulinidae, Chapman, Parr and Collins, 1934

**Genus** Lenticulina, Lamarck, 1804

**Type species:** - *Lenticulina quenstedti* Gümbel, 1862

*Lenticulina quenstedti*, Gümbel, 1862, (Plate 1 :C)

1971 *Lenticulina quenstedti* (Gümbel) forma- A Wernli,: 322, pl. 4, figs. 23, 27; pl. 10, fig. 1.

1989 *Lenticulina quenstedti* (Gümbel) -Morris & Coleman: 226, pl. 6.3.8, fig. 12.

**Material:** two tests

**Description:** Test involute, planispiral, elongate in outline. Peripheral margin sharply angular, well-developed keel; chambers 7-9 sutures strongly elevated, curved backward. Last chambers distinctly increasing in width as added; Aperture is terminal but not clearly visible. Chamber walls are calcareous, smooth, finely perforate and optically hyaline. Umbliculus are circle ring like.

**Remark:** The present specimens are identical to those described by Alhussein (2014) from Jurassic's of India they are also reported from Urandab carbonate formation of Ogaden South Eastern Ethiopia by (Shigut Geleta, 1998).

**Type species: *Lenticulina subalata* Reuss, 1854**

***Lenticulina subalata* Reuss, 1854 (Plate 1:D)**

1854 *Cristellaria subalata* sp. – Reuss: 68, pl. 25, fig. 13.

1969 *Lenticulina subalata*(Reuss) – Kalantari: 41, pl. 1, figs. 5-8.

1978 *Lenticulina subalata*(Reuss) – Bhalla& Abbas: 180, pl. 6, fig. 6; pl. 10, figs. 1-4.

1991 *Lenticulina subalata*(Reuss) – Bhalla& Talib: 99, pl. 2, fig. 8.

1993 *Lenticulina subalata*(Reuss) – Pandey& Dave: 198, pl. 6, figs. 4-6.

2008 *Lenticulina subalata*(Reuss) – Saad: pl. 3, fig. 6.

2009 *Lenticulina subalata* (Reuss) – Gaur & Talib: 238, pl. 2, fig. 1

**Material:** 25 tests

**Description:** Test simple nearly round; slightly elongated; involute. Chambers 7-9, surface smooth; sutures are relatively broad and strongly elevated, curved backward. Last chambers vary in size, become large (width) as they are added. Aperture is terminal but not clearly visible. Wall is finely perforate and optically hyaline. In some tests reddish-brown cement is present.

**Remark:** *Lenticulina subalata*(Reuss, 1854), are also known from Jurassic's of India, Alhussein (2014) and from Jurassic rocks of Khashm Al-Qaddiyah, central Saudi Arabia, (Youssef and El-Sorogy, 2014).

**Family** Verneuilinidae, d'Orbigny, 1840

**Genus** *Verneuilinoides*, Loeblich and Tappan, 1949

**Type Species:** *-Verneuilinoides minuta*, Said and Barakat, 1958

***Verneuilinoides minuta*, Said and Barakat, 1958 (Plate 1: E and F)**

1958 *Verneuilinoides minuta* Said and Barakat, p. 242, Pl. 4, Fig. 25.

1966 *Verneuilinoides minuta* Said and Barakat-Maync, Pl. IV, Figs. 10, 11.

1996 *Verneuilinoides minuta* Said and Barakat-Kuznetsova et al., p. 164, Pl. XIII, Figs. 3–5.

2004 *Verneuilinoides minuta* Said and Barakat-Galal and Kamel, p. 66, Fig. 4/3.

**Material: 23**

**Description:** Test small, tapering, subtriangular in section, periphery rounded; successive subglobular chambers slowly increasing in size and regularly arranged; composed of four whorls; sutures depressed; wall surface smooth with no indication of surface ornamentation; aperture is small and present at the base of the last chamber,

**Remarks:** *Verneuilinoides minuta* are also known from Kimmeridgian of Sinai (Egypt), Said and Barakat (2014); from Jurassic sedimentary rocks of Khashm Al-Qaddiyah central Saudi Arabia and Oxfordian and Kimmeridgian of Syria, (Youssef and El-Sorogy, 2014).

**Family** Haplophragmoididae, Maync, 1952

**Genus** *Haplophragmoides*, Cushman, 1910

**Type species:** *Haplophragmoides bartensteini*, Kalantari, 1969

***Haplophragmoides bartensteini* Kalantari, 1969 (Plate 1: I and J)**

1969 *Haplophragmoides bartensteinin*.sp.– Kalantari: 19, pl.7, figs.16-18a, b; pl. 8, figs. 4-5a, b.

1993 *Haplophragmoides bartensteini* Kalantari– Pandey& Dave: 122, pl. 1, figs. 3-5.

2009 *Haplophragmoides bartensteini* Kalantari– Gaur& Talib: 233, pl. 1, fig. 5.

**Material:** 17 test

**Description:** Test large, planispirally coiled; involute; periphery rounded; close coiled, with depressed umbilicus; chambers six and increase gradually in size as added; the last whorl show strongly enlarged chambers, sutures distinct and somewhat curved; wall finely arenaceous. Aperture is not clearly visible, but probably terminal.

**Remark:** These species also known from Middle Jurassic of Kachchh Basin, Western India Alhussen, (2014), Bajocian of Iran Kalantari, (1969) and Callovian to Oxfordian of India Pandey and Dave, (1993); Gaur and Talib, (2009).

**Family** Lituolidae, DeBlainville, 1827

**Genus** *Choffatella* Schlumberger, 1904

**Type species:** -*Choffatella .sp*

***Choffatella.sp* (Plate 1: G and H)**

**Description:** - Test relatively large, compressed; planispirally coiled; partial involute to evolute, chambers are numerous (13) and increase slowly in size; chambers are separated by strongly oblique sutures curving into the peripheral keel on the spiral side, and by slightly depressed sutures on the umbilical side. involute umbilical side; Chamber walls are arenaceous; finely perforate

**Remark:** *Choffatella* is known from Jurassic of Saudi Arabia Youssef and El-Sorogy (2015) also from Kimmerdigian of Egypt, Said and Barakat (1958).

### 5.3. Ostracods

Ostracods are 0.2 mm to 2.0 mm- sized crustacean arthropods, known since the late Cambrian to occur in nearly all types of aquatic environments. They are valuable proxies for paleoenvironmental conditions including salinity, oxygenation, substrate and water depths.

Ostracods are characterized by a bivalved shell (carapace) that is typically ovate or kidney-shaped in outline. The carapace encloses the soft parts and consists of two valves which overlap each other. The valves are mostly equally shaped and articulated by teeth and sockets hinge line. The surface of the valves is smooth or sculptured into ridges, ribs, spines or nodes. Fossil ostracods are defined by the shape of the carapace, carapace surface feature, type of hinge, placement of pores and muscle insertion scars.

In Shanan section more than 50 different ostracod fossils are extracted from washed marl sediment but the identification of them is difficult due to the poor preservation of ostracods. In the entire collected ostracod sample, their hinge, placement of pores and muscle insertion scars are not visible

under binocular reflecting microscope. For these reasons the classification of ostracods are taken to genus level where possible and some figures of the collected ostracods is given in plate 2.

The systematic classifications of ostracod taxa follow (Schudack et al 2013; Bate 1972; Sames, 2009; Beher et al., 2010; Sheppard,1981; Andreu et al., 2012 etc). The taxonomy is taken up to genus level.

**Phylum** Arthropoda Schwartz, 1998

**Class** Crustacea Brännich, 1771

**Subclass** Ostracoda Latreille, 1802

**Order** Podocopida Miiller, 1894

**Family** Cytherellidae Sars, 1866

**Genus** *Cytherelloidea* Alexander, 1929

**Type species:** - *Cytherelloidea*,sp

***Cytherelloidea*.sp (Plate 2: A and B)**

**Material:** - 2 carapaces.

**Description:** - Carapace subrectangular in lateral view; incurved ventrally and narrower anteriorly. Dorsal margin is straight slightly sloping downwards towards posterior. Ventral margin strongly incurved. Muscle scars and hinge are not visible. Wide peripheral rib on both valves is present.

**Family** Cytherideidae Sars, 1925

**Genus** *Procytheridea* Peterson, 1954

**Type species:** - *Procytheridea*. sp

***Procytheridea*.sp. (Plate 2: C and D)**

**Material:** - Three carapace.

**Description:**-Carapace subtriangular in lateral view; greatest length at mid-height; anterior margin rounded; posterior margin reduced and rounded triangular in shape; dorsal margin convex; ventral margin almost straight and subparallel to anterior margin. Teeth, hinge, muscle scars and marginal pore canals not visible.

**Family** Paracyprididae Sars, 1923

**Genus** *Paracypris* Sars, 1866

**Type species:**- *Paracypris. Sp*

***Paracypris.sp* (Plate 2:E and F)**

**Material:** - Two carapaces.

**Description:**-Carapace elongate-oval in lateral outline; Smooth slightly compressed anteriorly; greatest height at mid-length; one valve larger than another valve which it overlaps; anterior margin rounded; posterior margin pointed below mid-height; dorsal margin slightly arched; greatest overlap at ventral concavity.

**Family** Progonocytheridae, Sylvester-Bradley, 1948

**Genus** *Progonocythere*, Sylvester-Bradley, 1948

**Type species:** - *Progonocythere. sp*

***Progonocythere.sp* (Plate 2:G and H)**

**Description:**- Rectangular carapace tapering rounded to posterior, postero-ventral slope is somewhat steep. Valves are uniformly convex in dorsal view. Lateral border strongly overhanging ventral margin. Carapace ornamented. Valves vary in size. Hinge and teeth are not visible.

**Family** Bairdudae, Sars, 1888

**Genus,** *Bairdia*, McCoy, 1884

**Type species:**-*Bairdia. sp,*

***Bairdia* sp. (Plate 2; I and J)**

**Description:**-Large, thick shelled carapace with broadly arched dorsal margin that becomes concave terminally, especially towards posterior. Carapace surface is ornamented by evenly spaced small pits. Carapace is highest and widest medially and longest at ventral of mid-point. Anterior margin rounded, posterior margin small and pointed. Left valve larger than right valve which it overreaches on all sides and overlaps mid ventrally; Hinge and Muscle scars not observed.

**5.4. Bivalves**

Bivalves are class of phylum Mollusca characterized by a shell that is divided into left and right valves. The valves are connected to one another at a hinge. Most bivalves articulate along a hinge line by means of teeth and sockets. The plane of symmetry passes between the two valves parallel to the hinge line.

Main characteristics used for classification of bivalves are, nature of dentition (number, size and shape of the teeth), position the ligament, muscular scar, pallial line, shape and microstructure, concentric and radiating growth lines etc.

All Bivalve fossils collected from Shanan section are preserved as a mold and cast which makes it difficult to identify and name this fossils. For identification of bivalves, gastropods and brachiopod the description for each with figure is given. Then comparison with Jaboli (1943) and Keissling (2011) is made. The systematic classifications of invertebrate taxa follow more recent published works done on the respective taxa where ever possible and the image of identified bivalve fossil is given in plate 3 and 4.

**Phylum** Mollusk, Linnaeus, 1758

**Class** Bivalvia Linnaeus, 1758

**Order** Mytiloida Férussac, 1822

**Family** Gryphaeidae Vialov, 1936

**Genus** *Nanogyra* Sowerby, 1822

**Type species:***Nanogyra. sp.*

***Nanogyra.sp.* (Plate 4:C,D and E)**

**Material:** 31 specimens.

**Description:** All fossils collected from the field range in size from 3mm to 8 mm, they are convoluted (lunate) in shape and umbo curls round to the aperture, growth lines and spacing is random.

**Remarks:** This fossil is highly similar with species *Gryphae nana* of Keissling (2011); they are also reported from Harrar by (Jaboli 1959).

**Order** Heterodont, Neumayr, 1884

**Family** Astartidae, Boss 1989

**Genus:** *Astarte* j. Sowerby 1816

**Type species:** *Astarte sp.*

***Astarte sp.*(Plate 4:F and G)**

**Material:** 9 double valved specimens

**Description:** All species collected from the field range in size from 2 mm to 7 mm, they have irregular triangle shape and have clearly visible growth lines. Their length and widths are somewhat equal in size. Their umbo is sharp and curls round to the aperture, growth lines and spacing is somewhat equally spaced. They are wider in posterior.

**Remarks:** Internal features are not observed in the available material but the specimen is very similar in shape, size and concentric ribs to the form of *Astarte .sp.* as described and figured by (Jaboli, 1943).

**Family** Lucinidae Fleming, 1828

**Genus** *Lucina* Bruguière 1797

**Type species:** *Lucina.sp*

***Lucina.sp.* (Plate 3:D and E)**

**Material:** 1 double valved specimens

**Description:** Shells subcircular in outline or elongated and surface smooth. Growth lines gently visible at posterior margin, they have small umbo with large hinge line. Length from anterior to posterior is 18mm and from dorsal to ventral 19 mm.

**Remarks:** - The ribbing of the species is not clearly observed in the available material, but overall shape closely corresponds to species of genus *Lucina* as discussed and figured by (Jaboli, 1943).

**Family** Pholadomyoidea King, 1844

**Genus:** *Pholadomya* Sowerby, 1823

**Type species:** *Pholadomya.sp.*

***Pholadomya.sp.* (Plate 3: A, B and C)**

**Material:** one double valved specimen

**Description:** They have equally spaced growth lines and style of ribbing is both radiating and concentric, umbo is small with very short hinge line. Length from anterior to posterior is 23 mm and from dorsal to ventral is 15 mm.

**Remarks:** Genus *Pholadomya* are recognised by their unique perfectly spaced growth lines. In the present available material internal features are not observed, but overall shape and style of ribbing closely correspond to species of Genus *pholodomya* as described by (Jaboli, 1959).

**Order** Mytilida Férussac, 1822

**Family** Mytiloidea Rafinesque, 1815

**Genus** *Modiolus modiolus* Linnaeus, 1758

**Type species:** *Modiolus modiolus.,sp*

***Modiolus modiolus* sp. (Plate 3: F and G)**

**Material:** 1 one double valved specimens

**Description:** They are irregularly oval in outline; have broad rounded umbo, dorsal margin convex, ventral margin slightly concave. Very fine concentric lines are present. Length from anterior to posterior 33 mm and dorsal to ventral 22 mm.

**Remarks:** Internal features and growth lines are not observed, but overall shape closely correspond to genus *Modiolus modiolus* figured and discussed by (Jaboli, 1959).

### **5.5. Brachiopods**

Brachiopods are bilaterally symmetrical sessile marine organisms with an external shell consisting of two dissimilar but equilateral valves. Based their morphology they have been divided into two major groups as inarticulate and the articulate. The inarticulate have not an articulating hinge and are united by muscles. Their shells are composed of alternating layers of calcium phosphate and chitin. Articulate brachiopods have articulating hinges and calcitic shells. The body of brachiopods is enclosed by a valve except for the pedicle which serves to attach the animal to the substrate. The larger valve on the ventral side of the body is the pedicle valve, the smaller valve on the dorsal side the brachial valve. In Shanan section fossils of brachiopod is identified as its image is given in plate 4.

**Phylum Brachiopod** Duméril, 1805

**Class Rhynchonellata**, Williams et al., 1996

**Order Terebratulida**, Waagen, 1883

**Family Terebratulidae**, King, 1850

**Genus *Terebratula***, Muller 1776

**Type species:** *Terebratulla* .sp

***Terebratulla* .sp (Plate 4:A and B)**

**Material:** 4 double valved and 2 pedicle valve.

**Description:** - The shell is triangular in outline, with its widest part anteriorly. It has length of approximately 14 mm from anterior to posterior. The external surfaces of the valves are smooth except for very fine concentric growth lines gently visible at anterior margin. The pedicle foramen is circular opening, located in the beak. Have a very short hinge line, and there is weak observable sulcus and fold. The beak is short, and sub-straight to straight, as is usual in species of this genus.

**Remark:** In Ethiopia *Terebratulla* are also known from Mekele, Keissling (2011), from Harrar by Jaboli (1943) also from Blue Nile basin (Russo et al., 1994). The present sample is highly similar with species of this genus as discussed by Jaboli (1943) and (Keissling 2011).

## 5.6. Gastropods

Gastropods are class of phylum mollusk that has mostly an externally univalved shell usually coiled. The exterior of gastropod shells may be smooth or ornamented with ribs and spines. The shells of different gastropods vary enormously, and these variations are used to distinguish one species from another. The gastropod fossil collected from Shanan section carbonate are described and figure for identified fossil is given in plate 5.

**Phylum** Mollusk Linnaeus, 1758

**Class** Gastropod, Cuvier, 1795

**Order** Littorinimorph, Golikov and Starobogatov, 1975

**Family** Naticidae, Guilding, 1834

**Genus** *Ampullina*, Lamark 1821

**Type species:** *Ampullina*.sp

***Ampullina* .sp.(Plate 5: A and B)**

Material: 1 mold

**Description:** Thick, medium-sized; number of whorls about 3; whorl gently rounded; aperture is absent. The material is low spired gastropods composed which are highly asymmetrical in size and thickness. Length from anterior to posterior 30mm and has a Diameter of 27 mm in the anterior end and about 12 mm in the posterior.

**Remark:** The aperture and apex is not preserved so it's impossible to estimate whole no of whorls. But overall shape closely corresponds to *Ampullina.sp* as of (Jaboli, 1959).

**Order** Ptenoglossa, Gray, 1853

**Family:** Nerineidae Zittel, 1873

**Genus:** Nerinea, DeFrance 1825

**Type Species:** - *Nerinea .sp*

**(*Nerinea .sp* Plate5: C and D)**

Material: 1 mold

**Description:** The material is an internal mold low coiling composed of 4 whorls. Whorls become a little broader from the anterior to the posterior. Whorls are separated by a weak depressed like suture. Aperture, apex, columella and body whorl is not preserved,

Height: 32 mm in height (all whorls) and about 4 whorls are preserved

Diameter: 15 mm in the anterior end about 13 mm in the posterior

**Remark:** Upper Jurassic species of Genus *Nerinea* are recognized by their size, whorl shape and size, spiral shapes, tubercles of suture lines and shape of columella fold, (Fukada 1953). In the present material most of this are not observed. But the overall shape corresponds to *Nerinea somaliensis* weir as described by (Jaboli 1959).

### **5.7. Fossils under Thin Section**

Thin-section fossils present only a part of the biota present in the rock, for this that thin-section diversity is not equivalent to biotic diversity. Identifying fossils in thin sections may be difficult,

because, randomly cut sections of microfossils may exhibit very different shapes and outlines, resulting in an often confusing taxonomic situation of 'thin-section fossils', Racki and Sobon-Podgorska (1992), diagenetic alterations may produce 'diagenetic taxa', the lack of modern equivalent of many extinct fossils may cause very different opinions varying from author to author regarding the systematic position and classification of fossils known only from thin sections and Some fossils (e.g. larger foraminifera) common in thin sections require oriented sections to follow defined planes because they may be rare in randomly cut samples (Flügel 1982).

According to Flügel (1982) Most of thin-section fossils comprise six informal groups of cyanobacteria (calci-microbes) and calcareous algae, foraminifera and other protozoa (radiolarians, calcipionellid benthic sessile organisms (sponges, corals, bryozoans), shell-bearing organisms with valves (brachiopods, mollusks, ostracods) and multi-plate shells (trilobites, crustaceans, echinoderms). All these have their own system of identification one from another, Eg, foraminifera are identified in thin sections based on wall structure, arrangement of chambers and the form and position of the aperture. But taxonomic determination of foraminifera in thin sections of limestones may be difficult because only randomly oriented sections are commonly available, and wall structures are often destroyed by diagenesis.

Thin-section of fossils with shell-bearing organisms characterized by bivalved or univalved shells such as brachiopods, mollusks, ostracods and etc are difficult to identify. An identification of these bioclasts as to higher systematic levels is possible when original shell microstructures are preserved or unique diagnostic criteria are visible. In Shanan section different fossils are seen under thin section and based on their observable and diagnostic feature some of them are identified as their image is given in Plate 6,7 and 8.

## **CHAPTER SIX**

### **6. DISCUSSION**

#### **6.1. Introduction**

Thick layers of Jurassic limestone rocks (Hammanlei Formation) which deposited in Shanan section were investigated in field and lab analysis. The studied carbonates consist of mudstone, grainstones, packstones and wackestones within micrite and/or sparry calcite cement dominated by benthic foraminifera with minor brachiopods, echinoderms, bivalves, ostracods and gastropods.

Based on their varying contents and sedimentological features obtained from the carbonate unit of the area: - depositional environments, facies patterns and association, age, composite stratigraphy of the area and correlation with other area are discussed as follows:-

#### **6.2. Facies Associations and Depositional Environment**

Depositional environment is a geomorphic unit in which deposition takes places. Depositional environments can be interpreted and classified through facies analysis, which is body of rock characterized by a particular combination of lithology, texture, group of sedimentary structures, fossil content, color, geometr etc, (Flugel, 1982). In order to reconstruct Paleoenvironment microfacies types (which determine the compositional and textural constituents of carbonate rocks based on examination under thin sections) are grouped and different constraints methods or approaches are used. From those different approaches an integrated approach of microfacies analysis which combines different methods and uses information from the sedimentary record is widely used. Most microfacies analysis criteria aimed at a discrimination of ancient environments are qualitative. They refer to (1) modes of composition and preservation of carbonate grains (2) textural differences (grain size, sorting) (3) bioturbation and bio-retexturing of the sediment (Flugel 2004).

In microfacies analysis of carbonate rock fossils use as the most important indicators of ancient environments because strong interactions exist between organisms and their environment. Also carbonate rocks contain much of the fossil record of past life forms that provide important insight into environmental conditions of the past. Paleoenvironmental interpretations of carbonate deposits also depend on estimations of hydrodynamic conditions and processes. Depending on various

oceanographic factors (e.g. water depth, wave amplitude) the energy level may be fairly constant or may vary strongly over time. The energy of a water mass capable of moving sedimentary particles varies between low (low-energy sediments) and high (high-energy deposition). Generally high-energy environments include the intertidal zone, shallow-marine open platforms, inner ramps etc. Low-energy environments occur in protected areas, such as enclosed bays, estuaries, lagoons, inner platform areas, outer ramps and in deeper-water settings (Flügel, 1998). Textural criteria such as size, sorting and roundness of grains and matrix types of rocks, compositional data of fossils, carbonate and non-carbonate admixtures as well as sedimentary structures are also valuable indicators of water energy. The recognition of energy levels based on depositional textures gives an idea of the ideal relations between the winnowing of fine-grained particles, sorting and rounding of grains and the intensity of hydrodynamic processes. Outcrop observations are combined with detailed microfacies studies to provide the differences in the geometry and lateral continuity of facies, facies successions, and facies heterogeneity, which indicate depositional environments.

Accordingly analysis of thin section of carbonate samples collected during the study of stratigraphic Shanan section has revealed the presence of six main microfacies repeating themselves in cyclic manner. As seen from stratigraphic columns constructed on (Fig. 3.9). Detail description and photographs of some thin section for each of microfacies result is given in chapter four of this thesis. The carbonate exposures of Shanan section have various limestone bed sequences, sedimentary structures and textures. The general successive facies and facies belts of the carbonate units of Shanan section from field investigations and microfacies analysis results show low energy shallow water environment occasionally interrupted by episodes indicating a relatively high-energy environment and upper part of the section shows some relatively deep low energy environment again. But on the top end part of upper Shanan section there is around 4 m thick bedded reddish grainstone layer with cross bedding structure on it. The lower part of these reddish layers around 10m is a mudstone layers with marl intercalation. It is difficult to interpret these reddish layers as the low energy deposits found dominantly at the upper Shanan found below it. For these it can be concluded that they may be deposited due to the local sea level fluctuation taking place after the deposition of low energy layers.

Based on textural characteristics sedimentary structures and microscopic analysis environment of deposition of the section is interpreted. Accordingly the dominating depositional processes and the

carbonate deposits of the study area show depositions under shallow marine conditions and some offshore system depositional condition.

The studied carbonates rocks are dominated by skeletal fossil grains of benthic foraminifera with minor bivalves, echinoderms, brachiopods, crinoids, ostracods and gastropods. The carbonate facies patterns of the successions show the transgressions pattern of deposits and some cyclicity of the components within varying thickness of the beds bearing them throughout the area vertically. This cyclicity of the layers is most probably caused by depositional energies, depositional processes, small changes in sea levels and the change of morphologies of the depositional sites locally during their depositions. The cycles of the facies are mostly shallowing-up pattern at the lower Shanan units and some deepening up pattern at the middle and upper Shanan units which show the more sea level increments and deepening of the basin during the deposition of middle and upper parts of the successions.

Distribution of facies shows that three associations of facies followed each during early Callovian to Oxfordian. These three distinct facies associations have been identified based on relationship of facies with one another. From bottom to top they are as follows:-

- **Lower Shanan** (Microfacies types 1,2,3 and 4)
  - Consisting of low energy deposits of micritic, bioclastic and peloidal microfacies (microfacies types 1,2 and 3) and
  - Some high energy deposits comprising of oolitic microfacies (microfacies type 4)
- **Middle Shanan** (Microfacies types 5 and 6)
  - Consisting of moderately high energy deposits of biointra packstone to grainstone and biopel packstone to grainstone microfacies (microfacies types 5 and 6).
- **Upper Shanan** (Microfacies types 1 and 2)
  - Consisting of low energy deposits of micrite and bioclastic wackestone microfacies (microfacies types 1 and 2) present on top of Shanan section.

The existing of dominant finer peloidal grains, borrowing structures, micritized skeletal and non-skeletal grains (shown in microfacies type of 1, 2 and 3) those compared with 8 and 7 facies belts of Wilson (1975) and coarser oolitic grains of high energy deposit (MFT 4) which is compared with

facies belt 6 of Wilson (1975) these carbonate successions are best indicators of shallow marine carbonate depositional environments. Peloids are form in shallow marine low-energy platform carbonate settings such as the lagoonal areas, Prothero and Schwab (2014) because in lagoon sediment pellets formed by molluscs and crustaceans are abundant (Reading, 1996). The dominances of various skeletal grains and non-skeletal grains like intraclasts with some peloids(MFT 5 and 6) in middle Shanan indicate its depositions under shallow marine conditions with moderate energy. The alternative cycling of facies within this sub-unit also shows local change in sea levels or other processes during deposition.

In the upper part of Shanan section there is succession of layers with fine grained dark to blackish gray micritic layers as seen from Fig (4.1:C). Rare skeletal grains like: forams, bivalves and echinoderms are also imbedded in these micritic layers at places. Upper Shanan is dominated by bioclastic wackestone and micritic microfacies (MFT 2-1) with chert nodules between the layers and compared with facies belt 2 and 3 of Wilson (1975) which is deposited at basin margin to open sea conditions. This facies show some deepening up which may be due to high sea level rise during their depositions and show low energy deposits.

Generally those facies belts indicate depositions ranging from open shallow platform (shelf lagoon) to basin margin to open sea conditions as the carbonate facies of the area are compared with the facies belt 7, 6, 4, 3 and 2 of (Wilson,1975). Commonly carbonate facies of the area shows various sub-shallow marine depositional environments ranging from the carbonate deposits of low energy platform interiors of lagoon, high energy platform margin carbonate sand bodies, slope deposits and some deposits of basin margins and open sea. The overall facies associations of carbonate deposits of the area are showing a low gradient of depositional dip from domains of lagoon and shoreline high-energy shoals deposits to areas of foreshoal to basin margins and open sea low energy deposits as given in (Fig. 6.1). These are described as follows:

#### **6.2.1. Lagoonal Carbonates**

Lagoons form along carbonate coastlines where a beach barrier wholly or partly encloses an area of shallow water they have very limited connection to the open ocean. Seawater reaches a lagoon directly through a channel to the sea or via seepage through a barrier (Nichols, 2009). Lagoons generally develop along coasts where there is a wave-formed barrier and are largely protected from

the power of open ocean waves (Reading and Collinson, 1996). Carbonate lagoons are sites of fine-grained sedimentation forming layers of carbonate mudstone and wackestone with some grainstone and packstone beds deposited as wash over's near the beach barrier.

The micritic limestone layers at the bottom of the section (MFT1), bioclastic wackestone layers (MFT2) and peloidal grainstone layers (MFT3) in the lower Shanan section are the typical of low energy deposit of lagoon type. Wackestone and packstone are transitional between low energy mudstone and high energy grainstone deposits. They are accumulated on platforms where current activity has been insufficient to remove out the mud (Flugel, 2004). As a transitional they are located away from the edges of platforms or on deeper parts of ramps where there is some protection (Brain and Andre, 1992; Walker, 1992; Burchette and Wright, 1992). In lagoon sediments pellets formed by molluscs and crustaceans are abundant. Lime mudstone, bioclastic wackestone and packstone with calcareous algae and benthic foraminifera also indicating lagoonal environment for which the present observed layers can be particular example. The source of the fine-grained carbonate sediment and pellet in lagoons is largely calcareous algae and mollusks living in the lagoon, with coarser bioclastic accumulation from them (Flugel, 2004; Reading, 1996).

Peloid is a spherical to ellipsoidal particle consisting of micrite (lime mud) smaller than 2 mm with no recognisable concentric or radial structure. Small smooth peloids are interpreted as carbonate fecal pellets produced by organisms that consume carbonate mud (Flugel, 2004). According to Burchette and Wright (1992) carbonate fecal pellets are produced in marine and non marine environments but are more commonly preserved in sub-tidal and lower intertidal zones of inner platform or ramp setting sand in lagoon with low water energy and reduced sedimentation rates. Lagoons are typically shallow water depositional environments and mostly have a depth of <10m and they are sites for depositions of fine grained sediments forming mudstone to packstone (Reading, 1996). They are located behind barriers to ward land, in broad interiors of rimmed shelves or behind inner ramp shoal belts so they are protected environment from strong wave action (Tucker and Wright 1990). The inner most platform areas are commonly restricted or hypersaline and support only a low diversity biota.

### **6.2.2. Platform margin Carbonate Sand bodies**

Carbonate platform are shallow marine depositional environment of carbonates. The oolitic microfacies (MFT4) and some part of bioclastic microfacies layers of lower and middle unit those comprises large size ooids (reaching sand sizes) and rare amounts of skeletal within sparite cements (as shown in Fig 4.4) are the typical facies of platform margin carbonate sands/ oolitic sand barrier deposits. The grains in these facies are well sorted, well-rounded, tangential ooids; lithified forming horizontal beds of grainstone and some grains surrounded with micritic envelopes which is the result of reworking by wave and tidal currents at these margins. This interpretation is supported by presence of cross bedding structure found on the layers. Ooids reflect physical and chemical conditions of the depositional environments in marine settings and they are proxies for water energy. Ooids are formed in both high-energy and low-energy environments and have various shapes. Usually more or less they are spherical or ellipsoidal carbonate particles with uniform, concentric laminae coating a nucleus. In thin-sections tangential and/or radial structures of ooids can be recognized in the laminae. Concentric (tangential), micritic ooids, broken or distorted ooids are indicators of very shallow seas and common in high energy setting Flugel (2004) which are typical of ooid grains in this microfacies (Fig4.4:A-E).

Stronger or more frequent currents are mostly common in shallower depth. They abrade away micrite; allochems become better sorted and with continued abrasion better rounded (Prothero and Schwab, 2014). Bioclasts, ooids, and peloidal grainstones are usually occurring around high energy areas such as shoals and beaches in inner ramp/shelf (Burchette and Wright, 1992; Reading, 1996). These carbonate sand bodies and material in the form of bioclastic debris and ooids is reworked by wave action into ridges that form strand plains along the coast or barrier islands separated from the shore by a lagoon (Wright, 1984; Tucker and Wright, 1990). For this oolitic microfacies is interpreted to be deposited around high energy area such as carbonate shoals and Barrier Island or beaches. The texture of carbonate sediments deposited on barrier island and strand plain beaches is typically well-sorted and with a low mud matrix content (grainstone and packstone) which is seen on this microfacies. Carbonate sand bodies made up of bioclastic and oolitic sands occur extensively at the margins of carbonate platforms of all ages reflecting the dissipations of most wave and tidal energy at such margins (Tucker and Wright, 1990). Carbonate sand bodies are a prominent feature of high energy sub-tidal to intertidal in many platform settings. Their formation

shows that the presence of barrier/ islands at this margins. Barrier is a wave-dominated environment where wave action reworks marine sediment such as bioclastic material and other sediment due to long shore drift to form a barrier (Nichols, 2009).

### **6.2.3. Carbonate Foreshoal Environment**

The foreshoal environment is represented by packstone–grainstones with varied skeletal and non-skeletal components (Bádenas and Aurell, 2010). In the middle Shanan the Carbonate unit have coarser grained deposits of resedimented wackestone- packstone- grainstone facies (MFT 5 and 6) those are dominantly intraclastic, various sized peloidal grains and some skeletal (like mollusks, echinoderms, ostracods, corals, foraminifers etc). According to Brain and Andre (1992) carbonate grains like mud-free sediments, intraclastic packstone-rudestone and other boulder- rich sediments are deposited under slope deposits and most of them are resedimented. The abundances of intraclastic carbonate grains in this facies also indicate that the instability of the slope surfaces. Foreshoal areas can be characterized by accumulation of ooids, skeletal grains and peloids which occurring separately or associated together to form packstone to grainstone textures (Flügel, 2004). The intraclastic rich and bioclastic peloidal packstone to grainstone microfacies layers of middle Shanan which are indicators of fore shoal environment are conformably overlain by the micritic and bioclastic wackestone layers. The allochem rich layers are simply passing to the micritic dominating fine grained wackestone to mud stone layers They show the accretionary slope (low angle) type deposits (Reading, 1996). These deposits have alternative layers of mudstone, wackestone, packstone and grainstone layers with varying thickness. The sediment supply toward the platform foreshoal may be from number of sources (Walker, 1992).

### **6.2.4. Offshore Carbonate Facies**

Offshore is zone of outer shelf area below storm wave base predominantly a region of mud deposition. On these areas carbonate sedimentation is dominated by fine-grained deposits and chert nodules which are formed by redistribution of silica from the skeletons of siliceous organisms within the beds are also common in offshore environment (Nichols, 2009).

The upper Shanan section carbonate successions are mainly fine grained micritic and wackestone layers. They are thin-massively bedded and grayish, dark gray blackish and reddish in color.

Micritic rocks are composed of fine-grained calcite crystals and particles formed in place or by the accumulation of fine-grained pre-existing carbonate material. Calcareous mud in warm water setting comes from the breakdown of green calcareous algae, in organic precipitations from sea water and from disintegration of large skeletal particles into their smallest crystallographic unit. These mudstones accumulated in quite water areas that are not affected by tidal or strong oceanic currents (Tucker and Wright, 1990). Such habitats are found in deep water shelf/ramp areas below wave base or in the lee of islands and shoals (Brain and Andre, 1992).

The middle Shanan intraclastic skeletal and peloidal dominating deposits are conformably overlain by these lower energy deposits. The depositional area which is dominated with very fine materials of low energy deposits are the depositional area away from high energy in protected sites or in basin margin to open sea conditions (Reading, 1996). For which the present massive mudstone dominated layers will be the most typical example of carbonate deposits of low energy condition of outer shelf/ramp setting at basin margins or open sea conditions.

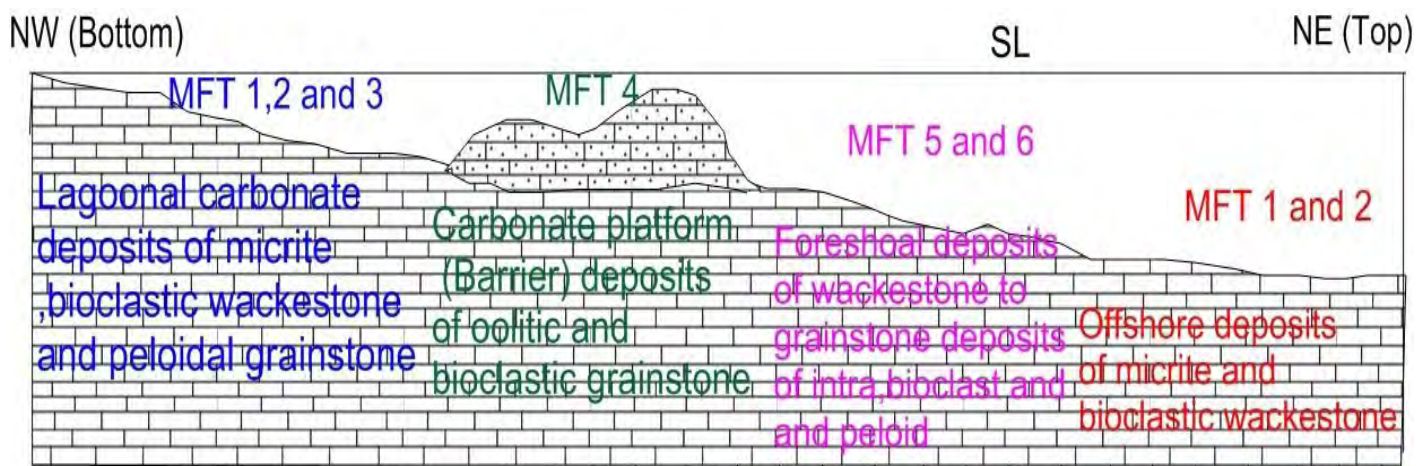


Fig. 6.1. Schematic diagram showing depositional model for part of Shanan section carbonate.

### 6.3. Biostratigraphy and Age of Shanan Section Carbonates

Biostratigraphic units or biozones are bodies of strata that are defined or characterized on the basis of their contained fossils. They help for correlating and assigning relative ages of rock strata by using the fossil assemblages contained within them. A biostratigraphic unit may be based on a single taxon, on combinations of taxa, on relative abundances, on specified morphological features, or on variations in any of the many other features related to the content and distribution of fossils in

strata. To be useful in biostratigraphic correlation and to determine the relative age of a rock, fossils have to be index fossils which are defined as geographically widespread, rapidly evolving, abundant or easy to find in the rock record and easy to preserve and to identify.

In Ethiopia biostratigraphy based on foraminifera is used in determination of age and for correlation of strata studied with carbonate succession of other near section to present studied section in Southeastern plateau and with other sedimentary basins of the country. The significant number of stratigraphically important microfossils encountered in all investigated Jurassic formations of Shanan section led to the proposal of microfossil zonation.

Based on the presence of index (zonal markers) of foraminifer fossils such as, *Pfenderina cf. salernitana* and *Kurnubia palastiniensis*, Shanan section carbonate rocks are dated to be entirely of Jurassic age (Fig. 3.9) particularly spans the Callovian to Oxfordian age.

*Pfenderina cf. salernitana* is found in the lower part of the section dominantly and rarely did it also find in the upper part of the section (plate 6: A, B, C and plate 8: I). In lower and middle Shanan it found mostly with assemblages of brachiopods, bivalves, gastropods, Dasycladean algae, *Nautiloculina circularis*, *Kurnubia palastiniensis*, *Verneulinoides minuta*, etc. In the upper Shanan *Pfenderina cf. salernitana* become rare and *Kurnubia palastiniensis* (plate 7: C, H and plate 8: B, C) become abundant which may indicate the disappearance of *Pfenderina cf. salernitana* is close at the top. In the upper shanan in addition to rare *Pfenderina cf. salernitana* and dominant *Kurnubia palastiniensis* rare *Haphlophragmoides bartenstein*, *Nautilocuina oolithica*, *Choffattella sp*, *Lenticulina subalata*, *Lenticulina quenstedti* etc are associated.

According to Sartoni and Crescenti (1962), Tasli and Tiner (2010) and Tasli (2001), *Pfenderina cf. salernitana* is used as an index fossil for the Bathonian to Callovian age. Monsour and Houston,

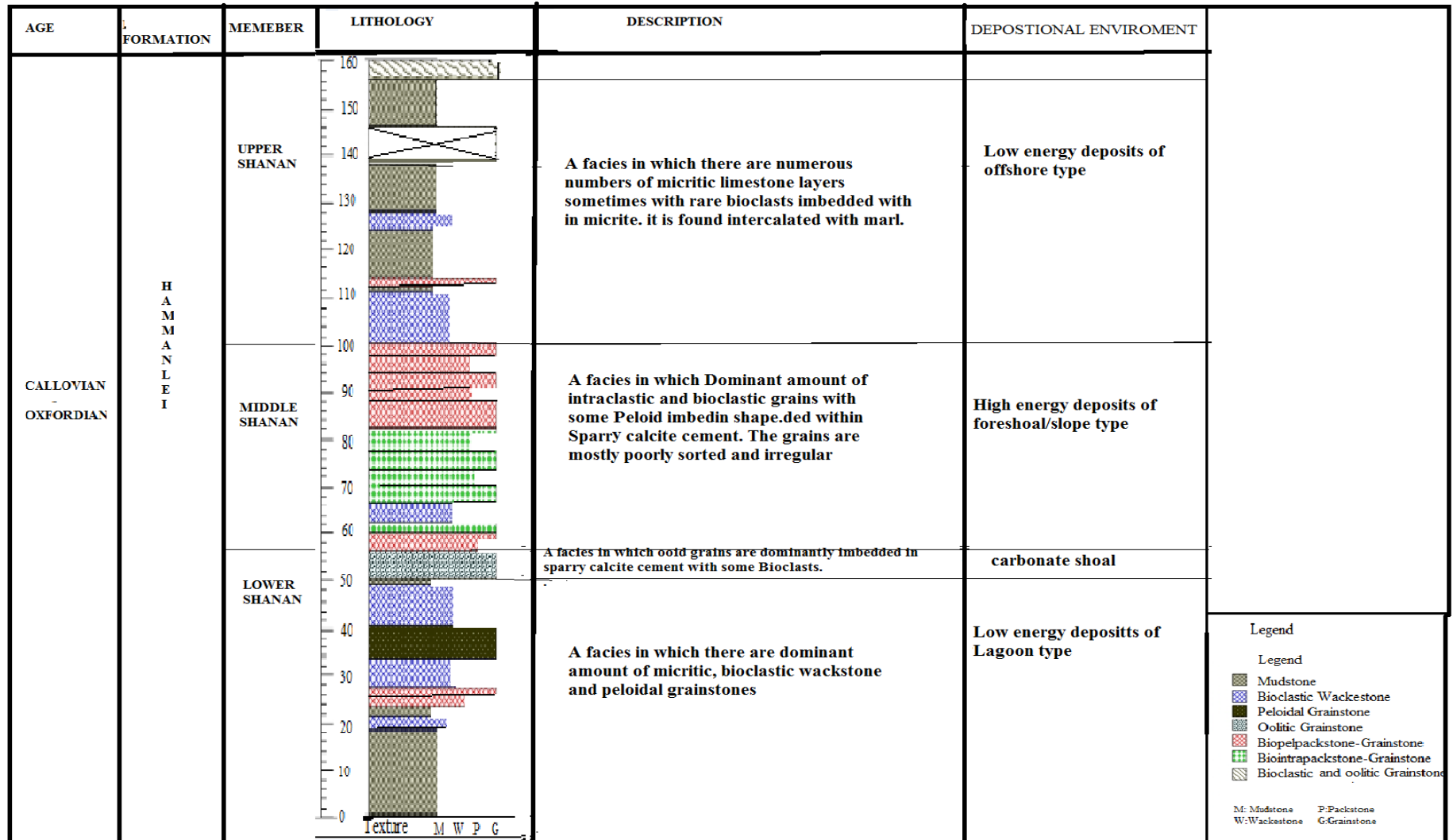


Fig 6.2. Composite stratigraphy of Shan'an section carbonate units, with detailed age, thickness, lithology description and their depositional environments.

(1975) also state that Ethiopian *Pfenderina* is derived from Bathonian and younger strata which are always directly overlain by *Kurnubia palastiniensis*. *Kurnubia palastiniensis* is an index fossil of Callovian – lower Kimmeridgian in age (Monsour and Houston, 1975; Sartoni and Crescenti, 1962).

#### **6.4. Composite Stratigraphy of Shanan Section**

The Jurassic succession of Shanan section represents thick Callovian-Oxfordian carbonate sedimentary succession which mostly deposited in shallow marine environment. Combining information from both fossils and rocks collected in the field and in laboratory has allowed for reconstruction of the depositional environments, to determine relative age of the carbonate rock of the section and to correlate with other sections and regional basins. As given in (Fig 3.9), the carbonate stratigraphic succession of the section which has a total thickness of about 161m is studied based on field investigations and data analysis. Based on their facies content observed in the field and thin section analysis the carbonate unit of the section which are estimated to be between Callovian-Oxfordian is grouped into lower, middle and upper Shanan.

Lower Shanan has a thickness of around 56m has dominant fine grained micritic layers at its bottom followed by bioclastic wackestone, peloidal grainstone and at its top part oolitic packstone to grainstone microfacies. Allochems are seen embedded within micrite cements and/or in sparite. Micritic limestones are usually purely micrite matrix and in rare cases some sparry calcite crystals and quartz grains are observed. Thin to medium bedded bioclastic wackestone and peloidal grainstones rarely intercalated with marl is followed the micrite facies. Ooid grains dominate the upper part of the lower Shanan. Sedimentary structures such as bioturbation, thin-thick bedding are common at bottom of lower Shanan and cross bedding structure is clearly observed on the top of lower Shanan on oolitic rocks. The lower Shanan shows relatively successive facies which comprise: lagoonal facies and carbonate shoals facies successively. As observed from petrographic analysis and microfacies result interpretation of micritic, bioclastic wackestone and peloidal grainstones microfacies are comprise to represent lagoonal facies and the top part of lower Shanan which is dominated by ooid microfacies with rare bioclastic grainstone show deposition on carbonate shoals. Macro and microfossils such as:- *Astarte* sp, *Nanogarya* sp, *Ampullina*. sp., dasycladeceanalgae, *Pfenderina cf. salernitana* (Shan

4), *Kurnubia palastiniensis* (Shan 6), *Nautiloculina oolitica* (Shan 26), *lenticulinas*, *Haphlophragmoides*, etc are present.

The 45 m thick allochem rich limestone in grains of intra and skeletal with some peloid and rare ooid characterize the middle Shan. These allochems are mostly embedded within sparry calcite cements and in rare case within micrite, the dominance of allochems shows deposition under shallow marine condition. Thick layers of reworked sediments observed on these layers show depositions around unstable high energy depositional site like that of the slope area, behind the carbonate barriers toward the sea. According to petrographic description and microfacies analysis middle Shan contains, bioclastic wackestone microfacies (MFT2), bioclastic intra packstone-grainstone microfacies (MFT5) and bioclastic peloidal packstone-grainstone microfacies (MFT7).

Deepening up facies due to the increments of the depth of sea level during its depositions can be estimated from mudstone to wackestone dominated layers of upper Shan present overlying the allochem rich layers of middle Shan. The sedimentary structures such as thin-massive bedding commonly observed. Stylolite and dike are secondary structures observed at upper Shan. Their color varies from gray, dark-black grayish and reddish. Micritic microfacies (MFT1) and bioclastic wackestone microfacies are common microfacies types of upper Shan which indicate offshore depositional environment.

The cyclic deposits facies of alternating from lower energy deposits mudstone-wackestone to high energy deposits of packstone-grainstone layers, with varying thicknesses throughout the section and top of the section dominated by low energy deposit of micrite in general indicate deepening up facies patterns. Carbonate unit of deposit for middle Shan is in foreshoal environments and upper Shan is most probably offshore environment.

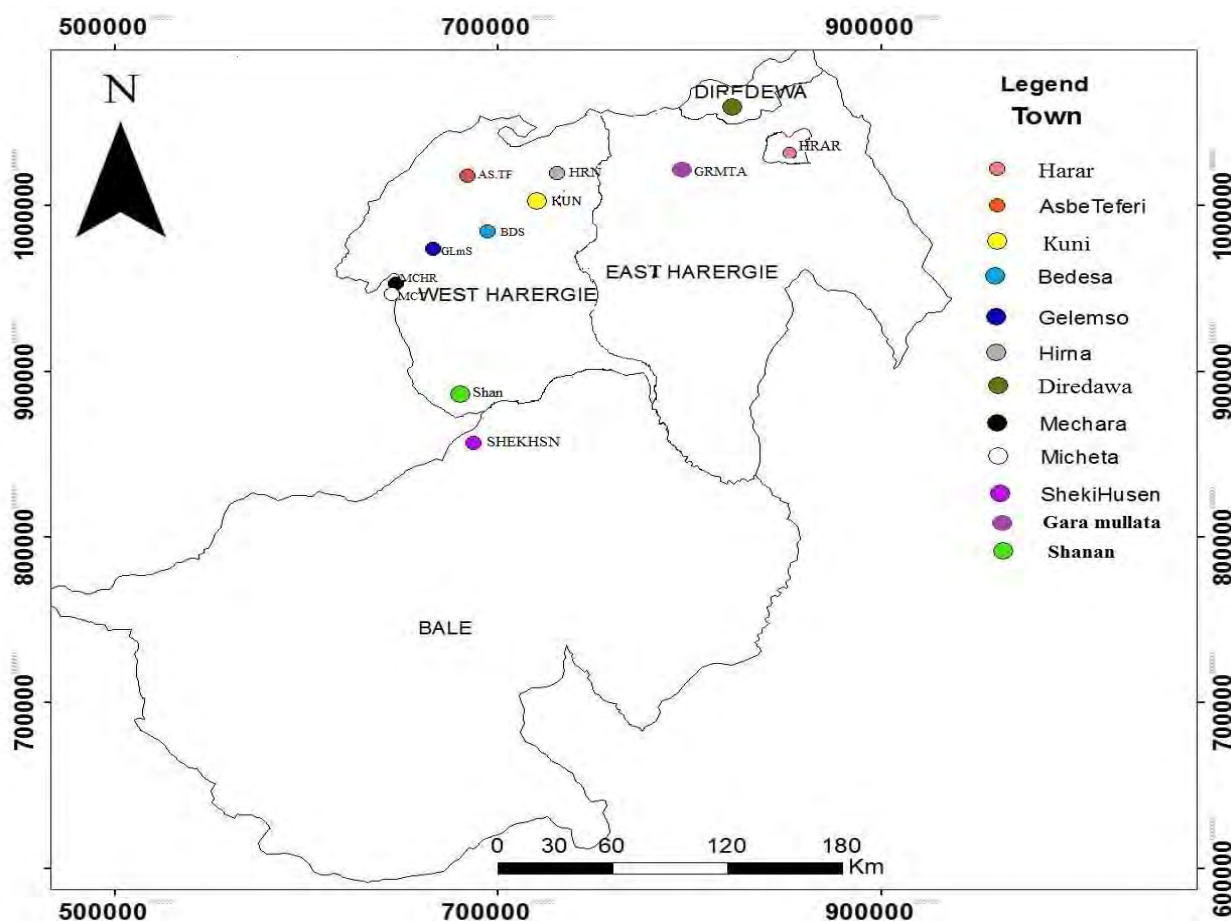
Correlation is method of establishing age relationship between rock units. It can be made, by comparing the physical characteristics of strata with each other or by comparing the type of fossils found in various strata (fossil correlation).

Shan section carbonate rock deposits which are Callovian-Oxfordian age can be correlated with chronostratigraphic equivalents and lithologically similar deposits of some SE Ethiopia

plateau sections identified by many workers (Fig.6.4) and within other Ethiopia basins (Mekele, Blue Nile and Ogaden basins), as given in (Fig. 6.5).

**6.4.1. Correlation with Some Studied Sections of South Eastern Ethiopian Plateau**

Carbonate rock deposits of Southeastern Ethiopian plateau is studied by many authors in different ways. All most all of the studies result in terms of age and depositional environment interpretation is similar. The most detail studies done on microfacies study were Ficarelli et al.,(1975) who study the microfacies property of Diredawa carbonates and Turi et al., (1980) study the microfacies of Sofomar, Kuni, Hirna and Gara mulata section carbonates. Greitzer, (1970) also study the Mesozoic carbonate deposits of Harrar in detail. All of these south eastern Ethiopian plateau Mesozoic deposits are somewhat correlable with the present studied unit (Fig. 6.4). The location map of the correlated section is given on figure 6.3.



*Fig.6.3. Location map of southeastern Ethiopian plateaus correlated with Shanan section.*

From detail studies of Turi et al., (1980) on the microfacies analysis of carbonate rocks of Sof Omar, Kuni, Hirna and Gara Mulata sections their lithology and age information is given as follows:-

Callovian to lower Kimmeridgian Antalo limestone deposits which has a thickness of 270 m is studied in Hirna section. It is grouped into five microfacies groups based on their petrographic and paleontologic analyses. This Antalo limestone is made up of calcarenites, calcisiltite and calcilutite. The bottom-middle parts of this carbonates are correlable with Shanan section carbonate rocks of present study. Bathonian to Oxfordian Antalo limestone which is mainly made up of calcarenites with fewer amounts of calcisiltite and calcilutite, often extensively dolomitized is characteristic of Antalo limestone at Kuni section. The middle part of this section is correlable with present study area.

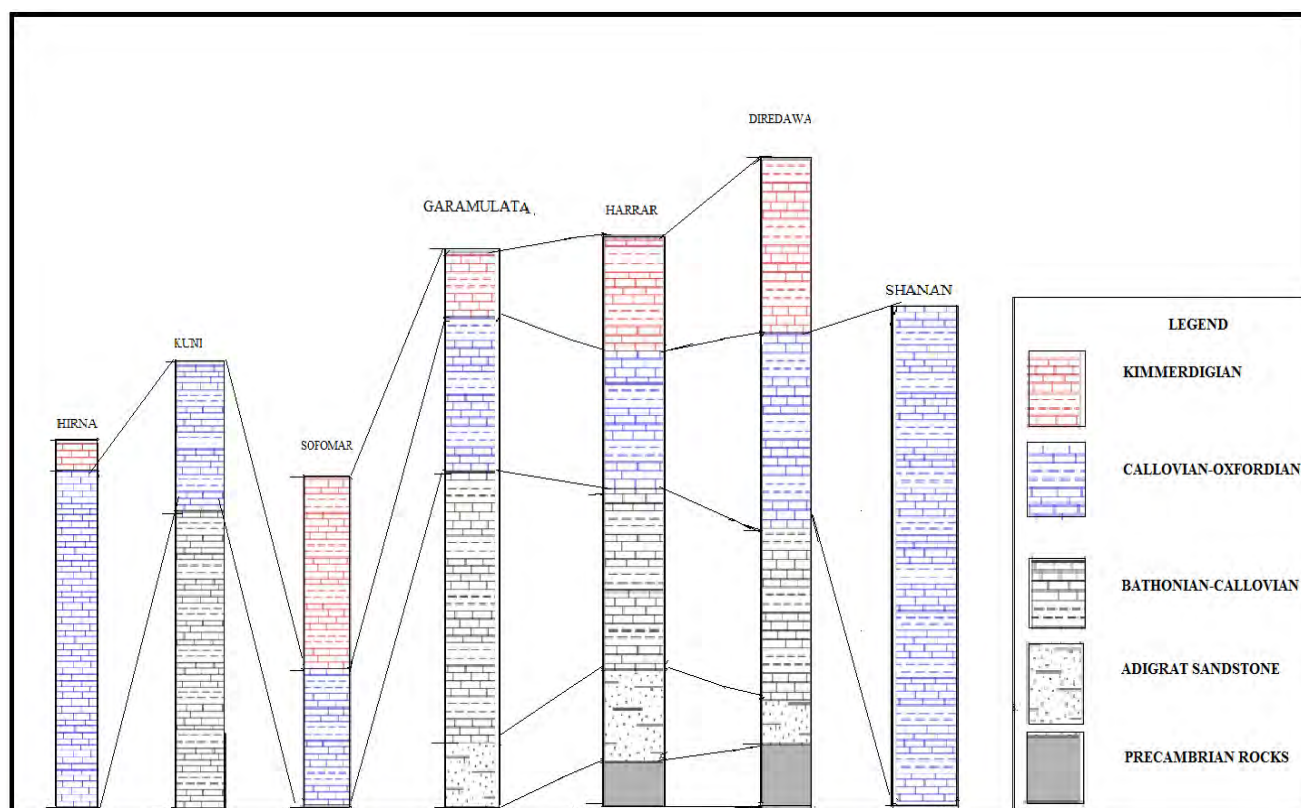


Fig 6.4. Mesozoic stratigraphy correlation between some areas from SE Ethiopian plateau, Sources: Dire Dawa area, Bosellini (2001), Harar, Greitzer (1970), Shanan (Present work) and Sof Omer, Kuni, Hirna and Gara Mulata (from Turi et al., 1980).

At Gara Mulata section of Antalo limestone made up of alternating layers of limestone, dolomitic limestone, and calcareous dolomite sometimes marly at its lower and calcarenites, calcisiltite and calcilutite at the middle and upper part of the unit consists is studied. Bathonian to lower Kimmeridgian age is given for carbonate deposits of this section. Accordingly Antalo limestones of the middle part are correlable with Shanan section carbonate units.

Sof Omar section which is located to south of Shanan section has 120m thick limestone layers which is characterized by thick whitish dolomitic layers at its lower part followed by calcarenite, calcisiltite and calcilutite; and at middle yellowish dolomitic limestones. Callovian-Oxfordian microfossils are present on these layers. Top part of this section is dominated by pale brown calcareous dolomite (Kimmeridgian-Tithonian). From these, the middle parts which are Callovian-Oxfordian are correlable with Shanan section carbonates.

Bosellini (2001), divide the Mesozoic carbonate succession of Diredawa into two distinct members as lower and upper carbonate. He assign age of Bathonian- Callovian for the lower unit based on (occurrence of *Pfenderella Arabica*, *Mesoendothyra croatica*, *Paleopfendrina salernitana* and *Salginoporella* cfr. *Selli*) and the age of the upper Antalo member is Oxfordian based on common occurrence of *Kurnubia palestiniensis*, *Pseudocyclammina* cfr. *Maynci*, *Nautiloculina oolithica*, *Alveosepta jaccardi* and *Trinocladus perplexus*. According to Greitzer (1970), the Mesozoic limestone deposits of Harrar region from bottom to top include: lower limestone and upper limestone which is Bathonian - Oxfordian age and Brown limestone and Dogou limestone which is Kimmeridgian age. From the age of both above discussed Diredawa and Harrar deposits Shanan section limestones can be equivalent with them in some parts. The correlation with each of above discussed section with the present studied Shanan section carbonate was made (Fig 6.4).

#### **6.4.2. Correlation with Sections of Other Ethiopian Basins**

Tectonic evolutions throughout NE-Africa and sea level fluctuations through geologic time have the great roles for the formation of Ethiopian sedimentary basins and thick sedimentary deposits within them. The Mesozoic sediment deposits of Ethiopia occur mainly in north western and south eastern plateau (Russo, et al., 1994). They are possibly related to the drifting phase and a major sea level high stand occurred all over east Africa with the drowning of the craton and

documented by the carbonate deposits occurred during early Jurassic – Oxfordian in different basins, (Bosellini, 1989; Russo et al., 1994).

Extensive carbonate Mesozoic deposits of Ethiopia are present in the Mekele outlier, in the Blue Nile Basin and in the Ogaden Basin (including western Harrarghe region) in the southeast. The correlation of Shanan section with these basins is based on general chronological and lithological correlation due to its closeness and correlable. Detail microfacies correlations are difficult because of scarcity of detail carbonate microfacies studies on these basins. The general chronological and lithological correlation of Shanan section with major basins of Ethiopia (Mekele basin, Blue Nile basin and Ogaden basin) is given in (Fig.6.5), and described in the following sections.

Russo et al., (1994) described about 420m thick carbonate succession, called ‘Antalo limestone formation’ present in Blue Nile (Abay) basin of Ethiopia. The Antalo limestone formation in Blue Nile basin can be generally subdivided into three parts; lower, middle and upper Antalo limestone. The lower part is consisting of a 180m scarcely fossiliferous and burrowed mudstone that grades into an oolitic limestone rich in corals, stromatoporoids, bivalves, gastropods, foraminifers and ostracods with occasional patches of, nerineids indicating a shallow water environment. The middle part often referred as marly limestone consists of a 200 m thick highly fossiliferous inter-bedding of marly limestone, marls and silty limestone. Based on the presence of some Ammonites, Terebratuline associated with Nanogyra, Rhynchonellid brachiopods and infaunal siphon-feeders shelf to open marine environment was inferred for Abay basin carbonate successions. The upper part has a total thickness of around 40m and it is composed of planar laminated oolitic and reefal limestone. Based on the occurrence of oolitic bars, coral patches, offshore and more protected facies inshore, this unit is interpreted to represent shallow water environment similar to the lower unit. The presence of some benthic foraminifera such as *Pfenderina* sp. and *Nautiloculina oolithica*) at the base of the Antalo limestone and occurrence of *Kurnubia palestiniensis*, *Parurgonina caelinensis*, *Conikurnubia* sp. and *Salpingoporella annulata* at the top of the unit suggests Callovian to Kimmeridgian age. The lower and middle part Abay basin limestone is more or less correlable with the Shanan section.

Beyth (1972a; 1972b) and Bosellini et al., (1995) described the carbonate limestone unit occur in the Mekele basin known by the name ‘Antalo Limestone’ in detail. In Mekele outlier the

thickness of the succession ranges from 300 m in the West to 800 m in the East. Beyth (1972a; 1972b) identified four facies for this unit, those are (i) well bedded to laminated, cross-bedded sandy oolite and coquina with minor amount of marl and a few chert beds, with macrofauna including mainly corals, gastropods, and echinoids, (ii) interbedding of marl and fine grained hard limestone with abundant brachiopods and some algal and chert beds, (iii) cliffs of coral and algal reef limestones interbedded with marl and biostromes, and (iv) black to grey microcrystalline limestone interbedded with marl. Bosellini et al., (1997) state that the limestone succession of Mekele outlier composed of thickening and shallowing up cycles which are deposited in a homoclinal ramp or on a wide cratonic margin and gently dipping to the southeast. The age of this Antalo limestone is Late Callovian to Kimmeridgian. Thus, the lower and middle part of Antalo limestone of the Mekele basin is correlable with carbonate rocks of Shanan section.

The Ogaden Basin found in south eastern Ethiopian plateau is studied by different authors in different direction. Abiyu Hunegnaw et al.,(1998), Shigut Geleta (1998) and Tamerat Worku and Astin (1992), state that the carbonate sediments of Ogaden basin are present overlying the Adigrat sandstone and they are; Lower, Middle and Upper Hammanlei formations which represent an early Jurassic to Callovian syn-rift marine sequence, and consist of the following lithologies: - in the lower section it contains limestone with intercalated shales, anhydrite, dolomite, and in the middle part of the section contains limestones with local oolitic and stromatolitic beds and bioclastic oolitic limestones in the uppermost section. The Callovian-Oxfordian Urandab Formation is composed of dark, laminated marls and limestones containing a pelagic marine fauna and corresponds to the maximum flooding sequence deposited during the break-up transgression. The Gabredarre Formation comprising bioclastic, locally oolitic and reefal limestones deposited in offshore bars and small reefal build-ups. It is upper Jurassic in age and represents a passive-margin sequence.

Based on various fossils obtained from them the age of lower Hammanlei ( Hettangian-Pliensbachian) , middle Hammanlei (Pliensbachian-Bajocian), upper Hammanlei (Bajocian-Callovian), Urandab Formation (Oxfordian) , Gabre Darre formation (Kimmeridgian- Tithonian) and Gorrahei formation (Berrisian-Albain) were assigned respectively by (Shigut Geleta 1998). The upper Hammanlei formation and Urandab formations are most probably correlable with the

Shanan section carbonate. In Ethiopia, overall regression was thought to prevail during latest Jurassic (Tithonian) and Berriasian times (Getaneh Assefa, 1991) which terminate carbonate deposits and clastic deposits start overlain carbonate unit.

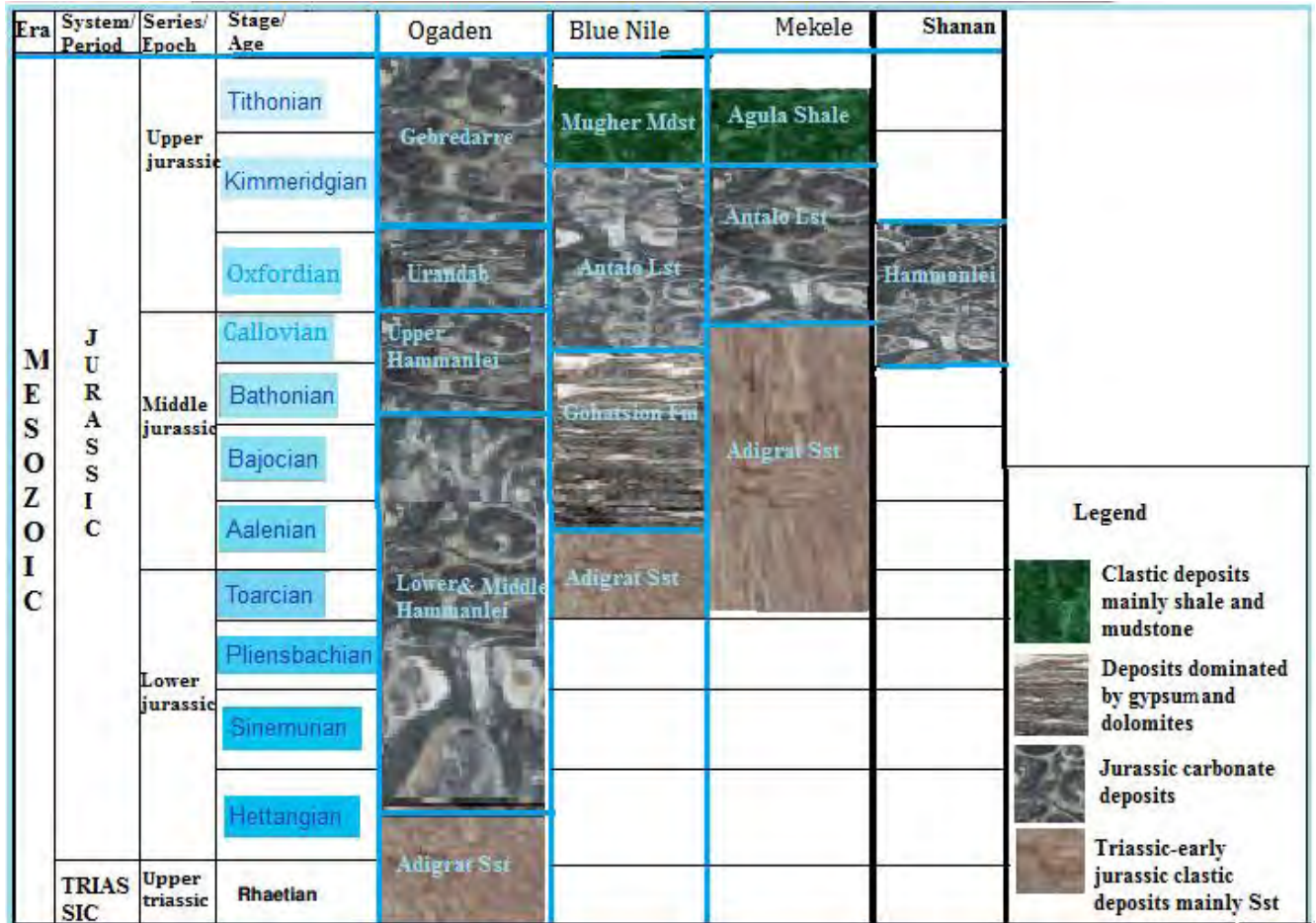


Figure 6.5. Mesozoic stratigraphy correlation throughout Ethiopian basins (Mekele, Blue Nile, Ogaden and Shanan section). Sources: Mekele (Beyth, 1972a:1972b; Bosellini et al., 1997), Blue Nile (Russo et al., 1994), Shanan (from present work) and Ogaden (Tamerat Worku and Astin, 1992; Abiyu Hunegnaw et al., 1998; Shigut Geleta, 1998).

### 6.5. Palaeogeographic Setting

Tectonic evolutions throughout NE-Africa and sea level fluctuations through geologic time in general have the great roles for the formation of Ethiopian sedimentary basins and thick sedimentary deposits within them. The development of most of these basins is related to the extensional tectonic events that have taken place since the late Paleozoic and continued up to

Tertiary (Merla et al., 1979; Blanford, 1970). The beginning of the breakup of Gondwana gave rise to the Jurassic flooding of the Horn of Africa with a marine transgression from the Paleotethys and the Indian/Madagascar nascent ocean (Abbate et al., 2015).

From the two major phases of rifting affecting east African region, the first phase was characterized by the widespread rifting in Karoo times (Late Carboniferous to Early Jurassic), these stretches from Ethiopia to South Africa and corresponds to the initiation of the break-up of Gondwanaland (Norton and Sclater, 1979; Bosellini, 1989) in that further subsidence took place. This subsidence, combined with sea-level fluctuations and produce cyclic patterns of shallow-marine carbonates, shales, evaporites and minor clastic deposits. The second rifting relates to the formation of the East African rift system (Cenozoic to recent).

An alternate sinking and uplifting of the landmass of the whole horn of Africa triggering transgression of the Indian Ocean from the southeast to the northwest characterized the early Mesozoic (Getaneh Assefa, 1991; Bosellini, 1989). The Jurassic transgression came from the southeast, reaching its maximum limit in western Ethiopia and Eritrea during the Kimmeridgian and deposited a sandy formation (Adigrat Sandstone), followed by neritic sediments composed mainly of limestone's (Antalo Limestone), a regression toward the southeast began at the end of limestone deposition (Portlandian) and a nearshore 'Upper Sandstone' facies (Amba Aradam Formation) accumulated above the Adigrat and Antalo Formations (Kazmin, 1973; Getaneh Assefa, 1991; Mengesha Tefera et al., 1996; Bosellini et al., 2001).

The regression of the sea from the Ethiopian region began in late Jurassic as the result of arching and doming of the Arabian-Somalian massif and sediments of varying facies (restricted marine, lagoonal and supratidal to inter-tidal) were deposited in structurally controlled domains. By late Cretaceous, the sea completely withdrew leaving behind regressive continental clastics deposits (Reynolds et al., 1997). Mesozoic limestones and gypsum present in the Blue Nile river area in central Ethiopia and largest volumes of limestone located in the eastern part of the country are the results of the wide spread transgressions and extensional deformation, which is related to the breakup of Gondwanaland that has taken place on the horn of Africa starting from early Mesozoic time (Bosellini, 1989).

During the Jurassic time the sea flooded the large continuous continental parts of Gondwana composed of parts of Africa, Madagascar, India and Arabia (Bosellini et al., 1997; Bosellini, 1989). Starting from the lower Jurassic (early liassic,) the sea started to advance on this varied landscape, first flooding low topographic regions of near the eastern continental margin of future Indian ocean (Meregh Formation of Somalia (Bosellini, 1989) or various rift basin dissecting Gondwana continent (Mandera- Lugh and Al Mado basins in Somalia, Ogaden, Blue Nile basin in Ethiopia) and only later (middle to late Jurassic) the inland and more elevated regions of the craton. According to the general stratigraphic relationship it seems very likely that carbonate deposits was deposited on a homoclinal ramp (Bosellini et al., 1997) or structurally speaking on a wide cratonic margin, gently dipping to southeast. In general the major carbonate deposits throughout NE-Africa and neighboring areas are the results of relative sea level fluctuation of continental scale.

The first flooding is time transgressive and reach those areas in different geologic times; Liassic in northern Kenya, central Somalia and part of Ogaden basin (Riccardi,1991), Bathonian in Dire Dawa and Harrar and late Callovian- early Oxfordian in Yemen and northern Ethiopia. For indicating paleogeographic setting for the carbonate deposits of the study area, the time between middle Jurassic middle Jurassic of Callovian to late Jurassic of Oxfordian will be essential times, since there is no unconformity throughout the unit, this time can help to shows the whole unit depositional conditions. Based on the available previous works on the paleogeography of the NE-Africa the early – middle Jurassic (Toarcian- Callovian) and late Jurassic (Kimmeridgian) times intervals between which the present study area carbonate deposits were formed have been selected. The paleogeographic maps of NE-Africa and Arabian platforms during the early Jurassic (Toarcian time) and late Jurassic times were given in (Fig. 6.6 & 6.7 respectively), those can shows the palaeogeographic conditions in Ethiopia and some surrounding areas, during the depositions of this carbonate units.

The early to middle Jurassic (Toarcian-Callovian) times: during the late Triassic, the time before Jurassic, in the north-eastern part of Arabia and east Africa, including Ethiopia formed part of a stable and slowly subsiding craton (Reynolds et al.,1997). A shallow gulf encroached from the northeast onto wide areas of the Arabian platform and propagated as far southeast as central Ethiopia. During this shallow marine clastic of Adigrat Sandstone formation deposit formed in

Ethiopia and other neighbouring country. Along the east African margin rifting occurred again during the early Jurassic superimposed on the older Karoo structures, heralding this time the full separation of east and west Gondwana (Reynolds et al., 1997). Crustal extension and rifting that continued throughout the middle Jurassic, enhanced by global eustatic sea level rise (Haq et al., 1987), caused marine transgressions that flooded wide areas of east Africa. Furthermore, the NE-inclined depositional dip was inverted towards the southeast, i.e. towards the developing rift between east and west Gondwana. Active rift subsidence enhanced by eustasy resulted in a marine transgression, which flooded wide areas of East Africa and the Arabian platform.

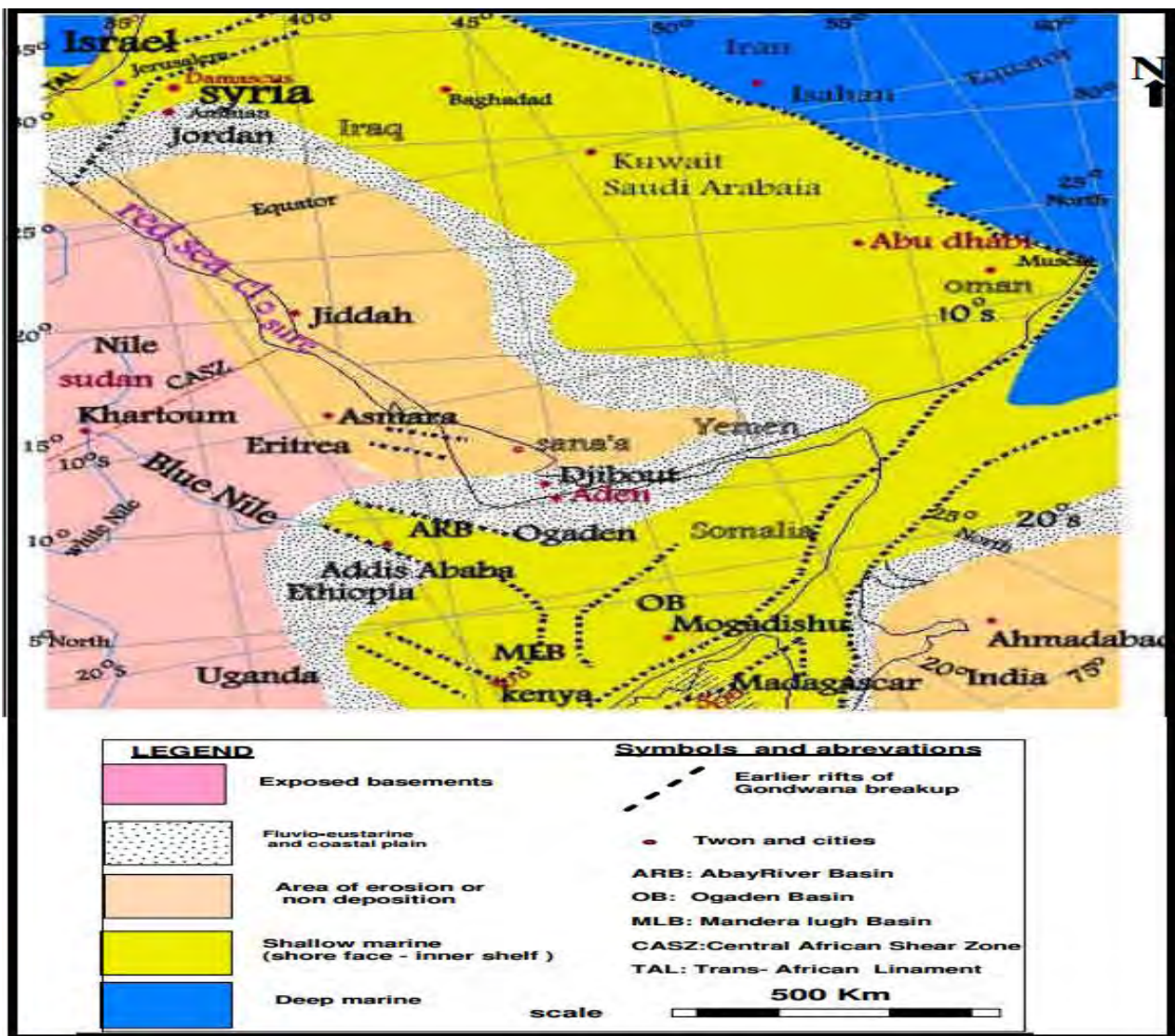


Fig 6.6. palaeogeographic map of NE- Africa and the SE part of the Arabian platform during Early Jurassic (Toarcian) (after Reynolds et al. 1997).

Middle Jurassic carbonate deposits which are most probably the result of these transgressions are reported from middle Hammanlei carbonate deposits of Ogaden basin, Shigut Geleta (1998) and from Antalo limestone formation of Blue Nile basin (Russo et al., 1994).

The Callovian to Oxfordian deposits of Shanan section which show some shallowing up facies in the lower part can be probably correlable with this transgression. Even if the contact of Shanan section carbonates with underlying unit is not investigated, but previous works in southeastern Ethiopian plateau explain that the carbonate unit of these area are underlain by shallow marine clastic of Adigrat sandstone which support these interpretation.

The northeast propagation of sea to the Arabian platform was largely complete during the Late Jurassic (Kimmeridgian) time. On the regional scale platform was still a shelf, showing weak structural differentiation that was predominantly covered by a very shallow sea (Bosellini, 1989; Riccardi, 1991). Initial formation of Indian Ocean occurred between middle and late Jurassic. Following a long period of crustal extension and rifting, break-up of Gondwana commenced in late Jurassic and a seaway began to open contemporaneously in southern Gondwana between south America-Africa and Antarctica. In northern Gondwana a seaway opened up and extends from the Tethys towards the south where its shoreline reached southern Madagascar (Bosellini, 1989; Riccardi, 1991). It's also time-transgressive and corresponds to an abrupt deepening of east Africa and southern Arabia shallow water ramps and carbonate platforms, a collapse most probably related to the separation of Madagascar from Africa. a major tectonic event occurred in early cretaceous from northern Ethiopia to Yemen and southern Ethiopia and Somalia. This propagated sea on the horn Africa during late Jurassic is also recognized by the different carbonate units, throughout the continents in various basins. From these, the upper shanan carbonates which are Oxfordian age are showing that during late Jurassic the area was covered by the sea. The equivalent carbonate units are also reported from Ogaden basin, Mekele basin and Blue Nile basins of Ethiopia as the workers are cited above in the correlation sections. The total paleogeographic map showing the extent of the sea on NE-Africa during late Jurassic is given in (Fig. 6.6).

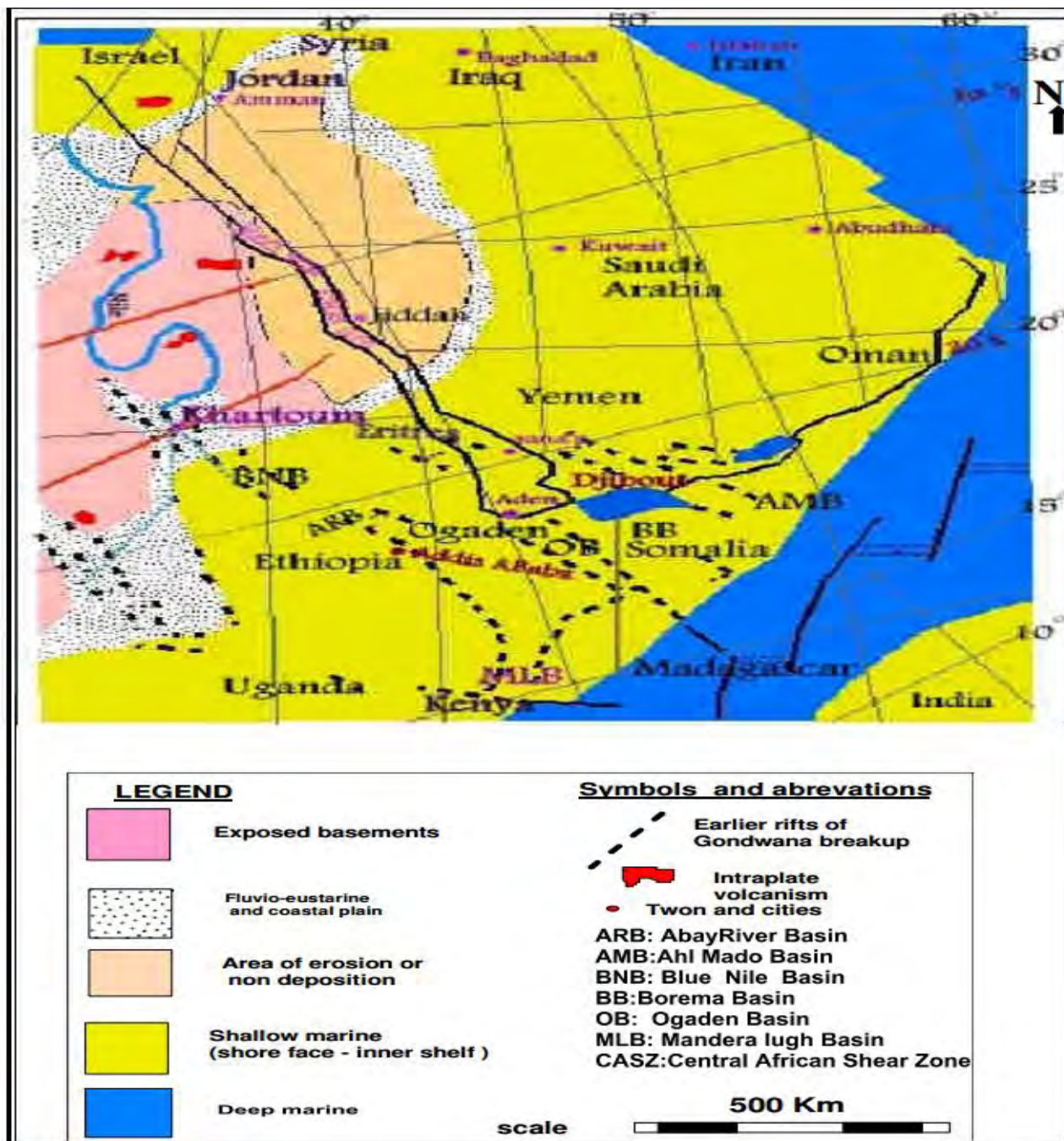


Fig 6.7. Palaeogeographic map of NE- Africa and the SE part of the Arabian platform during Late Jurassic period Kimmeridgian stage (after Reynolds et al. 1997).

## CHAPTER SEVEN

### 7. CONCLUSIONS AND RECOMMENDATIONS

#### 7.1. Conclusions

Geology of Shanan section is covered by thick Mesozoic carbonate deposit. A combination of field investigations, stratigraphy, petrography, microfacies analysis and paleontology on the Jurassic carbonate of Shanan section the following conclusions were adopted:

Stratigraphically, about 161m thick Callovian-Oxfordian age carbonate succession (Hammanlei formation) of Shanan section are subdivided into lower, middle and upper Shanan, from bottom to top. This classification is based on their lithological characteristics, faunal and floral contents, facies patterns and stratigraphic positions.

The microfacies type of this carbonate rocks are identified based on their petrographic study and divided into six major microfacies types (MFT 1-6), those are designated as: MFT (1) Micritic microfacies, 2) Bioclastic wackestone microfacies, 3) Peloidal grainstone microfacies, 4) Oolitic microfacies, 5) Bioclastic intraclast packstone-grainstone microfacies and 6) Bioclastic peloidal packstone-grainstone microfacies. Each of this microfacies where described, interpreted and also compared with SMFT of (Wilson, 1975). For generalization these six microfacies type were again compared with facies belts of Wilson (1975) ranging from open sea to restricted platform (2-8, except 5) from top to bottom, as their detail respective matching were given in microfacies analysis section.

Accordingly, the microfacies analysis studied carbonates units of Shanan has been deposited in shallow marine conditions of lagoon (MFT1, MFT2 and MFT3), platform margin (MFT 4) for lower Shanan deposits, middle Shanan show deposition in foreshoal environment (MFT5 and MFT6) and some marginal basin to open sea depositional condition of offshore (MFT 1 and MFT2) for the upper Shanan units. Lower Shanan is about 56 m thick and consists of micritic (MFT1) and bioclastic wackestone (MFT2), peloidal grainstone (MFT3) at bottom; and coarser oolitic rich grainstone (MFT4) beds at top part. Middle Shanan is about 46 m thick and conformably overlies the lower Shanan and consists of skeletal, peloidal and intraclastic dominated packstone-grainstone limestone beds of varying thickness. Upper Shanan is about

61m thick. It consist of thick beds of grayish, dark and reddish limestones dominated by massive micritic limestone's, with intermixing of silicified chert layers. Carbonate deposits of the area consists of some cyclicity of facies (which may be the results of small changes in sea levels) and shows the overall transgressions patterns of deposits; in which the deep offshore carbonate facies of upper parts are overlain the more shallower marine carbonate facies deposits of middle and lower units.

Carbonate rocks of Shanan section has various macro and microfossils. From these, Microfossils of Foraminifera such as (*Eoguttulina polygona* (Terquem, 1864)., *Lenticulina subalata* (Reuss, 1854), *Lenticulina quenstedti* (Gümbel, 1862), *Verneuilinoides minuta* (Said and Barakat, 1958) , *Haplophragmoides bartensteini* (Kalantari,1969) and *Choffatella.sp* and Ostracods of *Cytherelloidea.sp*, *Progonocythere.sp.*, *Procytheridea.sp.*, *Bairdia sp*, and *Paracypris .sp* and invertebrate macrofossils of Bivalves such as: *Pholadomya.sp.*, *Lucina.sp.*, *Modiolus modiolu.sp.*, *Nanogyra sp.*, and *Astarte.sp.*, Gastropods *Ampullina.sp.*and *Nerinea.sp* and Brachiopod *Terebratulla.sp.* are identified.The age of Shanan section carbonates is determined and dated to be Jurassic, particularly Callovian-Oxfordian by occurrence of index fossils *Pfenderina cf.salernitana* and *Kurnubia palastiniensis*.

Shanan section carbonate successions are correlable with some of the chronostratigraphic equivalents and lithologically similar deposits of some near area of SE Ethiopia plateau of (Harar, Sof Omar, Kuni, Hirna, Diredawa and Gara Muleta), and; within other Ethiopia basins (Mekele, Blue Nile and Ogaden basins).

## **7.2. Recommendations**

This study covers the depositional environment interpretations, paleontology and age assignments of the Shanan stratigraphic section. Identification of the depositional environment was based on microfacies analysis through petrographic study. This may face ambiguity on precise determination of depositional environment when it is applied in a small scale area. It needs detailed facies, particularly microfacies analysis of more sections with more or less uniformity in sampling. Therefore, for more understanding of the depositional environment and to reconstruct the facies model of the area, detail facies and microfacies study in more sections have to be done.

The carbonate deposits of the area comprise so many varieties of skeletal grains; these can reveal much interesting information for biofacies, paleoclimate and paleoenvironmental studies. Due to this, detailed biostratigraphic, micropaleontological and macropaleontological research works over the area will be worthy.

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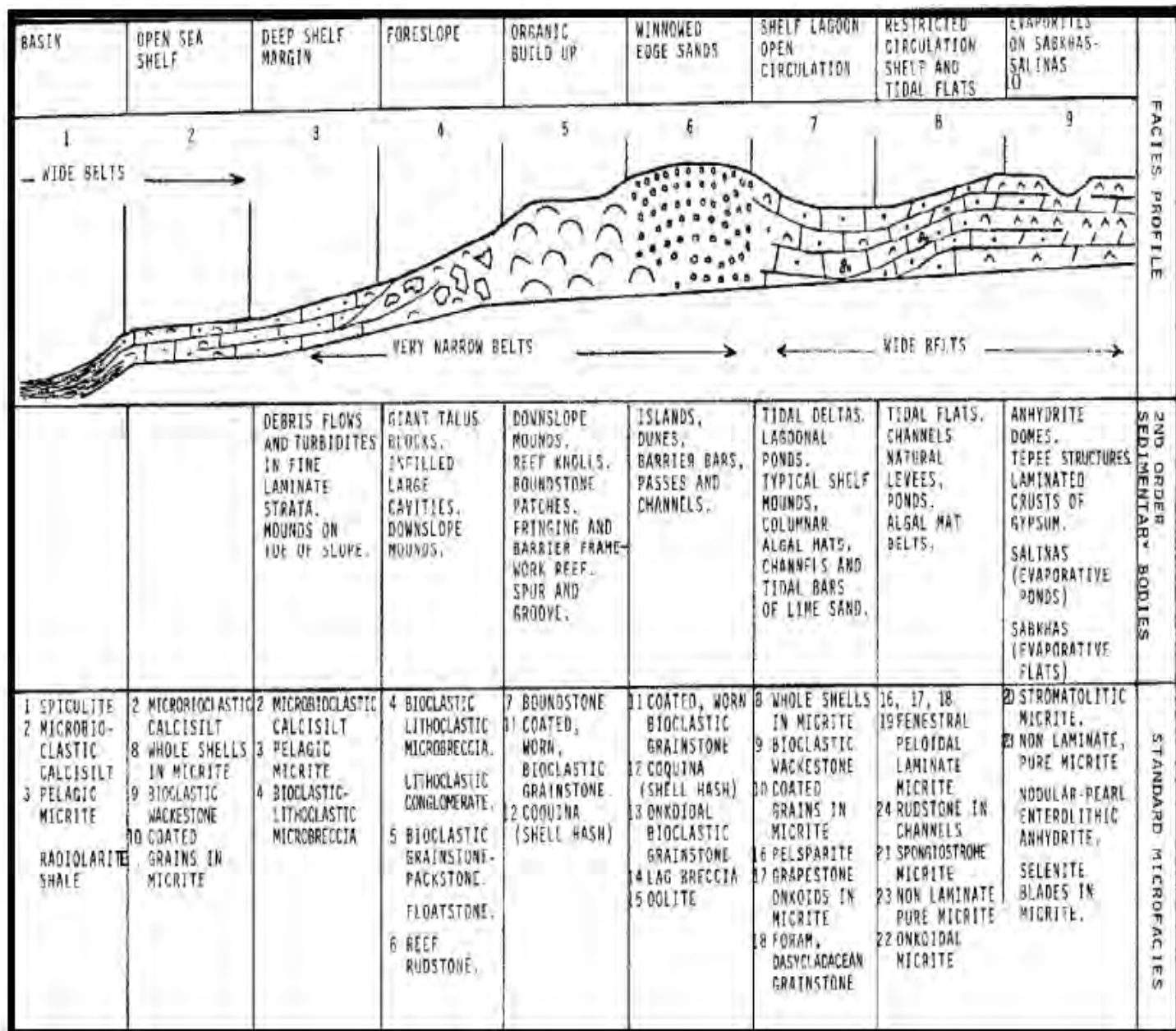
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## APPENDIXES

Appendix 1 shows the distributions of SMFT and Facies belts on the generalized carbonate platform morphology taken from Wilson (1975).



The picture shows the distributions of 24 SMFT within 10 facies belts on the generalized carbonate platform morphology after Wilson (1975) and they are used in this paper for comparisons and depositional environment interpretations for the presently obtained carbonate microfacies from the study area, as cited in the body.

Plate 1

*A-B) Eoguttulina polygona (Terquem, 1864), lateral view*

*C) Lenticulina quenstedti (Gümbel, 1862), umbilical view*

*D) Lenticulina subalata (Reuss, 1854) umbilical view,*

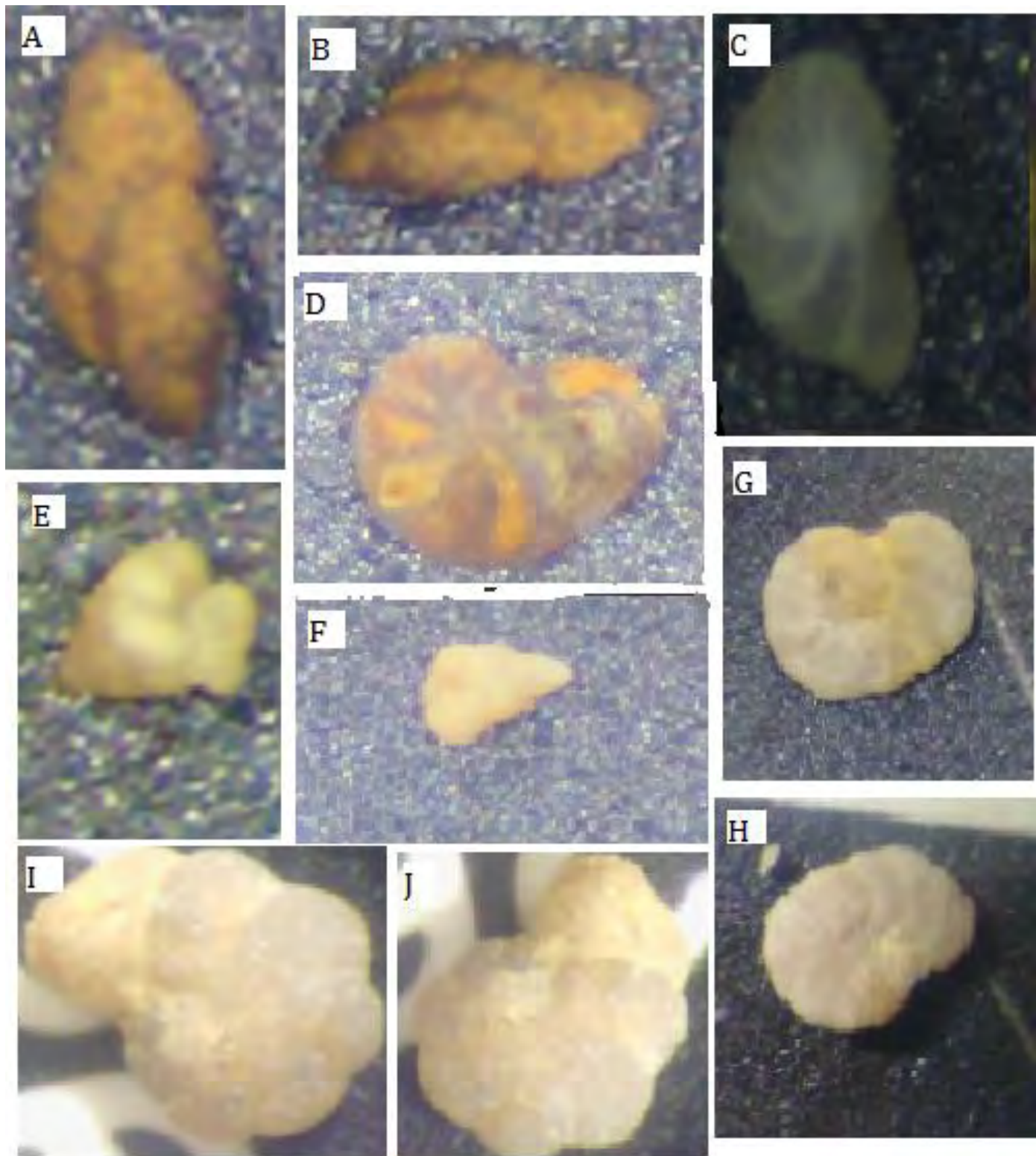
*E-F) Verneuilinoides minuta Said and Barakat, 1958 Apertural and lateral view respectively*

*G-H) Choffatella sp. spiral and umbilical view respectively,*

*I-J) Haplophragmoides bartensteini Kalantari, 1969. Spiral and umbilical view respectively.*

*All figures are taken x 35*

**Plate 1**



**Plate 2**

**A-B) *Cytherelloidea* sp,**

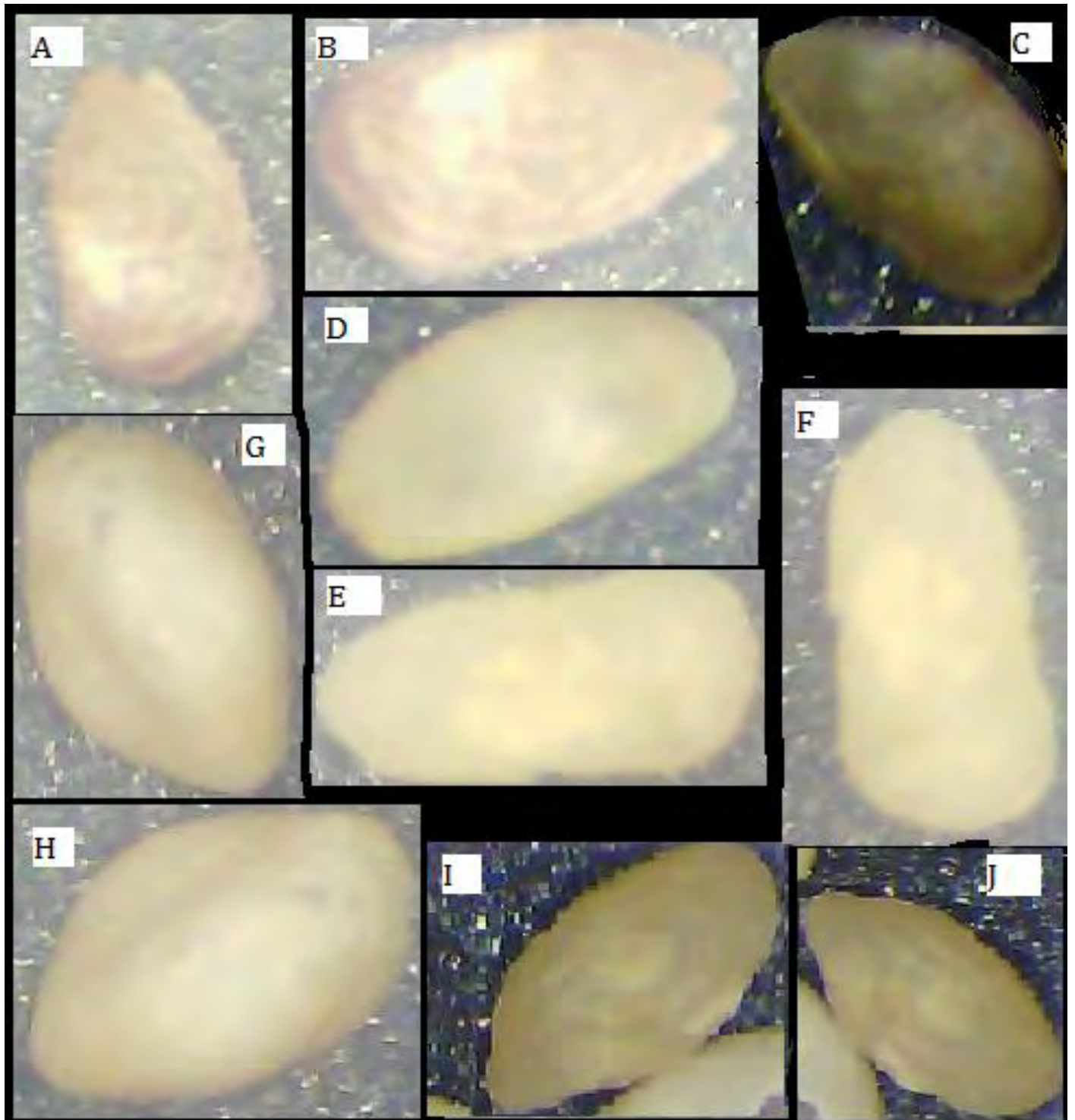
**C-D) *Procytheridea*.sp**

**E-F) *Paracypris* .sp**

**G-H) *Progonocythere*.sp**

**I-J) *Bairdia* sp. all figures x 35**

**Plate 2**



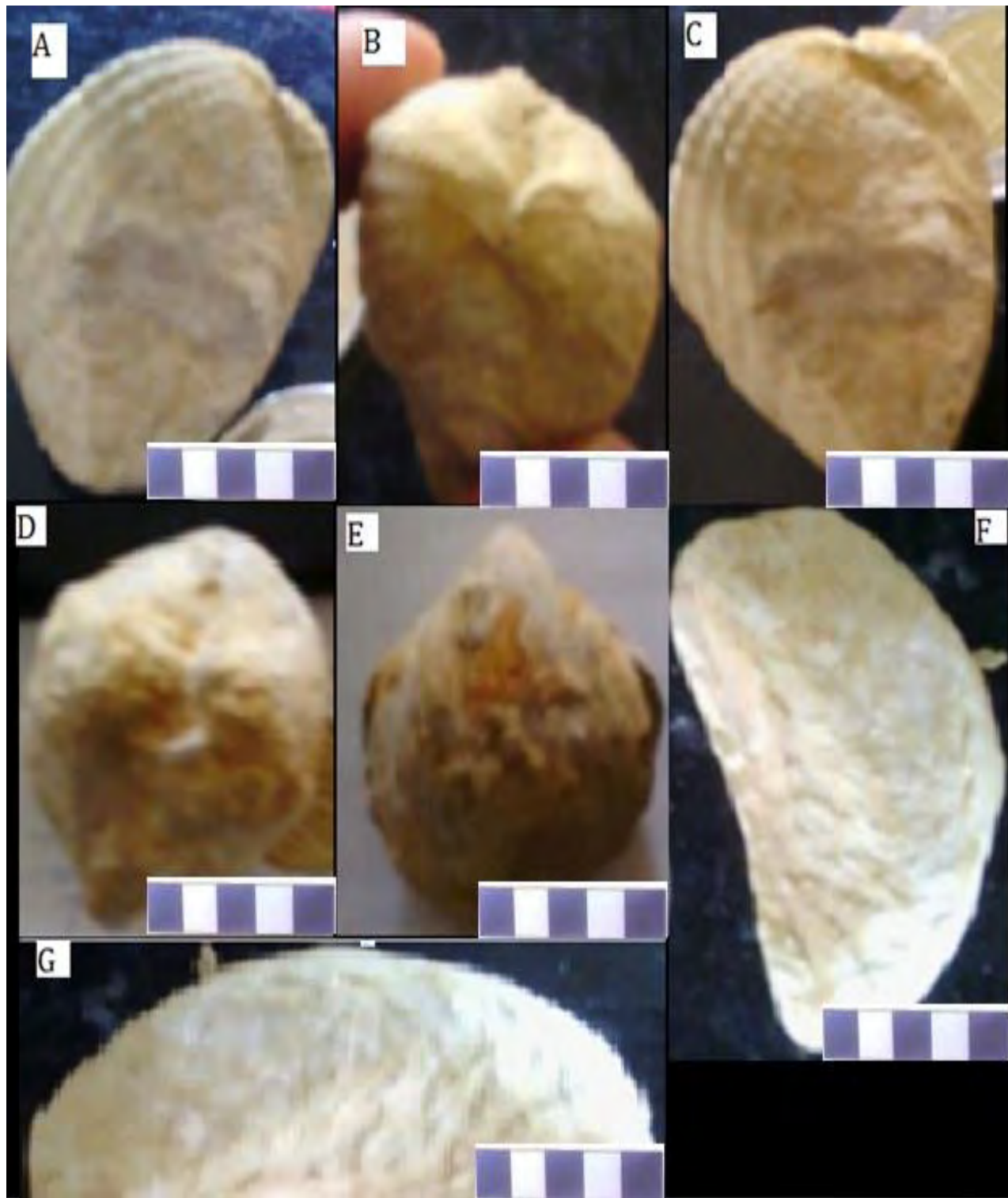
**Plate 3**

*A-C) Pholadomya. sp.*

*(D-E) Lucina.sp*

*(F-G) Modiolu modiolus.sp*

Plate 3



**Plate 4**

*A) Terebratulla .sp. Brachial valve view and small circular opening (arrow) pedicle opening.*

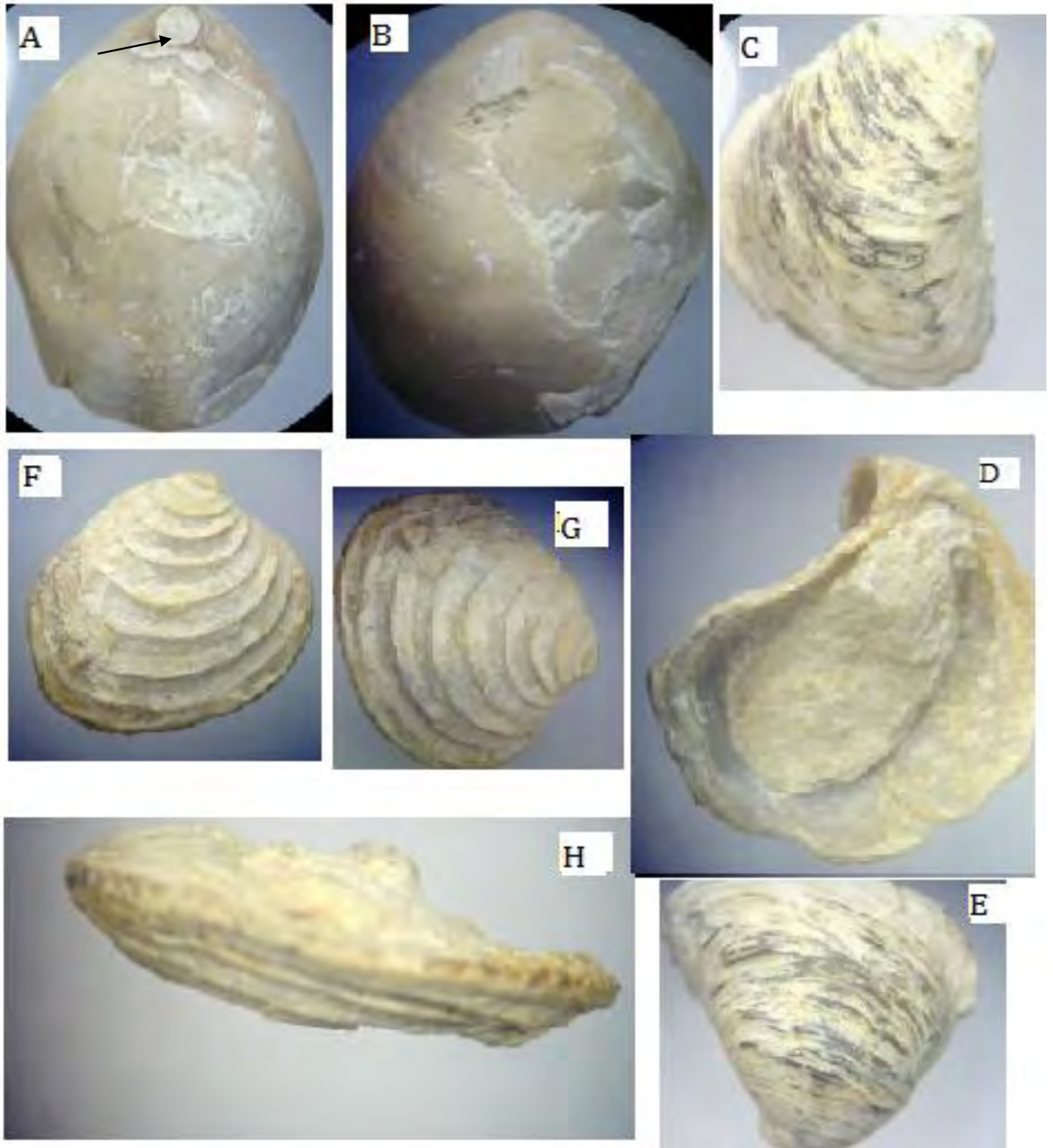
*B) Terebratulla .sp. pedicle valve view*

*C-E) Nanogyra sp..left valve, right valve and anterior view, respectively*

*F-G) Astarte sp. left valve of articulated,*

*H) Astarte sp. anterior view. All photos taken under reflecting microscope x 8.*

Plate 4



**Plate 5**

*A-B) Ampullina.sp.*

*C-D) Nerinea.sp.*

Plate 5



**Plate 6**

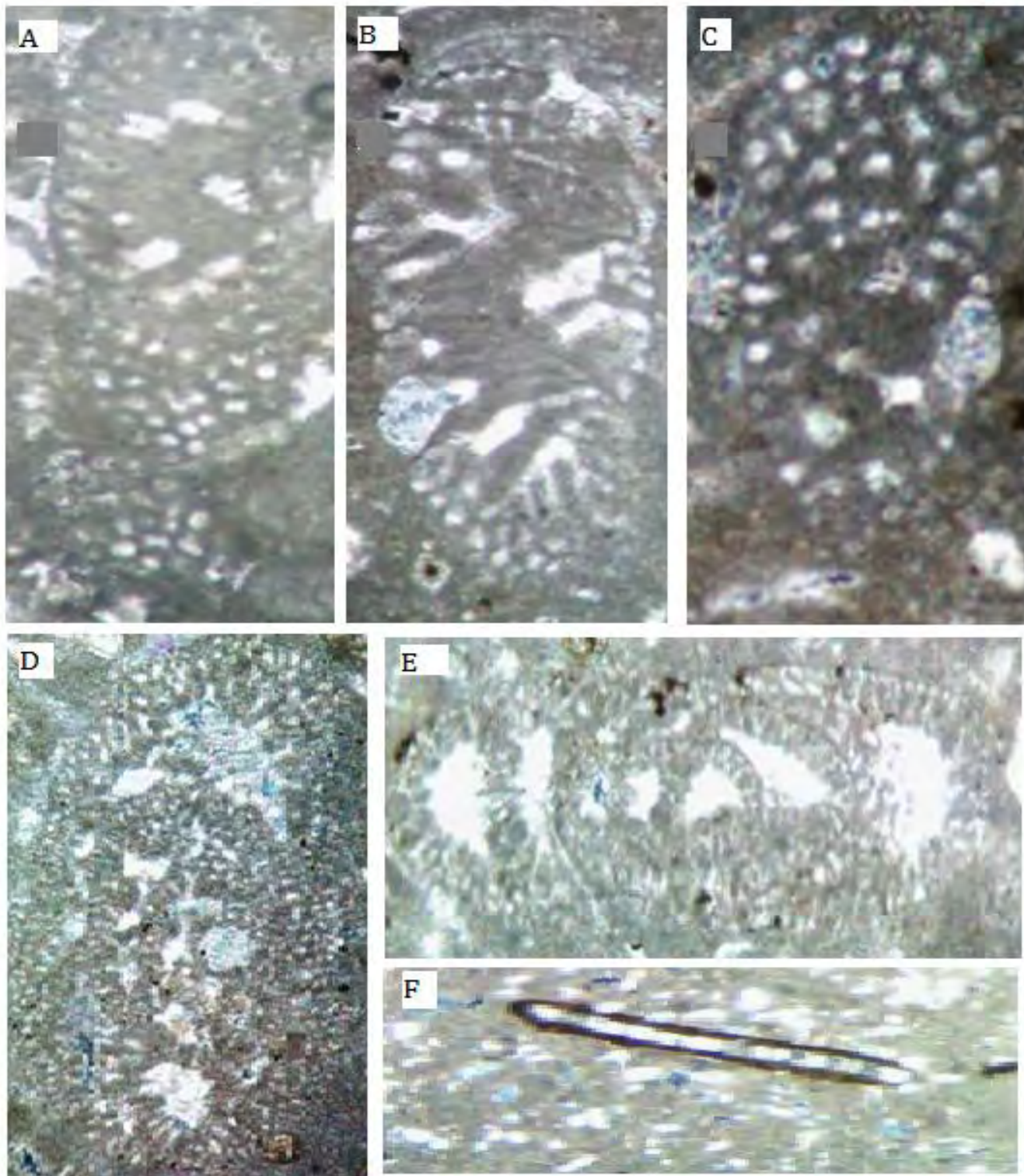
*A-C) Kurnubia palastiniensis. Axial section, from sample Shan 16, Shan 45 and Shan 6 respectively .all under XPL x40*

*D) Alveosepta sp. Equatorial section, sample from Shan 45, PPL x40*

*E) Alveosepta sp. Equatorial section, sample from Shan 28, PPL x40*

*F) Pseudocylammina sp, Sample Shan 26. Photographed in PPL x 40 magnifications,*

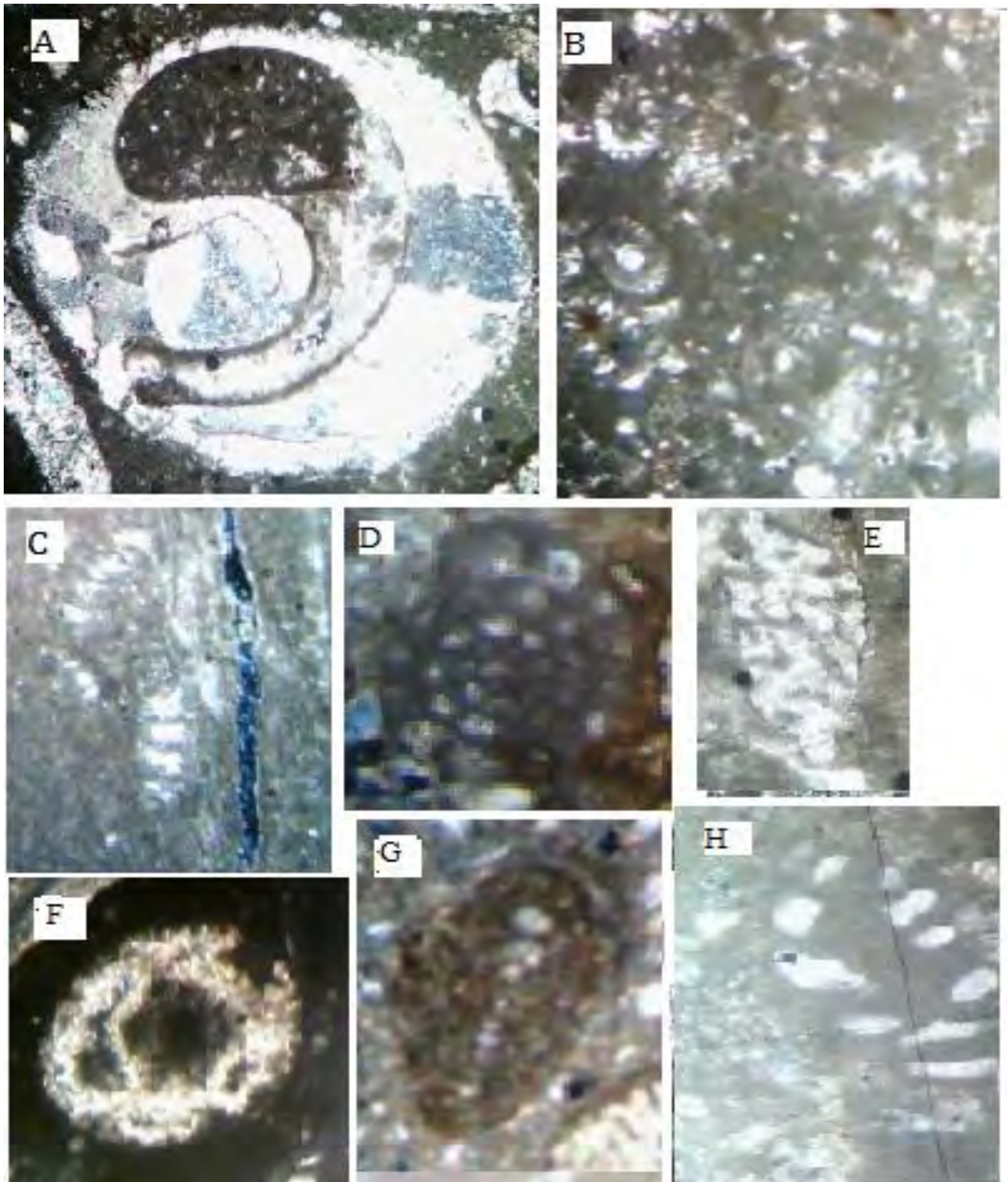
Plate 6



**Plate 7**

- A) Gastropod.Equilateral section, Shan 13, PPL x40*
- B) Dasycladacean algae.Equilateral section, Shan 20, XPL x10*
- C) Pfenderina cf.salernitana,subaxial section Shan 4, XPL x10*
- D) Nautiloculina Cicularis. Shan 45, XPL x10*
- E) Pfenderina. Sp. Axial section, Shan 33, PPL x40*
- F) Dasycladacean algae. Shanan 15, XPL x40*
- G) Nautiloculina oolitica. Axial section, Shan 26,XPL x10*
- H) Pfenderina cf.salernitana. Axial section, Shan 45, XPL x 40*

Plate 7



**Plate 8**

- A) *Siphovalvulina* sp. Axial section, Shan 25, XPL x4
- B) *Pfenderina* cf. *salernitana*. Sub axial section, Shan 43, PPL x40
- C) *Pfenderina* cf. *salernitana*. Equatorial section, Shan 43, XPL x 40
- D) *Dasycladacean* algae. Axial section, Shan 16, PPLx10
- E) *Valvulina* sp. axial section, Shan 16, PPL x 40
- F) *Alveosepta* sp. Axial section, Shan 16, XPL x10
- G) *Dasycladacean* algae. Axial section, Shan 19, XPL x10
- H) *Siphovalvulina* sp. Axial section, Shan 32, PPL x40
- (I) *Kurnubia palastiensis*. Equilateral section, Shan 32, XPL x40.

**Plate 8**

