FACIES AND MICROFOSSIL ANALYSIS OF JURASSIC CARBONATE UNIT IN LEMI AREA (JEMA SECTION) NORTHERN SHEWA; CENTRAL ETHIOPIA.

MSc. Thesis

By:

Geremu Gecho Arka

A thesis submitted to the school of Graduate Studies Of Addis Ababa University in the partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences (Paleontology and Paleoenvironment).

Addis Ababa University

Addis Ababa, Ethiopia

May 30, 2018

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ABSTRACT

A thick Jurassic carbonate succession of about 157m thickness was studied in Jema section, the Blue Nile basin; of the Northwestern Ethiopian Plateau. This study was mainly aimed on exploring the stratigraphy, paleontology, facies analysis, biostratigraphy and determination of the depositional environments of carbonate unit of the Jema section. Based on the petrographic study of 18 representative carbonate rock samples and 8 marl samples; the compositional and textural analysis of rocks were studied and grouped into six (6) microfacies associations and about 22 foraminiferal and 7 ostracodals species are identified; which characterizes for intertidal zone, shoal restricted marine and shelf facies to open circulation environments. The presences of micritic, bioclastic wackestone and peloidal grainstone microfacies in the Jema section indicate shoal to shelf facies deposits. The Pelsparite and algal stromatolite mudstone are indicators of carbonate intertidal to shoal deposits of shallow marine setting.

Based on the presence of index fossils such as Kurnubia cf. morrisi, Alveosepta jaccardi and Kurnubia palastiniensis with their associations of Conicokurnubia orbitoliniformis, Valvulina lugeoni, and Nautiloculina oolithica; the age of carbonate succession was determined to an age from ***Callovian to Oxfordian****. Paleontological study of the section in Abay basin shows the carbonate unit is rich in micro fossils and less in macro fossils that supply additional data for stratigraphic and Paleoenvironmental interpretations; particularly of foraminifers and ostracods explored. Among the macrofossils few groups of bivalves, gastropods brachiopods and echinoids are also identified. The carbonate deposits of the logged section are correlated with chronostratigrphically equivalent and lithostratigrphically similar basins in North western and Southeastern plateau of the country regionally and with the previously logged sections in the Bilu Nile Basin locally.*

Key words: - *Depositional Environment, Microfacies, Facies, microfossils, Paleoenvironment, biostratigraphy, Carbonate unit.*

Acknowledgement

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Table of Contents Page

List of Figures

List of Tables

List Appendixes

List of Plates

ACRONYMS ABRVETIONS

cf. Compare with

FB Facies belts

GPS Geographical Positioning System

H_2O_2 Hydrogen Peroxide

HCl Hydrochloric Acid

MFT Microfacies type

NGO Non-Governmental Organization

SEM Scanning Electron Microscope

SMFT Standard Microfacies Types

sp. Species

CHAPTER ONE

1.1. Background

The geology of Ethiopia consists of Precambrian basement complexes, late Paleozoic to the Early Tertiary sedimentary rocks and Cenozoic volcanic rocks in an ascending order. The Paleozoic and Mesozoic sedimentary successions are present in three distinct provinces including; the Mekele outlier in the north (Beyth, 1972; Bosellini et al., 1997); the Blue Nile Basin in the central part (Jepsen, 1964; Beauchamp, 1977; Russo et al., 1994); and the eastern margin of the Ethiopian Rift Harrarghe, and the adjacent Ogaden Basin (Kazmin, 1973; Merla et al., 1979; Bosellini et al., 2001; Asfawossen Asrat, 2015).

In the Mesozoic times, continental Jurassic sedimentation in Ethiopia was interrupted by the transgression of the Ocean. This sea level rise is documented in the Antalo Formation (Russo et al., 1994; Balemwal Atnafu, 2003; Gilamichael Kidanemariam et al., 2009). During Regression started in the Late Jurassic and resulted in the deposition of the predominantly continental sequences of the Mugher Mudstone and the Debre Libanose formations of the Abay River Basin (Getaneh Assefa, 1991). The topmost oolitic limestone of the Antalo Formation (Lagajima Limestone) includes invertebrates of Kimmeridgian age (Russo et al. 1994).

Facies of a deposition shows well-defined petrographic, geognostic and paleontological properties which can be clearly differentiated from the properties of other Facies in the same geological period (Flügel, 2004). In Facies analysis paleontological, sedimentological, geological, and geochemical data provide the basic information about the sedimentary environment, the lithogenesis, and the biotopes of organisms preserved as fossils (Amanz, 1838).

Microfacies analysis of carbonate rocks requires knowledge of modern carbonates and an understanding of biological and geological changes during the history of earth. Microfacies analysis are geological field studies and profiles, with special consideration of facies criteria (lithology, rock colors, bedding and lamination, sedimentary structures and textures, fossil content, stratigraphic relationships and geometric shapes of rocks and which includes the microfacies).

Among the various types of sedimentary rocks Carbonate rocks, such as limestone and dolomite 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 the geologic time (Flügel, 2004).

Paleoenvironmental interpretations derived from microfacies should be controlled by lithological criteria and sedimentary structures evaluated by the high information potential provided by fossils and biogenic structures. In the present studies the Microfacies types (MF) were classified following (Carozzi, 1989) and are comparable with Standard Microfacies types (SMF) of (Flügel, 1972) and (Wilson, 1975) and are shown against each other in parenthesis.

Compositional and textural constituents of carbonate rocks are highly interpreted based on microfacies analysis that examined in thin sections to reflect the depositional and digenetic 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).

The petrographic study of carbonates has been carried out for microfacies analysis on the basis of their textural, compositional and digenetic characteristics.

One of easier 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).

Carbonates are originated as skeletal grains or precipitates within the depositional environment; in contrast terrigenous clastic sediments are formed primarily by the disintegration of parent rocks and are transported to the depositional environment. So that the fossil remains of animals and plants preserved in carbonate rock are used for the interpretation of depositional environment, geological record dating, and biostratigraphy. The deep understanding of facies analysis and paleontology provides appeal information in understanding the history of the earth; in terms of geological record, paleoenvironmrntal changes, and basis of correlation of strata through the identification of taxa's.

This research thesis is intended to conduct the facies and calcareous microfossil analysis of the carbonate unit to reconstruct the paleoenvironmrntal and the biostratigraphy of the study area in particular.

1.2. Geographic Sitting of the Study Area

1.2.1. Location and Accessibility

This research thesis was conducted in the central part of Ethiopia, within Amhara Regional State of Ethiopia Central Shewa Zone Merharbete district in the vicinity of Lemi. The study area is located about 180 Km from the capital Addis Ababa and can be accessed via the main road to Alem Ketema. The road from Addis Ababa to Mekoturi (80 Km) is asphalted whereas the remaining 100 Km to Merharbete is gravel road. The Jema and Dufa River cuts are the main exposure to the limestone deposit in the study area; they are crossed by the main road to Alem Ketema.

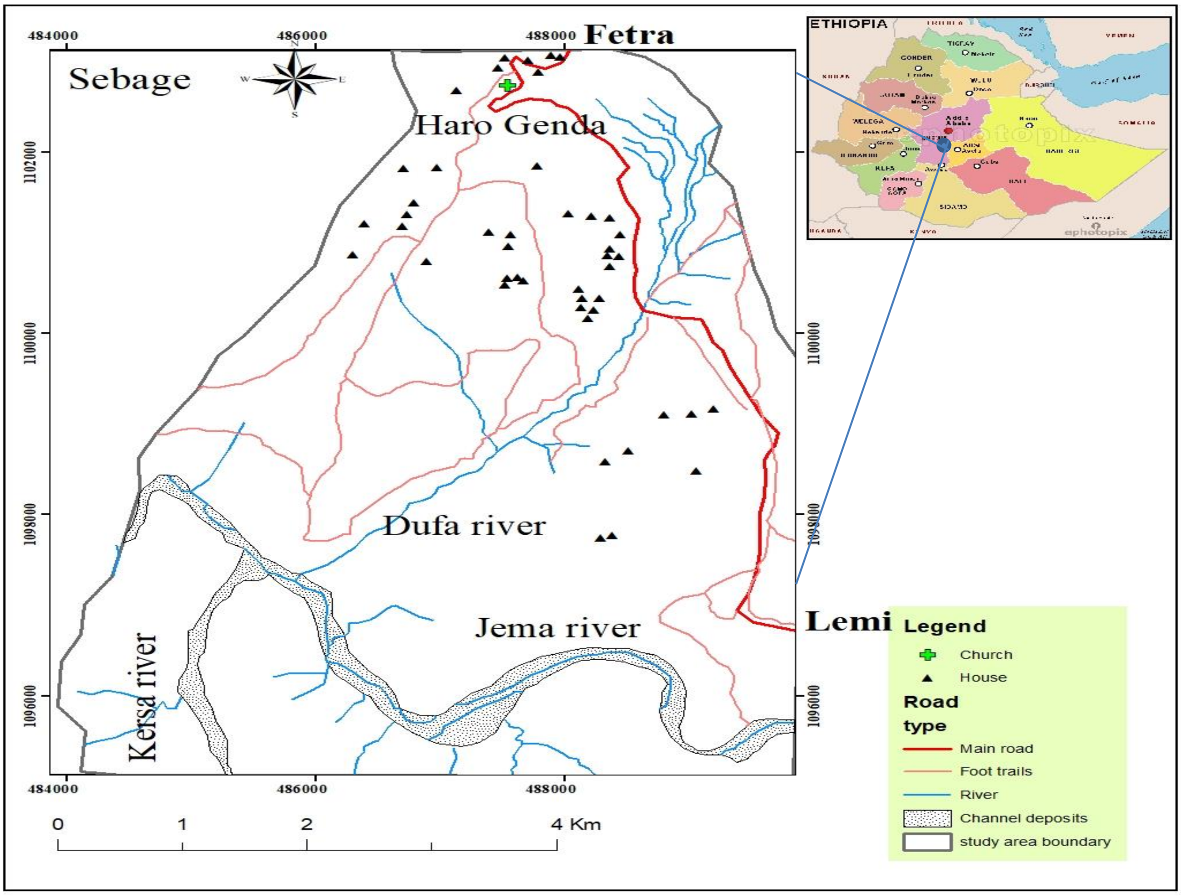

Fig. 1.1: The location map of study area

1.2.2. Physiography and Drainage

The study area is situated in Northern Shewa, Central Ethiopia. This is one of the districts of Shewa Zone, Amhara regional state of Ethiopia and the area encompasses varied topography ranging from lowland to rocky mountainous terrains. Physiographically the study areas fall within the North eastern central plateau of Ethiopian in Abay Basin. Jema River is the biggest river in the study area and it drain to Abay River (Bilu Nile River) which is longest river in Africa.

1.2.3. Climatic Condition and Vegetation

Generally, the area is largely characterized by semi-arid climate at lower elevation and wet climate at the highland areas in which the rainy season prevails from June to September. The largest part of the area is represented by "Weina Dega" climate zone with mean annual temperature of 20^{o}c and rainfall of 1500 mm as recorded in the National Atlas of Ethiopia. Generally mean maximum temperature is lower from March to May and mean temperature is lower in November to December as compared to the other months.

Scarce thorny bushes and some occasion are scattered at the lowlands whereas Eucalyptus trees are planted around villages are relatively higher altitudes and the natural vegetation's are severely destroyed in the study area for agricultural and domestic purposes.

1.2.4. Population and Settlement

The study area is dominantly populated by Amara People. The rural people made live on agricultural and animal farming. The land farm is highly exposed for erosion and land slide thus decreasing the fertility of soil for crop production. They grow maize, sorghum, "Teff", and wheat. Most of the farmers cultivate sorghum on the lowlands and "Teff", maize and wheat on the highlands. Some people used irrigation by using Jema River to harvest onion, green paper, sugar cane, potato, mango, papaya and orange.

The domestic animals that the local peoples usually raise are goat, sheep, chicken, ox and cow. They are accustomed to use donkey, horse and mule for transportation. Alem Ketema, Fetera and Lemi are the nearest towns to the study areas. The people in the town are engaged in agricultural and small businesses. Orthodox Christianity is the dominant religion in the area.

Towns and settlement are more confined on the highland where the weather condition is relatively more suitable, potable and where water is available than the low land area. Infrastructure like school, health centers, and water supply are found in every locality which is built by NGO and government. Hydroelectric power supply is available in Lemi, Fetera and Alem Ketema towns even in Haro Genda village. However Power was supplied to all towns from the main national grid.

1.3. Previous Works

Tremendous studies have been conducted in the Mesozoic Jurassic carbonate unit of Ethiopia including the Abay basin on different prospective. Among the earlier studies conducted in the basin and in the country includes, The Regional geologic unit of the Blue Nile basin has been established by different authors (Jepson et.al 1959, 1964), Mohr (1962), Kazmin (1975), Getaneh Assefa (1979, 1991), and Russo., et.al (1994)) portraying the succession of units from top to bottom as Tertiary volcanics and related sediments, Upper Sandstone (Debrelibanous Sandstone), Muddy Sandstone (Mugher Sandstone), Antalo Limestone, Gohatsion Formation(Abay Beds), Lower Sandstone(Adigrat Sandstone) and Paleozoic Sediment and Precambrian Basement.

Described Microfacies of the limestone in the Blue Nile Basin (Kalb and Oswald, 1974) studied the Mesozoic invertebrate fossils of Ethiopia.

Ficcarelli (1968), Canuti and Radrizzani (1975) Studied marine fossils of the Blue Nile section, Stratigraphic and structural evolution of the Blue Nile Basin, Northwestern Ethiopian Plateau (Gani et al. (2008), Sedimentary evolution of the Abay River (Blue Nile) basin, Ethiopia, (Russo, et al., 1991), The Gohatsion formation grades upward into a scarcely fossilferous and burrowed mudstone and then into an Oolitic limestone rich in corals, stromatoporoids, bivalves, gastropods, echinoids, foraminiferous and ostracods (Russo, et al., 1991).

Getaneh Assefa (1979, 1980, 1981, 1991) Established lithostratigraphic units of the Blue Nile Basin. Krenkel (1926) Described limestone, gypsum and shale unit of the Blue Nile, Stratigraphy and carbonate Microfacies of the Hernia Mesozoic sequence (Balemwal Atnafu, 1991) and Source rock potential of the Blue Nile (Abay) basin, Ethiopia (Wolela Ahmed, 2007).

Beyond these general and specific works of stratigraphy, paleontology, microfacies of the Mesozoic sediments in different basin of Ethiopia; microfacies analysis and paleontology of carbonate rocks in Jema section: Facies analysis of the Middle to the Upper Jurassic carbonates of the Blue Nile canyon, North centeral Ethiopia (Gilamichael Kidanemariam et al., 2009), south eastern Ethiopia was studied by (Beksa Ament, 2016). This research thesis work has been a detailed facies and microfossil analysis of a carbonate unit of Jema section in the vicinity of Lemi. In this particular vicinity the detailed facies and microfossil analysis had been the first detailed work. This enables to interpret the depositional environment of the carbonate unit of the section through, the identification of taxa of the identifiable Macro and microfossils, to estimate the biostratigraphy of the section and to correlate the basin with other basins in the region and in the country.

1.4. Statement of the Problem

Detailed macro and micropaleontological studies as well as facies analysis of a sedimentary basin is important to understand and reconstruct the paleoenvironment. Sedimentary basins are the most important areas for the study of fossils, past and recent depositional environments and stratigraphy. Most of these informations can be obtained through detail study of facies, paleontology and stratigraphy of the repository, Therefore the detailed study of the carbonate unit in the vicinity of Lemi, Jema section in the aspect of facies and microfossil analysis had been the first detailed work. The paleontological studies of an area after the identification of taxa would guide the work to the relative dating of the strata and interpretation the paleo depositional environment.

In Ethiopia there are about five main sedimentary basins. Their sedimentology and paleontology was roughly studied at regional level and some limited numbers of detail studies had been under taken on the basis of facies and microfossil analysis. With this regard the research thesis in the vicinity of Lemi, Jema section on the carbonate unit had been a detailed work on local level in the aspects of facies and microfossil analysis in interpreting Paleoenvironment of carbonate unit through the identifications of identifiable taxon found in the section.

Concomitantly this study was designed with the aim of attempting and coming up with the detailed stratigraphy of the Mesozoic Jurassic sediment in the area together with an interpretation of the environmental condition under which they were deposited on the bases of the microfacies description of the carbonate unit.

1.5. Objectives

1.5.1. General Objective

The main objective of this research thesis was to study detailed facies and microfossil analysis, in order to reconstruct the paleoenvironment of the carbonate unit in Jema section Lemi area Central Ethiopia.

1.5.2. Specific Objectives

- To identify and describe the micro and macro fossils in the Jurassic carbonate unit the study area.
- To produce the detailed stratigraphic section of the carbonate unit of the study area
- To describe detailed petrographic study of the carbonate rock unit of the study area
- To interpret the depositional environment of the carbonate unit in the study area.
- To correlate the local carbonate unit of the study area with other sections in the Bilu Nile basin, and other areas in Ethiopia.

1.6. Methods and Materials

In order to achieve the above stated objectives during the accomplishment of this research thesis work; different materials have been used and different methods had been applied. The methods that had been employed and materials needed for this thesis work were as follows; the overall work of this research thesis was mainly divided into three phases; data collection, analysis and synthesis, and interpretation and result in general.

The data collection work had begun with collection and reviewing of literatures followed by identification of the purpose of the study, setting objectives and methodologies were done and followed by data collection in the field and post-field works had generally involve selection of complete sections, sample collection during the field work, stratigraphic logging, and sample preparation in the laboratory, sample analyses, fossil description and interpretation in the field and in the laboratory during and after the field work to produce the data for discussion.

Detailed field studies following exposures on road and River cuts; collection of limestone and marl samples for farther analysis in thin section in the laboratory under the microscope, macrofossil collection, Ichnofossil sample collection and description, description of sedimentary structures in each stratum and generally the facies study had been carried out in the field. As well the Photographs of outcrops from the field, macro-fossils, sedimentary structures and both the carbonate grains in thin sections and the micro-fossils had been obtained by digital camera.

After data has been collected from the field, laboratory work for the rock and fossil samples had been described, analyzed and interpreted through the thin section analysis of the Microfacies of the carbonate sample, producing important field data for the stratigraphic log through the software, preparation, description, identification of the calcareous microfossils through the scientific technique (Oxidation Method). Finally the result will be discussed and reported.

Petrographic microscopes, Binocular microscopes, Digital camera, (Topo-sheet of Lemi area, Brunton compass, Garmin GPS, geological hammer, chisel, hand lenses, plastic sample holding bags, meter stick, sample bag, Dilute HCl ,Hand lenses, Beaker ,Brushes, Sieves, Hydrogen Peroxide (H_2O_2), mortar and pestle, Stereozoom binocular microscope, petrographic microscope and notebook with labeling materials are needed to conduct the field work.

1.6.1. Fieldwork and Sample Collection

Fieldwork complemented with the collection of approximately 18 carbonate rock samples, 8 marl samples and mold and casts forms 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 both during the field work. Detail descriptions for each of field activity were stated as follows:-

The collection of carbonate rock samples in the two selected stratigraphical sections were done from December 2017 to January 2018. Representative samples of the unit in the study area were collected for the laboratory analysis from surface following the river cuts and the foot roots which expose the units and take in to the exposures. All the exposed carbonate rock unit samples were collected form each contacts for petrographical analyses under thin section. The marl samples were collected for the micro paleontological analysis from the beds and below and above each contact.

During the fieldwork color, texture, fossil content and, sedimentary structures were collected Dilute hydrochloric acid was used to differentiate dolomite from calcitic limestone. Composite stratigraphy of about 157m total thick carbonate succession was produced, as their stratigraphic logs are given in (Fig 3.11 & 3.18) of the two subsections and in fig.6.1 of the section.

Collections of invertebrate macrofossil were conducted in the selected stratigraphical sections of the study area. Invertebrate macrofossil samples of the unit in the study area were mostly found as a mold and cast. Some of the fossils were removed from and collected from the rock units in the field. Those which were embedded within rocks were photographed and described. The description and identification of the invertebrate macro fossils were based on their shape and size made in the field Jaboli (1959) and Keissling (2011).

1.6.2. Laboratory Work 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 were discussed as follows: The laboratory work consists of microscopic examination of thin sections, as well as identification of micro fossils.

Eight (8) marl samples were collected in order to separate microfossils for micro paleontological studies. Samples were prepared in Addis Ababa university stratigraphy and sedimentology laboratory. In order to observe and study microfossils 100 grams of dry marl samples were placed in beaker, soaked in 60 ml of 30% concentrated H_2O_2 solution and were mixed with 75 ml of distilled water. Samples were then gently agitated and low boiled. After minimum of 48hr the samples were 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 2 hr.

The dried samples were then sparingly scattered on the black picking tray and scanned under binocular reflecting microscope (35x 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.

For petrographic studies, thin sections were prepared and studied under microscope, following the procedure of Folk (1959). The first part of the rock name refers to the allochem components and the second part to the cementing or matrix material. Because, of the above-mentioned advantages, the Folk's terminologies were adopted in the study of the thin sections of the limestone. The volumetric analysis of different constituents had done with the help of manual counter, for the petrographical classification of limestone. The textural study had been carried according to Dunham's classification (Dunham, 1962).

18 thin-sections were used to investigate the compositional variation of rock units in section. Each sample was viewed under a petrographic plane polarizing microscope for the petrographic analysis. Thin sections were 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 rock was 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 logging is done in the field of the area is produced and correlation with other basins made.

Macro fossil investigation was done by examining morphology and size, classification and nomenclature was undertaken by comparison with studies by Jaboli (1959) and Keissling (2011).

1.7. Limitation of the study

Ideal micropaleontological works with such objectives would inevitably involve undertaking laboratory analysis, to identify the species on the bases of their morphology through the scanning electron microscope (SEM); and conducting experiments in the lab for small scale visualization and simulation of the geological processes that took place at a much larger scale (both temporal and spatial).

There is immense limitations during the laboratory analysis of this thesis work because of the absence of a standard micropaleontological laboratory at the School of Earth Sciences, Addis Ababa University, where this research undertaking on. This has meant that the exposure to the real practical environment has been very limited.

Attempts have been made to counter these limitations to some extent on the laboratory case is that the Central Geological Laboratory, Geological Survey of Ethiopia was used for the preparation of thin section and Addis Ababa University School of Earth Sciences Laboratory of sedimentology and paleontology and petrography was used.

1.8. Significance of the Research Thesis

The known carbonate rock containing sedimentary basins of Ethiopia had not been studied in detail and only very few studies were made in terms of facies and microfossil analysis. This study in the best exposures and the most interesting deposits of the Antalo limestone are found in the central part of the Abay valley, and the side valleys such as the Jema, Wenchit and the Muger valleys; Therefore, the study area of this research thesis; the Jema section is of the best limestone deposit and has not been studied on the aspect of facies and calcareous microfossil analysis in detail.

In this regard the study has dealt with the detail facies analysis and calcareous microfossil analysis to produce the stratigraphy log, correlation of the unit with in basin and with other units in regionally. .

Detailed identification and description of fossils and facies during this thesis work was necessary for the understanding of the depositional environment and stratigraphic relationship between various units. Microfacies analysis of carbonate unit and the microfossil analysis of a particular unit is the most important method.

This research thesis is designed to conduct a detailed study of facies and calcareous microfossil analysis of the carbonate rock unit of Lemi area Jema section to produce the stratigraphic log in order to determine the relative age of each stratum of the carbonate section, interpret the paleoenvironment in addition to its input in scientific knowledge through the identification and description of calcareous microfossils, invertebrate fossils and ichnofossils found in the carbonate unit of the study area.

CHAPTER TWO

2. REVIEW LITERATURE

2.1. Regional Geology

Sedimentary basins are regions of the earth crust of long-term subsidence creating accommodation space for infilling of sediments (Allen, 2005). Subsidence results from various causes that include: the thinning of underlying crust, dynamic effects in the asthenospheric flow, mantle convection, plumes, and tectonic loading and changes in the thickness or density of adjacent lithosphere (Ingersoll and Busby, 1995). 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. The sediments filled in the basin and the best indicative of the environmental condition under which they were deposited. The inferences generated from the sediment during the facies analysis supported by the biotope are more important to interpret the environment.

Sedimentary rocks of Ethiopia accounts for more than forty present (40%) of the country (Asfawossen Asrat, 2015). There are about five main sedimentary basins in Ethiopia including the Ogaden Basin, the Blue Nile Basin, the Gambela Basin, the Mekele Outlier and the Southern Rift Basin (Wolela Ahmed, 2008).

Based only on surface geology and previous studies, the stratigraphy of the Blue Nile Basin is assumed to comprise a crystalline basement, Paleozoic sediments, lower sandstone (Adigrat sandstone (Triassic–Lower Jurassic), Gohatsion Formation (Toarcian), Antalo limestone (Bathonian - Kimmeridgian), upper sandstone (Mugher mudstone at the base and the Debre Libanos sandstone at the top (Cretaceous) and Tertiary volcanic rocks (Getaneh Assefa, 1991).

The East African region has been affected by two major phases of rifting. The first phase was the widespread rifting documented by the Karoo sediment during the Karoo times (Late Carboniferous to Early Jurassic) which stretches from Ethiopia to South Africa. It corresponds to the beginning of the break-up of Gondwanaland (Norton and Sclater, 1979; Bosellini, 1989). Hence as a result further subsidence events took place. These subsidence events combined with sea-level fluctuations produced cyclic patterns of shallow- marine carbonates, shales, evaporites and minor clastic sediments. This is documented in the deposition of continental and marine sediments in the Bilu Nile Basin; sedimentary basin of Ethiopia (Gani et al., 2008). The second phase of rifting is relates to the formation of the East African rift system (Cenozoic to Recent) (Gani and Abdselam, 2006).

The deposition of Mesozoic to Cenozoic sediments in Ethiopia was the result of an extension accredited to Triassic to Cretaceous NE–SW-directed extension related to the Mesozoic rifting of Gondwana land (Abbate, et al., 2015). The Blue Nile Basin was formed as a NW-trending rift, within which much of the Mesozoic marine and continental clastic sediments were deposited. This was followed by Late Miocene NW–SE-directed extension related to the Main Ethiopian Rift that formed NE-trending faults, affecting Lower volcanic rocks and the upper part of the Mesozoic section (Abbate, et al., 2015).

The Blue Nile Basin is situated in the Northwestern Ethiopian Plateau and is bounded to the E and SE by the tectonic escarpment of the uplifted western flank of the main Ethiopian rift and to the N and S by the Axum–Adigrat and Ambo lineaments, correspondingly (Abbate, et al., 2015).

The Bilu Nile Basin roughly contains about 1400m thick Mesozoic sedimentary rocks section of both marine and continental origin. The Mesozoic carbonate sediments are sandwiched between the Paleozoic to the Lower Jurassic lower sandstone (Adigrat sandstone) which unconformably overlies Neoproterozoic basement complex rocks and conformably overlain by the Upper Sandstone (Shumburo, 1968) or (Mugher mudstone and Debre Libanos sandstone) (Getaneh Assefa, 1991) which is unconformably overlain Early–Late Oligocene and Quaternary volcanic rocks (Abbate, et al., 2015).

The architecture of the Bilu Nile Basin is poorly known. It is a failed aulacogen basin; which is considered to be formed during the Mesozoic break-up of Gondwana land. It is a NW-trending Mesozoic rifts that exist throughout the present day Somalia, Ethiopia and Sudan (Bosellini 1989; Russo et al. 1994).

Mesozoic sediments of Ethiopia occur mainly in two vicinities: of the northwestern Ethiopian plateau, which includes the Danakil Alps (Mekele outlier) in Tigray region in Northern Ethiopia and the Abay River basin (Blue Nile) Basin of centeral Ethiopia; and the southeastern plateau, which comprises the Ogaden Basin (Russo.et al., 2004; Getaneh Assefa, 1991).

2.2. Mesozoic Limestone Deposits in the Blue Nile Basin

Detail geological mapping by Mohr (1971) of the Mesozoic sedimentary section of Mekele Outlier basin which is underlain by Neoproterozoic basement rocks and overlain by Early–Late Oligocene and Quaternary volcanic rocks. The carbonate unit was categorized into three groups based on their fossil associations.

According to this classification about 200 meters of yellow crystalline limestone and gypsum with dolomitic limestone and poorly preserved pelecypods at the base, about 400 meters of gray limestone with pelecypods and 100 meters of yellow crystalline limestone with corals are identified (Mohr, 1971).

Getaneh Assefa (1979) has extensively studied the Mesozoic sediments in Abay River and its tributaries, particularly the "Abay Bed" which he called it Gohatsion Formation. Previous researchers considered this formation as a bed. However from modem stratigraphic nomenclature point of view and its lithologic association composed of; gypsum, shale and limestone with intercalation of dolomite it is more logical (Gohatsion formation).

According to Getaneh Assefa (1981) the Gohatsion formation has an approximate thickens of 450m. It has an age of Early–Middle Jurassic (Toarcian to Bathonian), as determined from micro and macro fossil faunas studied in the basin.

The limestone unit (Antalo limestone) with an approximate thickness of 400m comprises thinly bedded with an average of 10 cm to massive limestone of 20cm to 4m thickens where deposited from Middle–Late Jurassic age on the basis of (Callovian to Kimmeridgian) based on the benthic foraminifers and from Kimmeridgian- Oxfordian age based Ammonite macro faunas fossils; which is given the name Antalo Limestone (Canuti and Radrizzani, 1975; Russo et al., 1994) respectively. Kurita et al., (2009) determined the age of the carbonate succession as ranging from Bathonian to Kimmeridgian based on dianoflagellate cysts.

According to Gilamichael Kidanemariam et al., (2009) the middle to Late Jurassic carbonates succession (Antalo limestone) is about 400m thick. It consists of oolitic grainstone, mudstone and wackestones at the base. These are overlain by a thick cliff forming nodular limestone mainly limestone and coquinitic marl sequence. This passes to packstones and oolite to micritic alternations that are overlain by corals and stromatoporoid floatstones.The middle part of the Limestone is fossilferous with alternating yellowish limestone and grey calcareous mudstones. The fossils found within this unit are dominated by shell fragments of brachiopod, bivalves and gastropods.

According to Blanford (1870) the upper Jurassic carbonate unit was termed as Antalo Limestone, which is originally assigned to the limestone unit of the northwestern Ethiopia plateau of Tigray, and was subsequently extended to the limestone unit of the Blue Nile basin. The 420 m thick carbonate succession, as described by Russo et al. (1994) and Balemwal Atnafu (2003), as cited in Dawit Liben (2010) conformably overlies the Gohatsion Formation; which has been subdivided into three parts.

The lower part of the documented limestone unit which is about 180m thick is characterized by burrowed mudstones that grades upward into oolitic and coquinoid limestones with or without an intercalated marl beds, and then into massive limestone beds with scattered patched outs of corals, nerineids and stromatoporoids, for which a shallow water environment was inferred (Russo et al., 1994).

The middle part of the unit with roughly about a thickness of 200m consists of highly fossilferous interbedding of marly limestones and marls. The presence of ammonite faunal species (*Lithacoceras* sp. and *Subplanites spathi*), in association with brachiopods species of (*Terebratula pelagica and Nanogyra*) and other infaunal siphone feeders (*Anisocardia*, *Venilicardia* and *Somalirhynchia somalica* and *Zeillleria latifrons*) suggests a shelf to open marine environment (Russo et al., 1994; Balemwal Atnafu, 2003).

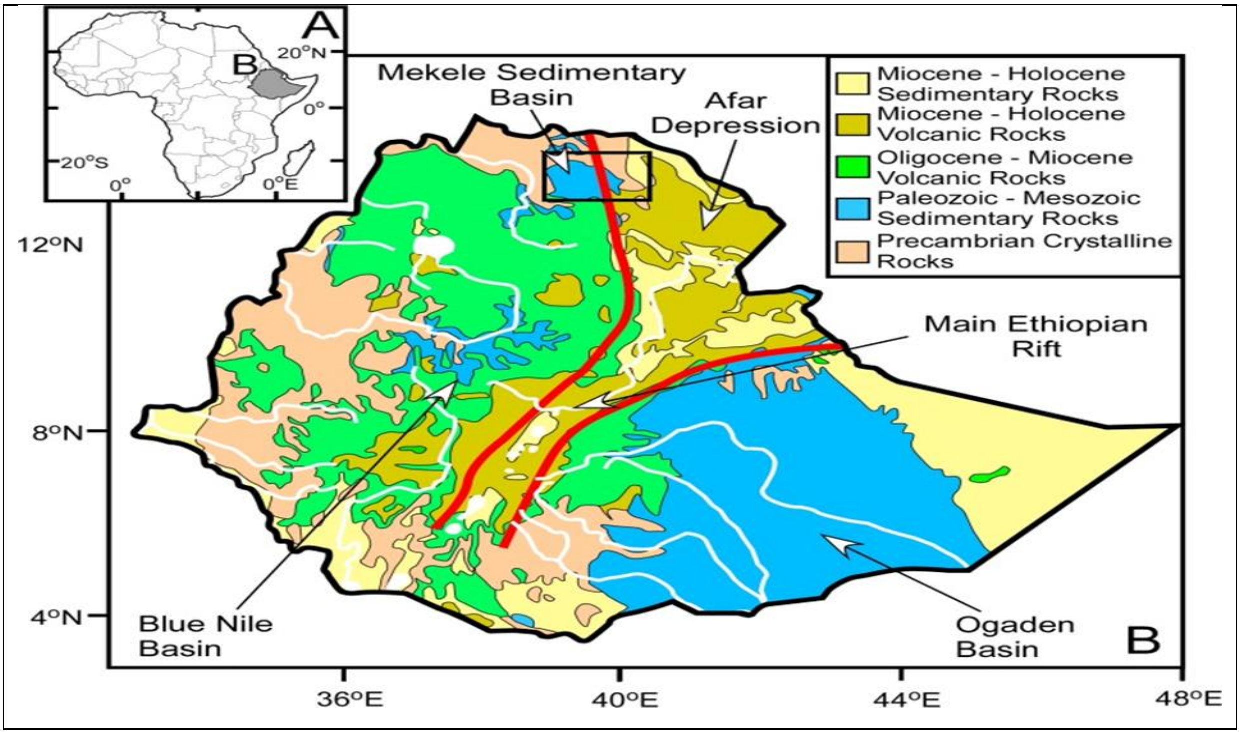

Fig. 2.1: Locations of Mesozoic sediments and basins of Ethiopia (Source: Ethiopian Institute of Geological Survey, by Mengesha Tefera et al., 1996).

The upper most part of the limestone unit which is approximately about 50m thick characterize by planar laminated oolitic and reefal limestones, which was interpreted to indicate the return of shallow water conditions. The presence of *Pfenderina* sp. and *Nautiloculina oolithica* at the base of the limestone unit points to a Callovian age (Russo et al. 1994). *Kurnubia palastiniensis*, *Parurgonina caelinensis*, *Conikurnubia* sp. and *Salpingoporella annulata* at the top of the unit indicates a Kimmeridgian age (Turi et al., 1990; Balemwal Atnafu, 1991, 2003 and Russo et al., 1994).

According to the detailed geological mappings by the Ethiopian institute of geological survey done by Mengesha Tefera et al., 1996; the distributions of the Mesozoic carbonate sediments in Ethiopia have been shown as follows in fig 2.1 above.

2.3. General Stratigraphic Succession of Northwestern Ethiopian Plateau

The Blue Nile Basin is situated in the Northwestern Ethiopian Plateau. It approximately contains about 1400m thick Mesozoic sedimentary section underlain by Neoproterozoic basement rocks and overlain by Early–Late Oligocene and Quaternary volcanic rocks in the Abay gorge (Getaneh Assefa, 1979).

According to Gani et al. (2008), the Blue Nile Basin been evolved in three main phases: pre-sedimentation phase, include pre-rift peneplanation of the Neoproterozoic basement rocks, possibly during Palaeozoic time; sedimentation phase from Triassic to Early Cretaceous and the post-sedimentation phase, including Early–Late Oligocene eruption of 500–2000m thick Lower volcanic rocks. The volcanics are related to the Afar Mantle Plume.

The Mesozoic to Cenozoic units were deposited during extension attributed to Triassic–Cretaceous NE–SW-directed extension related to the Mesozoic rifting of Gondwana. The Blue Nile Basin was formed as a NW-trending rift, within which much of the Mesozoic clastic and marine sediments were deposited. This was followed by Late Miocene directed extension related to the Main Ethiopian Rift that formed NE-trending faults, affecting Lower volcanic rocks and the upper part of the Mesozoic section.

The region was subsequently affected by Quaternary E–W and NNE–SSW-directed extensions related to oblique opening of the Main Ethiopian Rift and development of E-trending transverse faults, as well as NE–SW-directed extension in southern Afar (related to northeastward separation of the Arabian Plate from the African Plate) and E–W-directed extensions in western Afar (related to the stepping of the Red Sea axis into Afar).

These Quaternary stress regimes resulted in the development of N-, ESE- and NW-trending extensional structures within the Blue Nile Basin. The basin contains the basement complex rock, the Paleozoic to Mesozoic and Cenozoic sedimentary rocks and the tertiary volcanic rocks.

2.3.1. Paleozoic to Mesozoic and Cretaceous Sedimentary Rocks

As tremendous work has been done so far by different authors and workers on the sedimentary basins of Ethiopia through the detailed geologic mapping; about five formations were informally established for the Mesozoic sediments in the Blue Nile Basin (Getaneh Assefa, 1979, 1991).

The Precambrian basement complex rocks are at the base and above the basement complex rock: the first unit is the Lower sandstone (Adigrat sandstone) which is the oldest of the formation, shale and Gypsum unit (strata of Abay of Krenkel, 1926, Gohatsion Formation of Getaneh, 1981) which is the indicative of the transgression of the Indian ocean in to the basin, Limestone unit (Antalo Limestone), and the upper sandstone including (Shaly sandstone unit called Mugher Mudstone and the upper most top sandstone called Debre Libanos sandstone of Getaneh Assefa, 1981).

2.3.1.1. Adigrat Sandstone (Triassic to Lower Jurassic)

The lower sandstone unit documented in the Bilu Nile basin which varies in thickness in different localities; but roughly it is about 300m thick which also known as the Adigrat Sandstone and is considered to be Triassic–Early Jurassic in age based on some biostratigraphic data and comparison with adjacent areas providing fossil ages of (Permian–Triassic age from palynological evidence; Jepsen and Athearn 1961, 1964; Mohr 1962; Beauchamp and Lemoigne 1975; Russo et al., 1994).

The lower sandstone is set up unconformably covers the Neoproterozoic basement complex rocks and, successively, is overlain by the middle Jurassic shale and gypsum unit called the (Gohatsion formation of Getaneh Assefa, 1991), and considered to be the oldest recorded sedimentary deposits of Ethiopia; and the unit conquers the lower most part of the stratigraphic section in Ethiopian sedimentary basins.

The unit is lithologically characterized by pink to red in color, fine- to coarse-grained sandstones in texture which is rarely interbedded with grey mudstone beds. Among the primary sedimentary structures within this sandstone unit include dune-scale trough cross-bedding with set thickness ranging between 10 cm and 1m and with occasional pebbles and lithoclasts along foresets (Wolela Ahmed, 2008).

Generally, the Adigrat sandstone is characterized by monotonous fining-upward facies successions. An individual cycle starts with an erosional base overlain by lags, interpreted as channel features. Lateral accretion surfaces within the sandstones indicate lateral migration of the channels. The average azimuth of palaeocurrents measured from dune cross-strata is 1108. Locally, channels are vertically stacked and produce amalgamated sandstones, indicating high-energy and/or depositional setting with low accommodation volume (Wolela Ahmed, 2007).

Among the secondary sedimentary structures in the unit includes lateral accretion surfaces, horizontal stratification and ripple cross-lamination. In some places, silicified tree trunks up to 4m long, mud-cracks and vertebrate tracks are found within this unit. The presence of large mud-cracks and vertebrate tracks within the sandstones and suggest sub-aerial exposure of the flood plains in a continental fluvial environment (Mengesha Tefera et al., 1996).

2.3.1.2 Shale and Gypsum Unit

This unit is previously named the Abay bed and the lower unit of the Antalo group (Kazmin, 1972, 1975) of the Abay River lying between the lower sandstone (Adigrat sandstone) and the carbonate unit and later called the Gohatsion formation of (Getaneh Assefa, 1981). The unit is expected to have about 350m thick (Getaneh Assefa, 1991) as well with the thickness of about 580m (Mengesha Tefera et al., 1996). The unit is characterized by an intercalation of sandy limestone with calcareous sandstone and with thick gypsum alternating with shale and limestone.

The Gohatsion Formation is assumed to have an age of Early to Middle Jurassic (Toarcian to Bathonian) age, as determined from micro and macro fossil faunal studies by (Getaneh Assefa, 1981). A complex mixture of terrigenous and evaporitic rocks are considered to be deposited in the lagoonal environment, is overlying the Adigrat sandstone and this unit have no an equivalent unit exposed in the Mekele outlier, Danakil Block Mountains among the northwestern plateaus and correlable with upper Hamanlei formation of the southeastern plateaus of the Mesozoic sedimentary vicinities in Ethiopia.

The formation has a various thickness throughout the logged section in the basin by different authors 350m (Getaneh, 1980 and 1991; Wolela Ahmed, 1993) even though the unit is sub-divided in to three units; the lower, the middle and the upper unit.

The lower unit is composed of mudstone, fine-grained sandstone and rare limestone passing upward into the alternation of limestone, dolomite, shale and gypsum. This subunit seems that the lithologic association of transition zone from continental (fluvial) depositional environment to the lagoonal environment.

The middle unit which is dominated by the gypsum beds which is rarely interbedded with mudstone and very rarely with dolomite and fossilferous limestone; which is an indicative to the lagoonal environment for the deposition of an extensive gypsum beds and the area of deposition sized its communication to the open sea at the time of deposition and get up lifted to form lagoonal condition.

The upper part of the unit is known by shale, siltstone and limestone alternations with rare thin interbeds of gypsum at the lower part indicating that the area had a communication with the open sea and was progressively invading the area which result in the marine depositional environment at the top.

In the Blue Nile basin, the Adigrat Sandstones are followed by the Gohatsion marls and evaporites of Aalenian to Callovian age (Russo et al. 1994).

According to Beciep (1985) the lower part of the Gohatsion formation might be the lateral equivalent of Lower Hamanelei and transition and the middle part to the middle Hamanelei and the upper part the upper Hamanelei formation of the Ogaden basin.

2.3.1.3 Limestone unit (Antalo Limestone)

The name Antalo Limestone was first entitled by Blanford (1869, 1870) after the town Antalo in northern Ethiopia of the Tigray region. Later on the unit was well-described by Levitte (1970), Beyth (1972a, b), Merla et al. (1979), Bosellini et al. (1997) and Matire et al. (2000).

According to Beyth (1972a, b), through mapping of the Tigray region the thickness of the succession ranges from 300 m in the west to 800 m in the east; whereas the unit comprises of approximately about 600m fossilferous limestone with beds of shale and marl (Getaneh Assefa, 1991).

According to Getaneh Assefa (1991) the carbonate unit consists of approximately about 600m thick of fossilferous dominated carbonate interbedded with marl, shale and mudstone. The top most part of this unit is oolitic, massive and cliff forming limestone; which is called the Lagajima Limestone of Aubry (1886). The thickness of this unity varies from place to place with in the basin which is documented with the maximum of 170m. The rest part of the carbonate unit is dominated by marl and is thus informally called marly limestone. Getaneh Assefa (1991).

Bosellini et al. (1997) attempted to subdivide the limestone unit into four depositional sequences for the Mekele outlier of the northern Ethiopia; which are composed of thickening and shallowing up cycles. However, he excluded the lower 30 m thick barrier-lagoon deposits (i.e., his "Transition Beds") from his sequence stratigraphic analysis. These deposits may represent the transgressive part of his "A1 sequence" (Tucker, 1996). The limestone succession was deposited in a homoclinal ramp or on a wide cratonic margin gently dipping to the southeast (Bosellini et al., 1997).

A Late Callovian to Kimmeridgian age has been assigned to the Antalo Limestone by Bosellini et al. (1997) based on a rich benthic foraminifera fauna. However, Matire et al. (2000) proposed an Oxfordian to Kimmeridgian age for the unit based on ammonite fauna. The unit is regionally correlable with equivalents of Antalo Limestone with in NW of the Tigray region and correlated with the Urandab Formation in the Ogaden basin of the SE Ethiopian plateaus.

The unit is characterized by comprising thinly bedded (average 10 cm) to massive limestone of 2 to 4m. It is also known as the Antalo Limestone, which is of Middle–Late Jurassic age on the basis of Callovian to Kimmeridgian benthic foraminifers and macrofauna (Canuti and Radrizzani 1975; Russo et al. 1994).

It is found in the SW-flowing segment of the Blue Nile sandwiched between the Early–Middle Jurassic Shaly and gypsum unit, and either the Late Jurassic–Early Cretaceous Upper Sandstone unit (Mugher mudstone or the Debre Libanos sandstone) or in some vicinity to Early–Late Oligocene volcanic rocks.

The middle part of the Upper Limestone is fossilferous with alternating yellowish limestone and grey calcareous mudstones. The fossils found within this unit are dominantly brachiopod shells, bivalves and gastropods.

Locally, the bedded limestone is followed by nodular limestone containing a few tepee structures (diagenetic sedimentary structures formed as pseudo anticlines due to the expansion of surface sediment layers). The bedded limestone is also characterized by the occasional presence of 2–3m thick stylolite and intensely bioturbated horizons.

2.3.1.4 Muddy Sandstone unit (Mugher Mudstone)

The unit was previously known as the “Upper Gypsum” (Aubry, 1886; Merla et al., 1979) and the Shaly sandstone of Jepson and Athearn (1964). The name “Muger Mudstone” was adapted after a type section was established by (Getaneh Assefa, 1991) along the bank of the Muger River (N 09°37’/E 38°24 33”) in the eastern part of the Blue Nile canyon.

The succession is 15 m in the Gohatsion area but thickens eastwards to reach up to 320 m in the Jema river valley. In its type locality, it is 260 m thick and conformably overlies the carbonate unit of the Bilu Nile basin which is correlable to Antalo Limestone.

Based on lithology, (Getaneh Assefa, 1991; Russo et al., 1994) subdivided the unit into two parts. The lower part (15 m thick) is composed of alternating beds of nodular and vein-filling gypsum, dolomites, and shales, for which the authors assigned a supratidal and lagoonal environment. Estuarine environment has been proposed by (Goodwine et al., 1999; 2006). The rest of the succession (240 m thick) is characterized by interbedded sand-, silt and mudstones with local occurrences of lignite layers and scattered plant fragments. This siliciclastic succession was interpreted by (Getaneh Assefa, 1991) to represent deposits of a meandering river system.

Regarding the stratigraphic position of the Muger Mudstone (Getaneh Assefa, 1991) its age is assumed in the lower age limit to be early Kimmeridgian since it covers limestone and marl of an early Kimmeridgian age and the upper age limit is difficult to determine since both the Mugher formation and the over laying unit called the Debre Libanos sandstone are unfosiliferous.

An Early Cretaceous age was proposed for the upper part of the formation, on the basis of the occurrence of tooth plates of *Neoceralodus africanus* (also referred to *Asiotoceratodus tiguidensis),* teeth of the batoid *Rhinobatos* sp., shell fragments of pelomedusoid turtles, and teeth of sauropods (Wood et al., 1993; Werner 1995; Schmidt & Werner, 1998).

These biostratigraphic evidences appear to contradict with the attempt made by (Getaneh Assefa, 1991) to correlate the unit with the Agula Shale of northern Ethiopia in the Mekele outlier, which was dated as “not older than Kimmeridgian” (Bosellini et al., 1997).

Generally the Muddy sandstone unit called the Mugher formation varies in thickness in different vicinities of the Bilu Nile basin; the unit conformably overlies the carbonate unit and superimposed by the upper most sandstone unit (Debre Libanos sandstone)

2.3.1.5 Debre Libanose Sandstone (Upper most sandstone)

This unit, also known as Debre Libanose Sandstone, unconformably overlies the Upper muddy to Shaly sandstone unit. Since no biostratigraphic or radiometric age data are available, this unit is determined to be of Late Jurassic–Early Cretaceous age based on its stratigraphic relationship with overlying and underlying units (Getaneh Assefa, 1991; Russo et al., 1994). The Palaeontological age dating for the Upper Sandstone unit was documented as Early Cretaceous in southeastern Ethiopia (Gortani, 1973; Silvestri, 1973).

The sequence thickness varies in different places from 200 to 500m with an average thickness of 280m. The Upper Sandstone is encountered in the S-flowing segment of the Blue Nile below the tertiary volcanic rocks. It comprises thickly to thinly bedded sandstones, with bed thickness ranging from 1 to 40 cm.

The sandstones are characterized by white to pink in color, and are medium to coarse grained in texture. The Upper Sandstone shows dune-scale trough cross-bedding and horizontal stratifications as indicatives of continental deposits. Distinct pebbles horizons are locally present and small channels with lateral accretion surfaces are rarely observed. The overall depositional environment of this unit is interpreted to be continental alluvial to fluvial. Therefore, the unconformity (disconformity) at the base of this unit marks a regional regression when rocks of Early Cretaceous are absent. The boundary between the Upper Sandstone and the overlying Early–Late Oligocene volcanic rocks is indicated by a whitish–pinkish baked sandstone horizon which consists of sandstone with distorted sedimentary structures and also represents a major hiatus. The detailed stratigraphic description of the Upper Sandstone has been made by (Getaneh Assefa, 1991; Wolela Ahmed, 1993).

2.3.1.6 Cenozoic volcanic Rock

Quaternary volcanic events resulted in the eruption of about 300m up to 5500m thick basaltic rocks. This unit is exposed in the different vicinity of the Blue Nile Basin, but is encountered close to Lake Tana where the Blue Nile flows SE.

Here, these rocks are relatively fresh, lack columnar joints and are characterized by the presence of sheet joints, and vesicles ranging in diameter between 2mm and 1.5 cm. These are filled with green zeolite, calcite and quartz. Locally, this basaltic unit contains a few cm-thick reddish baked clay beds, and _50 cm-thick pyroclastic layers.

Patchy trachytic volcanic mounds are locally present. Red to brown palaeosol horizons of about 30 cm thickness indicates several eruption pulses. No normal faults are observed in the

Quaternary volcanic unit. However, this unit is characterized by the presence of NW- and NE-trending fractures.

2.4. Fossils of Jurassic Age in Carbonate units of Blue Nile Basin

Pervious works conducted in the Abay basin regarding the fossil and age determination include; Blanford, 1869; Jaboli, 1959; Currie, 1943; Kazmin, 1973; Gortani, 1942, Russo et al., (1994) and Kurita et al., (2009).

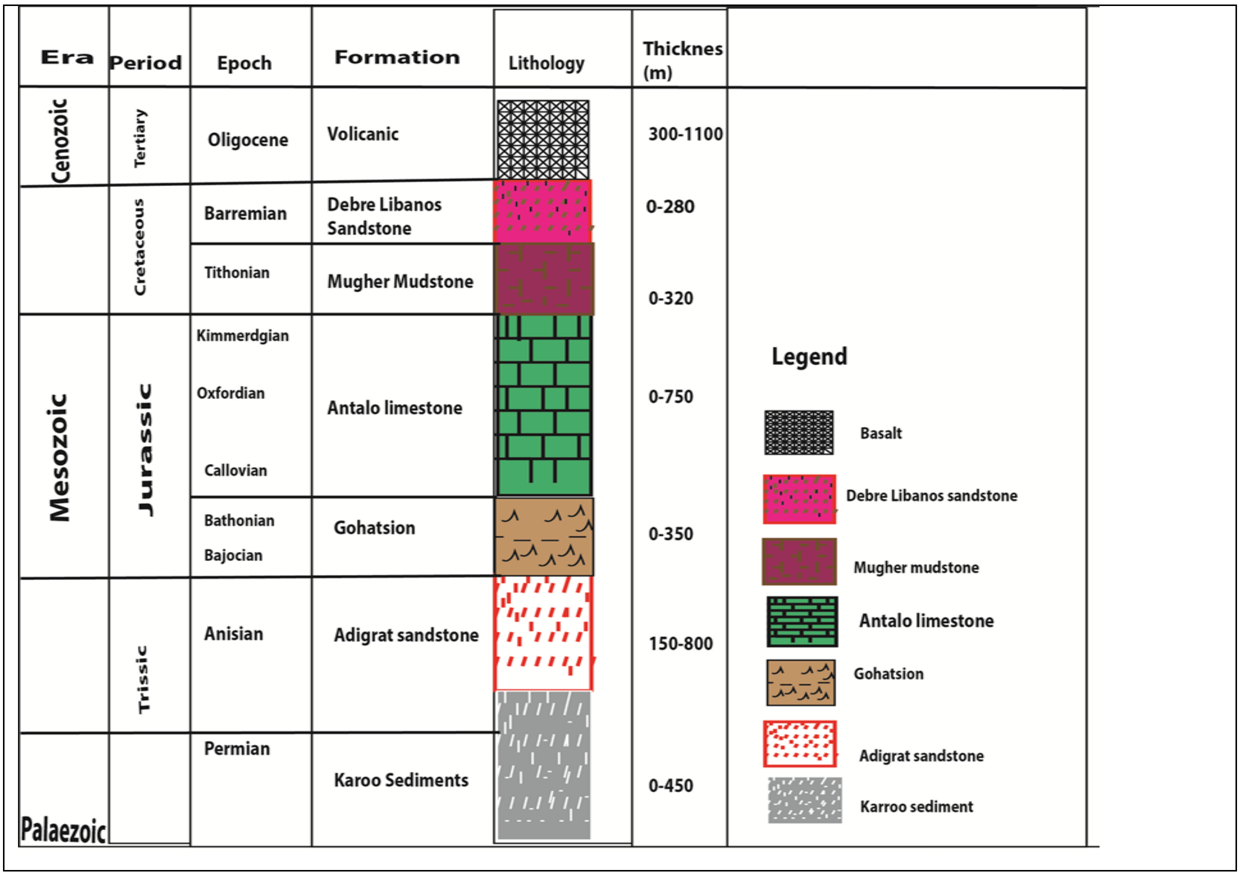

Fig.2.2: Reproduced from Chronostratigraphic and lithostratigraphic section of the Blue Nile Basin (Source from Getaneh, 1991; Wolela, 1997; 2007; 2008); of Dejen section.

According to Russo et al. (1994) The carbonate unit of the Abay Basin is dominated by the most important macro and micro faunas of *Pholadomya somaliensi*, *Mactromya daghaniensis*, *Homanya inornata*, *Musculus somaliensis*, *Daghanirhynchia daghaniensis* and some Gastropods in the lower bed whereas the marly layer of the Antalo Limestone contain chiefly *Gryphea costellata*. The genus *Pfenderina* occurs in Ethiopia together with several other members of the so called "Middle Eastern Jurassic fauna" such as *Pseudocylammina jaccardi, Everticyclammina virguliana, Kurumbia palastiniensis, Trocbolina palastinesis, Rbapydinonina deserta-amiji and Orbitopesella praecursor*. (Aziz, 1975).

CHAPTER THREE

3. STRATIGRAPHY OF THE JEMA SECTION

The present study is conducted in; Jema section of the Lemi area situated in North Shewa of centeral Ethiopia, of the North western Ethiopian Plateau. In the section thick Jurassic limestone units was deposited with an age of Late Callovian to Kimmeridgian based on benthic foraminifera fauna by Bosellini et al. (1997) and an age of Oxfordian to Kimmeridgian based on the ammonite fauna by Matire et al. (2000). In order to explore the depositional environment and facies of the carbonate unit; detailed field observation and description, microfossil preparation and study and microfacies analysis of the carbonate unit was done.

Under this section the detailed local stratigraphy, of carbonate succession, based on the field observations and petrographic studies is presented. The carbonate unit of the section was described as shown on the composite stratigraphy (Fig .6.1.); in an ascending order.

Marine transgression and regression in the Bilu Nile basin is documented by the evidences of carbonate sequence and related units; various units of the Jurassic Mesozoic sediments named as Gohatsion Formation as the begging of the marine environment by some authors called Abay bed, Antalo Limestone well documented carbonate unit and the Mugher formations which is logged with a varying thickness by different workers, throughout the Blue Nile basin of Ethiopia. The variation of the carbonate unit of the area in thickness as logged by different workers from place to place throughout the area, which most probably shows the response to the tectonic disturbance and sea level fluctuation during their depositions.

In Jema section the carbonate unit is highly exposed following the Jema River bank and the tributaries' of Dufa River cut. The detailed local stratigraphy of the carbonate succession of the area is described based on the field observation and petrographic studies. The thickness of carbonate units of the area is varying from top to bottom throughout the section from 10cm to 4m in different layers as bed structures; which is most probably shown as the result of sea level fall and rise during the deposition of the carbonate sediments.

The limestone unit in the study area is out cropped as a sharp cliff (20 to 30 meter thick) of an individual bed with 10cm to 4m; along the Jema river bank and their tributaries like Dufa stream extending laterally (for about 100 to 200m) north and south until it disappears being covered by intercalation of mudstone and clay stone unit (Mugher formation) from north and south (fig. 3.4).

The limestone units of the Jema section in the vicinity of Lemi vary in color from light gray to light yellowish and very fine to very coarse grained in texture. It is clearly seen that the limestone is horizontally bedded, jointed and fractured as shown in (Fig.3.2. A). the thickness of individual beds varies from 10cm to rarely 4m. Carbonate microfacies analyses indicate that the limestone varies texturally from micritic mudstone to fossilferous limestone.

The sequence consists of thin-thick bedded grayish weathered color and white fresh colored micritic, bioclastic, peloidal and ooid limestone rocks with thin layer of marl intercalations in the upper most part and grayish bioclastic, intra and peloidal packstone to grainstone at middle part of the section and the top part of Jema section is dominated by dark gray blackish, grayish and reddish mudstone and bioclastic wackestone with some thin layered intercalations of marls.

Various workers established that the Antalo limestone to have a thickness of 420m; but the actual thickness of the limestone unit cannot be established in the study area due to the lower unit (presumably) the Abay beds are not exposed in the study area. However, the thickness of the limestone both at Dufa and Jema has been recorded up to 145m where larger thickness of the limestone is not exposed and it is underneath the river beds. This indicates the enormous nature of the limestone resource in Abay basin in general that require further exploration and evaluation of industrial minerals in the basin.

Lithologically the limestone unit in Jema section in the vicinity of Lemi ranges from mudstone to grainstone according to (Dunham, 1962). The common lithologic and facies changes were vertically observed in the field and in the microfacies study of the carbonate rocks in the petrography. The detailed local stratigraphy for carbonate successions of the area is described based on the field observations and petrographic studies as follows:-

3.1 Lithostratigraphy of Jurassic limestone in Jema section; subsection 1

The limestone sequence is well preserved as the carbonate unit. The detail description of the carbonate unit has been made based on their lithology, colors, sedimentary structures, textures, fossil contents, stratigraphic relationships and their geometric relation. The carbonate unit in Jema section in the vicinity of Lemi is not well exposed as fully; to the expected thickness of Antalo limestone, but it is characterized by forming a cliff of steep up morphology along the River of Jema and the tributaries’ of Dufa. Carbonate unit in this area has thickens of about 145 m and have various invertebrate fossils of gastropods, brachiopods, echinoids, bivalves in the upper middle part of the unit as molds; and attempts has been made to identify the observed fossil molds of the listed groups.

Very thick layer of micritic limestone has dominated the studied facies which is shown as in (Fig 3.1.A) which varies in color from (grayish to dark-gray) weathered color and white fresh color while wackestone, grainstone and packstones facies types are identified and observed in the section with fair representations.

Thin-thick bedding, planar lamination and cross bedding as shown in (Fig 3.2. and fig 3.3) are among the common sedimentary structures observed in the section. Detail description to the carbonate unit of the Jema section which have been differentiated in the field has been discussed as follows from the bottom of the unit to the top part of the unit; based on the lithologic criteria, color, sedimentary structures, texture, fossil contents, stratigraphic relationships and their geometries as follows:-

At the bottom of the exposed carbonate unit in the section which is above the underneath unit including the Abay bed; which has been described as the lower and the middle layer of the middle part of Jema section have a thickness of 47m which is exposed as a sharp cliff that can be expressed by having light grayish to dark gray weathered color and very white fresh color as shown in fig 3.1.A & B having thick bedded micritic limestone with rare to devoid of fossils but this layer contains rare to abundant fossils of foraminifers as obtained from the thin section analysis and with no intercalation of marl looks like no beds present in the layer.

The contact between lower units of the Abay basin called the Abay bed the outcropped micritic lime stone is not exposed and out cropped in Jema section in the vicinity of Lemi and the rise and fall of the basin swallowing up ward resulted in the formation of about 8m the rock sample coded as RS 009 is obtained bioclastic wackestone in between second micritic bed of about 28m with in the sharp cliff in the Jema subsection 1.

The upper part of the middle layer of the Jema section in the vicinity of Lemi; the Antalo limestone which is around 14m thick this is dominated by the fossils of foraminifers with an intercalation of marl in between the individual beds as shown in fig 3.2. A & B and the exposed layer of this section are expressed by fractures and intercalations of marl at the top of the cliff of micritic limestone layer where bedding structures are clearly seen in this section. Whereas it varies in color from dark gray to light gray and texturally from very fine to fine gained micritic limestone or what we called mudstone.

At the top of the sharp cliff micritic limestone of the Jema section bioclastic wackestone to packstone layer was deposited and which is characterized by the step up cliff which is around 28m thick; with very thick intercalation of marl whereas the rock unit is expressed by the dominancy of the shell fragments of bivalves, brachiopods, gastropods and rarely of echinoids as shown in (fig. 3.4. A&B); this of the section is dominated by fossilferous with an alternating yellowish limestone and grayish calcareous mudstone.

Wackestone, grainstone and packstone at the top fairly represents the limestone beds in the section whereas the micritic limestone at the bottom of the section above the Abay bed which is underneath of the carbonate unit outcropped dominate in Jema section the study area. Bioturbation is very commonly observed on these grainstone and packstone layers of the carbonate units. The petrography of the collected sample indicates is that the rock unit fails in micritic to grainstone in type and which consists of micrite, sparry calcite crystals, bioclasts and peloids grains are observed.

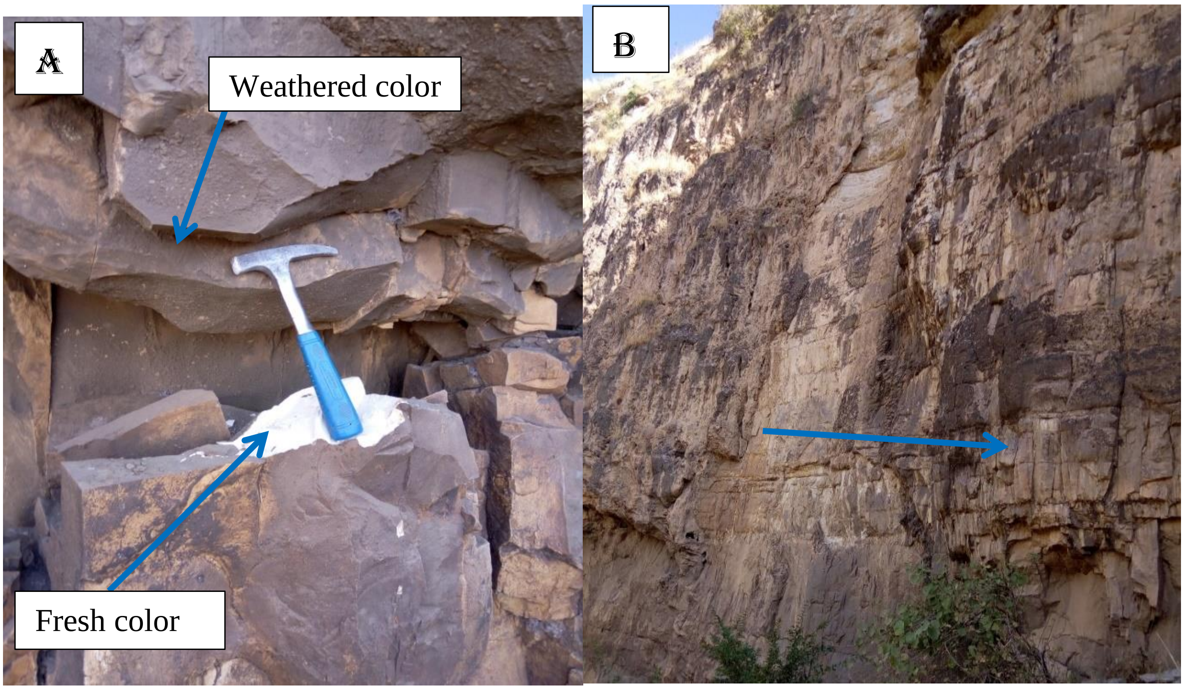

Fig. 3.1: Thick micrite layer of limestone with a bed thickness of about 4m in Jema section.

The upper unit is argillaceous, fine-grained, yellowish, dull-white, occasionally oolitic, alternating with variegated shale, locally some gypsum beds in the vicinity of Lemi near the sand contact, some beds are very rich in fossil fragments, detrital and highly weathered in Lemi area with the upper most carbonate unit of stromatolite facies of about 6m thick. All of the above mentioned units are logged at Jema section according to their ascending order, as given in (Fig.3.11) and described according to their dominant facies in detail as follows from the top to the bottom and the variation in texture from very fine to very coarse from the bottom to the top indicates swallowing up ward.

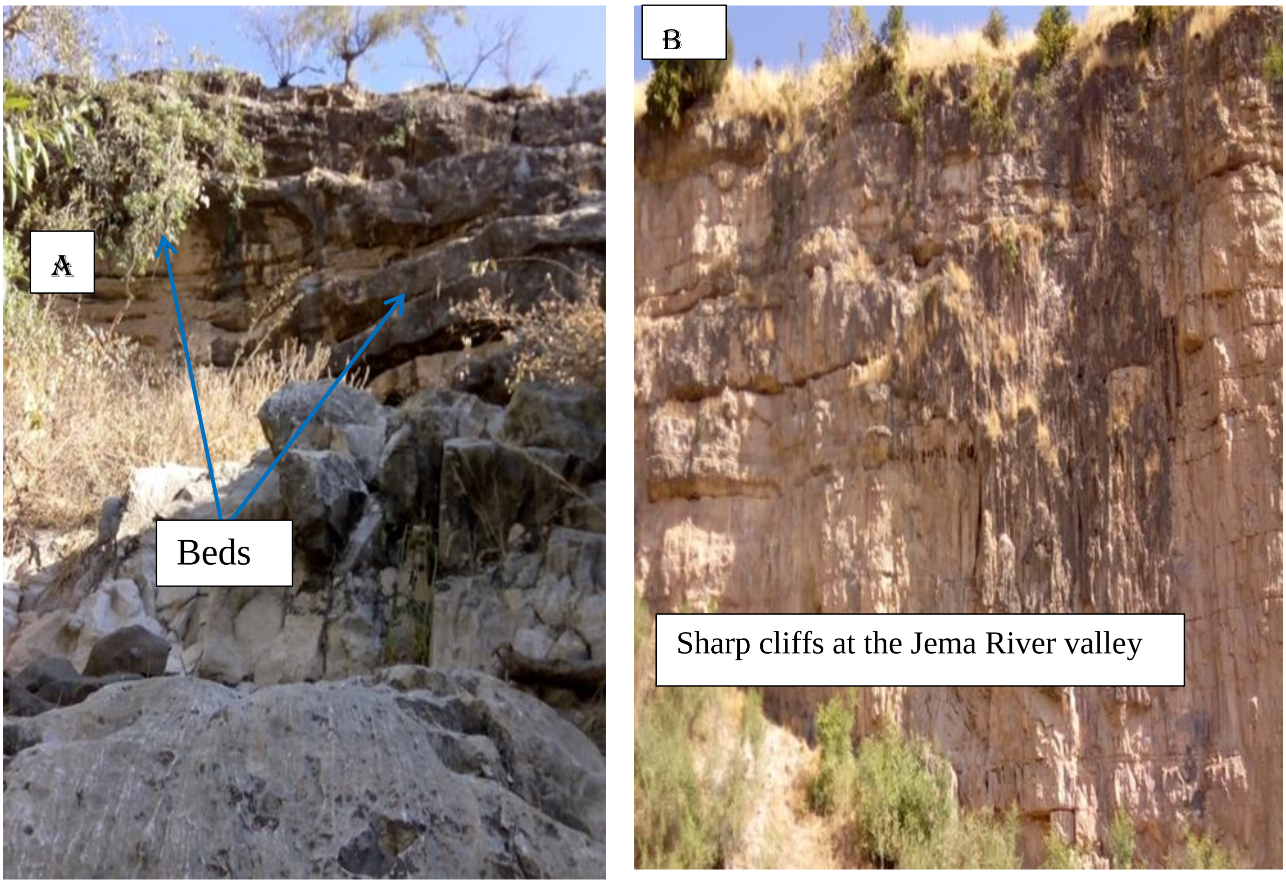

Fig.3.2: thick and fractured individual beds in Jema subsection 1 of the foraminiferal bioclastic wackestone

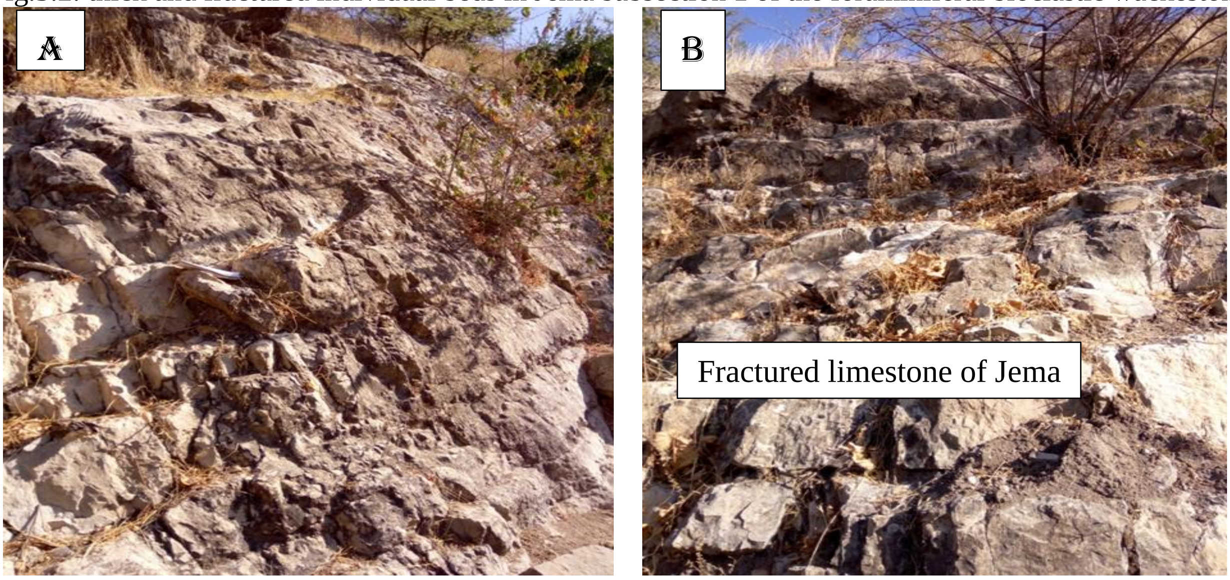

Fig. 3.3: Fractures among the secondary sedimentary structures observed in carbonate units of Jema section in the vicinity of Lemi

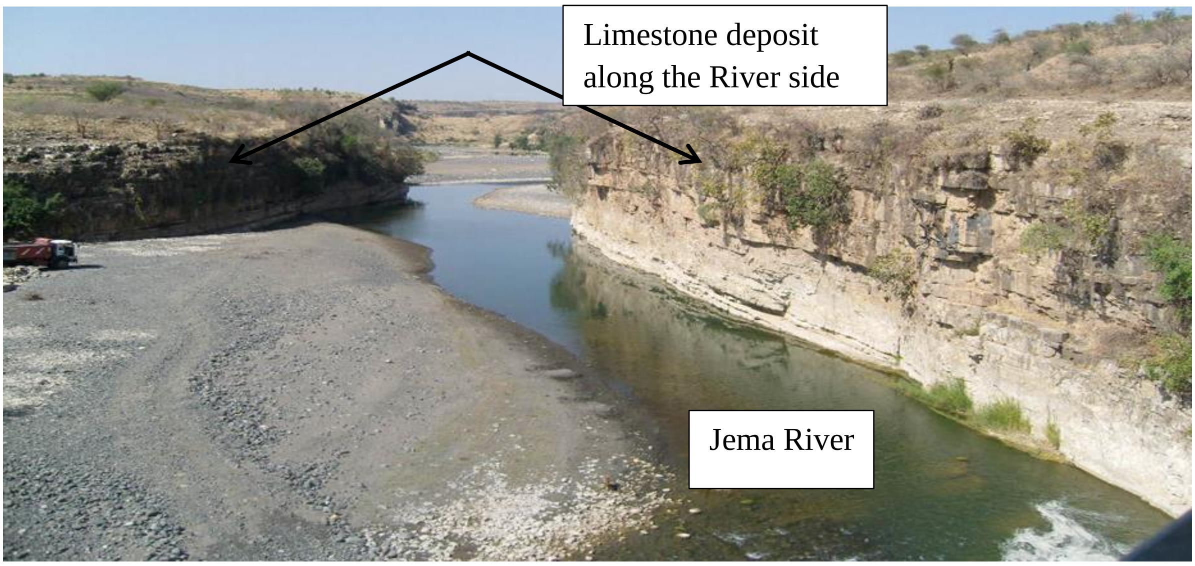

Fig. 3.4: The limestone unit in the study area out cropped as a sharp cliff (20 to 30 meter thick) of an individual bad with 10cm to 4m; along the Jema River

3.1.1. Bioclastic grainstone layers of Limestone unit

The bioclastic grainstone layer in Jema subsection 1 is found in the upper part through the section in intercalation with the marl with about a thickness of 26m. In the upper Jema section they are found overlaying the micritic limestone unit as discussed above. They are characterized by mostly grayish color and thin to medium bedded with the shell fragments of brachiopods, bivalves and gastropods. Mostly the layers containing the bioclastic limestone are intercalated with marl and also bioturbation is very commonly seen on these layers as shown in the Fig 3.5.

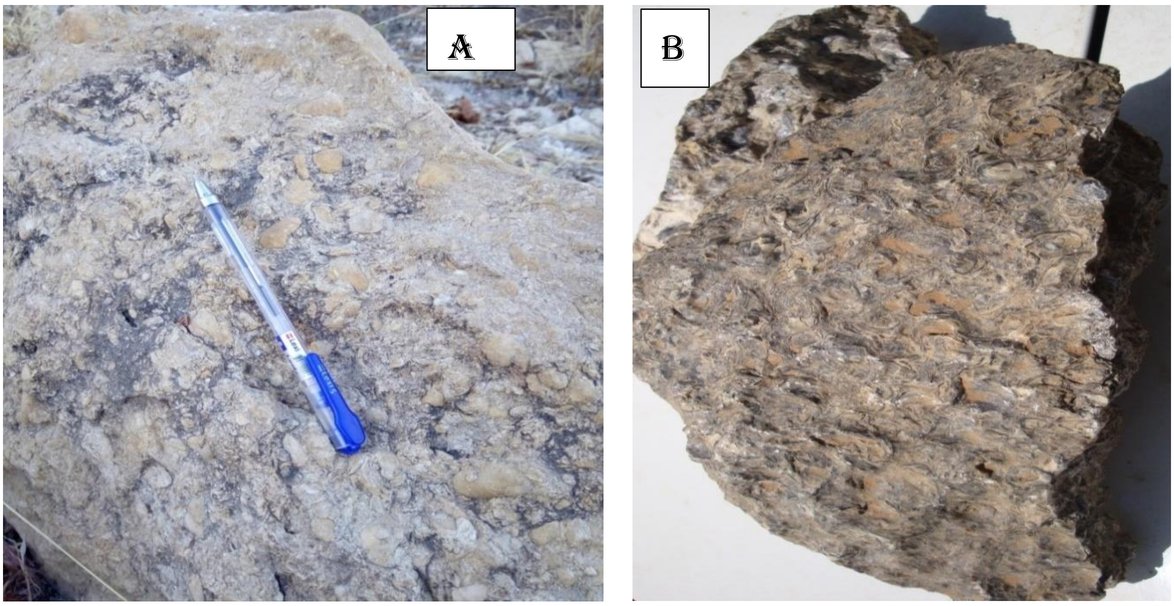

Fig. 3.5: light Gray to dark gray fossilferous limestone samples with shell fragments of bivalves and brachiopods collected in the upper part of Jema section from the bioclastic layer in the vicinity of Lemi

3.1.2. Peloidal Limestone layer

These carbonate layers have a thickness of around 12m. They are dominated by packstone to grainstone layers rich in peloids at top and bioclasts at the bottom with light gray color. All of these components are ranging in size from finer to sand-sized carbonate grains. This layer is intercalated with marl and dominated by bioturbation and shell fragments of organisms as shown in Fig 3.6.

Fig.3.6: Grayish peloidal limestone layer of the Jema section at the top of the limestone unit in Lemi area

3.1.3. Micritic limestone layer

Micritic limestone's of Jema section in the vicinity of Lemi are found as white when broken by hammer, light gray to blackish and dominantly grayish in color for the weathered samples which is having thin to thick beds of about 10cm to 4m of each. From the outcrop observation and petrography of these thick micrite layers of the section there are very rare amounts of other allochems like skeletal grains except faunas of foraminifera's. Some of the micritic layers of these section fractured and bioturbated as shown in fig.3.7 but at some place they are free from any bioturbation and highly intercalated with very thin layer of marl.

At the middle of the section of the micritic layer about 75m thick beds of fine grained, light gray micritic limestone are exposed and rare chert thin layers are also observed. Some faunas of Echinoid's are observed from the chert bed layer of the unit. Sedimentary structures such as thin to thick beds, stalgimaties are observed in the Dufa banks as shown in fig 3.3 above.

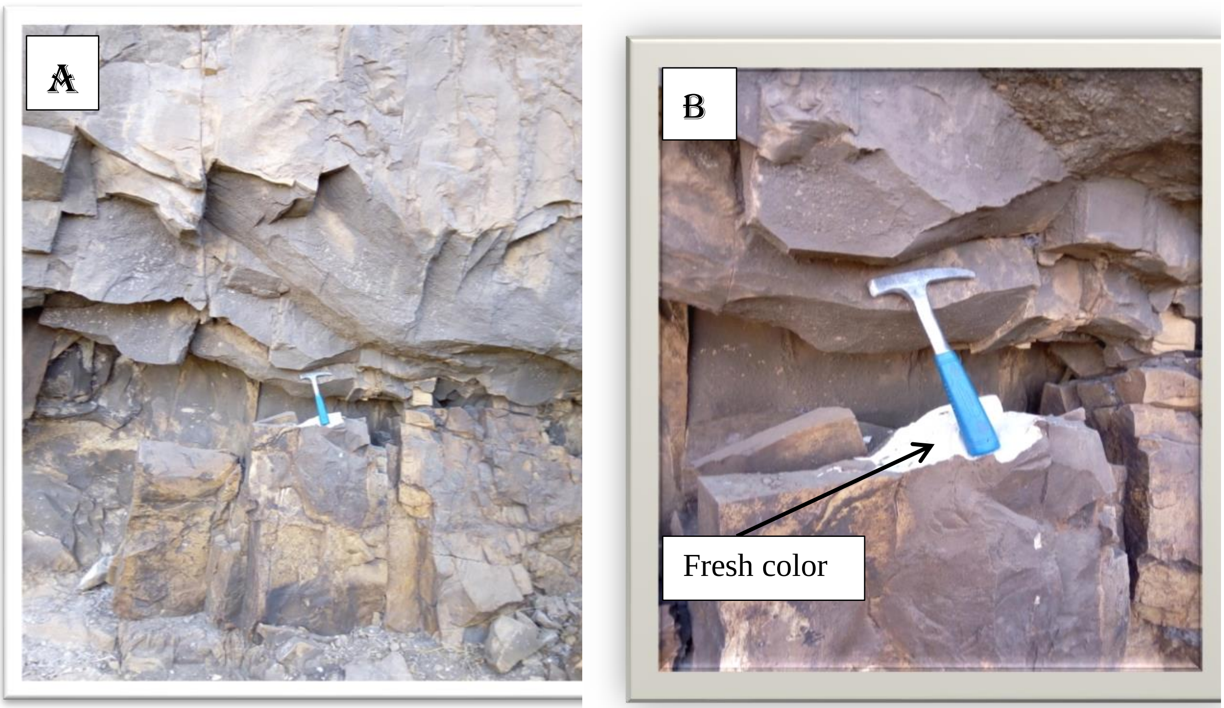

Fig. 3.7: Micritic limestone layer of Jema Section in the vicinity of Lemi

3.1.4. Bioclastic Packstone-Grainstone limestone layers

This layer of the limestone units in the vicinity of Lemi is characterized by various dominant grains of intraclasts and bioclasts with some peloids and ooids thin to thick mudstone layers are also present. They are dominant in the middle to upper section of the limestone unit above the micritic and below the Mugher mudstone formation. 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 35m. 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 bottom layer of this unit is characterized by Ichnofossils and the bioturbation of the unit by faunas as shown in the fig. 3.8 below.

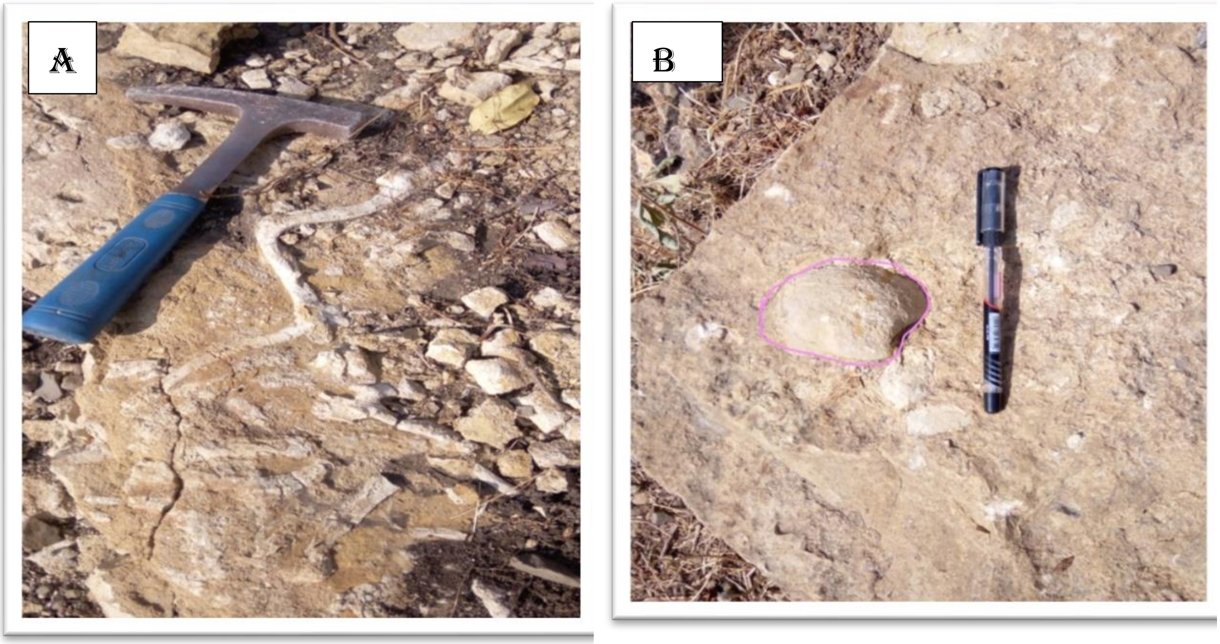

Fig.3.8: peloidial Packstone to grainstone layer of Jema Section subsection 1

3.1.5. Ooidial Limestone layer

This layer is dominated by packstone to grainstone layers rich in ooids at top and bioclasts at the bottom. The components are ranging in size from finer to sand-sized carbonate grains. This layer is intercalated with the marl. Each ooidial layers of the limestone is with about 10cm to 20cm thicknesses of bedding sedimentary structures. The marl samples obtained for the micropaleontological analysis from the beds of the intercalations are dominated by foraminifers and ostracods from the microfossil preparation and it is as shown in fig. 3.9 below.

Fig 3.9: Ooid layer in the upper part of the section subsection 1 the vicinity of Lemi Jema

In the upper most part of the carbonate unit of gypsum anhydrites are observed as the result of regression that formed in restricted marine shelf lagoonal depositional environment. The Gypsum anhydrite deposits as the result of regression in the upper most part of the carbonate unit in Lemi area of the Jema Section subsection of Dufa: The field microphotograph that shows anhydrite.

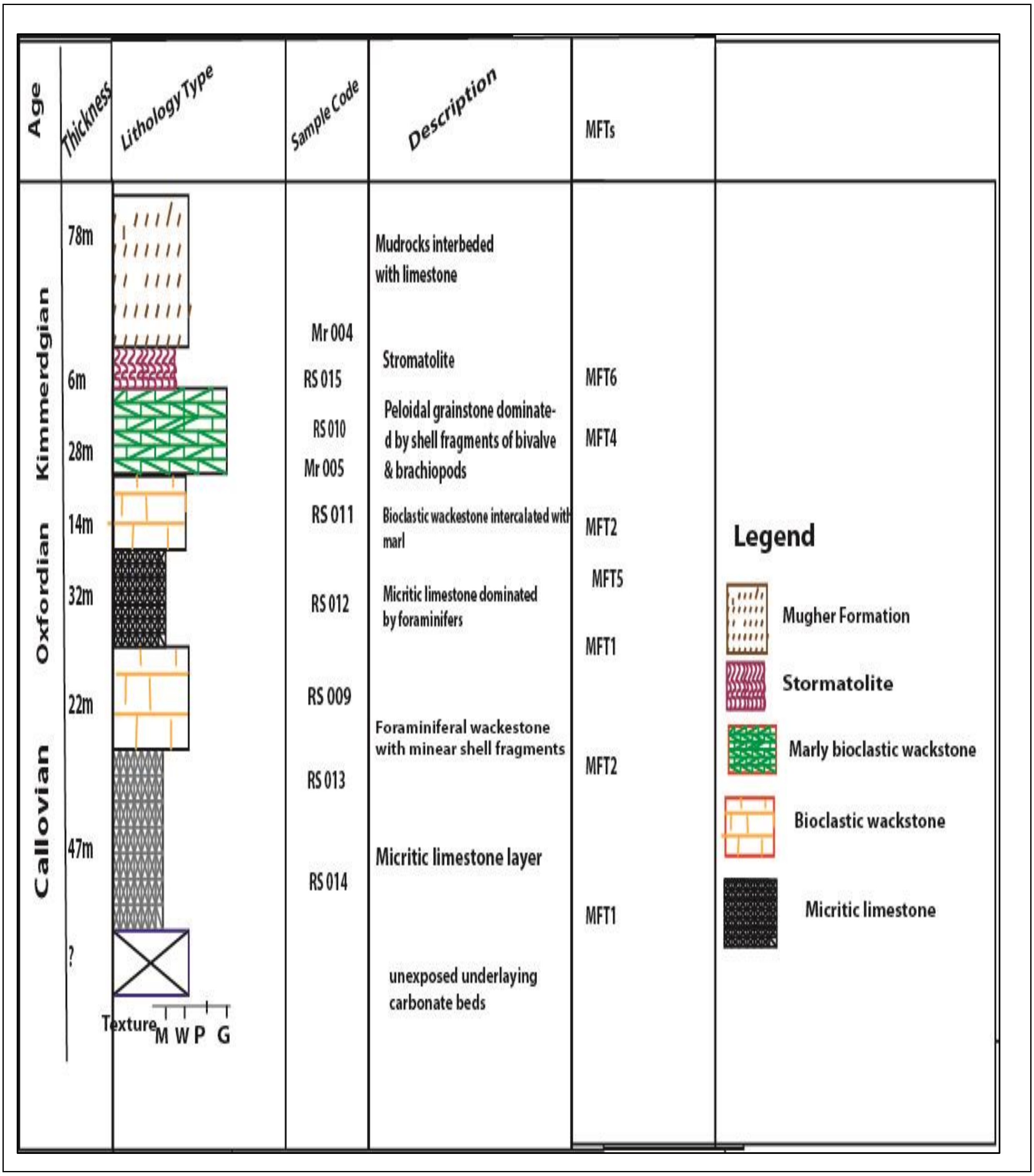

Fig. 3.11: Stratigraphic column of carbonate exposures logged at Jema Subsection 1 of the Lemi area (Not scaled).

3.2. Lithostratigraphy of Jurassic limestone in Jema section; subsection of Dufa

The limestone unit in this study area; subsection of Dufa crops out along the tributaries of Dufa stream extending laterally (for about 100 to 200m) north and south until it disappears being covered by intercalation of mudstone and clay stone unit (Mugher Formation) from north and south as shown in (Fig. 3.4) above. Carbonate unit in this area has thickens of about 176m and having various invertebrate fossils of gastropods, brachiopods, echinoids, bivalves in the upper middle part of the unit as molds; and attempts has been made to identify the observed fossil molds of the listed groups whereas foraminifers and ostracods are also extracted from the marl sediments that has been intercalated in between the beds of the carbonate layers.

The detailed local stratigraphy for carbonate successions of the area is described based on the field observations and petrographic studies as follows: - Very thick layer of micritic limestone has dominated the studied facies which is shown as in (Fig 3.12.) which varies in color from (grayish to dark-gray) weathered color and white fresh color while wackestone, grainstone and packstones facies types are identified and observed in the section with fair representations. A secondary structure such as stalagmite and stalactite is observed in the Dufa section as shown (Fig 3.14.)

Detail description to the carbonate unit of the Jema section which has been differentiated in the field has been discussed as follows from the bottom of the unit to the top part of the unit; based on the lithologic criteria, color, sedimentary structures, texture, fossil contents, stratigraphic relationships and their geometries.

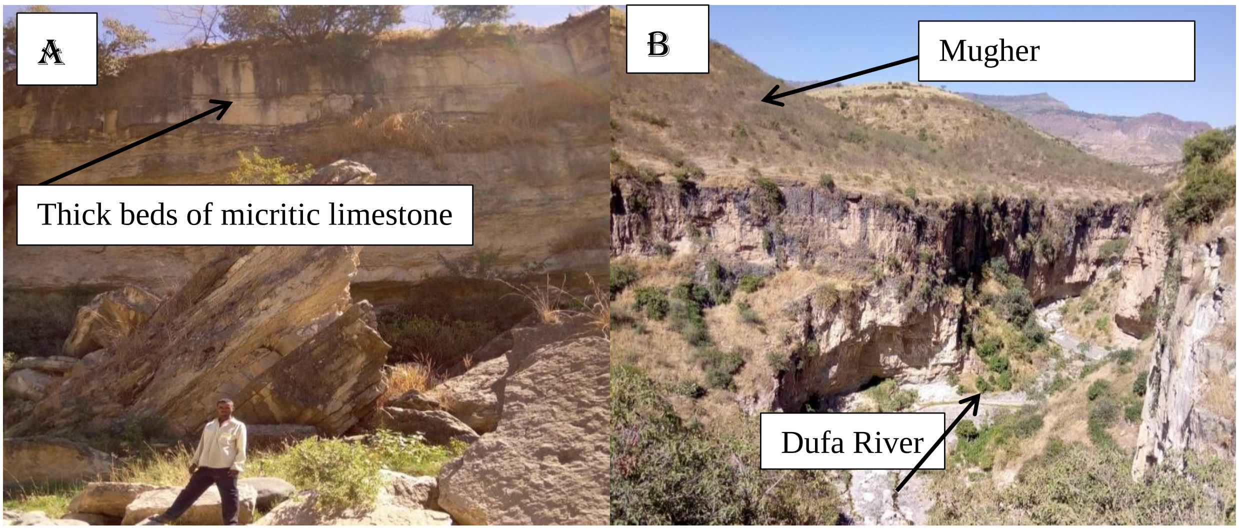

Fig. 3.12: Limestone unit deposited along the attributers of Dufa River as the subsection of Jema. The field photograph shown in **A** shows thickly bedded micritic limestone whereas of **B** shows the deposition of Mugher formation at the upper most part of the limestone unit.

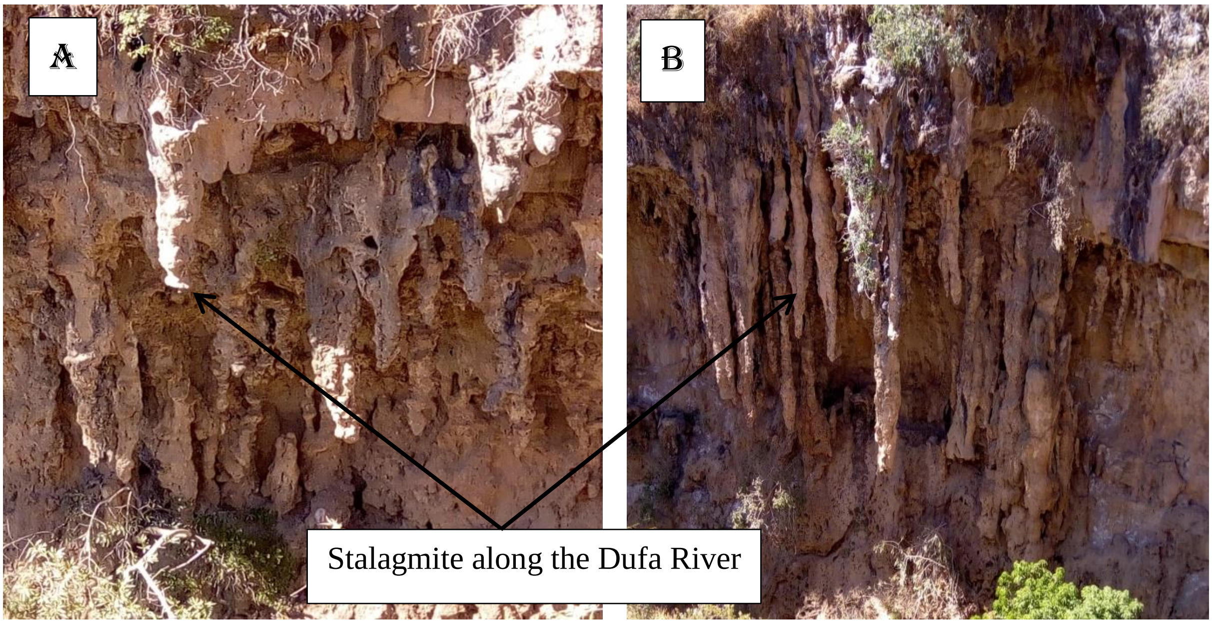

Fig. 3.13: Stalagmite is among the secondary sedimentary structures observed and obtained in carbonate units of Jema section subsection of Dufa in the massively bedded micritic layer

3.2.1. Bioclastic wackestone to packstone layer

The bioclastic carbonate layers in Jema section subsection of Dufa are found in different layers through the section. In the upper Jema section they are found beneath the micritic limestone unit as discussed below in the micritic limestone layer section. They are characterized by mostly grayish color and thin to medium bedding with the shell fragments of brachiopods, bivalves and gastropods. Mostly the layers containing the bioclastic limestone are intercalation in marl and also bioturbation is very commonly seen on these layers as shown in the fig 3.13.

The rock samples obtained from this layer includes RS 004, RS 005 and RS 006 and marl sample Mr 04; whereas there petrographic description has been made in chapter four; this layer of the Jema section of the Dufa subsection is about 41m thick.

Fig 3.14: Bioclastic wackestone to packstone layer photo obtained from the Dufa Subsection

3.2.2. Micritic limestone Layer

The micritic limestone of Jema section subsection of Dufa around Lemi are, light gray to blackish and dominantly grayish in color characterized by thin to thick beds (10cm to 4m) that alternate with thin beds of marl. From the outcrop observation and petrography of this thick micrite layer of the section there are very rare amounts of other allochems like skeletal grains except faunas of foraminifera's.

The micritic layer of the limestone unit in Dufa subsection of Jema.is the lower exposed layer of the section and the middle of the section of the micritic layer about (18m) thick is fine grained in texture and light gray in color. Some faunas of foraminifera's are identified from the thin section analysis for the rock sample obtained from this layer of the limestone unit which are coded RS 003 and RS 007 and the layer from which the sample are obtained as shown in fig 3.15 below. Sedimentary structures such as thin to thick beds are observed in the Dufa banks as shown in Fig 3.13 above.

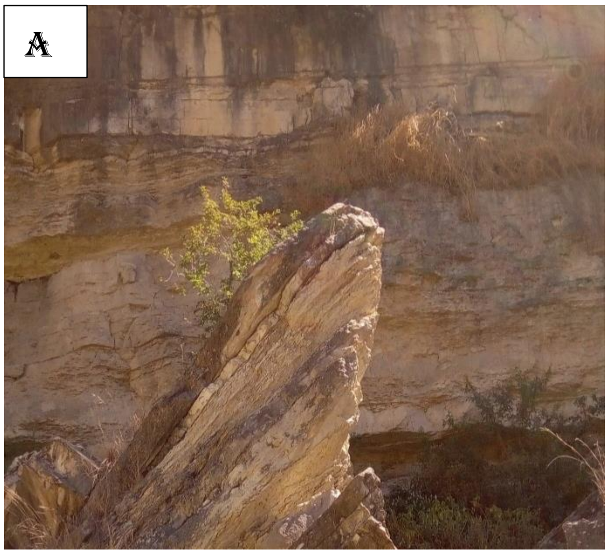

Fig. 3.15: The micritic limestone layer of the Jema Section subsection of Dufa in the vicinity of Lemi

3.2.3. Peloidal grainstone layer

These carbonate layers have a thickness of around 32m. They are dominated by packstone to grainstone layers rich in peloids at top and bioclasts at the bottom. All of these components are ranging in size from finer to sand-sized carbonate grains. This layer is intercalated with marl and dominated by bioturbation as shown in the fig 3.16.

Fig. 3.16: Grayish Peloidal limestone layer of the Jema Section in the subsection of Dufa along the Dufa River the tributaries of Jema River in the vicinity of Lemi

3.2.4. Ooidial Limestone layer of Jema section subsection of Dufa

They are dominated by packstone to grainstone layers rich in ooids at top and bioclasts at the bottom. All of these components are ranging in size from finer to sand-sized carbonate grains. This layer is intercalated with the marl of each layer with about 10cm to 20cm thickness. The marl sample taken from the bed is dominated by foraminifers and ostracods from the microfossil preparation and it is as shown in Fig. 3.17 below and this layer is beneath the Mugher formation and above the peloidal and bioclastic wackestone to packstone of about 60m thick.

Fig.3. 17: (A) oolitic grainstone, Dufa section around Lemi; (B) oolitic packstone of Dufa section around Lemi.

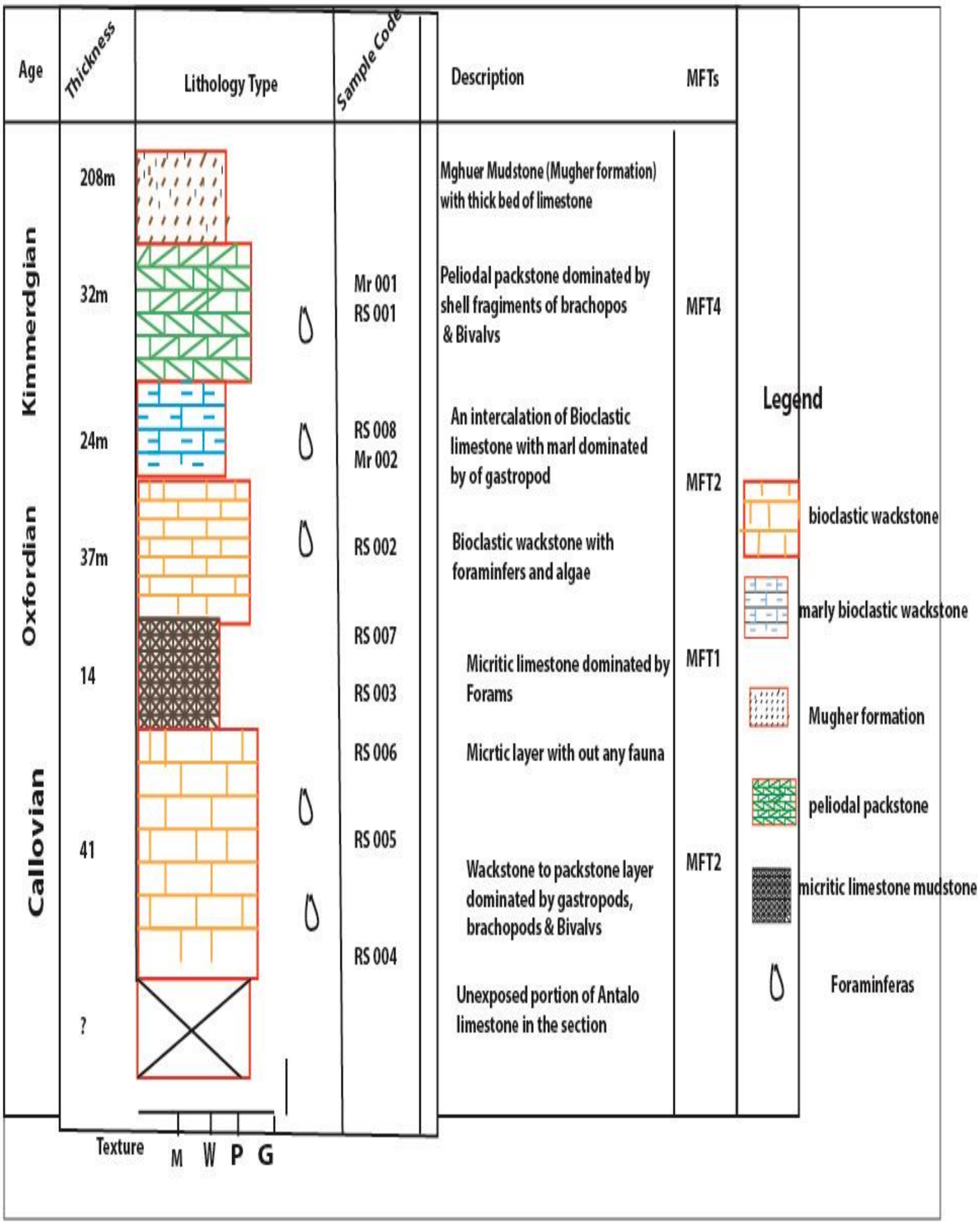

Fig.3.18: Stratigraphic column of carbonate exposures at logged at Dufa subsection of Jema section, Lemi area (Not scaled)

CHAPTER FOUR

4. PETROGRAPHIC DESCRIPTION AND MICROFACIES ANALYSIS

4.1. Petrographic Descriptions

Petrography is the most effective way of studying the mineralogical and other components of the carbonate rocks. The petrographic study and its result of the carbonate representative samples of the study area have been taken as the best way to explore the microfacies analysis of the proposed section of the carbonate unit. The volumetric analysis of different constituents was done with the help of manual counter, for the petrographical classification of limestone. The textural study was carried out based on Dunham's classification of the carbonates (Dunham, 1962).

For petrographic studies, about 18 representative rock thin sections were prepared and analyzed under microscope, following the procedure of Folk (1959). In the actual nomenclature of the studied rocks; the first part of the rock name refers to the allochem components and the second part to the cementing or matrix material. Because, of the above-mentioned advantages, the Folk's terminologies were adopted in the study of the thin sections of the limestone in this thesis work.

4.1.1. Petrographic classification of limestone

Petrographic classification is essential to microfacies analysis, interpreting rock properties and Paleoenvironmental interpretations of carbonate rocks. All the limestone classifications commonly used in facies analyses and based on textural and compositional criteria. The classifications proposed by Dunham (1962) and Folk (1962) have been followed.

Folk (1959, 1962) Limestone classification, is mainly based on the percentages (%) of allochemical grains, microcrystalline calcite matrix and sparry calcitic cement. This classification distinguishes allochthonous limestone's (mudstone, wackestone, packstone, grainstone) and autochthonous limestone's (here called boundstone or biolithite).

In addition to field observations made to the carbonate unit of Jema section in the vicinity of Lemi; detail explanations of 18 representative carbonate rock samples have been done 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 rock samples were limestone but they are varying in abundances and sizes of components and allochems from place to place throughout the studied section based on their stratigraphic position. 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).

From the petrographic study; texturally the collected samples from the Jema section in the vicinity of Lemi; shows various carbonate textures ranging from Mudstone (6 of total sample coded as RS 03, RS 003, RS 007, RS 012, RS 013 & RS 014), Bioclastic Wackstone (8 of total coded as RS 01, RS002, RS 004, RS 005, RS 006, RS 008, RS 009 & RS 011), Peloidal packstone (RS 02 & RS 010) and stromatolite of RS 015; whereas the grain sorting is poorly sorted to well-sorted of the carbonate unit in the section.

From the petrographic description of the carbonates in the section contains different types of carbonate rocks ranging from; Mudstone, Wackestone, packstone and grainstone of peloidial, skeletal grains, ooidial and interstitial materials were identified as a component of the carbonate rock in thin section. All these petrographic properties of each rock sample with their depositional environment and interpretations were made.

Also the photomicrographs of the collected samples with their petrographic descriptions are given. The petrographic description of the rock samples were made as follows in table 4.1:

Here is a note for table 4.1: on the next two pages that shows the petrographic analysis results for collected samples from the study area of the logged sections. All samples were collected during field work from the three local stratigraphic sections (along the Jema River exposure and Dufa River the tributaries ‘of Jema in the vicinity of Lemi; sequentially from bottom to top, randomly throughout the section as variation appeared in lithology.

After giving proportions for all major components, the rock name was given according to the Dunham (1962) and Folk (1962) carbonate classification schemes and SMFT respectively, in the right end column of the table.

Table 4.1: Petrographic description of carbonate rock samples collected from the Jema section in the vicinity of Lemi

Petrographic constituents (%) of the Limestone of carbonate unit in Jema section										
	Major Rocks Component							Rock Name		
	Allochems				Interstitial materials		Other	Dunham 1962	Folk	SMFTs
Code	Fossil	Ooid	Peloid	Intraclast	Micrite	Sparite				
RS 001	35	5	5	-	50	5	5	Wackestone	Biomicrite	SMFT1
RS 002	50	-	-	-	15	30	5	Wackestone	Biosparite	SMFT3
RS 003	5	-	-	-	90	5	-	Mudstone	Micritic	SMFT5
RS 004	45	-	-		50	5	-	Wackestone	Biomicrite	SMFT 3
RS 005	60	-	-	10	20	10	-	Wackestone	Biomicrite	SMFT3
RS 006	75	-	-	-	10	15	-	Wackestone	Biosparite	SMFT2
RS 007	8	-	-	-	92	-	-	Mudstone	Micritic	MFT5
RS 008	45	5	-	-	45	3	2	Wackestone	Biomicrite	SMFT2
RS 009	70	-	-	-	25	5	-	Wackstone	Biomicrite	SMFT2
RS 010	3	12	70	-	-	15		Peloidial grainstone	Pelsparite	SMFT 4
RS 011	79	-	-	3	-	15	3	Grainstone	Biosparite	SMFT 3
RS 012	5	-	-	-	95	-	-	Mudstone	Biomicrite	MFT1
RS 013	-	-	-	4	96	-	-	Mudstone	Micritic	MFT1
RS 014	-	-	-	2	98	-	-	Mudstone	Micritic	MFT1
RS 015	85	-	-	-	-	12	3	Packstone	Biosparite	SMFT6
RS 01	5	15	35	-	45	-	-	packstone	Biopelsparite	MFT2
RS 02	75	10	3		8	4		Grainstone	Peloidal grainstone	SMFT 4
RS 03	12	-	-	-	88	-	-	Mudstone	Biomicrite	MFT5

4.2. Microfacies Analysis

Microfacies refer to the whole sedimentological and paleontological to the criteria appearing in thin-sections under the microscope either due to sedimentation, deposition or biological activities during or after deposition. Microfacies analysis of carbonate from thin sections exhibit depositional criteria reflecting environmental constraints acting during and after sedimentation. Every facies of depositional environment has its own distinct petrographical, geographical and paleontological properties which can be clearly differentiated from other facies (Flügel, 2004).

Microscopic study is the most important of the various levels of observation possible in the broad field of carbonate petrography. But, despite the advantages that identifiable carbonate particles offer toward environmental interpretation, detailed petrographic study of limestone is difficult because of their susceptibility to diagenetic alteration.

An interpretation of depositional environment which is derived from the microfacies requires a detailed lithological data and sedimentary structures evaluated by the high information potential provided by fossils and biogenic structures. The microfacies types can be distinguished based on a depositional texture, fabric, digenetic features, allochems, fossils as well as qualitative and quantitative compositional data of the rock unit and the generalization of microfacies types leads to categorization of common microfacies data into 'Standard Microfacies Types' (SMFT).

According to Flügel (1982), the petrographic criteria used in establishing microfacies types of carbonates are texture of the rock, 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.

During this research thesis the analysis of all the obtained rock samples under the petrographic microscope investigated about six main microfacies types (MFT) within the carbonate succession have been identified. Microfacies types (Flügel, 2004) are defined according to criteria that allow attribution of specific environmental factors and specific depositional settings. The microfacies criteria used here include: depositional texture and fabric, grain composition and early diagenetic features. Each MFT and its occurrence were described and the environmental interpretation has been discussed as follows.

4.2.1 Microfacies Type 1

This microfacies type 1 represents for the most dominant carbonate unit of the section; micritic limestone (Mudstone) found in the study area in the vicinity of Lemi. It is characterized by numerous numbers of micritic limestone layers of fine to very fine grains in texture and rare in skeletal and non-skeletal grains less than 10% are present particularly of foraminiferies.

This facies is obtained from the rock samples coded as (RS 03, RS 003, RS 007, RS 012, RS 013 and RS 014) which are collected from the micritic layer of the section. All of these micritic limestone samples obtained from the section are cemented fully by micrite without any sparry calcite that can show any of diagenetic feature as shown in (fig 4.1: A & B). The entire layer of this micritic limestone unit of the section as shown in thin section in fig. 4.1: A & B below; varies in color from light gray to dark gray and associated with rare amounts of skeletal grains of foraminifers.

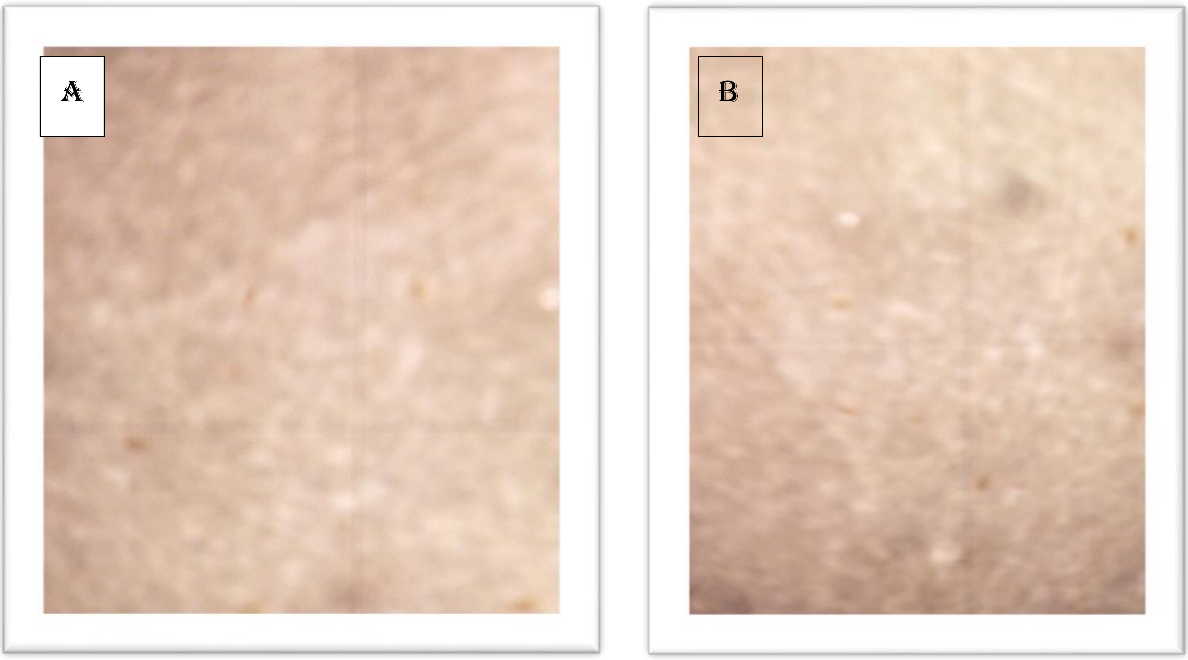

Fig. 4.1: A & B Micritic limestone photomicrography of Microfacies type 1 taken from the rock samples obtained in the layer which has been coded as RS 013 and RS 014 respectively.

In the entire layer of these mudstone facies have a thickness of around 75m in subsection 1 and 14m in subsection of Dufa consists of thin-thick bedded units around 10cm to 4m with no bioturbation and the bed layers were resulted due to pressure solution. Some of the mudstone facies of the carbonate unit of the study area is dominated by the fauna of foraminifera's.

Interpretations: limestone component 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& 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).

4.2.2 Microfacies Type 2

Microfacies type 2 of this section according to the Wilson cycle fails on bioclastic wackestone; these microfacies were characterized by the major components of bioclasts, with these regard the following were the obviously observed bioclasts in the thin section are shelled bivalves, foraminifers, gastropods, brachiopods, echinoderms and dasycladacean algae (green algae) occur as minor components.

The representative rock samples of this facies were collected from the upper part of the middle limestone layer and the rock sample were coded as RS 005 and RS 008. The photography of the rock sample under the petrographic microscope of this facies are shown as follows in (fig 4.2 A & B).

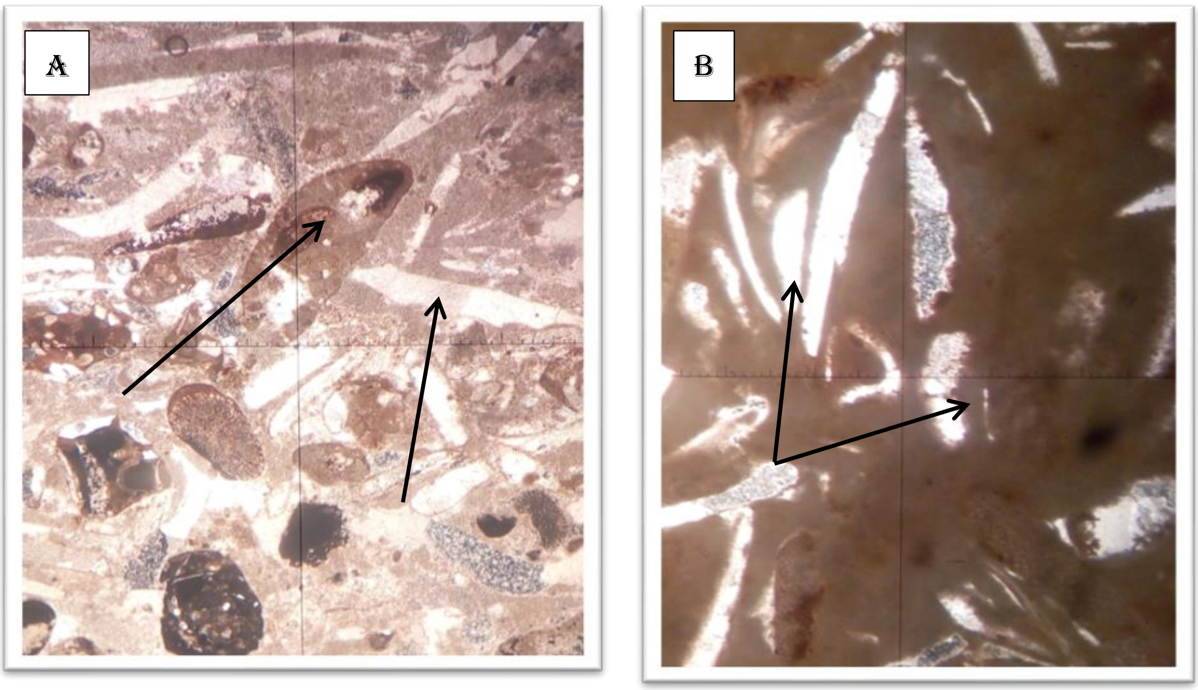

Fig. 4.2: Bioclastic wackestone micro facies type 2 obtained at the magnification of *40 taken from the representative rock samples obtained in the layer which has been coded as RS 02 and RS 008 respectively under the XPL which are obtained from both Dufa and Jema subsections.

Interpretations: Wackestone and packstone are transitional between low energy mudstone and high energy grainstone deposits. They are generally accumulated on warm water platforms where current activity has been insufficient to remove out the mud (Flügel, 2004). As such they tend to be located away from the edges of platforms or on deeper parts of ramps where there is some protection (Brain & Andre, 1992; Walker, 1992; Burchette and Wright, 1992). This facies deposited in shallow water with open circulation and compared with SMF type 9, which belongs to facies belt 7or 2, which deposited in open platform or shelf lagoon, or open sea shelf.

4.2.3 Microfacies Type 3

Microfacies type 3 according to Wilson cycle stands for microfacies of bioclastic wackestone to packstone. These microfacies were characterized by mostly grayish color, thin to medium bedded, hard and fine-grained limestone with some shell fragments imbedded within micrite (Fig 4.3 A-D). Mostly it is found intercalated with marl. Under thin section this microfacies is composed mainly of micrite with bioclastic grains of >10%.The representative rock samples of this facies in the section are coded as rock sample RS 002, RS 004, and RS 005, respectively.

Shell fragments of fossils of brachiopod, bivalves, foraminifers and gastropod are very commonly seen imbedded within micrite materials; sometimes with very less amounts of sparite as the cementing materials. In field observations the carbonate rock layers containing this facies are mostly seen as an intercalated with marl sediments. The petrographic properties of the representative samples for this microfacies are shown as follows in (Fig 4.3: A-D); whereas the bioclasts were micritized. This facies is compared with SMF type 9 of Wilson (1975) which belongs to FB 7or 2; that can be deposited in open platform or shelf lagoon, or open sea shelf.

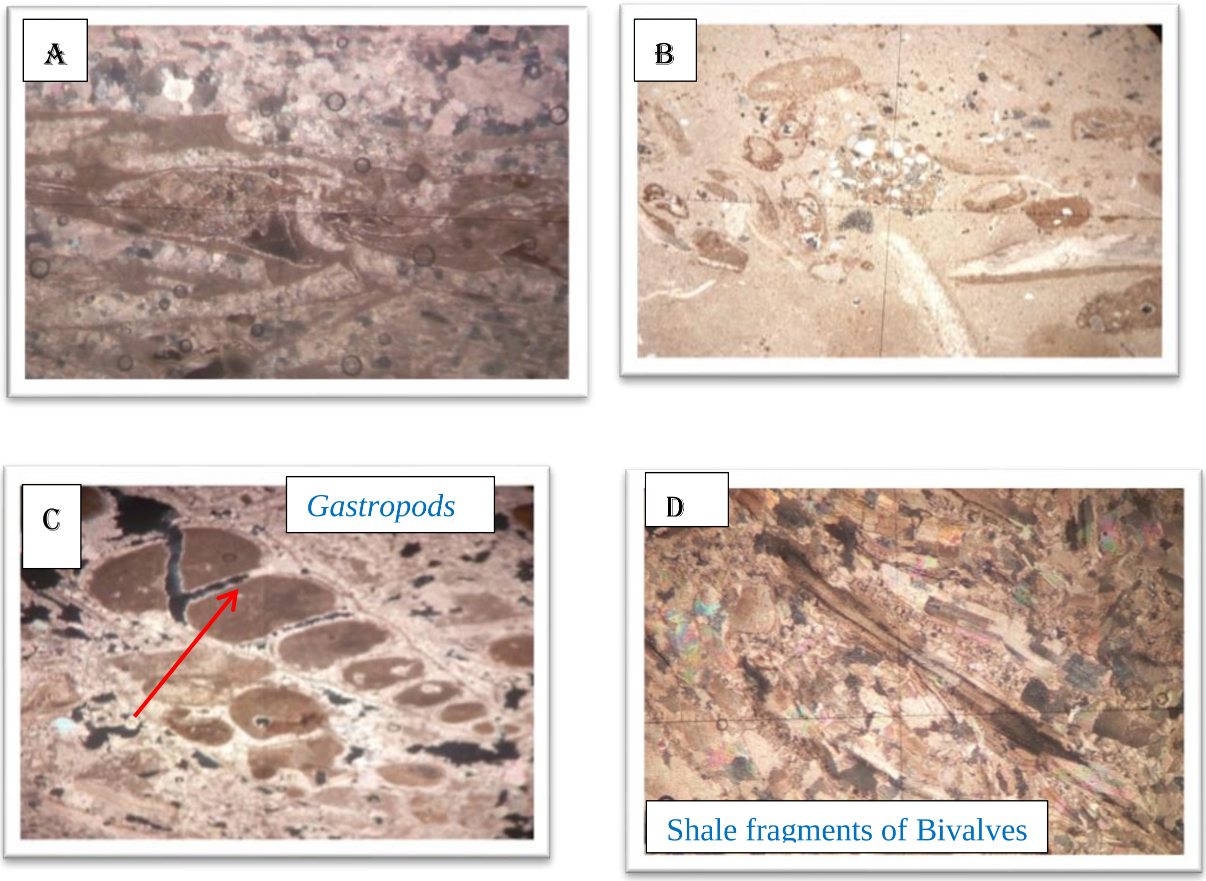

Fig. 4.3: A –D Bioclastic Wackstone to packstone photomicrography of Microfacies type 3 obtained at the magnification of *40 taken from the representative rock samples obtained in the layer which has been coded as RS 001, RS 006, RS 002 and RS 009 respectively under the XPL.

4.2.4 Microfacies Type 4

Descriptions: This microfacies is obtained from at the top of Jema section, below the Algal stromatolites. Microfacies type 4 stands for peloidal grainstone microfacies found in Jema section. This consists of what are probably hardened fecal pellets, in places admixed with concentrated Ostracod tests or foraminifera. This facies is characterized by abundant number of peloids with rare skeletal grains such as foraminifera and algae. This peloidal grainstone microfacies is mostly obtained at the bottom of the upper unit of Jema and represented by RS 010 and RS 02. The peloids grains in this microfacies are larger in sizes and a grain size distribution is moderate and well sorted.

This peloidal microfacies is compared to SMFT 16 of Wilson (1975) and belongs to facies belt 7or 8 which deposited in open platforms (shelf lagoon) or in restricted platform. The petrographic properties of the representative samples for this microfacies are shown as follows in (Fig 4.3: A-B).

Interpretations: Most pellets are lithified organic excrements (fecal pellets). Therefore, this peloidal microfacies are interpreted to have been deposited under restricted marine conditions and compared to SMFT 16, which belongs to facies belt 7 (open platform, shelf lagoon) or Facies belt 8(restricted platform) of Wilson (1975).

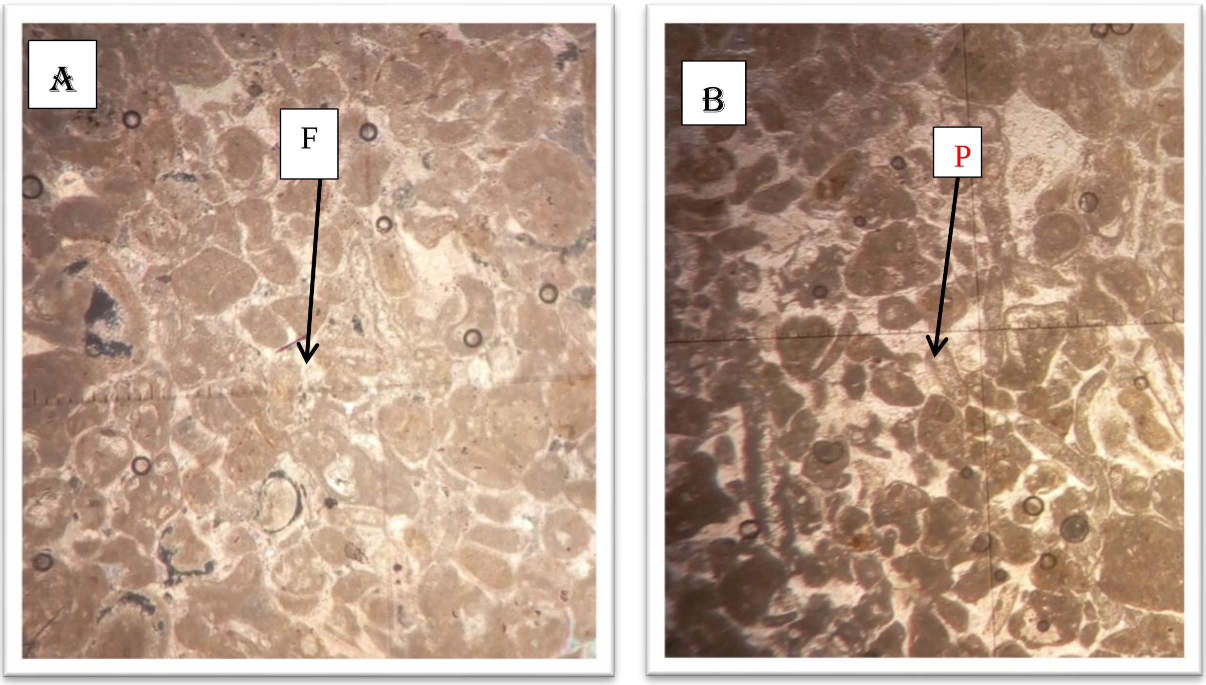

Fig. 4.4: A-B Micrographs of peloidal grainstone facies MFT4 in which the smaller sized peloidal grains (P) and rare amounts of smaller skeletal grains (F) are imbedded by microcrystalline marine cements (whitish materials filling the space between the grains). Grains are moderately to poorly sort. Micro photos which are taken with magnification A; x40, RS 010; B x10, and RS 01 respectively. All photos are taken under PPL.

4.2.5 Microfacies Type 5

Descriptions: This microfacies is obtained from the top of micritic layer of the Dufa and Jema subsections, below the bioclastic wackestone facies. Microfacies type 5 is represented by Foraminiferal wackestone which is characterized by the grains of foraminifers of *Nautiloculina oolithica, Alveosepta jaccardi, Kurnubia palastiniensis, Pseudocyclammina lituus* and *Valvulina lugeoni* and dasycladacean green algae (*lvanovia Khvorova, Salpingoporella annulata, Mesoendothyra croatica, Trinocladus tripolitanus, Trinocladus radoicicae, Acroporella hamata n. sp., Salpingoporella cf. grudii*) embedded within a heterogonous micritic matrix. This foraminiferal wackestone facies representative rock samples were obtained from the middle layer of the Jurassic limestone layer of the section.

The representative rock samples of this facies were collected from the upper part of the middle limestone layer and the rock sample were coded as RS 003, RS 03 and RS 007. The photography of the rock sample under the petrographic microscope of this facies is shown as follows in (fig 4.5).

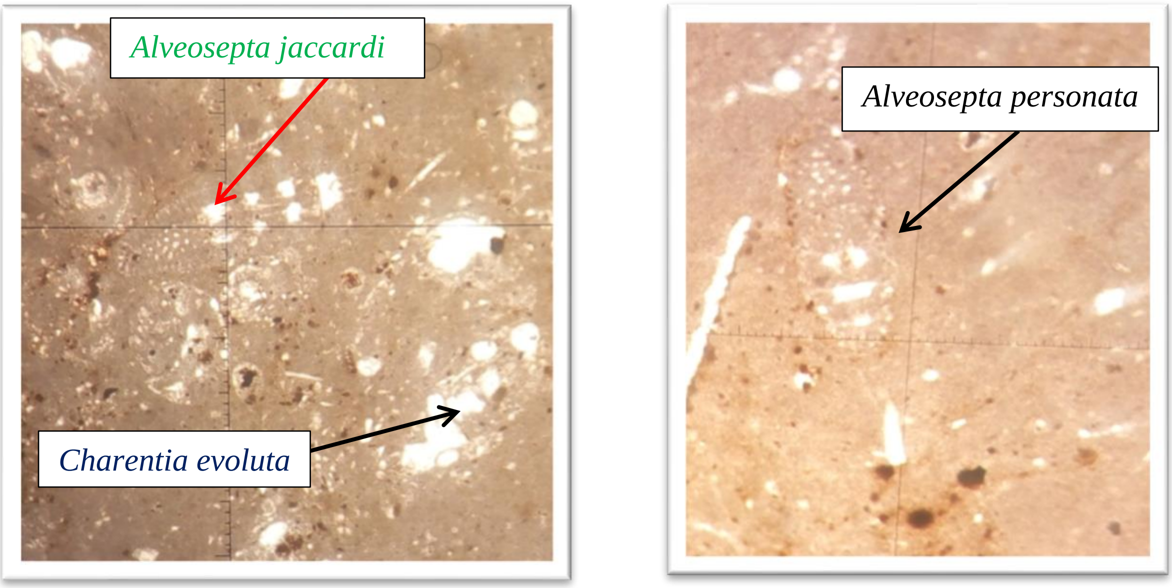

Fig. 4.5: A-B Microphotograph's of foraminiferal wackestone facies in which the larger sized benthic foraminiferies and rare amounts of smaller skeletal grains are imbedded by microcrystalline marine cements. Micro photos which are taken with magnification A; x40, RS 007; B x10, and RS 008 respectively. Both photos are taken under PPL.

4.2.6 Microfacies Type 6

Description: Dense and closely-spaced growth laminations swelling over distensions characterize this sediment. Fine lime mud is preferentially trapped on the highest areas. This microfacies type is represented by stromatolite facies whereas of this type SMF-20 Algal stromatolite mudstone (Flügel, 1972). Dense and closely-spaced growth laminations swelling over protuberances characterize this sediment. Fine lime mud is preferentially trapped on the highest areas resulting in a lamination contrary to gravity. Such stromatolitic structure is commonest in the intertidal zone.

The representative rock samples of this facies were collected from the upper part of the limestone layer and the rock sample was coded as RS 015, whereas no algal structures or bedding are discernible within the stromatolite mounds. The photography of the rock sample under the petrographic microscope of this facies is shown as follows in (fig 4.6).

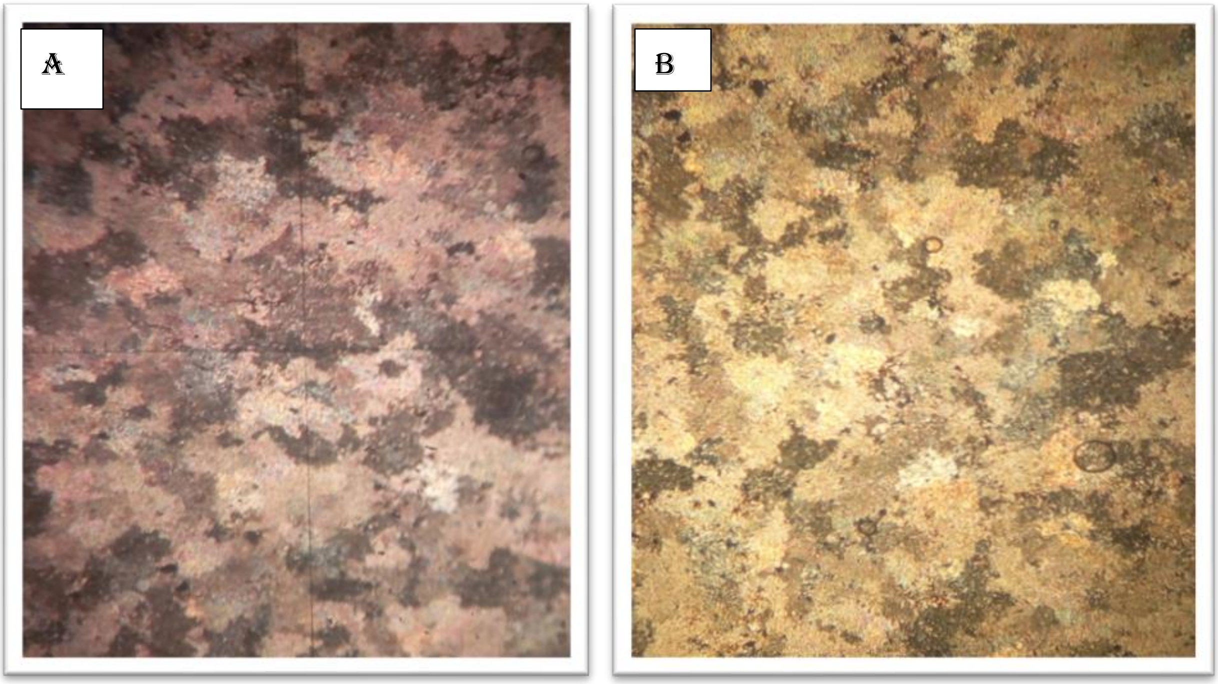

Fig. 4.6: Microphotograph's of Algal stromatolite facies Microphotogram which is taken with magnification A; x40, RS 0015; B x10, and RS 015 respectively. The in section A and B photos are taken under XPL and PPL respectively.

4.3. DIAGENESIS

The diagenetic process refers mainly to the Post-depositional alteration of freshly deposited sediments. But it is used in different contexts by sedimentalogists and it has acquired a broader meaning. Diagenesis encompasses all the processes, which affect the sediments after deposition. It includes processes such cementation to produce limestone and dissolution to form cave systems but it also include processes such as the development of micro porosity and changes in the trace elements.

According to the view of different sedimentalogists in different time; the definition of diagenesis is as follows, Gumbel (1862), who coined the term "Diagenesis" to refer the process which acts on the sediments after they are deposited. Walther (1894) defined the term to include all those physical and chemical changes which a rock undergoes after its deposition and without the introduction of pressure or igneous heat. The process according to Pettijohn (1957) is a complex one converting newly deposited sediment into an indurated rock. Blatt (1967) defined diagenesis as a process which involves physical and chemical changes that occur in the sedimentary aggregate between the time of their accumulation and the time at which a complete lithification takes place.

Limestone's formed on carbonate platforms and which maintain near sea level for extended periods is particularly susceptible to drastic, early diagenetic modifications. This is due to the reason behind is that, marine carbonate sediments consist of metastable carbonate phases, like aragonite and magnesium calcite (dolomite); which are easily dissolved and recrystallized by fresh meteoric acidic waters or mixtures of meteoric and marine waters, such as are encountered in surface and shallow subsurface conditions (Peter and Dana, 2003; Ahr, 2008).

4.3.1 Major Diagenetic features in the Carbonate Unit of the Lemi area

The diagenetic features of the study area are investigated based on, the petrographic analyses of collected carbonate' samples and field investigation conducted to decipher the diagenetic settings of the Antalo Limestone formation of the Jema section. Accordingly, the carbonate unit of the area is affected by various early marine and meteoric to late burial stage diagenesis processes.

The extensive diagenetic processes affecting the carbonate unit of the study area includes: compaction, fractures, micritization and cementation, with varying intensities and occurrence throughout the studied sections. All of these diagenetic processes are discussed, assigned to different diagenetic environments and supported with various evidences collected from field and photomicrographs obtained under the petrographic microscope in the laboratory in detail as follows:

A. Compaction

Compaction of different carbonate grains is the dominant diagenetic processes throughout the studied sections. The compaction of carbonate grains is due to burial and increasing overburdens pressure in the deposited sediments due to physical and biological means. Compaction processes is mainly the indicative of early to late burial stage diagenesis according to the work of different author's in the field of carbonate sedimentology; (McIlreath and Morrow, 1990; Adams and Mackenzie, 1998; Peter and Dana, 2003; Ahr, 2008). Compactions can be resulted due to physical or chemical process, in case both of which are abundant throughout the study area.

According to Adams and Mackenzie (1998), Physical compaction of the carbonate grains is the early to late diagenetic process under which the inter-grain space of the carbonate rock reduces; which results in the overall reduction of porosity of the rock. In case of poorly cemented sediments the component grains may break due to this compaction and the embayment among grains are also present. This and other factors produce fractures and concomitantly enhance the porosity and permeability of the rock to its aspect of economic quality.

In general mechanical compaction is evident by fracturing and the formation of sutured and concavo- convex contacts among the carbonate grains in the studied section. These features are commonly observed in the micritic, foraminiferal wackstone and peloidal wackstone to grainstone facies of the studied sections, mainly at Jema subsection 1. Some representative examples are given in in fig 4.7 A&B below.

B. Micritization

In the shallow marine environments similar to the carbonate deposits of the study area, some groups of light-dependent boring organisms like, blue-green algae may bore into skeletal materials. The borings, around 10µm in diameter, are filled with micrite after the death of the algae. If the process continues, the margin of a shell fragment or entire grains may become completely replaced by micrites (McIlreath and Morrow, 1990). The process is known as micritization and the replaced shell margin as a micrite envelope. Micritization processes take place almost everywhere but it is most prevalent in quieter water locations (Longman, 1980) and most of the time it's in early shallow marine warm water environmental diagenesis.

In this thesis, micritization processes are mostly observed at upper part of the carbonate units of the area, at Dufa subsection of Jema. The micrite envelopes are mainly around skeletal grains, rarely around some ooids as shown in fig 4.7; B and at places the micrite are replacing the whole skeletal grains. These micritic envelops are mostly preserving the morphology of the dissolved grains.

C. Cementation

Cementation is the most dominant diagenetic processes throughout the studied sections of Jema in the vicinity of Lemi carbonate units. 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). Cementation can occur several times in the diagenetic history of a carbonate rock beginning with cementation in the marine environment just after deposition (early cementation) and continuing through vadose, shallow, intermediate, and deep – burial environments (late stage cementation).

Cementation is an important diagenetic process, which endows strength and stability to the concerned carbonate rock which increases the physical and chemical properties such as, resists physical, as well as, chemical compaction and fracturing episodes.

In this study various types and many phases of cementation are found at varies levels throughout the studied area of the logged sections. The cementation occurred in the studied sections are also showing various setting like meteoric, marine and burial stages of cementation; those are differentiated on the basis of cements' morphologies, shape, patterns, color, sizes and relation with various substrates. The main commonly observed cement types are; inter-granular, microcrystalline crusts and others are observed that has been shown in fig 4.7 A, B & D bellow are among of them.

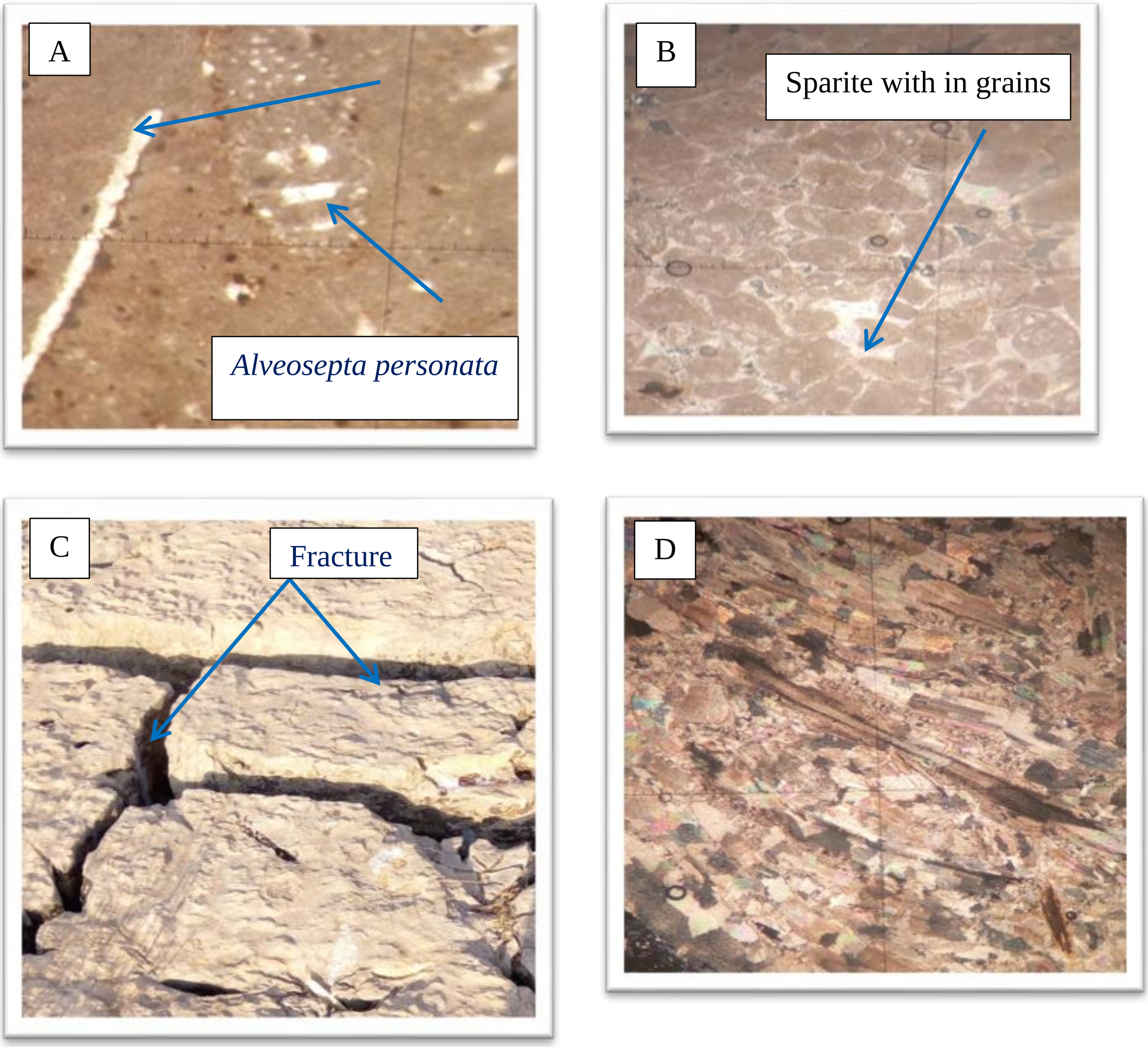

Fig.4.7: A, B & D shows the result of diagenetic process among the carbonate grains of the carbonate unit in the logged section of Jema under the microscope and C shows fractures observed and obtained in the field as a result of diagenetic process.

CHAPTER FIVE

5. PALEONTOLOGY OF THE JEMA SECTION

In the Jurassic carbonate unit of the Jema section in the vicinity of Lemi; different species of macro invertebrate fossils and microfossils were obtained and studied. The macro invertebrate fossils were preserved predominantly as molds and casts. The micro and macro faunal fossils collected from the section were prepared and identified in the laboratory down to the species and genus level as much as possible base on the morphology they possess which has been preserved in the rock.

Fossils are of great use in the environmental interpretation of sedimentary rocks and the biostratigraphy; with this context many useful observations have been made in the field by the keen eye and by the Stereozoom binocular microscope in the laboratory. In some cases the whole environmental interpretation of a sedimentary succession may depend on the presence of just a few fossils, and occasionally an interpretation has been induced by the discovery of new fossils. The field observations of fossils had accounted for their distribution, preservation and relation to the sediment, their associations and diversity.

Fossils are an important component of sedimentary rocks of the marine environments. First and foremost, they can be used for biostratigraphic purposes to determine the relative age of the rock succession and for correlations with successions elsewhere. The identification of fossils to the species level is not easy task and in most cases is best left to the paleontologists. However, there are various fossil handbooks and the Treatise of Invertebrate Paleontology that have been used to identify fossils during this thesis work.

Biostratigraphic units are bodies of strata's that are characterized by the index macro and micro fossil faunas it contains. In this aspect the study of fossil help for correlating and assigning relative ages of rock strata by using the fossil assemblages it contains. A biostratigraphic unit may be based on a single taxon or based on the combinations of taxa, on relative abundances, on specified morphological features, on variations in any of the many other features related to the content and distribution of fossils in the strata.

As the macrofossils are poorly preserved in the logged section; taxonomic identification has faced challenges and difficulties to a certain extent to the identification. So that the taxonomic classification applied; follows the identification and description of observable fossil morphology and comparison of previous works on carbonate units of Jurassic age was reviewed for both invertebrate macro and microfossils inter and intra-regional level.

Microfossils of foraminifers and ostracods were obtained through washing and extraction from marl samples and the description of their morphology was done using Stereozoom binocular reflecting microscope and comparison of published micropaleontological data done on the Jurassic limestone sediments of the world and of the region. Identification and description of fossils under thin section has been also carried out under the ordinary reflecting petrographic microscopes.

In this thesis the research has paid little or no attention to aspects of classification, as this is felt to be outside the scope of the present study which is devoted to the biostratigraphical and paleoenvironmrntal implications of the macro and microfossil faunal assemblages. Family, generic and specific or infra-specific names of previously described microfossil forms are used in this systematic account, whenever these appeared to be identifiable with the pervious author's material. The symbols such as "cf.", "aff." preceding the specific name indicate, respectively, simi1ariy or relationship with the named species; "?" indicates doubtful identifications (Glaessner, 1945).

During this research thesis work many genera's and species belonging to different groups of microfossils, are recorded and illustrated from the Jurassic deposits of the Antalo limestone, of Bilu Nile basin in the north western Plateau of Ethiopia; of Jema section in the vicinity of Lemi. The recognized microfossil-assemblages, although partly facies controlled, have proved useful in the biostratigraphical zonation, determination of relative geological age, and correlation of the examined rocks since Ammonites are not obtained.

Generally more than 250 micro and macro fossils faunas have been studied; those include macrofossils of: **Gastropods** (*Ampullospira bajocensis* and *Ampullospira* **(***Ampullospira***)** *brevispira*). Microfossils of **Ostracods**: (*Cypridea sp., Homocytheridea posteriohumilis, Chlamydotheca arcuata, Homocytheridea posteriohumilis* and *Pirileberis remota*) **Foraminifers** (*Alveosepta jaccardi, Redmondoides lugeoni, Bicazammina jurassica, Nautiloculina oolithica, Nautiloculina circularis, Choffatella caronae n. sp., Pfenderina gracilis, Conicokurnubia orbitoliniformis, Kurnubia wellings, Kurnubia palastiniensis, Kurnubia Cf. morrisi, Pfenderina neocomiensis, Pseudomarssonella biangulata, Pseudomarssonella plicata, Alveosepta personata, Pseudocyclammina lituus)* are among the identified once.

The group of micro and macro fossils faunas collected from the logged section of Jema in the vicinity of Lemi; those enumerated above are pronounced and discussed as follows:-

5.1. Ostracods

The Ostracod, sometimes known as 'seed shrimps', are small laterally compressed Crustacea enclosed within a protective shell. Ostracods are bivalved micro-crustaceans; which can be found in most aquatic environments, including continental, estuarine, marine and hypersaline water bodies (Holmes, 1992). They are Metazoa and belong to the Phylum Arthropoda (as trilobites), Class Crustacea (as lobsters and crabs). An important distinguishing feature Ostracodes share with other arthropods is the bilateral symmetry of their body form.

The paired body parts are enclosed in a dorsally hinged carapace composed of low magnesium calcite; which is commonly preserved in the fossil record. They are found today in almost all aquatic environments including hot springs, caves, within the water table, semiterrestrial environments, in both fresh and marine aquatic environments, within the water column as well as on (and in) the substrate. In fact almost anywhere that's wet, even if only for a brief period!

The Ostracoda is separated from other Crustacea by their laterally compressed body, undifferentiated head, and seven or less thoracic limbs and the bivalved, perforate carapace lacking growth lines.

The living Ostracods are further classified in many cases by variations in their appendages and other soft parts. Although exceptionally well preserved fossil ostracods with the soft parts intact have been found these are very rare and therefore the morphological features of the carapace have become vital in fossil Ostracod classification. The Ostracoda have been divided into five Orders, the extant **Podocopida** and **Myodocopida** and the extinct Archaeocopida, Leperditicopida and Palaeocopida (however, the latter groups may well not be ostracods in the strict biological sense).

In the marine environment benthic ostracods are utilized for palaeoenvironmental reconstructions. Freshwater and brackish facies commonly contain abundant ostracods which are used for environmental studies and for biostratigraphic zonations.

In Jema section more than 500 Ostracod fossils were extracted from washed marl sediment but the identification of them is difficult due to the **poor** preservation of the morphological features of shells. In the entire extracted Ostracod samples, their hinge, placement of pores and muscle insertion scars are not visible under Stereozoom binocular microscope. For these reasons the classification of Ostracods are taken to genus level where possible and some of the extracted and described ostracods is given in (plate 1. Fig. A-H) of this research thesis.

Systematic descriptions have been made; and this part of the chapter deals with the taxonomy of the genus or species of Ostracods present and identified from the carbonate unit of the marl sediments of the study area of the logged section. The greater part of the fauna is included here though a few unidentifiable forms of unstratigraphical significance are excluded.

A full description is given only for few of the genera or species; in all cases the study is referred to the relevant original references. The nomenclature used in describing the structural features of the Ostracod shell follows that of Moore (1961) with additional hinge terminology by Bate (1972). However the main challenge in identification and description of the ostracods in the unit was mainly the lack of external morphological features due to poor preservation which make the identification task so difficult.

Every species listed in this part of this chapter is illustrated and identified under the Stereozoom binocular reflecting microscope with a magnification of 35× and their description and systematics is given as follows:

Kingdome Animalia

Phylum Insecta

Class Ostracoda

Order Podocopida

Family Ilyocyprididae (Kaufmann, 1900)

Genus *Cypridea* (Bosquet, 1852) *Cypridea* Bosquet, 1852

Species: *Cypridea sp.*

Description:- Shells are medium sized, sub-quadrate to sub-trapezoidal in side view; highest one-fifth from anterior end; dorsal margin nearly straight; cardinal angles broadly obtuse ; ventral margin slightly convex, sinuous terminally, converging toward dorsum posteriorly; anterior margin broadly curved, truncate above, anteroventral marginal bend extended as a blunt beak, and marked posteriorly by a notch; posterior margin narrower; right valve much larger than left, overlapping and extending beyond right along free margins; along dorsum left valve overlaps right; valves not strongly convex; surface finely pitted except marginal zone which is smooth; anteroventral furrow and hood well developed.

Remark: - Sub-quadrate to sub-trapezoidal, medium-sized Cypridea having right valve larger than left, finely pitted surface medially and smooth marginal zones.

Occurrence: - This species is extracted and obtained from the marly intercalated limestone layer of the Antalo limestone in the vicinity of Lemi and shown in plate 1. Fig. A & B. of this thesis work.

Class Ostracoda Latreille, 1806

Subclass Podocopa G. W. Müller, 1894

Order Podocopida Sars, 1866

Family Cyprididae Baird, 1845

Genus *Chlamydotheca* Saussure 1858

Specie*s Chlamydotheca arcuata* (Sars, 1901)

Syn.: *Eucypris* (*Chlamydotheca*) *bennelong* King, 1905 (*sensu* Daday, 1905)

Description: Carapace as shown in (Pl. fig. D) of this thesis tumid in dorsal view, maximum wide just behind the middle, pointed and acuminated anteriorly and rounded posteriorly. In lateral view RV overlaps LV at the anterior and posterior margins. Hinge adont, dorsal margin rounded, and ventral margin convex in the middle of valve. Both anterior and posterior margins rounded, but anterior margin with a lobated fringe; where the surfaces of valves are smooth with delicate setae.

Occurrence: - extracted from and obtained from the marly intercalated limestone layer of the Jurassic Antalo limestone, in the vicinity of Lemi, Jema section. It is shown in (Pl. 1. Fig: D).

Family Cytherideidae (Sars, 1925)

Genus *Homocytheridea (*Bate, 1963)

Species *Homocytheridea posteriohumilis* (Błaszyk, 1967) Pl. 2, Fig. 13

Description and Remark:-

Occurrence: - extracted from and obtained from the marly intercalated limestone layer of the Jurassic Antalo limestone, in the vicinity of Lemi, Jema section. It is shown in (plate 1. Fig. C).

Family Cytherideidae (Sars, 1925)

Genus *Procytheridea* (Peterson, 1954)

Species: *Procytheridea sp.*

Description Carapace sub triangular 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 sub parallel to anterior margin. Teeth, hinge, muscle scars and marginal pore canals not visible. The image of the species is shown in Pl. 1. Fig: F).

Superfamily Bairdiacea Sars, 1888

Family Bairdudae Sars, 1888

Genus, *Bairdia*, McCoy, 1884

Species *Bairdia Sp.*

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.

Carapace subdeltoid in lateral outline, convex dorsally. Dorsal margin high with steeply inclined anterior and posterior slopes. Posterior margin acuminate, upturned. Shell surface finely punctate. The image of the species is shown in Pl. 1. Fig: G).

5.2. Foraminifera

The order foraminiferida or foraminifera as they are informally called forms they are the most important group of microfossils for two main reasons: first, is that they are abundant in rocks and numerous in species; second they provide valuable information in the dating of strata and the reconstruction of sedimentary environments. Foraminifera are an order of single-celled protests that live either as benthic on the sea floor or amongst the marine plankton. Foraminifera are found in all marine environments, they may be planktic or benthic in mode of life.

As previously revealed, foraminifera have been utilized for biostratigraphy for many years, and they are also proven valuable in palaeoenvironmental reconstructions most recently for palaeoceanographical and palaeoclimatological purposes. In terms of biostratigraphy, foraminifera have become extremely useful, different forms have shown evolutionary bursts at different periods and generally if one form is not available to be utilized for biostratigraphy another is.

The systematic classification of the foraminiferies in this study is mainly based on the taxonomic parameters such as wall structure, wall composition, and manner of coiling, shape and arrangement of chambers, number of chambers, peripheral shape and position and shape of septa. For the suprageneric and generic classifications of foraminifera as Loeblich and Tappan (1988) was the main reference material.

The 8 marl samples were collected and investigated for the micropaleontological investigation from the vicinity of Lemi, Jema Section; yielded more than 250 foraminiferal taxa: all of the taxa were calcareous benthic foraminifers. The brief description and characterization of each foraminiferal fauna is done and the synonymy lists for taxa are comparatively complete. In the “Remarks” important references to the respective taxa are cited, and their geographic distribution with referenced materials is described in plate 2 & 3.

The limestone unit of the study area, of Jema section is in the upper most micritic part is dominated by benthic foraminifers; consisting of about twelve (12) identified foraminifers species from the thin section of the carbonate rocks and twelve (12) from the marl samples through the micropaleontological preparations were identified and described.

The systematic description for apiece of the identified species is given as follows including: - *Alveosepta jaccardi* (Schrodt, 1894), *Bicazammina jurassica* (Haeusler, 1890*)*, *Valvulina lugeoni (*Septfontaine, 1977), *Redmondoides lugeoni* (Septfontaine), *Nautiloculina oolithica* (Mohler, 1938), *Charentia evoluta* (Gorbachik, 1968), *Kurumbia palastiniensis (*Henson, 1948*) Pseudocyclammina lituus* (Yokoyama, 1890), *Nautiloculina circularis, Conicokurnubia orbitoliniformis* (Septfontaine,), *Kurnubia cf. morrisi (*Redmond, 1964*), Kurnubia Cf. morrisi (), Pfenderina sp., () Kurnubia ex. gr. Palastiniensis (), Kurnubia wellingsi* (Henson, 1948), *Conicokurnubia orbitoliniformis* (Septfontaine, 1988) *Pfenderina neocomiensis (P*fender, 1938) .

Family Hauraniidae, (Septfonatine, 1988)

Genus *Alveosepta* (Hottinger, 1967)

Species Alveosepta jaccardi (Schrodt, 1894) pl. IV, fig. 7, 8

Type species: *Cyclammina jaccardi n. sp.;* Schrodt 1894, p. 734; Fide et al., 1940-2009).

*Alveosepta jaccardi; (*Schrodt; Hottinger 1967, p. 79, pl. 15, figs. 9-13; pl.16, figs.

Alveosepta jaccardi (Schrodt; Bassoulet, 199, p. 301

Remarks: - Transverse section show almost planispiral mode of coiling, slowly enlarging crescentic chambers and distinct subepidermal lining of entire chambers. The axial sections often show the streptospiral mode of coiling of the early stage. Morphologically Alveosepta is close to Choffatella and Pseudocyclammina, but differs in that it possesses the characteristic narrow space in the distal part of the hypodermis of the septa (Banner and Whittaker, 1991).

Range*:* - Middle to Late Oxfordian- Early Kimmeridgian

Occurrence: - This species is identified from the thin section of the micritic layer of foraminiferal wackestone with the rock sample coded as RS 03 and shown in Pl.3. Fig. A of this thesis.

Kingdom: Protista (Hogg, 1861)

Phylum: Sarcodina (Schmarda, 1871)

Class: Rhizopoda (Siebold, 1848)

Order: Foraminiferida (foraminifera), (Orbigny, 1826)

Family Textulariopsidae, (Loeblich & Tappan, 1982)

Genus *Bicazammina (*Neagu & Neagu, 1995)

Species *Bicazammina jurassica* (Haeusler, 1890)

Bicazammina jurassica (Haeusler et al., 1995, 216, pl. 2, figs. 44-53

Remark: - The longitudinal section shows an early biserial stage followed by lax-uniserial adult stage.

Range: - Callovian- Valanginian

Occurrence: - This species is obtained and identified from the micritic layer of Antalo Limestone of Jema section whose sample coded as RS 007 and shown in Pl.3. fig. N. of this paper.

Superfamily Lituolacea Blainville, 1827

Family Nautiloculidae Loeblich and Tappan, 1985

Genus *Nautiloculina* Mohler, 1938

Type species: *Nautiloculina oolithica* Mohler, 1938.

1938. *Nautiloculina oolithica* Mohler, p. 19, Pl. 4, Figs. 1–3, Pl. 19, th. 6, Pl. 4, Figs. 1–3.

1988. *Nautiloculina oolithica* Mohler – Loeblich and Tappan, p. 71, Pl. 54, Figs. 10–12.

2001. *Nautiloculina oolithica* Mohler – Clark and Boudagher- Fadel, p. 226, Pl. 2, Fig. 10.

Remarks: - The axial section show typical, broadly lenticular outline of the test and interior of the chambers that sometimes display short septal projections. The species differs from *Nautiloculina circularis* smaller size, larger number of chambers and in much broader periphery. It has also longer stratigraphical distribution.

Range: This well-known species from the Bathonian is characterized by a rounded periphery, no alar extensions in axial section, and non lobate equatorial periphery. Thick septa present in equatorial sections. This species was extinct during the Berriasian-Valanginian; but manly dominant during Oxfordian to Kimmeridgian.

Occurrence: - Obtained from the micritic layer of the unit of the section the sample coded as RS 007 the photo image of the species is kept in P3. E.

Family *Nautiloculinidae* **(**Loeblich & Tappan, 1985)

Genus *Nautiloculina (*Mohler, 1938; Bronnimann, 1967)

Species *Nautiloculina circularis* (Said & Barakat, 1959)

Type-species: *Nautiloculina oolithica (*Mohler, 1938)

1959. *Nautiloculina circularis* (Said and Barakat), pl. I, Fig.1.

1966. *Nautiloculina circularis* (Said and Barakat)-Derin and Reiss, Figs. 70, 71, 83, 254, 263.

1968. *Nautiloculina circularis* (Said and Barakat)-Bronnimann, p. 64, Fig. 3, Pl. 1, Figs. 1–8.

1985. *Nautiloculina circularis* (Said and Barakat)-Fourcade *et al.*, Pl. 3, Fig. 4.

2001. *Nautiloculina circularis* (Said and Barakat)-Tasli, p. 3, Pl. 1, Fig. 1.

Description and remarks: This form with lenticular shaped, involute-planispirally coiled test shows the umbilical fillings and axial depressions. (Bronnimann, 1968) distinguishes *Nautiloculina circularis from Nautiloculina oolithica* Mohler by the marked sub-acute periphery, axial depressions, and by the larger size and larger numbers of the whorls in the former. In this thesis work both species *N. circularis* and *N. oolithica* are shown in fig of (Pl. 2 & 3. fig. F & G and D) respectively.

Range: - Middle of Jurassic (Oxfordian to Kimmeridgian)

Occurrence: This species is obtained and identified from the upper portion of micritic layer of the logged section of limestone unit those rocks sampled as RS 007 & RS03.

Superfamily Ataxophragmiacea (Schwager, 1877)

Family Pfenderenidae Smout & Sudgen, 1964

Subfamily Kurnubiinae Redmond, 1964

Genus Kurnubia Henson, 1948

Species: *Kurnubia palastiniensis (*Henson, 1948) Pl. I, fig.2

1948. *Kurnubia palastiniensis* Henson, P. 609, Pl. 16, figs 8, 11, Pl. 18. Figs 10-11.

1948. *Valvulinella jurassica* Henson, P. 609, Pl. 16, figs 1-4, 10, Pl. 18, figs 8-9.

1964. *Kurnubia bramkampi* Redmond, P. 253, Pl. 1. Figs 1-3.

1966. *Kurnubia gr. Palastiniensis* Henson- Maync, P. 12, Pl. 5, figs 1-7

1988. *Kurnubia Palastiniensis* Henson- Sartorio & Venturini, P. 76.

1988- *Kurnubia Palastiniensis* Henson- Loeblich & Tappan, P. 154, Pl. 165, figs 1-6.

1994- *Kurnubia Palastiniensis* Henson- Chiocchini *et al*., P. 52, figs 17, 18.

1985- *Kurnubia Palastiniensis* Henson- Kuznetsova *et al*., P. 161, Pl. 11, fig. 9, Pl. 12, figs 4.

2002- *Kurnubia Palastiniensis* Henson- Noujaim Clark & Boudagher-Fadel, 685, Pl. 2, fig. 1.

Remarks: The specimens display wide morphologic variations and considerable differences in size. They vary from those smaller in size, only trochospirally, having a weakly developed central column and possessing a hypodermic network (Septfontaine, 1988) with first order partitions (Pl. 2, fig. F & Pl. 3. fig. J). In the latter forms, the proloculus is not visible. The central column seems to be weakly developed in highly conical specimens, whereas it is well developed in specimens having a relatively larger basal diameter.

Range: - Though difficult to decipher in detail because the test growth is frequently very irregular, this high trochospired species is easily recognizable in sections. The massive central columella is also trochospired and the subepidermal network with large meshes is characteristic. The test in the adult stage tends to become uniserial. This species ranges from middle Callovian to late Tithonian.

Occurrence: - This species is obtained from the micritic layer the Antalo limestone of the Jema section Rock samples of RS 007 & RS 012 which is the upper most layer of the mudstone and shown in Pl.3 fig. J.

Superfamily Ataxophragmiacea (Schwager, 1877)

Family Pfenderenidae Smout & Sudgen, 1964

Subfamily Kurnubiinae Redmond, 1964

Genus Kurnubia Henson, 1948

Species *Kurnubia wellingsi* (Henson, 1948) P1. I, figs 3-4, P1. III, fig. 1C, P1. IV, fig. 6A

1948. *Valvulinella wellingsi* Henson, P. 606, P1. 15, fig 9, P1. 16, fig. 5, P1. 18, fig. 1.

1962. *Valvulinella wellingsi* (Henson) – Smout & Sudgen, P. 590, Pl. 76, figs 1-8.

1964. *Kurnubia morrisi* Redmond, P. 253, Pl. 1, fig 4.

1966. *Kurnubia type wellingsi* (Henson) - Maync, Pl.5, figs 8-16.

1985. *Kurnubia wellingsi* (Henson) – Kuznetsova *et al.,* P. 162, Pl. 12, figs 5-6.

2002. Kurnubia palastiniensis Henson- Noujaim Clark & Boudagher-Fadel, P.686, Pl. 2, fig.

Remarks: - *K. wellingsi* is characterized by radial septal partitions, unpillared columella and surrounding tunnel shown in pl. 2. fig. p.

Range: - Oxfordian to Valanginian

Occurrence This species is obtained and identified from the micritic layer the Antalo limestone of the Jema section Rock samples of RS 007 & RS 012 which is the upper most layer of the mudstone and it is shown in Pl. 2 fig. P.

Family Pfenderinidae (Smout & Sugden, 1962)

Subfamily Kurnubiinae (Redmond, 1964)

Genus *Kurnubia* (Henson, 1948)

Species *Kurnubia* cf. *morrisi (*Redmond, 1964)

Kurnubia* cf. *morrisi Redmond**,** 1964 (Pl. II, Figs. 8-12, 14)

Kurnubia morrisi new species.- Redmond, 1964 p. 253, pl. 1, fig. 4.

Kurnubia cf. *morrisi* Redmond, 1967 - Hottinger, p. 93, pl. 19, figs. 35-37.

Description: Septal sutures are obscure. The wall is calcareous, microgranular without agglutinated grains, possessing a complete hypodermic network. The primary aperture is set in the inner margin of the peripheral zone where the septa do not meet the central column (Pl. 3. Fig. C).

The central zone has a trochoidally laminated appearance (Pl. 3. Fig. C) which recalls the apertural plate's intergrown with pillars in the Pfenderinidae. The base of the test is strongly convex in the center and very obliquely set to the axis of coiling.

Remarks: *K*. cf. *morrisi* has a larger test and central column, and a wider peripheral zone than all other described species of *Kurnubia* and a complete hypodermic network consisting of two generations of partitions in the adult stage. Furthermore, specimens of *Kurnubia* ex. gr. *palastiniensis* do not exceed 0.7 mm in basal diameter. Purely because of the trochospiral coiling, this form is not considered as *K. wellingsi* (Henson). Six to eight tiers of chamber lets per chamber, mentioned by Redmond (1964, p. 253), are not accountable in random thin sections.

Range: - Callovian

Occurrence: - This species is obtained from the micritic Antalo limestone layer of Jema section from the upper portion of micritic layer of Rock sample RS 012.

Family Pfenderinidae (Smout & Sugden, 1962)

Genus *Conicokurnubia* (Septfontaine, 1988)

Type species *Conicokurnubia orbitoliniformis (*Septfontaine, 1988) Pl. II, Figs. 13, 15, 16)

Species *Conicokurnubia orbitoliniformis* (Septfontaine, 1988)

Description and Remarks: - Test is sharply conical (Pl. 3. Fig. F), where chambers do not increase in diameter as added and broadly conical where chambers increase slowly in diameter. The base is slightly too strongly convex in the center, with a narrow imperforate rim.

From trochospired arrangement in juvenile stage the test rapidly becomes uniserial during adult stage showing an "orbitolinid" aspect. The aperture is areal and cribrate and the subepidermal network similar to that of Kurnubia palastiniensis.

Conicokurnubia orbitoliniformis occurs throughout the Jema section Upper Jurassic section, in association with *Kurnubia* ex gr. *palastiniensis*. In the random thin-sections, specimens with a marked uniserial stage of the latter might be confused with sharply conical specimens of *C. orbitoliniformis*. The width of the peripheral zone seems to be narrower than in *Kurnubia palastiniensis* and *Kurnubia* aff. m*orrisi*.

Range: - Oxfordian (?) to Kimmeridgian.

Occurrence: - This species is observed and identified from rock sample RS 007 which is obtained from the middle portion of the micritic layer of Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in Pl.3. fig. F.

Order Textulariida Delage & Herouard, 1896

Suborder Textulariina Delage & Herouard, 1896

Superfamily Chrysalidinacea Neagu, 1968

Family Paravalvulinidae banner, Simmons & Whittaker, 1991

Subfamily Paravalvulininae Banner, Simmons & Whittaker, 1991

Genus *Redmondoides* Banner, Simmons & Whittaker, 1991

Species *Valvulina lugeoni (*Septfontaine, 1977)

1977. *Valvulina lugeoni*, Septfontaine, p. 612, Pl. 2, Fig. 2-5; text Fig. 6.

1987. *Valvulina* aff. *Lugeoni* Septfontaine, Sotak, Pl. 4, Figs. 4-5.

2004. *Valvulina lugeoni* Septfontaine, Ivanova and Kolodziej, Fig. 1 E.

2005. *Redmondoides* cf. *lugeoni* Septfontaine, Schlagintweit et al. p. 40, Pl. 25 a-d.

2006- *Valvulina* spp., Kobayashi and Vuks, Fig. 6 (12).

2008- *Valvulina lugeoni* Septfontaine, Ivanova et al., Fig. 6 H.

Redmondoides lugeoni (Septfontaine) (Pl. 3, figs. 17-27; Pl. 4, figs. 1-9, 16-23; Pl. 5, figs. 11

Description and Remark

Range: Bajocian (Septfontaine, 1977) -Valanginian (Ivanova and Kolodziej, 2004).

Occurrence This species is observed and identified from rock sample RS 007 which is obtained from the middle portion of the micritic layer of Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in P3. Fig. B.

Family Pfenderinidae (Smout & Sugden, 1962

Genus: *Pfenderina*

Species: *Pfenderina spp.*

Occurrence: - This species is observed and identified from rock sample RS 03 which is obtained from the upper portion of the micritic layer of Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in P3. Fig. G.

Suborder Orbitolinina (Kaminski, 2004)

Superfamily Pfenderinoidea (Smout & Sugden, 1962)

Family Pfenderinidae (Smout & Sugden, 1962)

Subfamily Pfenderininae (Smout & Sugden, 1962)

Genus *Pfenderina* (Henson, 1948)

Species *Pfenderina neocomiensis (P*fender, 1938) (Fig. 6.M-O) Pl. 73, figs, 1-9; pl. 74, figs. 1-3; Pl. 75, fig, 1; text –fig. 1, A-D.

1938 - *Eorupertia neocomiensis* n. sp. - Pfender -p. 236, Pl. XVI, figs. 1-7.

1961 - *Pfenderina neocomiensis* (Pfender, 1938) -Smout & Sugden, p. 585-588, Pl. 73, figs. 1-9; Pl. 74, figs. 1-3; Pl. 75, fig. 1.

1995 - *Pfenderina neocomiensis* (Pfender, 1938) -Bucur *et al.*, p. 369, Pl. 6, figs. 4-6.

1948 (1947) - *Pfender neocomiensis* (Pfender); Henson

Remark and Description: The test is high trochospiral with a thickened (columellar) central zone. The chambers are small and numerous separated by oblique septa. The wall is agglutinated/microgranular imperforate. Primary aperture is multiple, secondary one being represented by an intercameral passage (groove), spiraling around the thick axial zone.

Range: - Bathonian or Callovian.

Occurrence: - This species is observed and identified from marl intercalated sediment through the micropaleontological method of extraction; Marl 03 which is obtained from the upper portion of Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in Pl. 2. Fig. N & O.

Suborder Orbitolinina (Kaminski, 2004)

Family Cyclamminidae (Marie, 1941)

Genus *Pseudocyclammina*

Species *Pseudocyclammina lituus* (Yokoyama, 1890)

Type species: *Cyclammina lituus* (Yokoyama, 1890)

Pseudocyclammina lituus Yokoyama, 1890 Pl. 7, Figs. 1-4

1890. Cyclammina lituus n. sp.; Yokoyama, p. 26, pl. 5, fig.7

1991. Pseudocyclammina lituus Yokoyama; Altıner, p. 189, pl. 4, fig. 10, p. 195, pl. 7, fig. 14

2004b. Pseudocyclammina lituus Yokoyama; Bucur et al., p. 65, pl. III, fig. 1

2006. Pseudocyclammina lituus Yokoyama; Kobayashi & Vuks, p. 840, text-fig. 5 7-14

2007. Pseudocyclammina lituus Yokoyama; Krajewski & Olszewska, p. 301, textfig.6F

2008. Pseudocyclammina lituus Yokoyama; Omaña & Arreola, p. 805, text-fig. 4a-d

2010. Pseudocyclammina lituus Yokoyama; Ivanova & Kolodziej, p. 29, pl.4, figs. 1-10

2011. Pseudocyclammina lituus Yokoyama; Roozbahani, p. 55, pl. 1, fig. 5

Description and Remark: - Test is early planispirally enrolled and later uncoiling. Wall is coarsely agglutinated with coarse subepidermal network. Aperture is cribrate covering the apertural face. *Pseudocyclammina* and *Everticyclammina* may appear similar in some thin sections. *Pseudocyclammina* differs from *Everticyclammina* by its cribrate aperture. Aperture of *Everticyclammina*, however, is a simple, short vertical areal slit.

Known Range: - The stratigraphic distribution of *Pseudocyclammina lituus* ranges from Oxfordian to Hauterivian (Ivanova & Kolodziej, 2010). Oxfordian (Hughes, 2004; Velić, 2007) - Hauterivian (Canérot, 1984).

Occurrence: - *Pseudocyclammina lituus* has been identified from the middle passion of Antalo limestone of the carbonate unit. This species is observed and identified from rock upper most part of micritic sample RS 007 which is obtained from the middle portion of the micritic layer of Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in Pl.3. fig. K.

Order Textulariida (Delage & Hérouard, 1896)

Suborder Textulariina (Delage & Hérouard, 1896)

Superfamily Chrysalidinoidea (Neagu, 1968)

Family Paravalvulinidae (Banner *et al.*, 1991)

Subfamily Paravalvulininae (Banner *et al.*, 1991)

Genus *Redmondoides (*Banner *et al.*, 1991)

Species *Redmondoides lugeoni* (Septfontaine, 1977) (Fig. 4.H)

Species *Redmondoides lugeoni* (Septfontaine, 1977) (Pl. 3, figs. 17-27; Pl. 4, figs. 1-9, 16-23.

1977 - *Valvulina lugeoni n. sp*. – Septfontaine, p. 612-613, Pl. 2, figs. 2-5.

1987 - *Valvulina lugeoni* Septfontaine, 1977 - GRANIER, Pl. 14, fig. g.

1991 - *Redmondoides lugeoni* (Septfontaine, 1977) - BANNER et al., p. 127, figs. 46-54.

2016 - *Redmondoides lugeoni* (Septfontaine, 1977) - GRANIER et al., p. 259, Pl. 1, fig. 17.

1987- *Valvulina* aff. *Lugeoni* Septfontaine, Sotak, Pl. 4, Figs. 4-5.

2004- *Valvulina lugeoni* Septfontaine, Ivanova and Kolodziej, Fig. 1 E.

2005- *Redmondoides* cf. *lugeoni* Septfontaine, Schlagintweit et al. p. 40, Pl. 25 a-d.

Description and Remark: - Initially attributed to the genus Valvulina by Septfontaine (1977), this species has been revised by Banner et al. (1991) and included in their new genus *Redmondoides*. The test is quadriserial throughout, with thick protocanaliculate wall. The chambers are low with thinner flap covering the aperture in the central part of the test. The junction of these flaps in axial part of the test shows typical figures in hooks or "floating plates" cut transversely these flaps.

Description: Large-sized conical, trochospiral test with thick microgranular/agglutinated walls and septa. The test is quadriserial throughout most ontogenetic stages. The microgranular material that forms the test walls and septa may develop canaliculated features in some specimens. Aperture is interiomarginal enclosed by a flat lip (Pl. 3. fig. H).

Known Range: Callovian -lower Tithonian.

Occurrence: - This species is observed and identified from rock sample RS 007 which is obtained from the middle portion of the micritic layer of Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in Pl. 3. fig. H.

Family Lituolidae, DeBlainville, 1827

Genus *Choffatella (*Schlumberger, 1904)

Species: *Choffatella sp.* (Pl. 2. Fig. I)

Description: Test are relatively large, compressed; planispirally coiled; partial involute to evolute, chambers are numerous and 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 it is extracted from sediment sample Mr003 which is from upper Jema section.

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

ORDER Lagenida Lankester, 1885

SUBORDER Lagenina Delage and Herouard, 1896

Superfamily Nodosariacea Ehrenberg, 1838

Family Nodosariidae Ehrenberg, 1838

Subfamily Nodosariacea Ehrenberg, 1838

Genus *Pseudonodosaria*

Species *Pseudonodosaria vulgata* (Bornemann, 1854)

Pseudonodosaria vulgata (Borneman, 1854) (pl. 5.19, figs. e)

Glandulina vulgata Borneman, 1854, p. 31, pl. 2, figs 1–2.

Pseudonodosaria vulgata (Borneman). -- Cifelli, 1959, p. 318, pl. 5, fig. 3.

Remarks: We based our description on identification done by Cifelli, 1959.

Occurrence: - This species is extracted from marl sediment obtained from the intercalation of limestone which is coded as Mr. 001 and shown in Pl.3. fig. A & B.

Class: Rotaliata

Subclass: Textulariana

Order: Lituolida

Family: Pfenderinidae

Genus *Pfenderina* Henson, 1948

Species *Pfenderina gracilis* (Redmond, 1964)

Pfenderina gracilis Redmond, 1964 (Plate 1, Fig. 14)

Pfenderina gracilis (Pl. 2. C.)

Pfenderina gracilis Redmond, new species Plate 1, figures 14-16

Description: Test small, fusiform, an elongate trochoid spiral composed of moderately high, simple chambers, five to the whorl in the later part of the test; chambers with smooth surfaces and moderately inflated; both lateral and spiral sutures distinct, their surfaces having a finely granular aspect; wall consisting of imperforate microgranular calcite;

apertural plates small and almost hemispherical, successive plates not overlapping their predecessors completely but being systematically displaced either to the right or the left depending on the individual, and forming thus upon subsequent infilling a rod of solid shell material in the form of an open corkscrew-like spiral.

Remarks: This species is known from Bathonian –Callovian age of Saudi Arabia, C. D. Redmond (2014). Also other species of *Pseudomarssonella reflexa* and *Pseudomarssonella plicata* are identified from this marl sample obtained in the carbonate unit.

Subclass Textulariia Mikhalevich, 1980

Order Loftusiina Kaminski, 2002

Family Cyclamminidae Marie, 1941

Subfamily Choffatellinae Maync, 1958

Genus *Choffatella* (Schlumberger, 1904)

Type species: - *Choffatella cruciensis*

Material: 10 specimens (**Plate 2: J)**

Description: -Test are relatively large, compressed; planispirally coiled; partial involute to evolute, chambers are numerous and 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 and chamber walls are finely perforate. It is extracted from sediment sampleK1S3 which is from upper Sodoble section.

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

5.3. Gastropods

Gastropods are class of phylum mollusk and Kingdome animalia that has mostly an externally univalved shell and 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 Jema section of the Jurassic carbonate unit are described and figure for the identified fossils are given in plate 5.

Gastropods are one of the most diverse groups of animals, both in form, habitat, and habit next to insects. They are by far the largest group of molluscs, with more than 62,000 described living species and 13, 000 named genera for both recent and fossil records. They are extremely diverse in size, body and shell morphology and habit and occupy the widest range of ecological niches of all molluscs, being the only group to invade the land.

Kingdome Animalia (Linnaeus, 1758)

Phylum Mollusk (Linnaeus, 1758)

Class Gastropod, (Cuvier, 1795)

Order Littorinimorph, Golikov and Starobogatov, 1975

Superfamily Naticoidea (Forbes, 1838)

Family Ampullinidae (Cossmann, 1918)

Genus *Ampullospira* (Harris, 1897)

Species *Ampullospira (Pictavia) bajocensis* (D' orbigny, 1852) (Plate I: 40–43)

1852 -*Natica bajocensis sp. nov*.–D' Orbigny, p. 189, pl. 289, figs. 1-3.

2004- *Ampullospira bajocensis* (D' Orbigny)–Szabó and Jaitly, p. 16, pl. I, figs. 40-43.

1852: *Natica Bajocensis* D'orbigny — p.189, pl. 289, figs 1–3.

1852: *Natica Pictaviensis* D'orbigny — p. 191, pl. 289, figs 8–10

1868: *Natica Bajocensis* D'orbigny — Laube, p.4, Tab. I, Fig. 5.

1892: *Natica Bajocensis* D'orbigny — Hudleston, p. 263, Pl. XX, 13a, 13b.

1997: *Ampullospira (Pictavia) bajocensis* (D'orbigny, 1852) Fischer & Weber, p. 70, 71, Pl.

2003: *Pictavia bajocensis* (D'orbigny, 1852) — Gründel, p.76, Pl. 9, Figs 5–10.

Description: - Narrow but distinct, concave subsutural ramp present from early whorls (suture canaliculate). Aperture elongate, peristome remnants suggest short columellar lip; no trace of peristome modification observable.

Remark: Shell is highly spired and relatively slender and consists of four whorls. Sutures are deep.

Range: - Late Callovian

Occurrence: - This species is observed and identified from upper part of bioclastic wackstone to packstone layer the limestone succession of the Antalo limestone in Jema section in the vicinity of Lemi, whereas is shown in P5. A.

Kingdome Animalia (Linnaeus, 1758)

Phylum Mollusk (Linnaeus, 1758)

Class Gastropod, (Cuvier, 1795)

Order Littorinimorph, Golikov and Starobogatov, 1975

Superfamily Naticoidea (Forbes, 1838)

Family Ampullinidae (Cossmann, 1918)

Genus *Ampullospira* (Harris, 1897)

Species *Ampullospira (Pictavia) lorierei* (D'Orbigny, 1852);

1852- *Natica lorierei sp.* nov.—D'Orbigny, p. 190, pl. Cclxxxix, figs. 6–7.

2001- *Ampullospira (Pictavia) lorierei* (D'Orbigny) -Fischer et al., p. 90, pl. 2, fig. 16.

2004- Ampullospira (Pictavia) lorierei (D'Orbigny)-Szabó and Jaitly, p. 16, pl. II, figs.

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. This gastropod specimen is collected from upper part of Sodoble section and there are also many gastropods shells fragments under thin section but it is difficult to identify it species.

Remark: - Shell is medium-sized; largest specimens consist of four whorls, base strongly convex, and umbilicus narrow. The studied specimens are similar to Ampullospira sp. of Hirsch (1979), pl. 11, figs. 14‑15.

Occurrence: - Fischer et al. (2001) reported this species from the Middle Callovian sediments in Saudi Arabia; Szabó and Jaitly (2004) reported this species from Lower Callovian Chari Formation of Kachchh, western India. Moreover in the present study, this species is recorded from the Middle Jurassic of Antalo limestone formation of the Abay basin of the Jema sections.

5.4. Echinoderms

The echinoids are sea urchins and sand dollars. They are benthic groups; which most commonly eating sediment or plant material. They are mostly characterized by having five-fold (pentameral symmetry). Echinoderms are exclusively marine; and most are benthic. They are present in virtually all marine environments of normal salinity, from the shallow intertidal to the abyssal zone. Many echinoderms are suspension feeders, while others are predators, scavengers and herbivores. A few are deposit feeders. Members of class

Echinoidea are commonly known as Sea urchins**.** Some of the common names of Echinoidea are Sand dollar (Sea disc, Heart urchin, and Cake urchin, Sea bicuit. *Fellaster zelandiae?* (Gray, 1855).

Echinoderms in thin-sections: Crinoid and echinoid fragments are most common in shelf carbonate environment deposited limestones; holothurian and ophiuroid elements are less abundant in thin sections, but may be important microfossils found in acid residue samples of shallow-water and basinal limestones.

In thin-sections generally cross-sections and longitudinal sections of spines (plates) are easily decipherable in limestones. Sea urchin spines can be found in shallow water carbonates as well as in deep water carbonates known from the Ordovician to the Recent. The observed echinoid spins both in the field and from the thin section of the collected sample as shown in fig 5.1 of this thesis.

Echinoids are traditionally divided into two sub groups. The regular echinoids with almost perfect pentameral symmetry include the Cidaroidea (since Late Paleozoic) and the Sea urchins since Late Triassic. In the irregular echinoids a secondary bilateral symmetry is superimposed upon the primary pentaradiate pattern.

Common constituents in thin sections of Limestones are echinoid spines. Sections of echinoid spines exhibit characteristic internal radial patterns that are useful taxonomically. In cross section spines may be hollow (diadematoid type) *Hardouinia mortonis* common name Sea Urchin

Fig. 5.1: Echinoid spine syntaxial overgrowth cements on limestone A, Echinoid spine. The cross section in thin section B.

5.5. Bivalves

Bivalves are common shelled organisms like clams, oysters, and mussels which are generally filter feeders and live in or on top of the seafloor sediments as among the benthic organisms. These are extremely common marine invertebrates today but less common as fossils the further back in geologic time you go. They differ from brachiopods in having symmetry between the dorsal (top) and ventral (bottom) valves (shells).

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 Jima section are preserved as a mold and cast which makes it difficult to identify and name of 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) has been 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 Mactromya spp.

Shell moderate in size, equivalved, ovate, distinctly elongated, and often crescent-shaped. Both valves are equally convex, ornamented with radial ribs. Fig: 5.2.

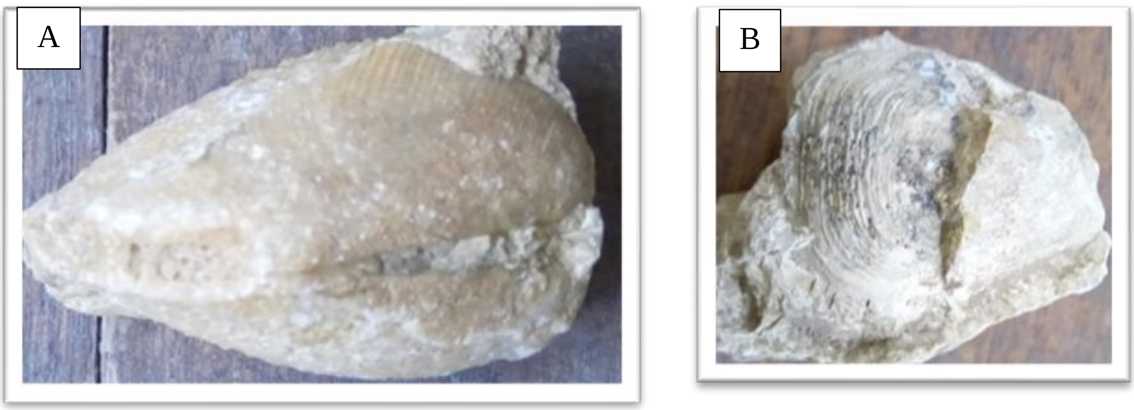

Fig. 5.2: The molds of bivalves obtained in the logged section of Jema in the vicinity of Lemi

5.6. Brachiopods

Brachiopods are shelled organisms which have left-right symmetry across their valves (shells). They lived attached to the seafloor and were very abundant in the geologic past (Paleozoic Era) but are fairly rare today. They were filter feeders.

Brachiopods are organisms with a pair of conjugated valves or bilaterally symmetrical sessile marine organisms with an external shell consisting of two dissimilar but equilateral valves. Based on the presence or absence of teeth 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 Jima section fossils of brachiopods are collected; but identification is the most challenging aspect due to the poor preservation of the morphological feature important for this purpose as their photos are given in fig 5.3 below.

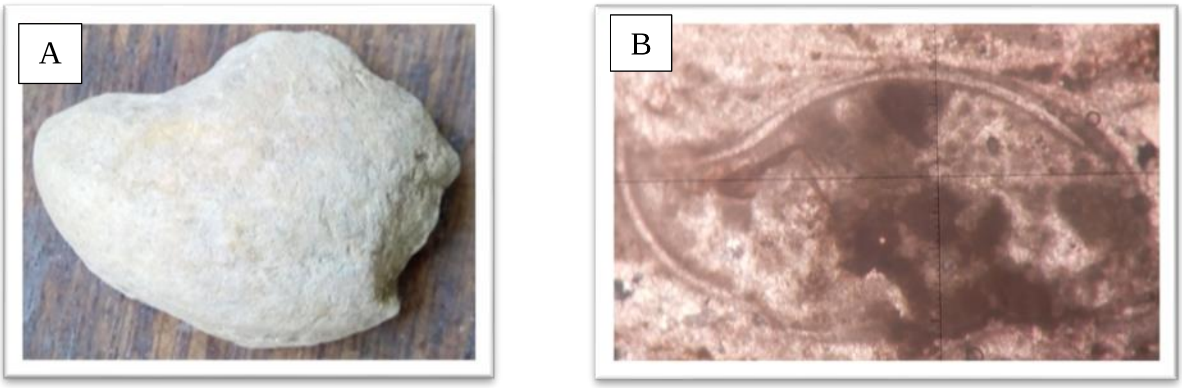

Fig. 5.3: A Brachiopod fossil molds obtained from the logged section of Jema & C from thin section and fig. B. Nanogyra sp. right valve

5.7. Calcareous Algae

Calcareous algae in the true sense of the word are only benthonic and planktonic algae with a biochemically precipitated $CaCo_3$ skeleton, often some algae are designated "calcareous algae", because they contribute to carbonate precipitation and the formation of laminated fabrics (algal mats and stromatolites) by interacting in physical and biological processes.

During an extensive investigation of microfacies of the Mesozoic carbonate rock units in Jema section, it was found that some of these sampled rock units under the petrographic microscope shows the occurrence of dasycladacean algae.

In the Jurassic carbonate unit of the study area, the dasycladacean algae are the bioclastic constituents of the mudstone and bioclastic wackestone facies.

Salpingoporella pygmaea obtained from the rock thin section coded as RS 003 and shown in plate 5 fig. D

Trinocladus radoicicae A

Genus *Salpingoporella Pia 1918*

Specie*s Salpingoporella annulata* Carozzi 1953 Plate 2, figures 4-7

Salpingoporellaan nulata Carozzi. -ELLIOTT 1968,p . 72, pl. 20, figs.

*3, 44, 6 and 7- Basson and E*dgell *1971, p. 420, pl. 4, figure*

3. - Bassoullet et al. 1978, p. 231, pl. 27, figs. 4-9. - Bernier1984, p. 471, pl. 3, figs. 1-3.

Description: Rod-like, thick-walled tabular thallus with regular successive verticils of single branches which widen to the exterior and open as simple pores. The pores alternate in position from one verticil to the next. The interverticil walls are gently convex.

Occurrence: Middle to Upper Jurassic, Antalo limestone of Abay basin from the bioclastic facies of the carbonate unit.

Description: Cylindrical thallus showing successive verticils of radial primary branches that swell out markedly before dividing into thinner secondary branches (probably four). The secondaries divide in turn into several tertiaries, although most of the specimens show only primaries and secondaries.

Occurrence: - This species of algae is obtained from the foraminiferal wackestone layer of the carbonate unit as the sample is coded RS 008 which is taken from the bed below the marly intercalated unit. This species is labeled in plate 8 fig. G & H.

Family: Triploporellaceae (PIA, 1920) Berger & Kaever, 1992

Tribe: Triploporelleae (PIA, 1920) Bassoullet et al., 1978

Genus: *Acroporella* (Praturlon, 1964) Praturlon & Radoicic, 1974

Species: *Acroporella hamata n .sp.* (PI. 1; Figs. 5-8,11; PI. 5; Figs. 14-16; Text-Figs. 4,5)

Description An oblique-longitudinal section of an unsegmented thallus which is obtained from thin-section RS 008, figured in Plate. 8; Fig. I, is illustrating the euspondyle arrangement of the branches, and the hooked appendices at the primaries.

Remark: Cylindrical, unsegmented thalli with tubular slightly ovoid, elongated and slightly outwards widening primary branches, regularly bent towards the axial stem; distally arranged secondaries are only poorly visible, due to the outwards decreasing calcification.

Tribe: Triploporelleae (PIA, 1920) Bassoullet et al., 1978

Family: Triploporellaceae (PIA, 1920) Berger & Kaever, 1992

Genus *Trinocladus (*Raineri, 1922)

Species *Trinocladus tripolitanus* (Rmneri, 1922) (PI. 2; Figs. 11-15)

5.8. Sponges

Sponges are a group of organisms in Kingdome animalia in phylum Porifera; are an exclusively aquatic, with a few exceptions. Spicules are structural elements that found in most sponges. They provide structural support and deter predators. Large spicules that are visible to the naked eye are referred to as megascleres, while smaller, microscopic ones are termed microscleres.

Calcareous sponges: The non-systematic term is used in a rather loose manner for 'calcisponges' exhibiting calcite spicules or a calcareous skeleton. The sponge spicule extracted and identified from marl sample through the extraction of microfossils of MR 005 is *Leucetta;* whereas they are triactine and tetractine needles of calcareous sponges.

Fig. 5.4: The Triactine and tetractine needles of calcareous sponges.

CHAPTER SIX

6. DISCUSSION

A thick layer of Jurassic carbonate unit which is correlable with carbonate unit called Antalo limestone of the northern Ethiopia is deposited around Lemi; Jema section of the Bilu Nile basin in the centeral Ethiopia; was explored through field investigation and laboratory analyses of petrography and micropaleontology during this thesis work. The studied carbonate unit consists of mudstone, bioclastic wackestone and peloidal grainstone to packstones within micrite and/ sparry calcite cement dominated by benthic foraminifera with minor brachiopods, echinoderms, bivalves, ostracods and gastropods.

The results of the lithostratigraphic and biostratigraphic studies; six (6) different lithofacies are identified; based on the skeletal and non-skeletal component analysis (carbonate grains), as well as the bioclasts were used. The available data once integrated and the results obtained were helpful in developing a detailed Lithostratigraphy and biostratigraphy, in correlating the logged section locally and regionally and to interpret and reconstruct depositional environment of the logged section and the studied area of the Middle to the upper Jurassic carbonate unit.

The lithostratigraphic log along with the distribution of lithofacies and their details as per the samples studied in the outcrop accompanied by thin sections data analysis is shown in (Fig. 6.1). The details in conjunction with the extracted microfossils have been used to document and interpret the depositional environment of the formation, as well as the determination of the biostratigraphic ranges. The detailed interpretation of the outcrop is given under separate points of depositional environment and biostratigraphy

Based on macro and microfossil analysis and sedimentological features obtained from the carbonate unit of the study area through field investigation and petrographic study (thin section analysis) discussions are made on the bases of: - biostratigraphic and age determination, composite stratigraphy of the area and local and regional correlation of the section besides depositional environments; facies patterns and association as follows:-

6.1. Depositional Environment and Facies Association of Jema Section

Depositional environments are of sedimentary environment of a complex physico-chemical and biological conditions, under which sediment accumulates and consolidates (Krumbein and Sloss, 1963). A depositional environment is a particular type of sedimentary environment, in which net sedimentation proses, occurs over a span of time.

Environmental analysis of ancient sediments is important not only for academic purpose, nevertheless also has numerous economic applications; in search for fossil fuels and certain types of mineral deposits. In order to explore the depositional environment and facies of the carbonate unit in the study area; detailed field observation and description, microfossil preparation, extraction and study and petrographic study of carbonate unit for the representative rock and sediments samples of the section have been investigated.

The microfacies analysis of the carbonate rock samples collected from the logged section of the study area; shows that the carbonate sediments were deposited in a shallow marine environment of low energy facies which is represented by the bioclastic lime mudstones and wackestones; whereas the skeletal wackestones indicate an open marine environment within the platform interior. The packstones to grainstones represent high energy environment such as barriers and shoals.

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.

Therefore, Marine environment might be very shallow or the seashore is close that could allow for the deposition of this fine-grained sandstone in the Lemi area even in the vicinity of Fetera.

For the interpretation of the depositional environment of the outcrop in the study area, several parameters are used including the sedimentary features present on the surface of the outcrop, the skeletal and non-skeletal components obtained from the petrographic analysis of the collected representative rock samples, the habitat of certain representative faunas present in the lithofacies and the microfossils extracted from the sediments. According to the present field observations and lab data analysis, the general carbonate facies patterns show the transgressions pattern of deposits.

The variation in texture from very fine to very coarse mean from wackestone to mudstone indication upward whereas the textural change from mudstone to wackestone, form wackestone to packstone and grainstone indicates swallowing up ward.

Most of the foraminifera identified and described in the study area of the Jema sections with the mentioned assemblages are lived in shallow marine water environment. The

Pfenderinidae obtained from RS 007 are confined to one sedimentary facies group of clean, shallow marine water limestone, but seldom occur in the shallowest sediments such contains abundant ooliths (Murat and Scolari, 1956).

The assemblage of *Pseudocyclammina lituus, Alveosepta jaccard* and *Nautiloculina oolithica* which is quite frequent in these deposits of the upper micritic layer of the middle unit in the logged section of the limestone unit and occur mostly in fine grained facies (mudstone) is indicative of more open environments, from external-inner to outer platform settings. The layer containing this association of foraminiferal fauna is lack of components of the carbonate sands; which is and indicative to an area of less water-energy marine environments.

The existence of dominant finer peloidal grains, bioturbated structures, micritized skeletal and non-skeletal grains, and coarser oolitic grains of high energy deposits (shown in microfacies type (MFT 3, 4 & 6), which are similar to 8, 7 and 6 facies belts of Wilson (1975), throughout the outcrop of these carbonate successions are best indicators of shallow marine carbonate depositional environments of restricted circulation shelf to shoal environment.

As some descriptions and interpretations were given in the previous sections in terms of depositional environments, based on the various skeletal and non-skeletal sediment obtained and the dominating depositional processes, the carbonate deposits of the study area shows the depositions under shallow marine conditions for the lower to the middle sub-units (marginal basin to open sea) and some depositional conditions for the upper most sub-units offshore system.

As descriptions and interpretations were made in chapter four of this thesis above in terms of facies which indicates the depositional environments; based on the various skeletal and non-skeletal sediment obtained and the dominating depositional processes, the carbonate deposits of the study area shows its deposition under shallow marine settings; the middle micritic unit which is outcropped as the sharp cliff is deposited in the restricted circulation shelf facies to open circulation, the bioclastic wackestone in shoal environments as compared with FB 6 of the Wilson cycle and the Pelsparite (peloidal grainstone) in the restricted marine shoals as in Wilson cycle FB 7 & 8 and the algal stromatolite facies id deposited in the restricted marine shelf lagoons formed after the take out of the marine environment.

The middle part of the carbonate unit of the succession is dominated with fine grained texturally and light gray micritic limestone layer in color, with very thin clastic shale layers at its upper parts. The upper most part of the micritic unit is dominated by foraminifers and very rare or sometimes lacking of skeletal grains of (bivalves, brachiopods, gastropods and echinoderms) at the middle which imbedded in these micritic layers at places.

The sub-unit which is dominated by bioclastic wackestone and micritic microfacies (MFT 1, 2 & 5), those compared with facies belt 2 and 7 of Wilson (1975), and those deposited at shelf facies to open circulation conditions. The facies throughout this subunit shows deepening upward; those may be due to rise in the sea level during the depositions of this subunit.

The carbonate facies of the study area is compared with the facies belt 2, 6, 7 & 8, of Wilson (1975), from bottom to top of the units. Those facies belts indicate depositions ranging from restricted marine shelf lagoon shallow platform interior to basin margin (shelf) to open sea conditions (shelf facies – open circulation). Commonly the carbonate facies of the study area displays various sub-shallow marine depositional environments ranging from the shoreline carbonate deposits of low energy platform interiors (of inter tidal flat) and some offshore deposits (of shelf and open sea) deposits. These are described as follows with the model shown in (fig 6.4):

6.1.1. Restricted Marine carbonate facies

The Peloidal grainstone or Pelsparite samples obtained at the top margin of the carbonate deposit with frequent peloids and some calcispheres are documented as the evidences of tidal flats. Peloids correspond to fecal pellets and to small reworked mud particles. This sediment is common on tidal flats (Standard Facies Belt 8), but is found also in open-marine platform limestones (SFB, 7). Thus, we assign the sample to SMF Type 4. Sediments corresponding to this type occur, after Wilson, in open marine shelf environments as well as in shelf lagoons with open water circulation.

6.1.2. 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 of the Carbonate unit logged in the area have coarser grained deposits of redeposited wackestone- packstone-grainstone facies (MFT 3) those are dominantly intraclastic, various sized peloidal grains and some skeletal (like mollusks, echinoderms, ostracods, corals, foraminifers etc.).

The intraclastic rich and bioclastic peloidal packstone to grainstone microfacies layers of middle Jema section which are indicators of foreshoal environment are conformably overlaying 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).

6.1.3. 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 middle 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 to upper jema micritic limestone of slightly dominating lower energy deposit which outcropped well in the logged section is conformably overlaid by the bioclastic and peloidal wackestone to packstone. 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).

The massive mudstone outcropped and dominated layers of limestone in the section is the most typical example of carbonate deposits of low energy condition of outer shelf/ramp setting at basin margins or open sea conditions.

6.1.4. Shelf to Open Circulation Carbonate Facies

Carbonates of shelf and open circulation 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 layer in the studied section (MFT1) and the bioclastic wackestone layer (MFT2) in the logged section of the study area are the typical of low energy deposit of shelf to open circulation type. Wackestones and packstone are transitional between low energy mudstone environments. They are accumulated on platforms where current activity has been insufficient to remove out the mud (Flügel, 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). The source of the fine-grained carbonate sediment in this facies is largely calcareous algae and mollusks living in the environment, with coarser bioclastic accumulation from them (Flügel, 2004; Reading, 1996).

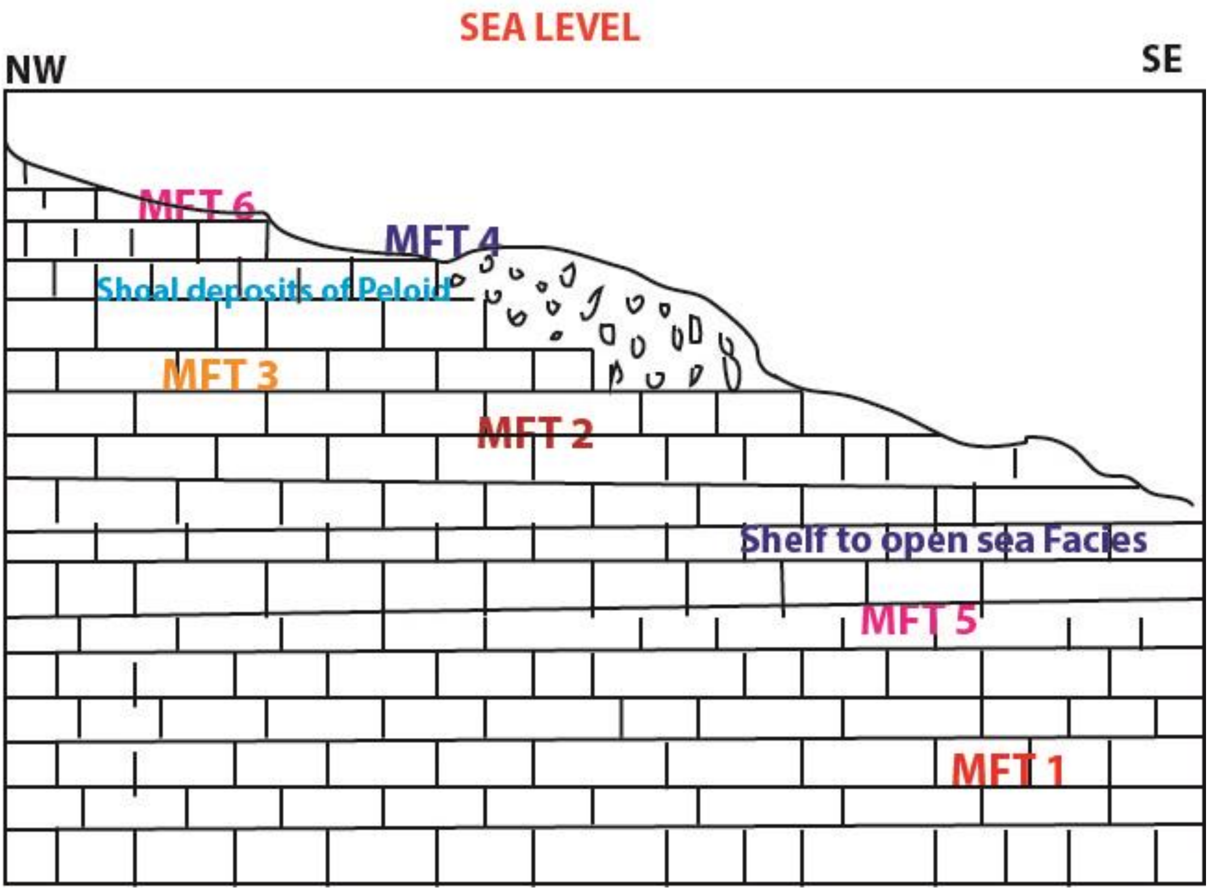

Fig.6.4: Schematic diagram showing depositional model of the Jema section carbonate successions in Lemi area.

6.2. Biostratigraphy and Age of the carbonate unit of Jema Section

The determination of relative age of the rock and the biostratigraphic correlation fossils recorded in the rock unit are very important; whereas for this purpose those fossils have to be index; which are defined as geographically widespread, rapidly evolving, abundant or easy to find in the rock record and easy to preserve and to identify.

The present study has been conducted North Shewa centeral Ethiopia, of the North western Ethiopian Plateau. In the section a thick Jurassic limestone unit was deposited with an age of Late Callovian to Kimmeridgian based on benthic foraminifera fauna by Bosellini et al. (1997) and an age of Oxfordian to Kimmeridgian based on the ammonite fauna by Matire et al. (2000).

In Ethiopia many scholars have done biostratigraphy for the Jurassic thick succession of limestone both in south, centeral and northern part of the Mesozoic carbonate deposits country; based on microfossils of foraminifers and macrofossils of Ammonites. Significant number of stratigraphically important microfossils of foraminifers are extracted and identified from Jurassic carbonate of the Jema section logged in this thesis has guided study to the suggestion of biozonation to the logged carbonate unit as follows:

The larger benthic Foraminifera obtained from the study area are stratigraphically significant, in the shallow water environments where they are the most important fossils, and where other markers like Ammonites and Calpionellids are not present. The stratigraphic value of the larger foraminifera, as well as the comparison with the biostratigraphic standards based on them in the Bilu basin; endorsed the dating through their assemblage observed in the analyzed carbonate unit.

Based on the presence of index foraminiferal fossils dominantly from the upper portion of the micritic limestone which is the middle portion of the Antalo limestone and the foraminiferal microfossils extracted and identified from the marly intercalated limestone unit in the upper most portion of this unit; which is the well outcropped (exposed) and logged section of the study area on the stratigraphic position of the Antalo limestone; the following biozonation has been made:

The assemblage of ***Pfenderina gracilis & Kurnubia cf. morrisi*** as an index foraminifer of Callovian age in associated with *Kurnubia palastiniensis*, *Bicazammina jurassica*, and *Redmondoides lugeoni*; obtained from the micritic layer of the Jema section; has to be dated entirely of Jurassic age particularly the span from the Callovian age predominantly the identification of *Redmondoides lugeoni*, these can be assigned the middle bed to the Late Jurassic.

Alveosepta jaccard as index foraminifera of Upper Oxfordian to Early Kimmeridgian in associated with *Nautiloculina oolithica*, *Nautiloculina circularis, Conicokurnubia orbitoliniformis*, *Pseudocyclammina lituus,* for Oxfordian to Kimmeridgian age. The *Alveosepta jaccardi* biozone was used previously by Ascoli (1981, 1988) and Williams et al. (1990) to characterize the Kimmeridgian of Canada and Sarfi and Yazdi-Moghadam (2016) as a Late Oxfordian –early Kimmeridgian zone in northwest of Iran.

In the study area of the logged section, genus *Kurnubia* and *Nautiloculina* Henson, (1948) as the two biozonation widely distributed in the Jurassic carbonate; which are also common in the carbonate sediments of the logged section of Jema whereas according to Henson (1948) *Kurnubia cf. morrisi* was used as the zonal marker for Callovian age.

Rock units which yield *Kurnubia palastiniensis* and *Nautiloculina oolithica* can be dated as Upper Jurassic (Oxfordian to Kimmeridgian) in age (Tasli, 2001; Velic, 2007). In particular the presence of *Alveosepta jaccardi* which dominated upper part of the micritic foraminiferal wackestone suggests the age of an Upper Oxfordian to Lower Kimmeridgian age (Sartorio &Venturini, 1988; Velic, 2007). Hence in this case, beds from which the rock sample coded as RS 03, RS 007, (Jema section) and RS 012 (Jema section) can be precisely dated as Kimmeridgian, while the underlying beds can be dated as Oxfordian.

Alveosepta jaccardi is an index species, of the Middle-Late Oxfordian-Early Kimmeridgian age. The association of *A. jaccardi* with *K. palastiniensis* is considered as terminal Oxfordian-Early Kimmeridgian (Bouaouda et al., 2004). (Maync, 1960; Hottinger, 1967; Septfontaine, 1981; Pelissier & Peybernes, 1982; Pelissier et al., 1984; Septfontaine et al., 1991; Tasli, 1993; Luperto-Sinni & Masse, 1994; Bassoullet, 1997). Septfontaine (1981) also proposed an *A. jaccardi* biozone, Middle Oxfordian to Early Kimmeridgian).

6.3. Composite Stratigraphy of Jema Section

From the field investigations of this thesis work; the carbonate unit of the Jema section in the vicinity of Lemi, have been logged to have about 157m thick and some part of the carbonate unit undelaying the outcropped and the logged unit is unexposed and carbonate unit of the studied section is ranked the biostratigraphic age ranged of from Callovian-Kimmeridgian.

Based on the index foraminifers of *Pfenderina gracilis* and *Kurnubia cf. morrisi* in association with *Kurnubia palastiniensis*, *Bicazammina jurassica*, and *Redmondoides* *lugeoni*; for the lower bed of Callovian to Oxfordian and *Alveosepta jaccardi* as index foraminifera of Upper Oxfordian to Early Kimmeridgian in associated with *Nautiloculina oolithica, Nautiloculina circularis, Conicokurnubia orbitoliniformis, Pseudocyclammina lituus,* for Oxfordian to Kimmeridgian age for the upper Jema.

The carbonate succession is superimposed by the Mugher formation in the study area and at the bottom the lower sandstone unit (Adigrat Sandstone) in the vicinity of Ejere which is dated as Triassic-Bajocian (Bosellini, 1989) also the Mugher mudstone (Mugher formation) at Lemi is superimposed by the Upper sandstone (Debrelibanous sandstone) which is dated about Aptian-Albian (Balemwal Atnafu and Tesfaye Kidane, 2012), giving the overall composite Mesozoic stratigraphy of the area, as given in (Fig.6.1).

The detailed field description for each layers of the carbonate unit have been given in chapter three and it facies in chapter four of this thesis work; but under this section, the overall distinctions among these layers; based on the results obtained from the microfacies analysis, diagenetic descriptions, depositional patterns and biostratigraphic senses have been elaborated in detail as follows:

The outcrop of the carbonate unit; as the lower exposed carbonate unit in the Jema section is characterized by marly to silty texture and light gray to white gray for weathered and fresh color respectively. The rock samples collected from this unit is characterized by the les in the variety of fossil faunas that can been perceived with naked eye and under the petrographic microscope in the lower portion and in the middle portion, on the other hand the micritic layer is more abundant in foraminiferal fauna at the upper most part including the *Kurnubia palastiniensis, Alveosepta jaccardi,* and *Nautiloculina oolithica*.

The presence of those large benthic foraminiferal fauna with a very narrow life span suggested the carbonate unit to be rated in an raged from the Callovian time; which is supposed to be deposited in the open sea circulation and the presence very fine sediment with absence of invertebrate macro faunal shell fragments is an indicative of non-turbulence condition during the deposition of the carbonate sediment.

The overlaying unit; which is marly intercalated bioclastic wackestone containing echinoids, gastropods, bivalves and brachiopods; the bioclastic wackestone is gradually up graded in to fossilferous limestone unit at the upper most part of the layer; whereas the top part is dominated by the shell fragments of brachiopods, bivalves.

Due to the shallowing upward the upper most part of the carbonate unit of the logged section is documented with the occurrence of peletic, stromatolites and fossilferous limestone unit which are an indicative of offshore and inshore (shore) depositional environment.

The thick Jurassic carbonate unit logged in Jema section documented in the Bilu Nile basin; is an evidence to the transgression of Indian ocean in the region of east Africa and covered by evaporites (Gypsum unit) as the top is another conformational evidence for the marine regression from the land and the basin with lagoonal depositional environment; subsequently the continental fluvial channel deposit of the upper sandstone (Getaneh Assefa, 1991) is another evidence; the illustration to the logged section of Jema in the vicinity of Lemi from the lower exposed micritic to the upper fossilferous unit in the stratigraphic position has been shown in (fig 6.1) below.

In the Abay basin, five formations are informally established for the Mesozoic sediments (Getaneh Assefa, 1979, 1991) from top to bottom as the Upper most sandstone unit (Debre Libanos sandstone), Muddy sandstone unit (Mugher mudstone), Limestone unit (Antalo limestone), Gohatsion Formation (Abay beds) and Lower sandstone unit (or Adigrat sandstone). All of these Mesozoic strata in most parts of the country in the Abay basin are masked by tertiary volcanic rocks; however the carbonate unit was the main target.

Based on the presence of index (zonal markers) of foraminifer fossils such as, *Pfenderina gracilis* & *Kurnubia cf. morrisi* in association with *Kurnubia palastiniensis, Bicazammina jurassica,* and *Redmondoides lugeoni* from middle Jema section of carbonate rocks are suggests the age to be entirely of Jurassic age particularly spans the Callovian to Oxfordian age. Whereas the presences of *Alveosepta jaccardi* which is the index foraminifer of Upper Oxfordian to Early Kimmeridgian in associated with *Nautiloculina oolithica, Nautiloculina circularis, Conicokurnubia orbitoliniformis* and *Pseudocyclammina lituus,* for Oxfordian to Kimmeridgian age for the upper Jema. So that Callovian to Kimmeridgian age was dated for the carbonate unit of Jema section.

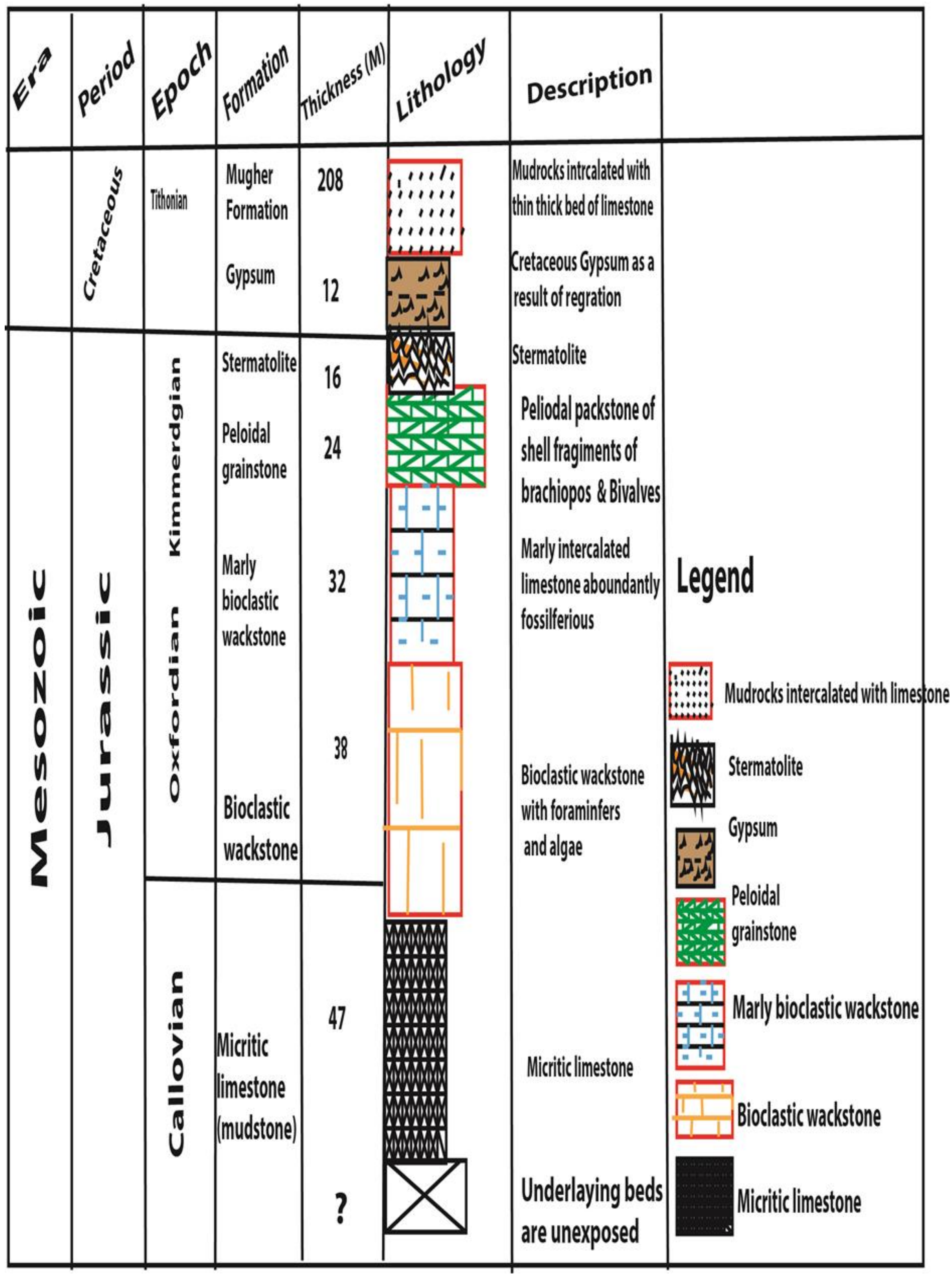

Fig. 6.1: Stratigraphically logged Jurassic carbonate of the Jema section in the vicinity of Lemi

6.4. Correlation

The thick Jurassic carbonate unit logged in the Jema section of the study area is situated; in the northwestern Ethiopian plateau of centeral Ethiopia; which is comparable with the Antalo Limestone. The carbonate unit deposited in the Bilu Nile basin called the Lagajima limestone (Aubry, 1886) which is an equivalent of the Antalo limestone of Mekele and Urandab formation of Ogaden those are correlable in regional level even if the thick varies through the basins. In Ethiopia since detailed geological mappings started and through the time up to today different Authors and institutions have done facies studies and developed stratigraphic loges for different purpose.

The logged section of the study area; has been correlated locally and regionally with some of the chronostratigraphic equivalents and lithologically similar deposits, identified and established by different workers and authors from some proximal area of NW Ethiopia plateaus of the Bilu Nile basin in local range and within other basins of Ethiopia (Mekele from the NW and Ogaden basins from the SE) in regional sense. The correlation that has been made in local and regional wise has been shown in (Fig.6.2 & 6.3) below.

6.4.1. Local Correlation of Jema Section

Mesozoic deposits in the NW parts of Ethiopia plateau of the Bilu Nile basin; in some local areas and sections likes Mugher, Gundo Meskel and Ejere with the Jema section which is under investigation in this study (Serawit Amene and Tamrat Mojo, 1999, 1996).

The logged sections in the previous studies are correlable with the present studied section of Jema in the vicinity of Lemi locally since they are among the sections logged in the Abay basin of the NW Ethiopian succession of the carbonate unit as shown in (Fig. 6.2.) below.

These logged sections of the local areas are also located to NW Ethiopian plateau of the Abay basin like the present studied area, at different distances, within Shewa region of centeral Ethiopia, similar to that of present study area of Lemi. Lithologically the locally correlated logged sections of the Abay basin are relatively similar in the thickness of the documented Antalo limestone; moreover they are also comparable in the micro and macro fossil faunas in the units they contain.

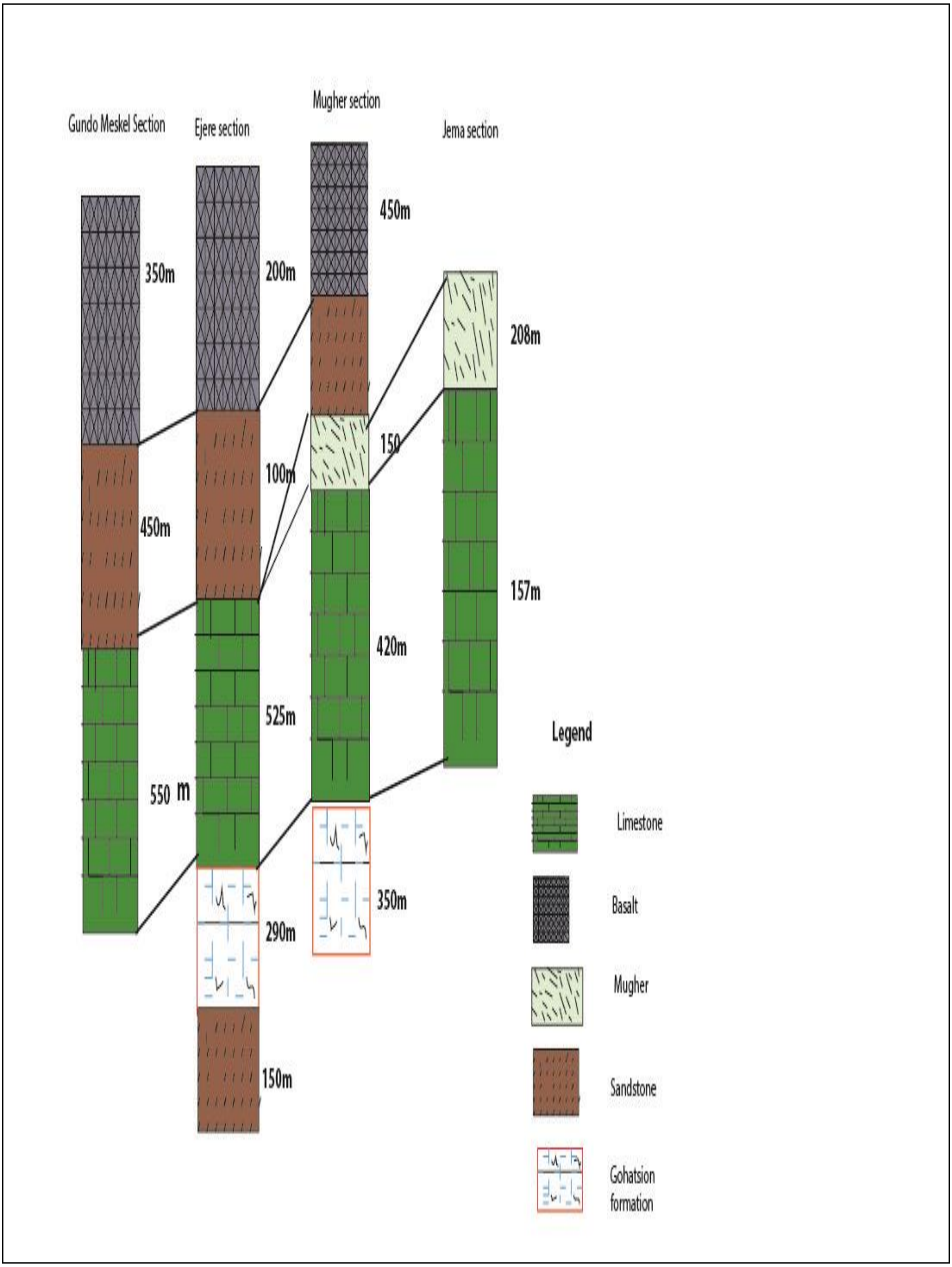

Fig. 6.2: Mesozoic stratigraphy correlation between some areas from NW Ethiopian plateau. Sources: Ejere and Gundo Meskel, (Ministry of Mine and Energy, 1996), Jema section (present work) and Mugher (Getaneh, 1981).

6.4.2 Regional Correlation of the Jema Section

The major transgression of and Indian ocean in to the east of Africa; from the Early Jurassic – Oxfordian time is most likely 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 in different basins particularly the Antalo limestone in the Bilu Nile basin and in the Mekele outlier and Urandab Formations in Ogaden basin (Bosellini, 1989; Russo et al., 1994 and Abbate et al., 1974).

In regional sense the larger, extensive Jurassic carbonate deposit exposed and documented in three regions of two vicinities in Ethiopia; which is an indicative of this marine transgression in to Ethiopia including: the Mekelle Outlier with in the NW Ethiopian plateau in north part, the Blue Nile Basin in central Ethiopia with in NW plateau and the Ogaden Basin in the SE (including western Harrarghe region and Dire Dawa area).

Very little detail carbonate microfacies works are done and entirely no any works of the micropaleontological analysis has been made on these carbonate units of the basins; this makes the correlative work difficult based microfacies and micropaleontology throughout all these basins.

The carbonate unit in the Blue Nile basin (Antalo Limestone) is considered to be correlative with the carbonate units in Mekelle outlier in the northern part of Ethiopia and Urandab Formation of the Ogaden Basin in the southeastern Ethiopian plateau regional geological setting.

In this thesis work, only the general chronological and lithological correlation among Jurassic deposits within those major Mesozoic sedimentary basins of Ethiopia (Mekele outlier, Blue Nile basin and Ogaden basin) and the logged section of the study area of the Bilu Nile basin were attempted in this work, as shown in (Fig.6.3), and described in detail.

In Blue Nile basin of Ethiopia, situated in the centeral Ethiopia of the NW plateaus, with a thick Jurassic carbonate succession of about 420 m, also called 'Antalo Limestone Formation' are described by Russo et al. (1994) and Getaneh Assefa (1979, 1980, 1981 and 1991).

This succession is found conformably overlying the Gohatsion Formation of about 450m; which has on correlable unit in Mekele outlier and correlable with its equivalent unit in Ogaden basin of the Hamanlei formation and the carbonate unit (Antalo limestone) is generally subdivided into three parts; lower, middle and upper limestone. The lower part is consisting of a 180m devoid of fossilferous 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; but this part is not exposed in the section of Jema in the vicinity of Lemi.

According to Russo et al. (1994) the middle part often referred as marly limestone consists of about 200m thick highly fossilferous inter-bedding of marly limestone, marls and silty limestone in texture. A shelf to open marine environment was inferred to this unit; based on the presence of some ammonites, Terebratuline associated with Nanogyra, rhynchonellid brachiopods and infaunal siphon-feeders (by the same author). The upper part reaches a thickness of 50m.

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 (*Pfenderina sp.* and *Nautiloculina oolithica*) at the base of the Antalo Limestone suggests Callovian age (Russo et al. 1994). While the occurrence of *Kurnubia palastiniensis, Parurgonina caelinensis, Conikurnubia sp*. and *Salpingoporella annulata* at the top of the unit indicates a Kimmeridgian age.

The middle and the upper part of the regionally described Antalo limestone of the Abay basin (Russo et al. 1994) is more or less correlable with the logged and exposed unit of Antalo limestone in the vicinity of Lemi; whereas the lower part of the Antalo limestone is not exposed in the logged section of the study area.

In the Mekele outlier of NW Ethiopia, the carbonate deposits is also known by the name 'Antalo Limestone' were described in detail by Levitte (1970), Beyth (1972a, b), and Bosellini et al. (1997). The thickness of the succession ranges from 300m in the West to 800m in the East. Beyth (1972a, b) identified four facies for this unit. Those are (i) a cross-bedded sandy oolitic and coquina with minor amount of marl and a few chert beds, with microfauna including mainly corals, gastropods, and echinoids, (ii) interbedding of marl and lithographic limestone with abundant brachiopods and some algal and chert beds, (iii) cliffs of coral and algal reef limestone's interbedded with marl and biostromes, and (iv) black to grey microcrystalline limestone interbedded with marl.

Bosellini et al. (1997) attempted to subdivided the same limestone unit into four depositional sequences, which are composed of thickening and shallowing up cycles and also he noted that the limestone succession was deposited in a homoclinal ramp or on a wide cratonic margin gently dipping to the southeast and they assigned the age of the Antalo limestone to be Late Callovian to Kimmeridgian age.

Accordingly, the Antalo limestone of the Mekele basin is correlable more with the middle and upper sub-unit of the present studied carbonate unit of Lemi area. There is no correlable limestone unit for the Lower sub-unit of the present studies in Mekele basin similarly not exposed in the studied section.

According to (Abbate et al., 1974; Worku and Astin, 1992; Hunegnaw, 1998), the carbonate unit of the Ogaden basin; a threefold Jurassic partition is present overlying the Adigrat sandstone at the bottom: Lower, Middle and Upper Hamanlei Formations which is correlable with the Gohatsion formation of the Bilu Nile basin and an age of early Jurassic to Callovian has been assigned to this syn-rift marine sequence.

The upper Hamanelei formation which is correlable with the Gohatsion formation of the basin is lithologically characterized by: limestone with intercalated shales (in the lowermost section); anhydrite, dolomite and limestones with local oolitic and stromatolitic beds (in the middle section) and bioclastic oolitic limestones (in the uppermost section).

The Urandab Formation corresponds to the maximum flooding sequence deposited during the break-up transgression (Callovian- Oxfordian), and is composed of dark, laminated marls and limestone's containing a pelagic marine fauna. The Gabredarre Formation (Upper Jurassic) represents a passive-margin sequence comprising bioclastic, locally oolitic and reefal limestones; these limestones were deposited in offshore bars and small reefal build-ups.

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

From these sequences, there is no carbonate correlative for lower and middle Hamanlei Formation; they are most probably correlable with the Adigrat Sandstone Formation of the Dire Dawa of the Ogaden basin.

In Ethiopia, overall regression was thought to prevail during latest Jurassic (Tithonian) and Berriasian times (Assefa, 1991; Schimidt and Werner, 1998) which terminate carbonate deposits; throughout most part of Ethiopia clastic deposits overlain carbonate unit starting from this time.

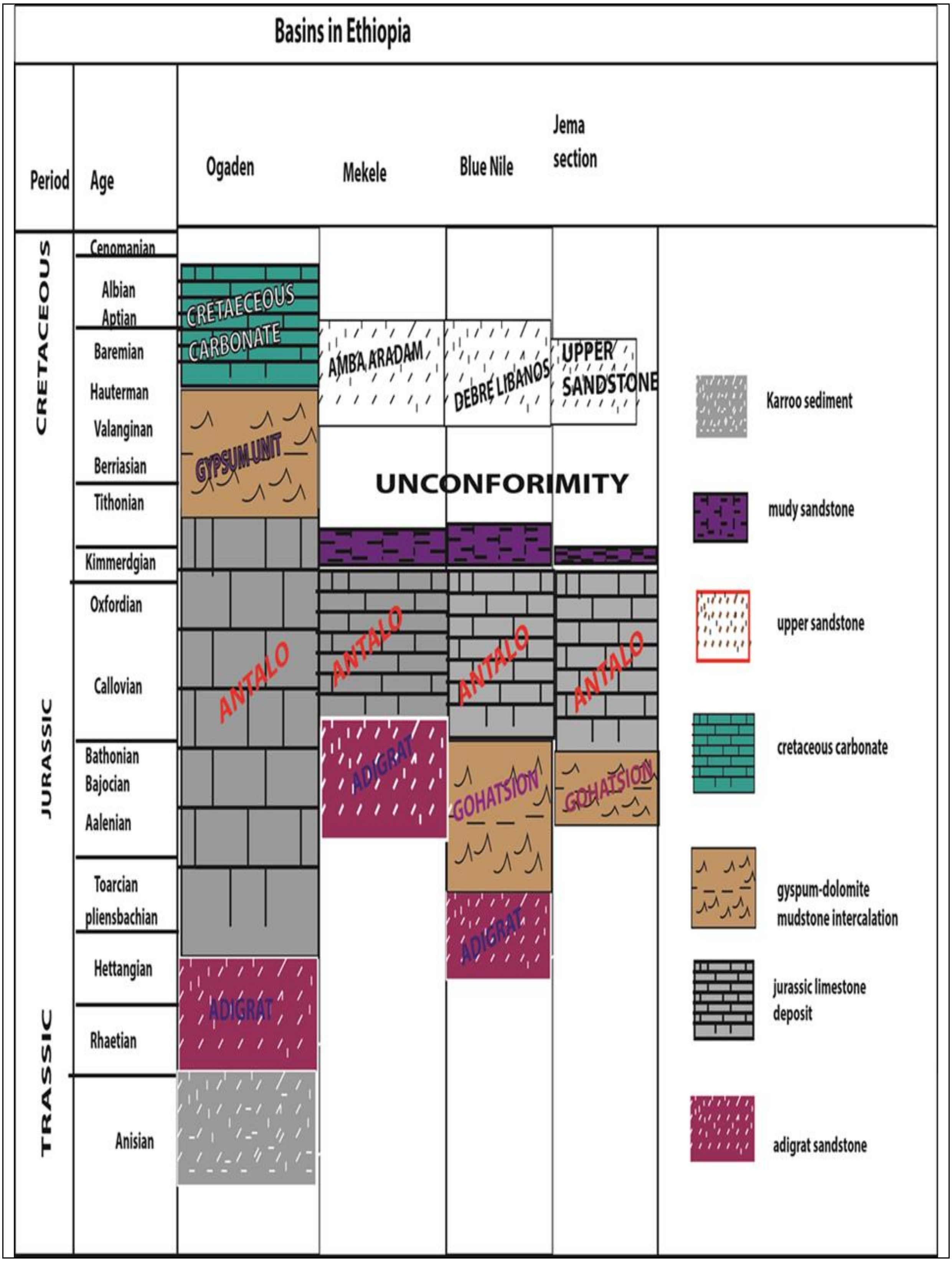

Fig.6.3: Mesozoic stratigraphy correlation throughout Ethiopian basins (Mekele, Blue Nile, & Ogaden) Sources: Mekele (Levitte, 1970; Beyth, 1972a& b; Bosellini et al., 1997), Blue Nile (Russo et al., 1994), Ogaden (Abbate et al., 1974; Worku and Astin, 1992; Hunegnaw, 1998; Shigut, 1998).

CHAPTER SEVEN

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusion

The carbonate sedimentary succession of the study area has been identified; the thick Jurassic carbonate succession of the area is explored through the combined work of field investigations, stratigraphy, petrographic study (microfacies analysis) and macro and micropaleontological studies the Jurassic carbonate unit of Jema section conclusions have been adopted as follows:

Based on the field investigation and the laboratory analysis made to the carbonate unit deposited in the study area; six different microfacies are identified to determine the depositional environment and different biozones of foraminifera assemblage was suggested to determine the biostratigraphy of the unit, with regard to the Bilu Nile basin the study have suggested and concluded that the outcrop is the best representative to the middle and upper part of the Antalo limestone of the Callovian to Kimmeridgian age. The studied outcrop as a sharp cliff in the studied area have been subdivided into six lithofacies ranging from deep shelf marine calm water mudstones to shallow marine high energy oolitic grainstones.

Based on the lithofacies identification made along with their carbonate components (skeletal and non-skeletal grains) the depositional environment of the Antalo limestone of the logged section in the study area has been considered to be from shelf facies to open circulation to the intertidal zone through the shoal to the restricted marine environment of the shallow marine environment.

The identified microfacies types of the logged carbonate unit based on the thin section analysis, field observation and paleontology were divided into six major microfacies types (MFT 1-6), those are designated as: MFT (1) Micritic microfacies, 2) Bioclastic mudstone microfacies, 3) of bioclastic wackestone to packstone facies, 4) peloidal grainstone microfacies, 5) Foraminiferal wackestone facies and 6) stromatolite facies. However all the identified facies where described, interpreted and compared with SMFT of (Wilson, 1975).

Evidently each facies types were again compared with facies belts of Wilson (1975) ranging from open sea to restricted platform from top to bottom respectively; as their detail respective matching were given in microfacies analysis section of the pervious chapters.

Therefore, the microfacies analysis made in the carbonates unit of the Jema section; have put forward is that the unit was deposited in shallow marine conditions of: inter tidal zone for stromatolitic facies (MFT6) which is compared with MFT 20 of Wilson, whereas the (MFT3 & MFT4) show deposition in shoal restricted environment to shelf and shoal environment and some shelf facies to open sea depositional condition of (MFT1, MFT2 and MFT5).

Two foraminiferal ranges have been identified in the outcrop based on the occurrences of 30 species of foraminifers and Ostracods described are: *Alveosepta jaccardi (Schrodt, 1894), Bicazammina jurassica* (Haeusler, 1890*)*, *Valvulina lugeoni* (Septfontaine,), *Redmondoides lugeoni* (Septfontaine), *Nautiloculina oolithica* (Mohler,) *Charentia evoluta* (Gorbachik, 1968), *Kurumbia palastiniensis (*Henson, 1948*) Pseudocyclammina lituus (Yokoyama), Nautiloculina circularis, Conicokurnubia orbitoliniformis* (Septfontaine,), *Kurnubia cf. morrisi (*Redmond), *Pfenderina sp.*, are among them respectively.

The age of the logged carbonate unit in the Jema section is determined and dated to be Jurassic, particularly Callovian-Oxfordian by occurrence of index fossils *Kurnubia cf. morrisi, Kurnubia palastiniensis* and *Alveosepta jaccardi* with their assemblages.

The Jurassic carbonate succession of the logged section of Jema in the vicinity of Lemi is correlable with some of the chronostratigraphic equivalents and lithologically comparable deposits in the local nearby areas of NW Ethiopia plateau of the Bilu Nile basin (Ejere, Gundo Meskel and Mugher). Regionally it is correlated to other sedimentary deposits of Ethiopia basins (Mekele, Blue Nile and Ogaden basins).

The carbonate unit of the study area as it is located in the Bilu Nile basin is called the Antalo limestone; which is equivalent to the carbonate unit in the Mekele outlier whose name is originally given at the village of Antalo in Tigray region in the north and also correlable the Urandab formation of the Ogaden basin in the south chronostratigrphically and lithostratigrphically.

7.2. Recommendations

This study covers the facies analysis for the interpretation depositional environment, micro and macro fossil studies (paleontology) and biostratigraphy of the Jema stratigraphic section of the Lemi area. However, the following recommendations were given for further works that goes beyond the present thesis work, for additional values rather than the academic purpose: The Mesozoic stratigraphy of Abay River Valley (Bilu Nile Basin) seems that it was well established, but to define its lateral variations and continuity within the Abay Basin still it needs some more detailed studies at particular selected sites in the basin.

As a various workers established detailed stratigraphy; is that the Antalo limestone to have a thickness of about 400m - 420m; but the actual thickness of the limestone unit cannot be established in the study area due to the lower unit (presumably) the Abay beds are not exposed in the study area. However, the thickness of the limestone both at Dufa and Jema has been recorded up to 157m where larger thickness of the limestone is not exposed and it is underneath the river beds. This indicates the enormous nature of the limestone resource in Bilu Nile basin in general that require further exploration and evaluation of industrial minerals in the basin.

This thesis work covers an interpretation of depositional environment on the bases of microfacies study through the microscope, macro and micro paleontological studies to assign the biostratigraphy of the carbonate unit of the Jema stratigraphic section. Identification of the depositional environment was based on the field observations made and microfacies analysis through petrographic studies of the rock samples.

The identification of the facies, the collection and observation of the field in such a short time span may face ambiguity in conveying an accurate determination of depositional environment when it is applied in such a small scale study areas; so that such a work needs detailed facies studies and different data sources including a precise field records of geological and paleontological data as well as sampling strategies that consider the vertical and lateral variations in these data are vital for the success of microfacies studies.

Laboratory methods study microscopic features and mineralogical and geochemical data, particularly microfacies analysis of more sections with more or less uniformity in sampling. Therefore, for better understanding of the depositional environment of the study area, detail field and microfacies studies with sufficient time, resources, and budget in the sections has to be done.

The carbonate sediments of an area comprise abundant varieties of skeletal grains; these can reveal much interesting information for biofacies, paleoclimate, as a petroleum and oil reservoirs and Paleoenvironmental studies; Furthermore, detailed biostratigraphic, micropaleontological and macropaleontological research works over the area will be worthy. Since thick Jurassic carbonate succession is deposited in the area; needs farther studies that can hold an attention from the cement and byproduct factors to meet the national demand of the construction industry of the country and the region of east Africa.

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APPENDIXES

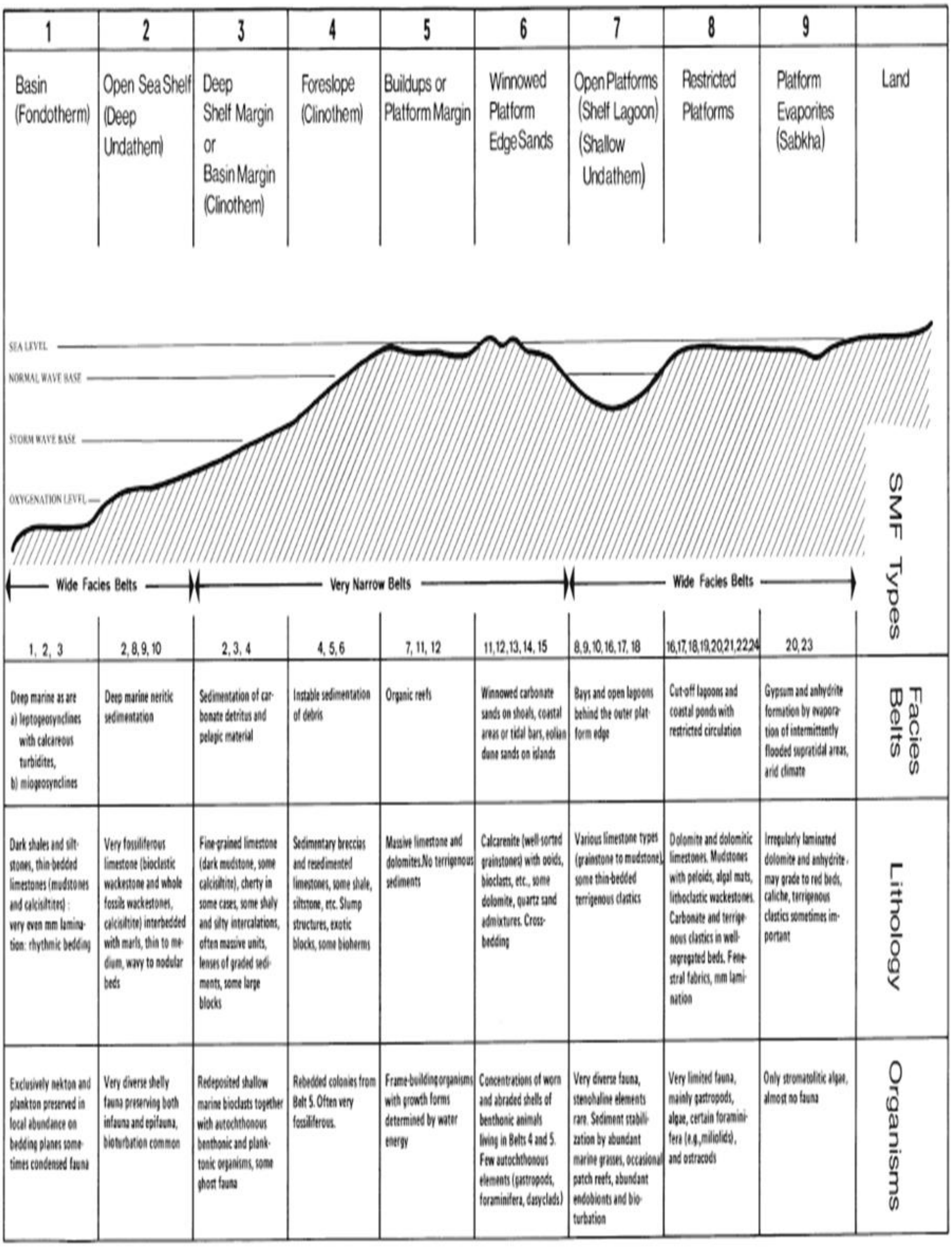


Fig. 55. Facies scheme after Wilson (1975). Sequence of the Standard Microfacies Types

Appendix 1: Idealized sequence of Standard Facies Belts from, L. Wilson (1970, 1974).

Plate 1: Ostracods extracted from the marl sediments

A. *Cypridea sp.* Right side of a shell that is imperfect posteroventrally

B. *Cypridea sp.* Image is obtained under x 35 magnification

C. *Homocytheridea posteriohumilis* (BLASZYK, 1967); x 35 magnification

D. *Chlamydotheca arcuata,* Image is obtained under x 35 magnification

E. *Procytheridea. Sp.* Image is obtained under x 35 magnification

F. *Baridia sp.* Image is obtained under x 35 magnification

G. *Pirileberis remota* (Grekoff,) lateral view of the right valve

Note; all below enumerated ostracodal fossil specimen images are taken under Stereozoom binocular microscope with magnification of x35.

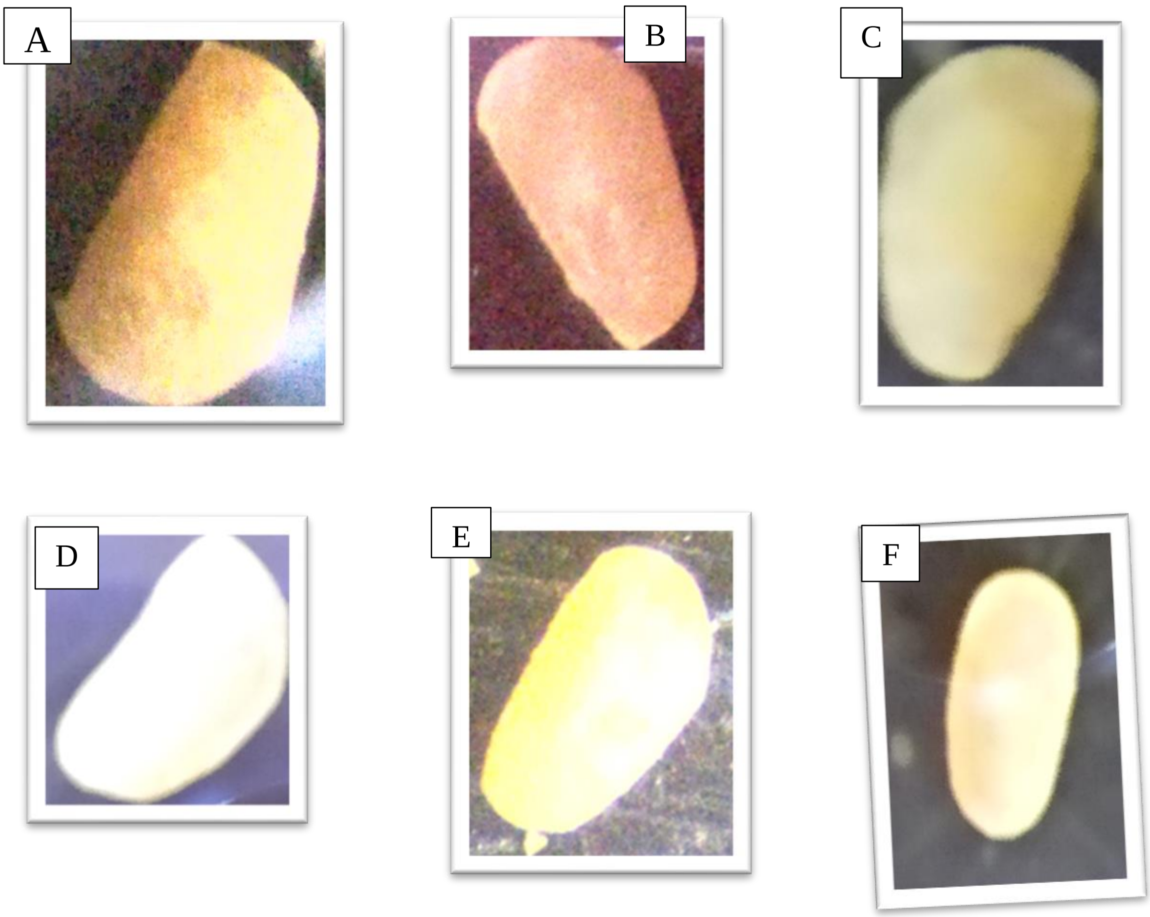


Plate 2: Foraminifers extracted from the sediments

A. *Pseudonodosaria vulgata (*Bornemann, 1854*)* under x 35 magnification

B. *Pseudonodosaria vulgata* (Bornemann, 1854) under x 35 magnification

C. *Pfenderina gracilis* (Redmond, 1964) under x 35 magnification

D. *Pseudomarssonella plicata* (Redmond, 1964) under x 35 magnification

E. *Pseudomarssonella reflexa* (Redmond, 1964) under x 35 magnification

F. *Nautiloculina circularis* (Said & Barakat); apertural view; X 35.

G. *Nautiloculina circularis* (Said & Barakat); under x 35 magnification

H. *Pfenderina neocomiensis* (Pfender;); under x 35 magnification

I. *Choffatella sp*.(Schlumberger, 1858) under x 35 magnification;

J. *Choffatella* cruciensis, (Pictet & Renevier, 1858) k1s3, under x35 magnification

K. *Choffatella decipiens* (Schlumberger, 1858); under x 35 magnification

L. *Lenticulina muensteri* (Roemer); under x 35 magnification

M. *Pseudomarssonella biangulata* (Redmond,); under x 35 magnification

N. *Pfenderina neocomiensis* (Pfender, 1938); under x 35 magnification

O. *Pfenderina neocomiensis (Pfender, 1938); under x 35 magnification*

P. *Kurnubia wellings* (Henson, 1948); under x 35 magnification

Note; all above listed foraminiferal fossil specimen images are taken under Stereozoom binocular microscope with magnification of x35.

Plate 2: Foraminifers extracted from the sediment


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P

Plate 3: Foraminifers identified from thin section

A- *Alveosepta jaccard* (Henson,);

B- *Valvulina lugeoni* (Septfontaine,);

C- *Kurnubia Cf. morrisi* (Redmond,);

D- *Nautiloculina circularis* (Said & Barakat,);

E- *Nautiloculina oolithica* (Mohler,)

F- *Conicokurnubia orbitoliniformis* (Septfontaine,);

G- *Pfenderina sp.* (Pfender,);

H- *Redmondoides lugeoni* (Septfontaine, 1977),

I- *Alveosepta personata* (Tobler,); axial section *Kurnubia palastiniensis* (Henson)

J- *Kurnubia palastiniensis* (Henson,)

K- *Pseudocyclammina lituus* (Yokoyama, 1890); subaxial section

L- *Conicokurnubia orbitoliniformis (*Septfontaine, 1977);

M- *Alveosepta personata* (Tobler,) ; axial section

N- *Bicazammina jurassica* (Haeusler, 1890);

O- *Charentia evoluta* ();

Plate 3 Foraminifers identified from thin section

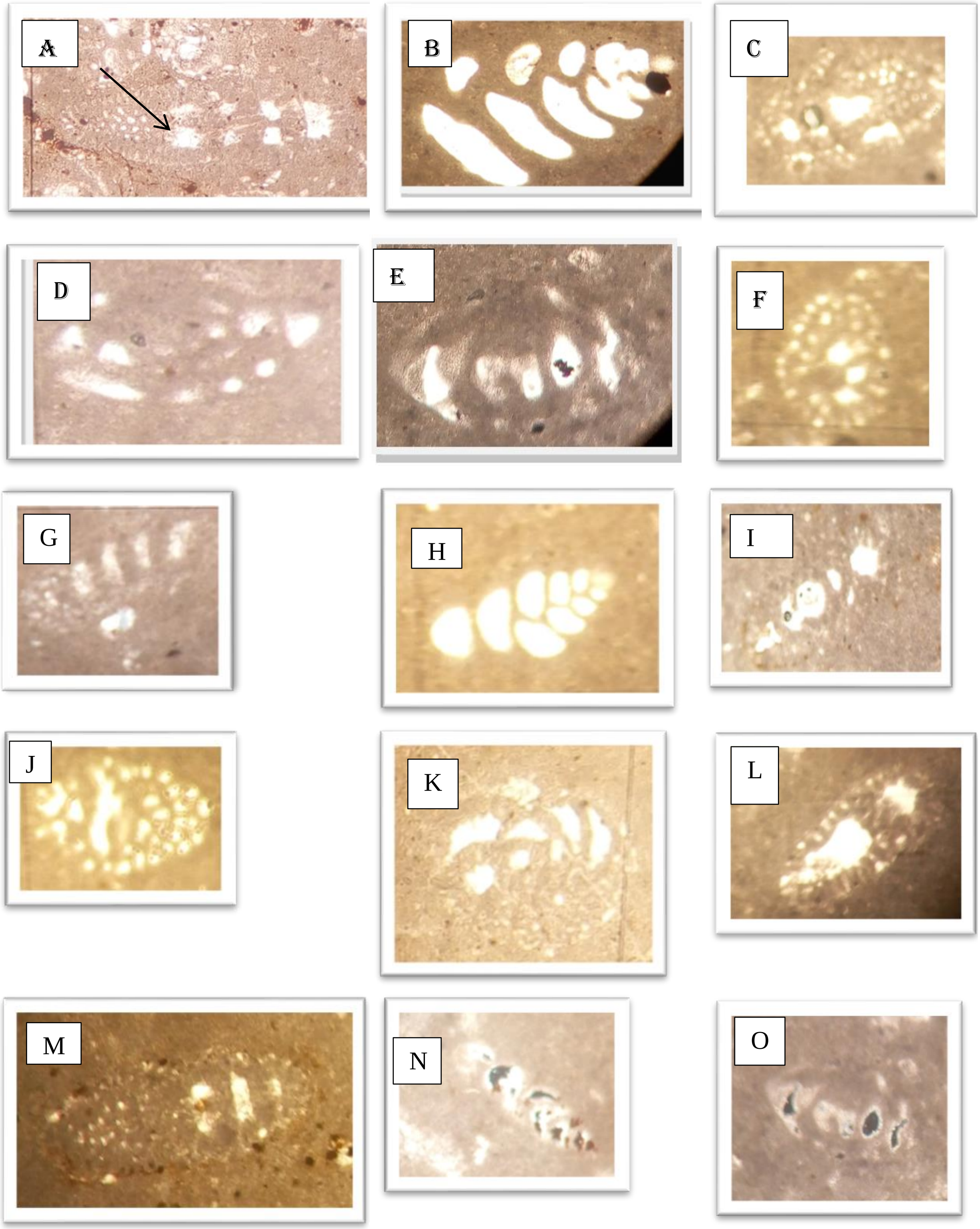


Plate 4: Gastropods

A. *Ampullospira bajocensis* (D'Orbigny, 1852); Jema section.

B. *Ampullospira (Pictavia) bajocensis (D' orbigny, 1852)*

Plate 5: Calcareous Algae identified from thin section

A. *lvanovia Khvorova.*
B. *Salpingoporella annulata Carozzi*
C. *Mesoendothyra croatica*
D. *Trinocladus tripolitanus*
E. *Trinocladus radoicicae*
F. *Trinocladus radoicicae*
G. *Acroporella hamata n. sp.*
H. *Salpingoporella cf. grudii*

Plate 5: Calcareous Algae identified from thin section

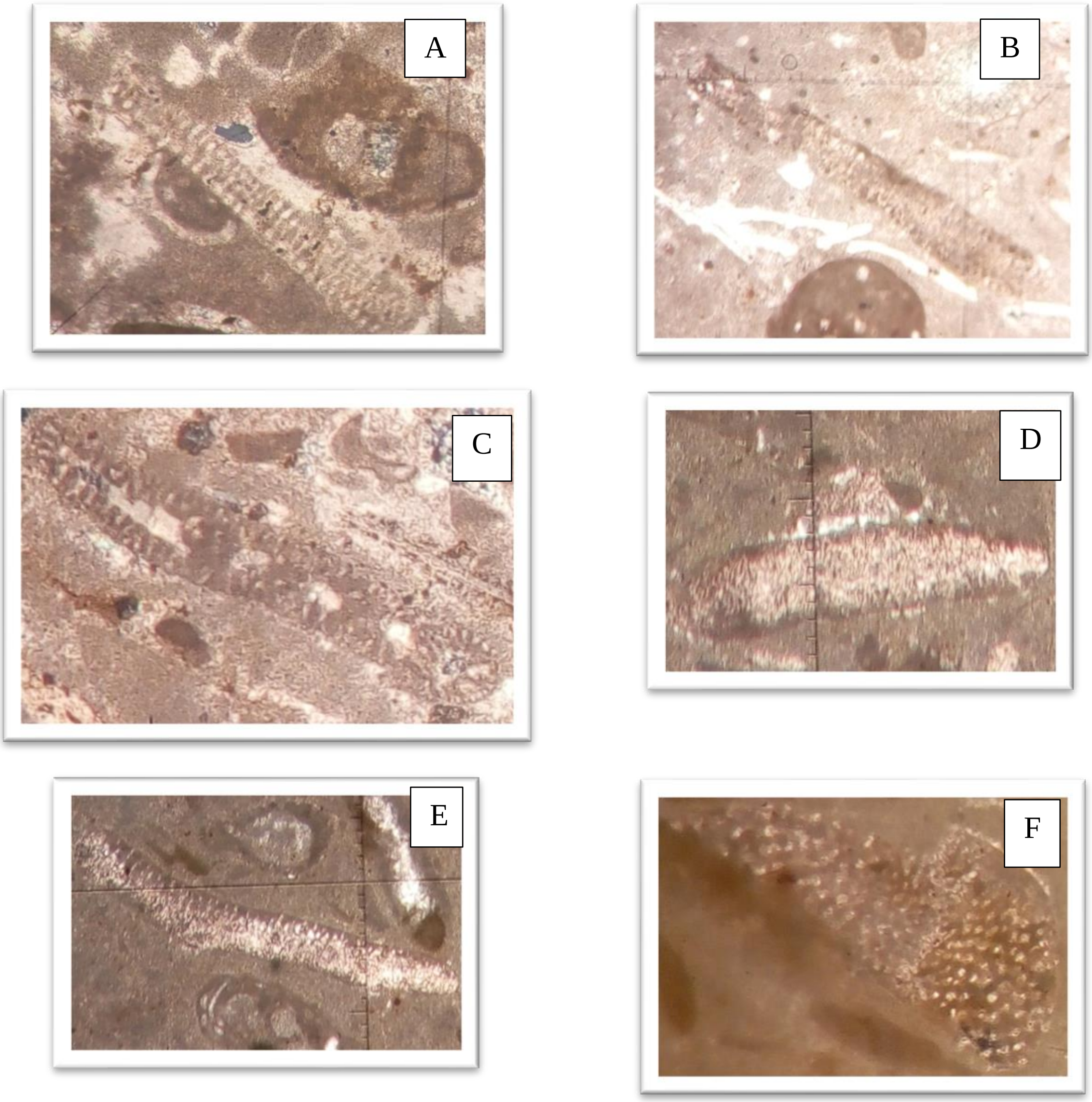
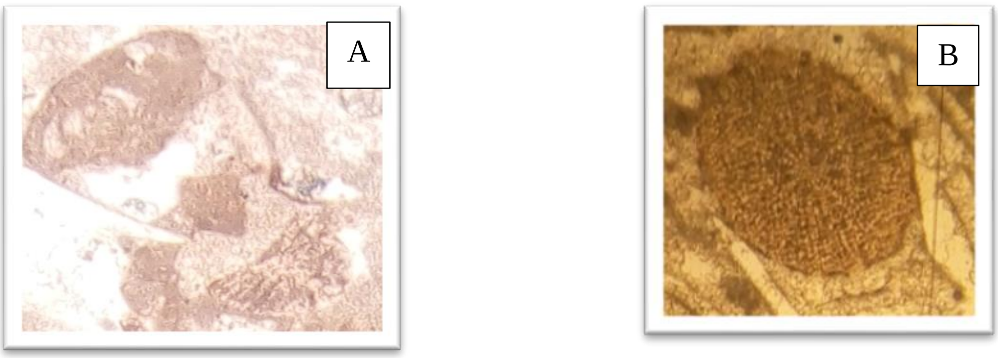


Plate 6 Coral from the thin section

A. Reef corals: Transversal section of *Calamophylliopsisflabellum* (Michelin).
B. Growth type. Transversal section of *Stylosmilia corallina* (Koby).



Declaration

This is to declare that the thesis prepared by **Geremu Gecho Arka,** entitled: Facies and Microfossil Analysis of Jurassic Carbonate Unit in Lemi area (Jema section) Northern Shewa; Central Ethiopia and submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences (Paleontology and Paleoenvironment) compiles with the regulations of the University and come across the accepted standards with respect to the originality and quality. I, the under signed candidate, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used in this thesis have been dully acknowledged.

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Geremu Gecho (Student) Date

This is to certify that the above declaration made by the candidate is correct to the bests my knowledge and it has been submitted to examination with my approval as a university advisor.

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Dr. Balemwal Atnafu (Advisor) Date