ADDIS ABABA UNIVERSITY

SCHOOL OF EARTH SCIENCE

PALEONTOLOGY OF THE JURASSIC CALCAREOUS UNIT AT SHEKET, SECTION MEKELLE BASIN, NORTHERN ETHIOPIA

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Addis Ababa, Ethiopia

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A thesis submitted to

The School of Earth Sciences of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Geological Sciences (Paleontology and Paleoenvironment)

By: Rahwa Gebrehiwet

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This is to certify that the thesis prepared by Rahwa Gebrehiwet entitled: "Paleontology of the Jurassic Calcareous unit at Sheket section, Mekelle Basin, Northern Ethiopia" and submitted in partial fulfillment of the requirements for the degree of Master of Science in Geological Science (paleontology and paleoenvironment).

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Addis Ababa, Ethiopia

June 2024

DECLARATION

I hereby declare that the thesis, "**Paleontology of the Jurassic Calcareous unit at Sheket section, Mekelle Basin, Northern Ethiopia**" is my original work, carried out under the supervision of Dr. Balemwal Atnafu. It has not been submitted to any university or other institution for the purpose of receiving a degree or diploma program and all sources of materials used for this thesis are duly acknowledged.

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This is to verify that the candidate's above declaration, which has been submitted for review with our consent as university advisors, is authentic to the best of our knowledge.

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ABSTRACT

The Mesozoic sediment rock in Ethiopia outcrop in three different area Mekelle basin, Abay Basin and Ogaden basin. In Mekelle basin the Mesozoic carbonate unit studied in different aspects. The detail facies and paleontological of studies have been conducted in sheket section. This study main aim is to detail investigation of micro and macro paleontology of calcareous unit in the Sheket section by investigates field observation and Petrographic analysis. By using that method micro and macro fossil, the age and the paleoenvironmental was able to determine. Based on the field observation by describe the thickness, texture and color different units were recognize: bedded and Micritic Limestone mostly interbedded with Marl, calcareous shale and Fossiliferous limestone, Marl which gray color and found interbedded with mostly with micritic and fossiliferous limestone but also with calcareous shale, fossiliferous limestone have brown color and have macro sized of bivalve fossil and calcareous shale have laminated and Fissility nature mostly found intercalated with marls. In addition to field investigation twenty thin sections were examined by using Petrographic microscope. Based on both Petrographic analysis and field investigation ten Microfacies type have been recognizing: Bioclastic packstones/Floatstone, Foraminifera Bioclastic/ packstone, Oobiosparite/grainstones, Oopelbiomicritic/wackestone, Bioclastic packstone, Crinoid grainstones, Bioclastic Mudstone, Bioclastic wackestone, Bioclast spiculite /packstone and Peloidal-Bioclastic /wackestone. And also four adjacent depositional environments were interrelated based on micro facies analysis, facies association and lithology those are open marine shelf, slope, plate form margin and deep basin. The overall depositional environment is from shallow to deep marine environment. The diagenetic process that affected the Antalo limestone during the studies includes fracture, cementation, dissolution, micritization neomorphism and silicification. There are different types of micro and macro fossil in the study area based on paleontological studies like coral, gastropoda, bivalve, ostracode, Echinodermata, cephalopoda and foraminifera are recognized. The age of carbonate unit of sheket section indicates as: from Bathonian to Callovian due to the presence of index fossils of *pfenderella Arabica, Pfenderina neoucomiensis*. Due to the presence of Genus praechrysalidina there is possibility this carbonate unit may be extended to Tithonian. The sheket sections of carbonate unit were correlated with intra regional section of mekelle basin.

Key words: Sheket, Microfacies, micro and macro fossil, facies association and Mekelle basin

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List of Acronyms

GPS	Global position system
M	Meter
MFT	Microfacies type
SMF	Standard Microfacies
FN	Facies zone
XPL	Cross polarization light
PPL	Plane polarization light
FWWB	Fair weather wave base
Amsl	Above mean sea level
E	East
EN	Eastern north
H2O2	Hydrogen Peroxide
HCL	Hydrochloric acid
SK	Sheket section

CHAPTER ONE

1.1 Introduction

1.1.1 Back ground study

About 33 of the surface area of Ethiopia is covered by sedimentary rock and found in five major basins: Ogaden Basin, Abay Basin, Gambela basin, the Mekelle Outlier and the Southern Rift Basin (Wolela, 2008).

The Mesozoic sedimentary rock in Ethiopia are outcrop in three different areas, namely the Mekelle outlier (Mekelle basin) within north (Blanford, 1870; Merla and Minucci, 1938; Bosellini et al., 1997; Martire et al., 1998, 2000), Abay Basin in the central (Jepsen and Athearn, 1964; Beauchamp, 1997; Assefa,1991; Russo et al., 1994; jain, 2019) and Ogaden basin start the Eastern margin of the Ethiopia rift to ward southern east (Hunegnaw et al., 1998; Bosellini et al., 2001). Of the all the above were deposit on gently sloping homoclinal ramp distinct by rift related fault. The Ogaden basin witnesses the primary marine transgression and exhibits the most expanded sedimentary sequence with in Ethiopia. Because of high possibility of hydrocarbon reservoir within Ogaden Basin is not only highly referenced but also most studied one for the Ethiopian Jurassic. Nevertheless, regardless of the above mentioned factor, chronological ages of these sedimentary units and for the whole Ethiopia Jurassic are in fluctuation and needing to be revised quickly (Sreepat Jaina, Abha Singh, 2019).

1.1.2 Literature review

Siliciclastic and carbonate units from Paleozoic to Mesozoic are covered around 8000 km^2 and 1200-2250m thick succession in Mekelle Basin (Beyth, 1972; Bosellini et al., 1997; Arkin et al., 1971). These units originated in three separate basins during different sedimentation phase together with the first and second basins, they played a role in the deposition of the Paleozoic Lower Enticho sandstone, Edaga Arbi and upper Enticho glacial deposits, respectively in the meantime, in the third Basin, the Mesozoic units (Adigrat sandstone, the Amba Aradam sandstone, Agula Shale and Antalo limestone) were formed from the Triassic to the cretaceous (Beyth, 1972). The Antalo limestone and Adigrat sandstone were formed by widespread transgression that comes from East and the South while the Agula Shale formation and Amba Aradam formation were by later stage of regression.

The Northern Ethiopia stratigraphy is divided into seven units: basement, Enticho Sandstone, Edaga Arbi Glacial, Antalo limestone, Adigrat sandstone, Agula Shale, Amba Aradam formation (Dawit Lebenie Enkurie 2010; Damenu Adefris et al., 2022).

Adigrat sandstone is the first Mesozoic sediments in the area (also known as "lower sandstone") of late Triassic-Early Jurassic age (Merla and Minucci, 1938; Blanford, 1869). Sandstones is widely exposed around the Mekelle basin and form limited remnants in various area of the Tigray plateau and alongside the Eastern escarpment, unconformable over the older Paleozoic deposits or later to the North, directly over planted Precambrian basement (Minucci and Merla, 1938).

The sandstone is occurring in a fluvial environment, with some cross-bedding structure and fossil wood, suggesting a broad alluvial plain cross-cut through meandering channels (Bosellini et al., 1997). Garland (1980) observed a regular transition to costal marine deposits. Due to the Syn-sedimentary faults, the thickness of Adigrat sandstone is changeable. In the South West Mekelle around Abi-Adi it reaches about 700m and thins toward the East (Beyth, 1972). Around Eritrea and Adigrat the upper part of the Adigrat sandstone is more or less cover by a thick lateritic crust (Minucci and Merla, 1938, 1961). Boundary between the Adigrat sandstone and the overlapping marine Antalo Supersequence is transition through 20-30 m thick shale with intercalation of calcarenite and sandstone (Sagri et al., 1998; Bosellini et al., 1997;). The presence of laterites soils and iron-bearing soil layers is evidence of repeated changes in sea level through the first stage of transgression period (Bosellini et al., 1997). Ages of the transitional strata are upper Callovian – lower Oxfordian. The Antalo Supersequence is a succession of shallow water transgression made up of weathered Shale and Limestone (Bosellini et al., 1997). And widely expose in the Mekelle outlier (M.Coltorti, 2006).

1.2 Description of the study area

1.2.1 Location and accessibility

The location of the study area lies in latitude 143000 to 1504000 N and longitude 550000 to 580000 E with elevation of 1542 to 2684 amsl (Figure 1). It is 780 km from Addis Ababa the capital city of Ethiopia and 50.3 from main road of Mekelle to ward Abala.

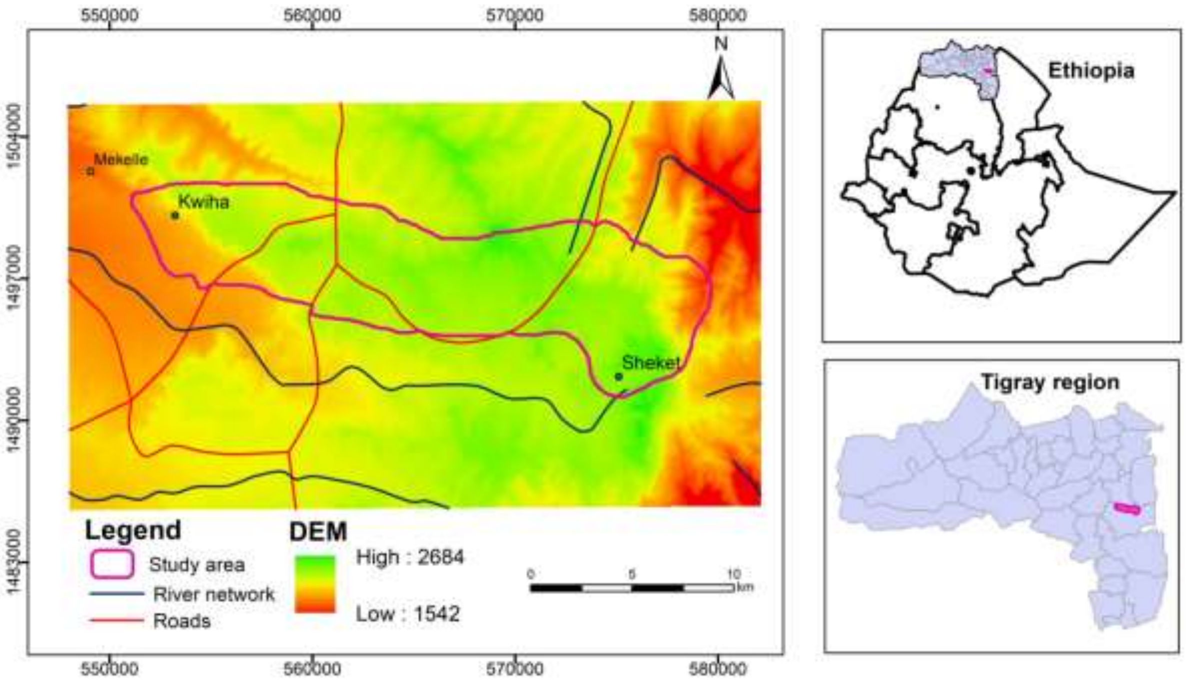


Figure 1: Location map of the study area

1.2.2 Physiography

The Mekelle outlier is apart from the escarpment on the east by watershed and is bounded on north, west and southwest by tigray plateau. It is characterize by gentle progressing relief, cut by few step gorge in the main river and bounded on all side by imposing cliff at least 400m height.

The elevation of the research area 1600m and have only 700mm annual rainfall which only fall in July and August vegetation is spar and rock.

1.3 Problem statement

Paleontological investigations or study's are help to understand the paleoenvironment, to determine the age of the rocks and it help to know the species of micro and macro fossil in different areas. There are a lot of scientists and researchers that studied in mekelle basin in detail of geological and paleontological studies like Bosellini et al.,(1997), Adefris et al., (2022), Dawit (2010),Robert Bussert and Eckart Schrank (2007), Beyth (1971) and many other scientists are studied well in mekelle basin in different sections like Wekro, Hagere Selam, Adigrat, Abi-adi and others but within the area of sheket there is no detail paleontological explanation it only done the general Geology of the area because of lack road accessibility. But now because of the road accessibility from Mekelle to Abala is solved it needs to study well in order to give additional information in to the Mekelle Basin, study like paleoenvironment investigation, age of the calcarious unit, stratigraphic log of the research area and detail investigations of macro and micro fossil. This study help to know the paleoenvironment distribution, the age of calcareous unit and give detail analysis the micro and macro fossil in the sheket section and compare with the regional geology.

1.4 Objective

1.4.1 General objective

The main goal of the research area is detail investigation of macro and micro paleontology stratigraphic log and paleo environmental reconstructions of calcareous unit in Sheket section, Mekelle Basin.

1.4.2 Specific objectives

- ✓ To give a detail Stratigraphic section of sheket section
- ✓ To Identify micro and macro fossils in the research area
- ✓ To Interpret of depositional environment
- ✓ To date the calcarious unit in sheket section

1.5 Research questions

Based on the general and specific objective these questions must be identified and answered

- ✓ What kind of micro and macro fossil are found in sheket calcarious section?
- ✓ What is the paleoenvironment of the research area?
- ✓ What is the age calcareous unit in the research area?

1.6 Significance and expected outcome of the research

1.6.1 Significance

The research area of this research in Mekelle basin Mekelle-Abala outlier the limestone deposition is not studied well in micro and macro fossil analysis detail. There for this study help to understand the study are better in micro and micro fossil and paleo environment reconstruction. And also give useful information for other researchers which studied in that area.

1.6.2 Expected out came

- ✓ Reconstruction ancient environment of the Research area
- ✓ Detail information about micro and macro invertebrate fossil
- ✓ Determine the age
- ✓ Correlation the log the section with other study section in mekelle basin and other region

1.7 Previous work

In Mekelle Basin there are a lot of scientists and researchers that are studied the geological, paleontological and stratigraphic investigation among them are Alfonso Bosellini et al., (1997)." The Mesozoic Mekelle Outlier succession studied the stratigraphy succession of mekelle basin with its description". Damenu Adefris et al. (2022) " Stratigraphic and facies analysis of the Antalo limestone (Callovian-Tithonian),Mekelle Basin ,Northern Ethiopia "this study focus in the detail description of the Antalo limestone in different section like wekro, hagere selam, Agula, chelekot etc. Damenu Adefris (2020) "Benthic foraminifera assemblages and Biostratigraphy of the Antalo Limestone, Mekelle Basin, Northern Ethiopia", this study focused in identification, description and stratigraphic distribution of different foraminifera and other species in giba, wukro, mesobo, chelekot and hagere selam sections. Robert Bussert and Eckart Schrank, "Palynological evidence for latest Carboniferous-Early Permian glaciations in Northern Ethiopia "this research focused in the glaciations sediments and the age of this sediment. Michael Beyth (1971), "Paleozoic-Mesozoic Sedimentary Basin of Mekele Outlier, Northern Ethiopia" it focused in the lithologically units in the depositional environment of mekelle basin. Wolfgang Kiessling et al. (2020) "Marine benthic invertebrates from the Upper Jurassic of northern Ethiopia and their biogeographic affinities" and Y. Arkin (1971) Geological Map of Mekele Sheet Area ND 37-11 Tigray Province.

CHAPTER TWO

Geological setting

2. Regional geology

There are two phase of breakdown of Gondwana during Paleozoic -Mesozoic era. The first phase (rifting phase) lasted from 300 to 205 million years ago (Schandelmeier and Reynolds, 1997; Scotese et al., 1999; Golonka and Ford, 2000; Wolela, 2014), when a large intracontinental rift ("Karoo rift"), formed along the borders of Eastern African passive margin (Wolela, 2014). The second phase lasted from 205 to 157 million years ago (Wolela, 2014; Worku and Astin, 1992). At this phase, Gondwana disintegrated into many blocks and began to separate. The transition from rifting to drifting was also facilitated by transgressions caused by Jurassic sea level highstand (Samuel G et al., 2019). The massive transgression of carbonate unit mark the Jurassic time gap in the horn Africa, including Ethiopia, known as Antalo Limestone Formation, within Abay and Mekelle basin, and Hamanlei limestone Formation, within Ogaden basins (Jain, 2019a). These carbonate units are traditionally been assign to the Lower Jurassic, within the Ogaden basin, of the Kimmeridgian (upper Jurassic) (Jain et al., 2021).

The Mekelle Outlier in Tigray province Ethiopia represents a sequence of upper Paleozoic and Mesozoic sedimentary rocks lying unconformably on Precambrian basement. The Mesozoic sequences are unconformably overlain via Cenozoic flood basalt, which helps to prevent the Mesozoic rock from erosion (Bosellini et al., 1997). The larger circular outlier covers about 8000km2 and is bounded with tectonic lineaments toward South, East and North. Most notable is the enormous cliff of the Ethiopian rift in the East region (Wolfgang Kiessling et al., 2010).

The Mesozoic Mekelle Basin is consider to be portion of the Mesozoic East African rift Basin in addition to the Northwest-Southeast trending rift controlled basins Southern yemen and Northern somalia that formed as the result of Gondwana breakup (Barnes, 1976; Kazmin, 1975). These basins have been invaded from south by the Jurassic sea transgressing and reached their utmost extent during the Callovian period (Barnes, 1976; Brassier and Geleta, 1993; Dainelli, 1943). An east-west thickens of the Mesozoic sequence in the Mekelle basin supports this situation (Bosellini et al., 1997). But, there is an another situation that confirmed that in Bathonian ,East Africa was conquered by a marine transgression coming from the North nearby the Trans-Eritrean Trough that starting in southern Arabia (Arkell, 1956)(Damenu Adefris et al., 2022).

Lately, Jurassic Biostratigraphy of the Ethiopia has been simplified by the discovery of ammonoids and nautiloids (Jain, 2019a; Jain et al., 2020; Jain and Schmerold, 2021), calcareous nannofossils (Singh and Jain, 2019), and palynomorphs (Santos et al., 2021). Previous, most of the diagnostic age record of ammonites and all unlocalized specimens belong to the top of the Antalo limestone formation exposed with in Ogaden basin and tentatively assign to the top Kimmeridgian Beckeri region (Dacque, 1905, 1914; Venzo, 1942, 1959; Scott, 1943; Zeiss, 1971, 1947). This fauna was recently re-evaluated and re-assigned to the upper Tithonian Hybonotum zone, as also previously suggested by Zeiss (1971).

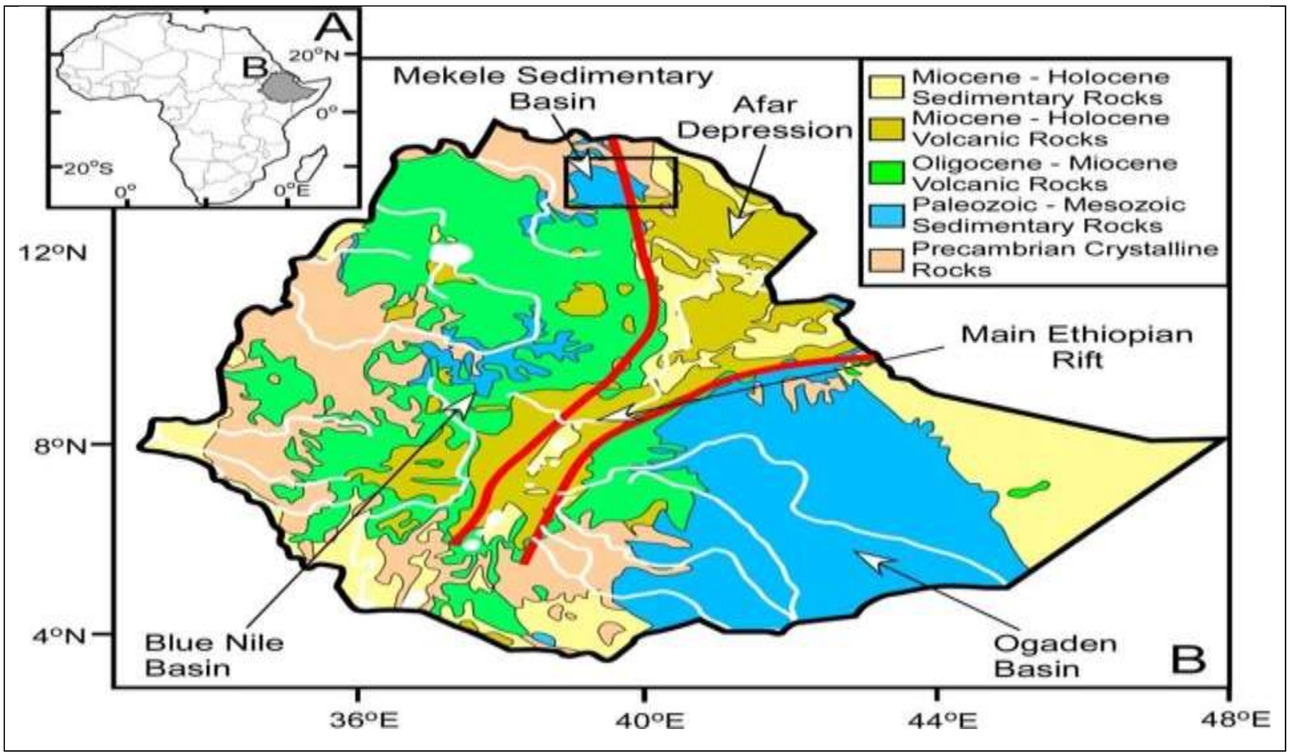


Figure 2. 1Locations of Mesozoic sediments and basins of Ethiopia: (Source: Ethiopian Institute of Geological Survey, by Mengesha Tefera et al., 1996).

2.1 Stratigraphy of Mekelle Basin

According to Blanford (1869, 1870), Dow et al. (1971) and Beyth (1972a, b), the stratigraphy of Northern Ethiopia are divided into seven units: Basement, Enticho Sandstone, Edaga Arbi glacial, Adigrat Sandstone, Antalo Limestone, Amba Aradam Formation of Shumburo (1968) and Trap series. More refinements have been made later by other workers and these will be included in the description and age constraints of each unit, which is outlined below (Dawit Lebenie, 2010).

2.1.1 Basement

The basement up on where all the younger formation was deposition contains the old rock of the Precambrian with 600 million years old. They are exposed in the areas where the younger overly rocks have been eroded. The Precambrian contains variety of volcanic, sedimentary and intrusion rock which has been metamorphosed to variety degree. In the Northern Ethiopia the basement rock contain golden deposited (A. mogessi et al., 2002).

2.1.2 Paleozoic to Mesozoic sedimentary succession in Mekelle Outlier

2.1.2.1 Enticho Sandstone

The Enticho Sandstone is named after the town Enticho in northern Ethiopia (Dow et al. 1971). It is overlies by Neoproterozoic basement rocks with an angular unconformity and up to 200 m thick in northern Ethiopia. The Sandstone sequence, which is mainly composed of quartzarenites, was interpreted to represent the arenaceous facies of the Edaga Arbi Glacials (Dow et al. 1971, Beyth 1972 a, b, Garland 1980). More recently, however, Bussert & Dawit (2009b) and Dawit & Bussert (2009) recognized a lower subunit of glaciomarine origin and an upper subunit deposited in a shallow-marine environment. Thickness ranges from around 80 m in South to more than 100 m in the North. The sandstone succession is composed four upward-coarsening units. The lower three progradational units contain successive cross-bed sets, which exhibit bipolar foreset dip directions that resemble large-scale herringbone-type cross-bedding suggesting deposition in a tide-dominated shelf setting. The uppermost unit consists of cross-bed sets with unimodal foresets oriented constantly towards the North, indicating deposition most likely in braid plains and/or braid deltas. The fine-grained sediments in the lower parts of the upwardcoarsening units contain traces including Arthrophycus alleganhensis, Arthrophycus leniares, Scolicia, Didymaulichnus and rare Zoophycos indicating Cruziana Ichnofacies.

Towards the top of each unit scattered vertical burrows are present that may belong to Skolithos Ichnofacies. Based on fossil siphonoromid impressions, Saxena & Assefa (1983) assigned an Ordovician age for the Enticho Sandstone in general. Bussert & Dawit (2009) assigned a Late Ordovician (Hirnantian) age for the glacigenic lower part because of their similarity with other Hirnantian glacigenic sediments widespread in North Africa and on the Arabian Peninsula. Some of the trace fossils mentioned above, esp. Arthrophycus alleganhensis indicates an Early Silurian age for the overlying shallow marine sediments (Dawit & Bussert, 2009). Hence, the succession correlates with other post-glacial (post-Hirnantian) shallow marine sequences in North Africa and the Arabian Peninsula. Its presence in northern Ethiopia suggests that the post-Hirnantian transgression had extended farther southward into Gondwana than thought before (Dawit Lebenie, 2010).

2.1.2.2 Edaga Arbi Glacials

Edaga Arbi glacial was measured near the town (lat. 14 03N, long 39 05 E) where unit composed of 15-20 of dark gray tillite at the base. Then 27 m of massive siltstone and shale overlie by 60m of red and green shale (Beyth, 1972).

2.1.2.3 Adigrat Sandstone

Adigrat sandstone is named by Blanford (1870) after the city Adigrat (bosolline 1997). It is a Triassic to middle Jurassic clastic unit located in the Basin formed at beginning of the Jurassic Transgression (Dainelli, 1943). It lies unconformably at the upper of Edaga Arbi Glacials, distinct by the middle Permian to upper Triassic unconformity (Damenu Adefris et al., 2022).

The Adigrat Sandstone have maximum 670 m thick and thins westwards over a short distance to about 80 m above the Tekeze River and disappears completely north of the Adigrat-Axum road (Beyth, 1972).

The sandstone is gray or red, fine grained, well sorted and very matures, and is probably the consequence of the reworking of the underlying glacial sandstone (Bosellini 1997). The absence of the calcarious and any trace fauna, the abundant ferruginous and lateritic beds, and the occurrence of fossilized wood fragment suggest this sandstone to be either estuarine, deltaic or continental deposited in a basin which was frequently subaerial (Beyth, 1997).

2.1.2.4 Antalo Limestone

The Antalo limestone has been divided in to four based on largely constituted of parasequences displaying systematic vertical and lateral change.

A-1: it is the most widespread carbonate unit sequence of Mekelle Basin. It is 20-30 m thick and lies on shale, limestone or sandstone of transitional bed. Upper part of this sequence have consider with a coral-stromatoporoid with lack of relief. Both of corals and stromatoporoids are silicified and rust color. In the basal part of the sequence is grainstones dominated by scleractinians and other corals which are subglobose. Stromatoporoid are absent or they are very rare. In the top of the unit is a wackestone which are finer with the dominant of both corals and stromatoporoid. The etallonia are the most dominant among the corals. At the upper part the corals are disappear and the lime mudstone is very rich in branching stromatoporoids. Bivalve, Brachiopoda and echinoids spines occur through the unit.

A-2: it has 100-120m thickness. It consists of shale, marlstone, very rich in Brachiopoda and some of ammonites with scattered coquninas and associated with some coral stromatoporoid.

A-3: the sequence is fairly well developed near mekelle but west ward near the basin margin. The thickness is bout 25om in the mekelle area, and 120-130 m near hagere selam and abi adi. It starts with shale and marlstone with the interaction of some coquinas.

A-4: Thick succession of marl, shale and marly limestones overlies the last stromatoporoid layer of sequence A3.

Facies of antalo limeston in mekelle basin (Beyth, 1997)

They have four facies antalo limeston

- ✓ The frist facies is a sandy oolite and coqunia with a minor amount of marl and few chert beds. This facies is well bedded to laminated and contain crossbedding and common symmetric ripple markes. The macrofauna is mainly brachiopods, corals, and echinoderms.

- ✓ Marl is found interbeded with lithographic limestone and minor coquina. This unit is consistes of mainly of brachipods.
- ✓ Eastward the antalo limeston change in to the cliff of coral and algal reef limeston and biostorm interbeded with marl.
- ✓ Black to gray-brown microcrystal limstone is interbeded with black marl mainly at the base.

2.1.2.5 Agula Shale:

The "Agula Shale" named after the town Agula in Northern Ethiopia after Beyth (1972a) identified a shaly unit in the upper part of the Antalo limestone. Nonetheless, Bosellini et al., (1997) included the shaly unit to his "Antalo Supersequence". The unit may reach the maximum thickness of 300 m. It is consisted, from base to top, of festoon cross-bedded, well-sorted, Laminated black shales and mudstones, fine quartzarenites, dolomites and gypsum beds with nodular or chicken wire structures, and oolitic or coquinoid limestones (storm beds) with small gastropods and pelecypods. These facies association is interpreted to represent lagoonal, peritidal, and sabkha environments (Beyth 1972a, b; Bosselini et al., 1997).

Later authors reported a fauna that including Modiolus cfr. Intricatus, Palaeonucula, Corbulomima and Placunopsis and assign a Late Kimmeridgian age for the unit. The succession is, in places, extensively intruded and dismembered by the Mekelle Dolerites. The presence of carbonate breccia may probably be related to fault systems, which were active in the late Jurassic that might have created some rocky shores or carbonate cliffs (Bosellini et al., 1997).

According to Bosellini (1989), the Agula Shale represents, the final regression that led to the general withdrawal from Jurassic sea in Northern Ethiopia, and most likely from the all of East Africa.

2.1.2.6 Amba Aradam Formation

This formation, was formerly known as Upper Sandstone (Blanford 1869), was named after its type section near the town Amba Aradam (N 13°20′/E 39°34′) in northern Ethiopia (Shumburo, 1968). The thickness of Amba Aradam Formation is about 200 m and rests with angular unconformity on carbonates and clay stones of Agula Shale (Bosellini et al. 1997). It consists of red or white sandstones with interbedded violet to purple mudstones and silt, lenses of conglomerates and lateritic paleosols. The sandstones are often cross-bedded and form fining-upward sequences, which are interpreted by Bosellini et al., (1997) as "point bar sequences" deposited in a fluvial meandering river system. The lower and topmost parts of the succession are intensively lateralized. Bosellini et al. (1997) described the presence of eolian sediments at the bottom of the formation, even with the lack of age diagnostic. Amba Aradam formation is 100-200 thick and overlain by trap basalts mainly consist of fluviatiles sandstone and shale, purple, violet, or yellow, with numerous laterites soils rich in vadose pisoids (Bosellini, 1997).

2.1.2.7 Trap series

Flood basalts (trap) are the youngest example of major in continental volcanic plateau in Ethiopia. It covers a region of about 600, 000 km2 with a layer of felsic and basalt volcanic rocks. The thicknesses of this are variable but it reaches in some places. According Mohr and Zanettin (1988) and Mohr (1983b) the entire volume of shallow and volcanic intrusive rock is about 350 000km3 .The chemical and mineralogical composition of the flood basalt is comparatively uniform. Most of them are aphyric to slightly phyric, and contain phenocrysts of plagioclase and clinopyroxene with or without olivine (Bruno Kieffer et al., 2004).

According to V.Kazmin trap series are divided two, the first one is ashangi group which consist dominantly of alkaline basalt with interbedded pyroclast and rare rhyolite eruption from fissure and the second groups are shield group these shield volcano consist mainly of prophyritic amygdaloidal olivine basalt (Kazmin, 1975).

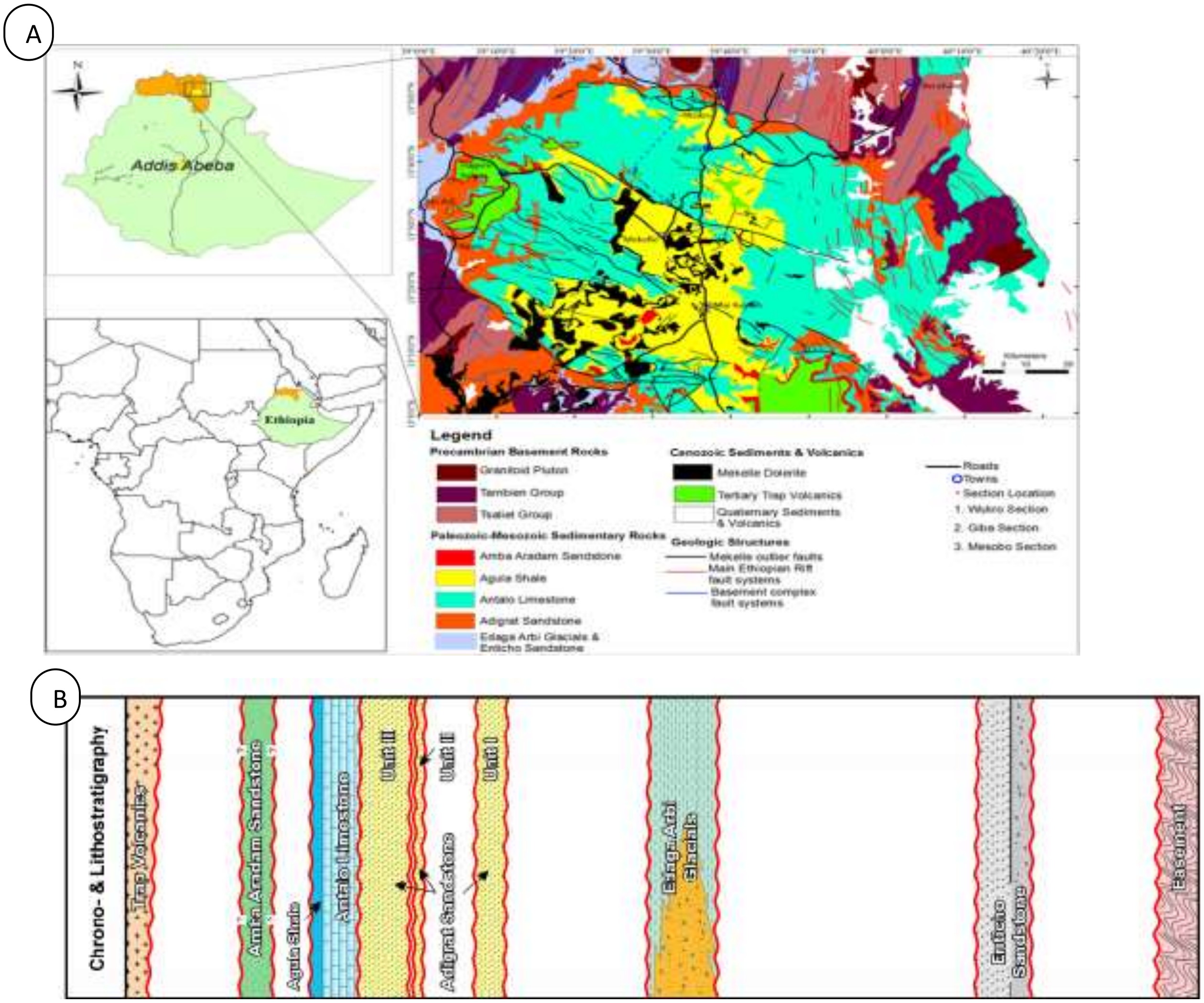


Figure 2. 2: Geological map of the Mekele basin and the surrounding area (A), (Arkin et al., 1971) and the stratigraphy of Northern Ethiopia B, (Dawit, 2010)

2.2 Paleontology of Mekelle Basin

The Marine faunas was the first evident in the calcareous sandstones of the transition beds between Adigrat sandstone and the Antalo limestone. Foraminifers Kurnubia palastiniensis and Nautiloculina oolithica in these transition beds suggest a late Callovian/early Oxfordian age. In sequence Antalo limestone, wackestone and packstones predominate. The AL1 cliff-forming represents a shallowing-upward sequence of wackestones and packstones. AL1 is rich in stromatoporoids and corals (Wolfgang Kiessling et al., 2011).

Trace fossils where found top upper of the section, on the upper bed surfaces of ripple laminated, massive to horizontally laminate coarse-grained silt- and fine-grained sandstones, interpreted to represent turbidites in a distal ice-contact lake. The most abundant type occurs both as convex or concave curved to straight bilaterally symmetrical horizontal ridges or grooves. The traces are 3.2–5 mm wide and up to 8 cm long and contain multiple fine curved ridges and furrows oriented oblique to the track itself and a clear median ridge or furrow. A number of the traces ends in convex terminations resembling elongated ‘‘coffee beans’’. Trace of like ‘‘Coffee bean’’ also appear in isolation forms; and they be similar to Isopodichnus traces described by Ledendecker (1992)and Glaessner (1957) from Devonian and Early Permian glacigenic sediments, although they have small scratches or small depressions oriented at right angles to the main rail. The best analogue seems therefore to be traces illustrated by Kruck and Thiele (1983) from the Lower Permian glacigenic Akbra Shales of Yemen. Traces in the Age section may record the colonization of the turbidite beds immediately after their deposition by grazing organisms, possibly arthropods (Robert Bussert, 2007).

A stromatoporoid (Cladocoropsis mirabilis) species has been identified, representing the Kimmeridgian age (Arreola and Omaña, 2008). Dasyclad green alga is also considered as biostratigraphic marker of the Upper Jurassic – Lower Cretaceous (Yilmaz, 1999; Velic, 2007; Mircescu et al., 2016).

In general stratigraphic distribution intervals of the identified age diagnostic taxa have been described as follows

- Lower Jurassic to lower Cretaceous “*Siphovalvulina variabilis*” (Septfontaine, 1988) “*Nautiloculina oolithica*”(Mohler, 1938), Bajocian – Tithonian;
- “*Kurnubia morrisi*” (Redmond, 1964), Oxfordian – Kimmeridgian;
- “*Kurnubia palastiniensis*” (Henson, 1948), Callovian – Tithonian; “*Kurnubia wellingsi*” (Henson, 1948), Callovian – Kimmeridgian;
- “*Nautiloculina circularis*” (Said and Barakat, 1959), Callovian – Kimmeridgian; “*Freixialina planispiralis*” (Ramalho, 1969), Kimmeridgian – Tithonian;
- “*Redmondoides lugeoni*” (Septfontaine, 1977), Lower Aalenian – Tithonian;
- “*Conicokurnubia orbitoliniformis*” (Septfontaine, 1988), Oxfordian – Kimmeridgian;
- “*Miliolinella quinquangula*”(Loeblich and Tappan,1994), Upper Oxfordian – Lower Kimmeridgian; “*Choffatella tingitana*”(Hottinger, 1967) ,Oxfordian – Tithonian;
- “*Alveosepta jaccardi*”(Schrodt, 1894), Upper Oxfordian – Kimmeridgian;

- "*Praekurnubia crusei*" (Redmond, 1964), Bajocian – Lower Kimmeridgian;
- "*Everticyclammina virguliana*" (Koechlin, 1942), Oxfordian – Tithonian;
- "*Kurnubia jurassica*" (Henson, 1948), Upper Callovian – Kimmeridgian;
- "*Pseudocyclammina lituus*" (Yokoyama, 1890), Lower Oxfordian – Hauterivian;
- "*Valvulina lugeoni*" (Septfontaine, 1977), Bajocian – Recent;
- "*Calpionella alpina*" (Lorenz, 1902), Upper Tithonian – Lower Berriasian; "
- "*Clypeina jurassica*" (Favre, 1927), Middle Kimmeridgian – Lower
  "*Salpingoporella gr. pygmaea*" (Gümbel, 1891), Kimmeridgian – Lower Hauterivian;

(Damenu Adefris 2021)

CHAPTER THREE

3. Method and instruments

3.1 Method

There are three general method than can use to investigate or to determine field work, laboratory activity, determine the age carbonate rock sample and identify the environment of study area. Those are :

3.1.1 **Pre-field work:** pre field work are done before the actual field work. It including a lot of activitys takes place among those the most important work that need to be done are

- ✓ Review previous geological data: finding and evaluate previous geological fieldworks is the most important prefield work. It include reading published and unpublished previous researches related to the study are
- ✓ Examine geological map of the research area
- ✓ Examine the objective carefully like what is the general objective of the paper? What are the questions and the answer? This helps to know what are the expected result of the field work.
- ✓ Select the best method to collect rock and fossil sample
- ✓ Identify possible hazards study area and its surrounding like animal attack, natural disaster, war (military) problems and etc and
- ✓ Get full information about the area
- ✓ Prepare instruments that are used during the field

3.1.2 **Field work**: is direct observation of out crop, landscape, exposures .this field work will conducted around sheket section, Mekelle outliers around November 29. The filed conducting in to different subsection for around 14 days.

The observation that conducting in sheket section include detail lithological description like texture, color, thickness, composition, fossil content and also trace fossil identification will be Separation of dolomite from limestone by using Hcl and taking represenatative photography of the lithology, fossils(including trace fossil) will be takes place.

Sample collection

Sample will collecting from the sheket section by the different of each lithology in the area. Totally from 30 to 40 sample of shale, marl and limestones will be collecting and also micro and macro fossil will collect for further analysing in the petrographic lab. During the data collection careful observation of thickens, structure and taken representative picture will be takes place.

3.1.3 Post- field work

After the field work done there are same activity that takes place in the laboratory like analysis the sample that takes from the study are differentiate micro fossil using petrographic microscope and give detail interpretation and analysis about the research area and the sample. In order to do those thing there are steps that should takes place like Soaking, washing and dry the sample after that diffrentiate micro fossil using petrographic microscope and describe them by there species and give interpretation and analysis about the paleoenvironment, the age of the lithology and etc..

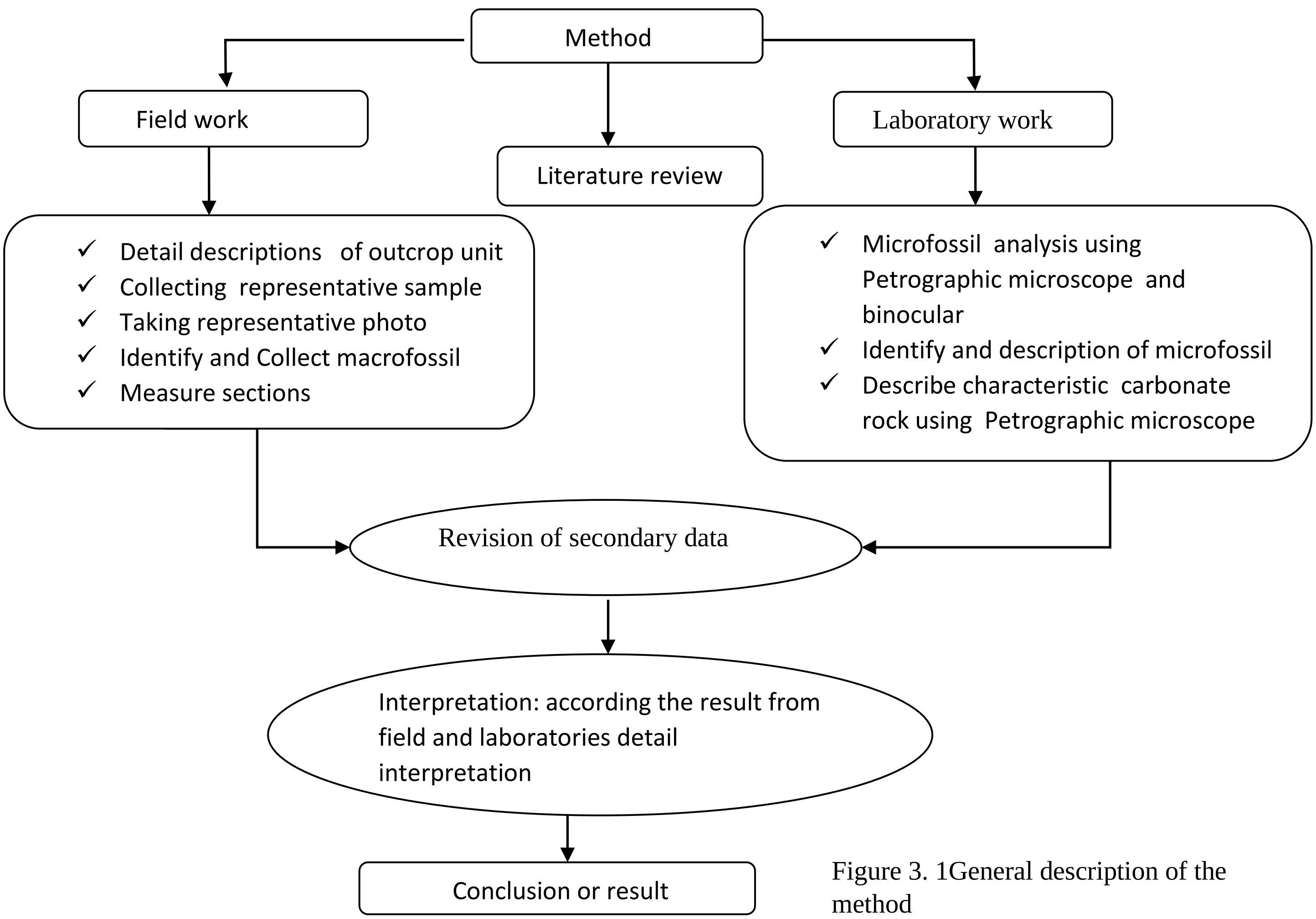


Figure 3. 1General description of the method

3.2 Instruments

These instruments are used in field data collection and in laboratory help to accomplish the general and specific objective of the research those are:

3.2.1 Field instrument

In the field to collect samples and describe the field area different kind of insturment are involved those are geological hammer, dilute 10% HCl, GPS, sample bag, plastic sample bag, marker, pen, note book, meter stick, hand lenses, topographic map, , virtual camera, pensile etc.

Figure 3. 2: Field instruments

3.2.2 Laboratory instrument

To identify and describe macro and micro fossil in the laboratory different paleontological instrument used like 250ml standard beaker, tunnels, sieve number 35, 45, 60,120, and 450, Petrographic microscope, binocular microscope, H_2O_2, distal water, brush, note book, pencil and software.

Figure 3. 3: Laboratory instrument

CHAPTER FOUR

Local Geology and Stratigraphic Log

There are a different kind of lithology in the sheket section or in the study area those lithology are classified or diffrentiate based on there color, grain size, sorting, sedimentary structure, thickness and fossil content. In general in the study area we found three kind of lithology these are marl, shale and limestone. These three are divided into different lithology based on there formation these are

Carbonate unit

4.1 **Micritic limestone unit**: this is found in the base of the section around 25m thickness. It consists of dominantly micritic limestone. There are also some marl and marly limestone. Mostly the micritic limestone it have brown color and fine grain to medium grain size. Most of the micritic limestone is have highly precipitated calcite. They are also massive (Figure 4.1 A) to laminated (Figure 4.1, B) beds. The marl in this micritic unit has gray color and poorly sorting. There are different macro fossil like bivalve, gastropoda and corals and also microfossil like radiolaria, foraminifera, bivalve and Brachiopoda.

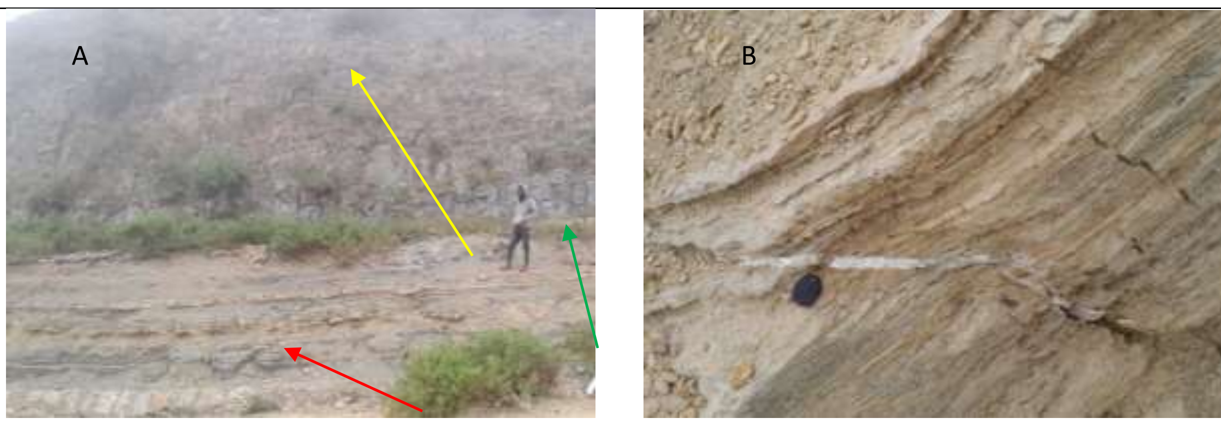


Figure 4. 1: Micritic limestone: A, massive micritic limestone(yellow color) with some shale(red arrow) and marl(green) from S1K12,B, bedded limestone from S1K11 with some fractured and vent that filed by calcite

4.2 **Marly micritic limestone**: This lithology has grayish color with laminated bedding and moderate sorting. This is found above the micritic limestone and has 50m thickness. There are a lot of calcite precipitated (Figure 4.2, C) in the rock with some veins and fractures. There is also vegetation coverage. In this unit there is also some marl with poorly sorting and fine grain size with 1 m thickness and micritic (Figure 4.2, A) limestone 2 m of thickness and brown color and well sorting with fine grain size.

Figure 4. 2: Marly limestone from S1K1 A, above and below the red arrow are pure Marl and between them is Micritic Limestone B, Marly Limestone, C, calcite precipitated in Marl (later precipitated)

4.3 **Fossiliferous limestone**: this unit is in the middle of the section and found above the marly limestone with 20 m thickness. Mostly have light brown, brown and yellowish color and have fine grain size and moderate to well sorting (Figure 4.3). Within this unit there are micritic limestone and marl. Most of the micritic limestone are brownish color and laminated structure with moderate sorting. And the marl is grey color and poorly sorting and fine grain size. There are also micro and macro fossils like bivalve, belemnite, gastropoda.

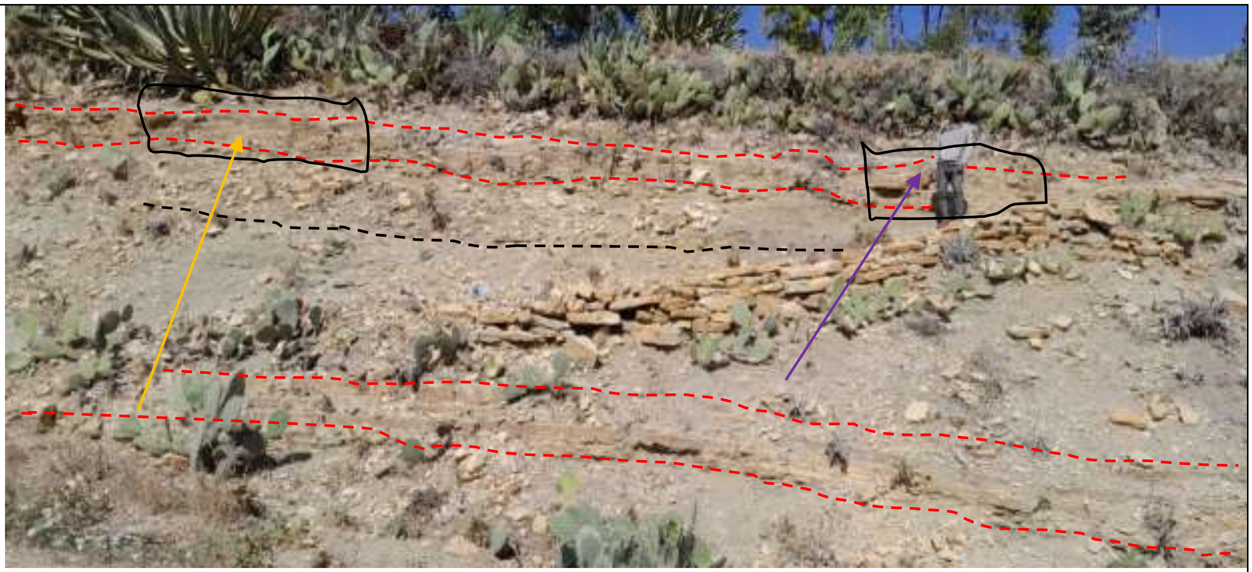


Figure 4. 3Fossiliferous Limestone from with different size of bivalve, the orange arrow indicates the size of the fossil are large and the purple one is the size the fossil have small in size

4.4 **Shale**: this unit is found in above the fossiliferous limestone. The shale have different color on the top and bottom it like whitish color where as in the middle with small thickness it is more like blue color (Figure 4.4 C). The top and the bottom the formation massive bedding where as the middle one have small laminated structure on the below bottom the formation there are also some blue shale with Fissility structure. Generally the lithology has moderate sorting with some Fissility, laminated and fracture sedimentary structures.

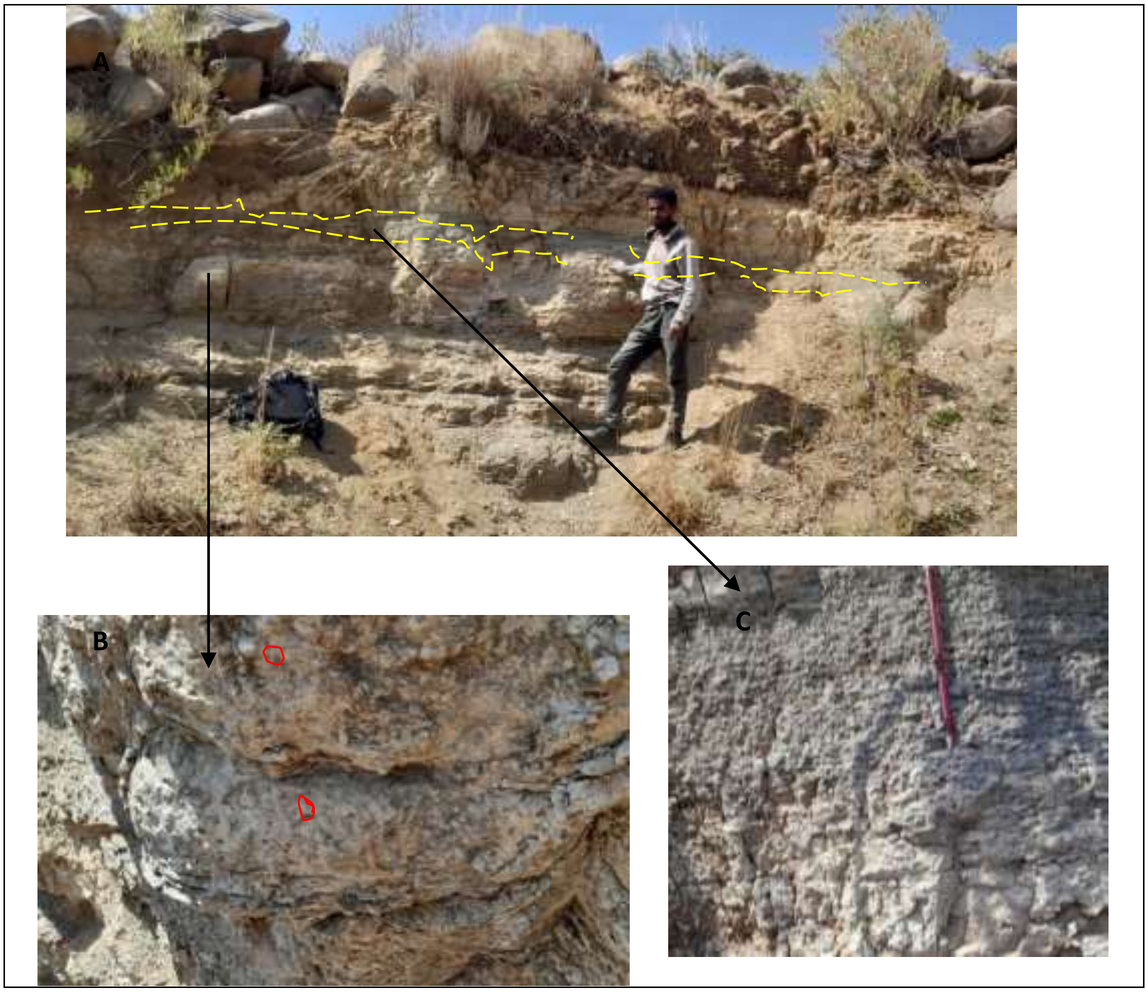


Figure 4. 4: Shale in S1K3 A, general the whole formation, B, whitish color Shell with some structure c, blue color shake with small laminated structure

4.5 **Marl unit**: this is found in the top of the section dominantly with 80m thickness. Within this unit there are like marl, marl limestone intercalation with black limestone.

4.5.1 **Marl**: this is dominated in the top part of this unit. It is it has yellowish, gray and light colors. And mostly it is fine grain, poorly sorting and have different macro fossil like gastropoda and bivalves. The content of fossil is different from one place to other.

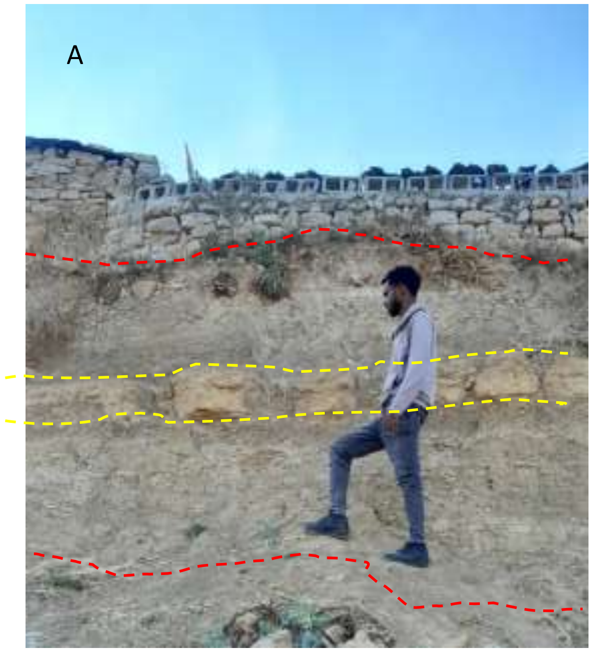


Figure 4. 5: Marl from S1K1 above and below the red arrow is Marl

4.5.2 **Black limestone**: is found below the marl in the top part. Ii have well sorting with fine grain size and it is found in easting 562633 and Northing 1484104.

4.5.3 **Marl limestone intercalation** : In the base of the lithology there is marl dominated but also have some shale that have laminated structure and the shale have some Fissility structure. There is also some fracture. Above the marl and shale there is micritic limestone with dark color with 20m Thickness it continues horizontally without break or disturb. Above the micritic limestone there is the formation which is affected by deformation it means there is no horizontal continuity. In this formation there are some carbonate nodules with some shale is Fissility nature. There also some vein that are filed with calcite. Above this formation there is micritic limestone with some marl some of the micritic limestone have laminated nature with small thickness of layers. Below the marl there is 10cm Thickness of ooids limestone with whitish color and well sorted.

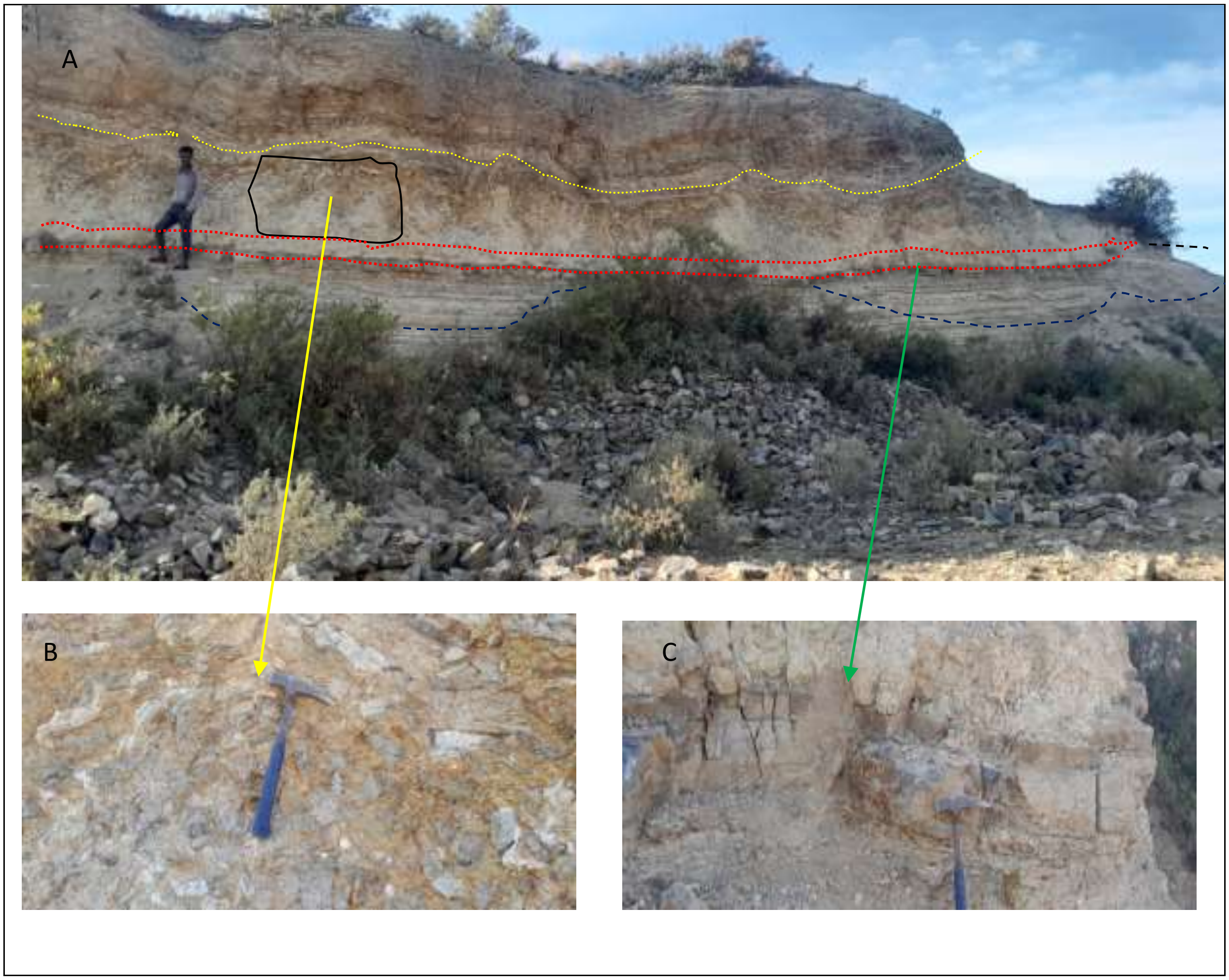
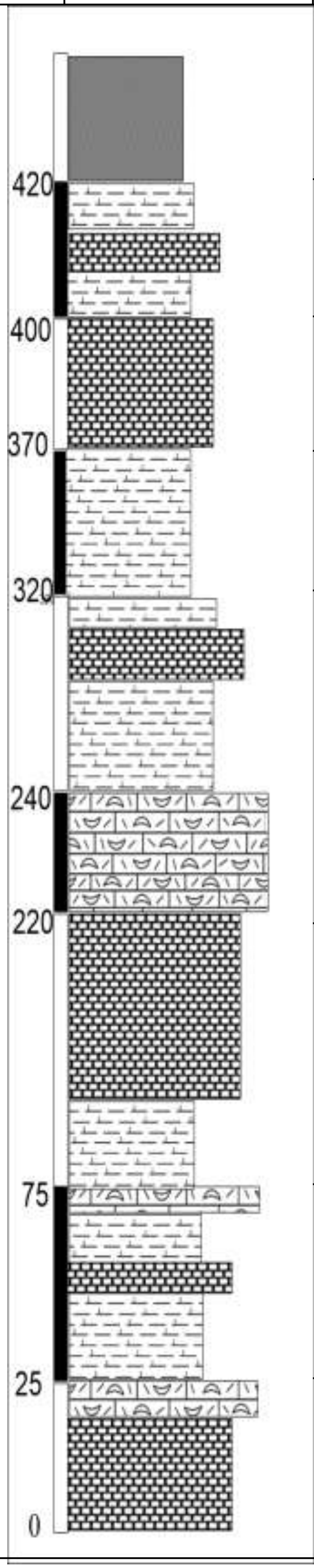


Figure 4. 6: Marl limestone intercalation (S1K5), from A to B, the yellow line shows some Shale and Marl and some carbonate nodules and from A to C the green line shows Micritic Limestone

Stratigraphic log

The stratigraphic log of sheket section has been done (Figure 4.7).

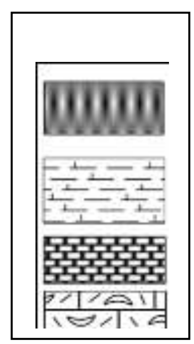
Scale (m)	Lithology	Remark



Remark:

- Shale
- Calcareous marl with layer of micritic limestone
- Micritic limestone
- Calcareous shale
- Calcareous Marl with some layer of micritic limestone
- Fossiliferous limestone
- It is dominated by massive Micritic limestone but it include also calcareous marl and shale
- Dominated by marl but also have micritic and fossiliferous limestone layers
- Dominated by Micritic limestone but it includes fossiliferous limestone

LEGENED



- Shale
- Calcareous shale/marl
- Micritic limestone
- Fossiliferous limestone

Figure 4. 7: Stratigraphic log Sheket section

CHAPTER FIVE

Paleontology

Paleontology is the study of ancient life through its remai or the trace of the activity as recorded by ancient sediments. Paleontology analyzes fossilized remains of plants, animals and other organisms to understand there evolution, behaviors, ecology, and the environment there were living. Those remain are any preserved evidence of the past life such as bones, shells, imprints or trace of ancient organisms that have been preserved in a rock or sediment over geological time.

In the carbonate unit of sheket section there are 4 type of macro fossil with different species like bivalve, gastropoda, spine Echinodermata and coral. There is also more and more microfossil. These are washed and identifying in sedimentology laboratories and finally they are ready for the taxonomy classification. The macro fossil are a little be difficult to do the taxonomy because the poor preservation. The taxonomy of microfossil is done from the thin section and from marl sample by the help of binocular microscope.

5.1 Corals

Coral reefs are massive limestone structures that provide food and shelter for marine life. Hard corals play a significant role in constructing the solid limestone (calcium carbonate) structure of coral reefs. Developed over extensive periods, spanning hundreds to even thousands of years, certain coral reefs are vast enough to be observable from outer space.

Scleractinia coral are primary example of colonial organism whose morphology directly detects life history strategies (Jackson, 1979).

Coral are a colony of very many genetic identical polyps. They are two types of coral which is hermatypic which is reef building and ahermatypic which is non reef building. Generally they are invertebrate marine with phylum Cnidaria. They have septa (septum-singular) which is radiating vertical plate lying with corallites walls (figure 5.2). Scleractinians corals are key for maintenance of biodiversity and ecological function of coral reefs (Haiyang Zhang et al., 2021).

Phylum Cnidaria- Hatschek, 1888

Class Anthozoa –Ehrenberg -1830

Subclass Hexacorallia-Haeckel, 1896

Order Scleractinia -Bourne, 1900

Family Acroporidae –Verrill, 1902

Genus - Anacropora –Ridley, 1884

Morphology: Anacropora consists delicate branch with closely spaced corallite and they are small. The main number of septa are six with additional subside one. The corallite are empty. This is found on the middle part of the sheket section.

Remark: with similar morphology o Anacropora are find in red sea, Indian ocean and subtropical pacific ocean according to Carden C. Wallace and Batty L (2001).

Stratigraphic range: middle Jurassic

Phylum Cnidaria- Hatschek, 1888

Class Anthozoa –Ehrenberg -1830

Subclass Hexacorallia-Haeckel, 1896

Order Scleractinia -Bourne, 1900

Suborder FaviIna –Vaughan and wells, 1943

Superfamily Faviicea –Gregory 1900

Family Faviidea-Gregory 1990

Morphology: they have thick septa and they are distinct arranged. Flat rounded shape theca. With moderate corallite. This is also founded in the middle of the sheket section.

This family had been studied by : James A. Murray (1880) in Persian Gulf of India and forskal 1775 found Faviidea in the Qeshm island which is known before as southern Persian Gulf, Gulf of Aden, Southeast Africa and Indo-Pacific.

Stratigraphic range: middle Jurassic to present

Remark: this family also found in Atlantic and pacific oceans and also Persian gulf of India ocean and Arabian Sea by James in 1880

5.2 Bivalves

Bivalves, a class of mollusks, are distinguished by their two-part shells, typically composed of calcium carbonate. The valves may be either equal or unequal in shape and size. These shells are connected by a flexible ligament and can be opened and closed using powerful adductor muscles. Found in marine, freshwater, and terrestrial environments. These organisms play vital ecological roles as filter feeders, contributing to water quality by removing plankton and other particles. Additionally, they hold economic importance as food sources and serve as indicators of environmental well-being (figure 5.4).

Bivalves play a crucial role in contributing to the content of limestone in various environments, including marine, freshwater, and brackish habitat. They are found in upper, middle and lower part of the study area.

Phylum Mollusca –Linnaeus, 1758

Class bivalve - Linnaeus, 1758

Order –cardiida-ferussac, 1822

Super family veneroidia – Rafinesque, 1815

Family –veneridea –Rafinesque, 1815

Morphology: the family veneridea have an oval shape and the two umbo are more curvature. They have also growth line. With two equal valve and they are 2 to 3 centimeter of size.

Remark: this family of veneridea is similar with veneridea of New Zealand and New Caledonia of Ronald in 2005.

This is studied by

H.E. Vokes 1980 general of bivalve and Ronald N. Gordner 2005, middle-late Jurassic bivalves

Phylum Mollusca –Linnaeus, 1758

Class Bivalve - Linnaeus, 1758

Order Veneroidia- H. and A. Adams 1856

Family Mesodesmatidae –Gray, 1840

Genus Mesodesma- Deshayes, 1832

Morphology: two almost equal bivalve with 3 centimeter size and wedge shape and smother surface. Because it is damaged it is hard to identify deeply.

5.3 **Gastropods**

Gastropods are abundant constituents of limestones. They are known throughout the Phanerozoic, but are most abundant in the Mesozoic and Cenozoic. Small fragments of gastropods are distinguished from bivalves by the existence of multiple layers of well-developed crossed-lamellar microstructures, small composite prisms, and nacreous layers associated with layers exhibiting dissimilar microstructures. Most gastropods are preserved as molds and casts Gastropods live in marine, freshwater and terrestrial environments. Most gastropods are mobile benthic organisms, but some have become adapted to sedentary life and to pelagic life (periods) (Flugel, 2010).

Gastropods are characterized by a single, coiled shell (in most species) and a muscular foot used for locomotion. They also have a well-developed head with sensory organs like tentacles and eyes, and a radula, a feeding structure used for scraping food. Their respiratory system varies but typically involves gills or a lung-like structure called a pallial cavity. Fossilized gastropod shells provide valuable information about their past morphology (figure 5.3).

Phylum- Mollusca- Linnaeus, 1758

Class –Gastropoda-Cuvier, 1797

Subclass- prosobranchia-Milne Edwards, 1797

Order –archaeogastropoda- Thiele, 1925

Suborder- macluritina –Cox and knight, 1960

Supper family- macluritacea – Fischer, 18

Family –macluritidae- Fischer, 1885

Morphology: they have coiled shell with flat whorl and have moderate spiral. The apex is slightly down ward. It is dextral.

Remark: the family is similar with Siberia and Alaska of Davied M.Rohr, A.P. Gubnov 1997, of macluritidae

Bridge and cloud 1947, buttes 1926, Wilson 1924 and Zittel 1882 some of researcher that studied macluritidae family

Phylum-Mollusca - Linnaeus, 1758

Class- Gastropoda - Cuvier, 1797

Subclass- prosobranchia- Milne Edwards, 179

Order- archaeogastropoda- Thiele, 1925

Suborder- macluritina- Cox and knight, 1960

Super family- euomophalacea de-koninck, 1881

Family –euomphalidae- de-koninck, 1881

Morphology: They have small whore and it is rounded but slytily shouldered(Figure C).Whore is contact, base slightly concave view from above and below (Figure B) but in the figure C the suture have space. both are belong to the same family but figure B have more rounded whorl and more spiral than figure B.

J.SowerBy (1814), Kayser (1889), and Hall (1879) are one of that studied this family

Phylum-Mollusca - Linnaeus, 1758

Class- Gastropoda - Cuvier, 1797

Subclass- prosobranchia- Milne Edwards, 179

Order- archaeogastropoda- Thiele, 1925

Suborder – pleurotomarina- Cox and knight, 1960

Super family-plurotomaiacea – swainson, 1840

Family – euomphalopteridea - koken-1896

Morphology: They have large apertures and moderate spirl. The whorl is rounded and last whorl is very large. They suture are visible and attached the whorl. They are dextral.

5.4 **Foraminifera**

Foraminifera are eukaryotic unicellular microorganism inhabiting all marine environments (Sabbatini et al., 2014). Foraminifera are prime important in Microfacies analysis. The shells of benthic foraminifera have major constituted of shelf carbonate at least since the late Paleozoic and planktonic foraminifera from pelagic limestone from late Mesozoic (Flugel, 2010).

Class foraminifera

Suborder textulariina Delage and Herouard 1896 135

Superfamily Textulariace Ehrenberg 1839

Family Textulariidea Ehrenberg 1838

Genus Textularia Defrance 1824

Stratigraphic range: late carboniferous to present

Morphology: Textularia have agglutinated biserial test and slightly inflated chamber. The champers interconnected by small apertures. They have stacked appearance.

Textularia: Defrance 1824

Textularia: David W. Haig 1997.

Textularia: G.D.Sutherland and C.R. Stelck 1972.

Textularia: T.Toksvad 1983.

Textularia: Charles T.Schafer and Flona E.Cola 1986.

Remark: genus Textularia also found in Pahang river estuary, Pahang, Malaysia by Muhamed Naim et.al 2014.

Super family pfenderinodea -Smout and Sugden 1962

Family pfenderinidae - Smout and Sugden 1962

Genus Pfenderina - Henson 1948

Species *Pfenderina neoucomiensis* -pfender 1938

Stratigraphic range: Bathonian/ Callovian

Morphology: it has cylindrical shape and gently curved. The camper well is smooth and arranged. It curved fashionable with shell. Each champers interconnected forming a series of champers. The size of Pfenderina neoucomiensis is few micrometres.

Pfenderina neoucomiensis: Henson 1938,

Pfenderina neoucomiensis: Murat and Scolari 1956.

Pfenderina neoucomiensis: Marie and Mongin 1957.

Pfenderina neoucomiensis: Hudson 1958.

Pfenderina neoucomiensis: Hudson and Chatton 1959.

Remark: Pfenderina neoucomiensis also found in southern France and western Switzerland by Murat and Sclaria 1956 and also in Shuqra formation of southern west Arabia by Hudson 1985.

Superfamily miliolacea-Dlage and Herouard, 1896

Family –miliolidae- Ehrenberg 1839

Stratigraphic range: Early Neocomian

Morphology: The test of Miliolidae composed of numerous champers called planispiral test which is the champers are arranged in flat spiral. The champers is connected by the single central tube called median suture. The champers increases in size as they spiral outward from the center . The sizes of the miliolidae are few micrometers.

Miliolidae: Ehrenberg 1839.

Miliolidae: Cushman 1917

Miliolidae: Glaessner 1945

Miliolidae: Sigal 1952 and Pokorny 1958

Miliolidae: Loeblich and Tappans 1972

Remark: Remark: this is also found in Akajima Island (Japan) Paratur, 2002

Class foraminifera - lee 1990

Family pfenderinidae Smout and Sugden 1962

Genus pfenderella Redmond 1964

Species *pfenderella Arabica* Redmond 1964

Morphology: *Pfenderella Arabica* has elongated and single shelled and the last champers thickened and have some pores and also they have moderately high spiral. It has some ornament.

Remark: *Pfenderella Arabica* can also found in Saudi Arabia based on C.D Redmond 1964 which have similar elongated and inflated champers.

Stratigraphic range: late Bathonian

Class foraminifera

Order taxtulariida -Delage and Herouard 1896

Genus praechrysalidina - Luperto Sinni 1979.

Morphology: They have trochospiral test which is the champers are arranged in spiral around the central axis and the outer part of the shell are smother. The champers has globular shape. The opening of the final champers boarded by distinct rim.

Praechrysalidina: Luperto Sinni 1979.

Praechrysalidina: Hayward Bruce W. 2013.

Stratigraphic range: -late Oxfordian -late Tithonian

Remark: this also found in Kerman province central Iran (2014)

5.5 **Ostracode**s

Phylum arthropoda Latreille, 1829

Class Ostracode Latreille, 1829

Order Podocopida Sars 1866

Suborder Cytherocopina Grundel 1967

Species *Cytheretta (Fleuxs) Trifurcata* Luembimova and Guna 1960

Morphology: Cytheretta (Fleuxs) Have bivalve shell mostly symmetrical. And they have also tooth and sockets. The socket is a depression or cavity in one valve of the ostracode corresponding to the tooth other valve fits snugly. The tooth are small and pointed projection on the edge of valve that fit in to the socket of the opposite valve.

Remark: This species similar to Cytheretta of Khosla from 1979 from lower Miocene Gujarat, India

Foraminifera

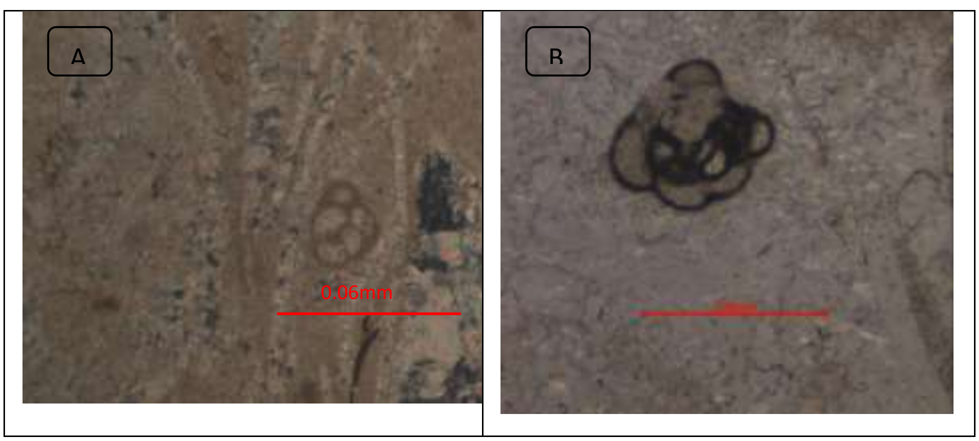
A, Genus Textularia, from sample S1K19, 4X

B, family of miliolidae, from sample S1K13B, 4X

C, species of Pfenderina neoucomiensis, from sample S1K19, 4X

D, Genus praechrysalidina, from sample S1K19, 4X

E, *pfenderella Arabica*, from sample



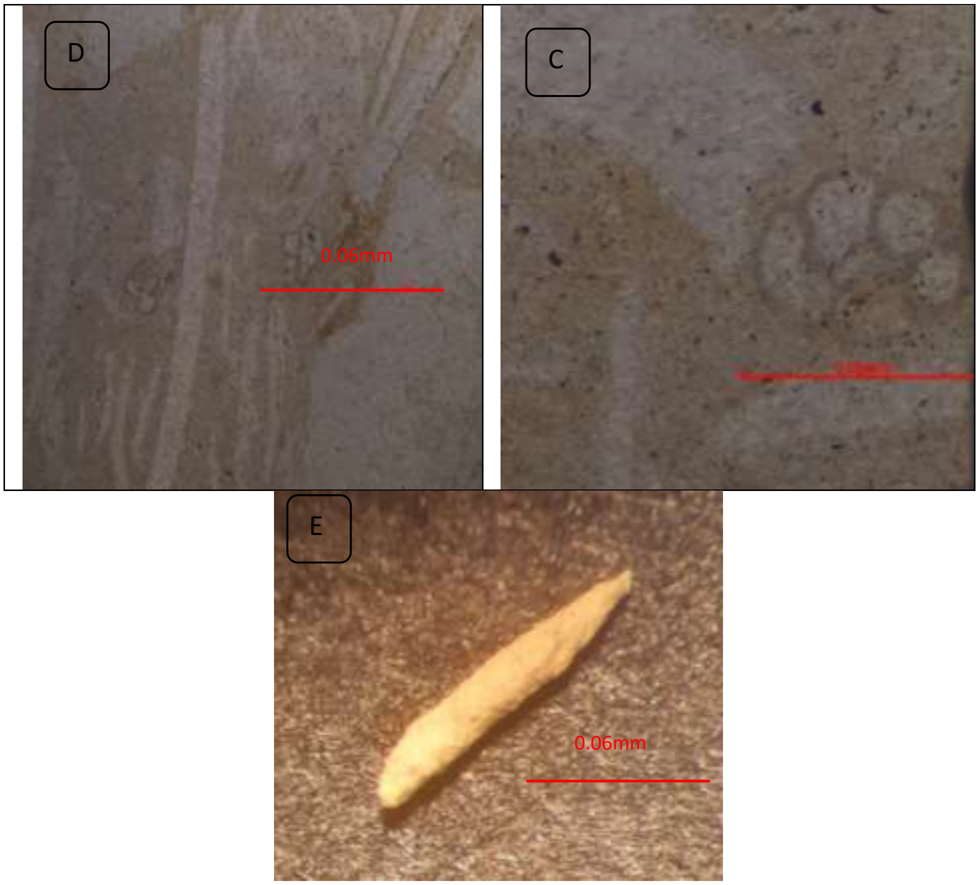


Figure 5. 1: Foraminifera fossils A, B, C and D are from thin section and fossil E is from Marl sample

Corals

A, Genus Anacropora,

B, Family Faviidea,

Figure 5. 2: Corals

Gastropods

A, family- macluritidae

B, Family –euomphalidae, 4X

C, Super family- euomophalacea, 4X

D, family – eumophlopteridea

D

Figure 5. 3: Gastropoda (Figure B and C have the same family)

Bivalves

A, Family –veneridea, 4X

B, Genus- Mesodesma, 4X

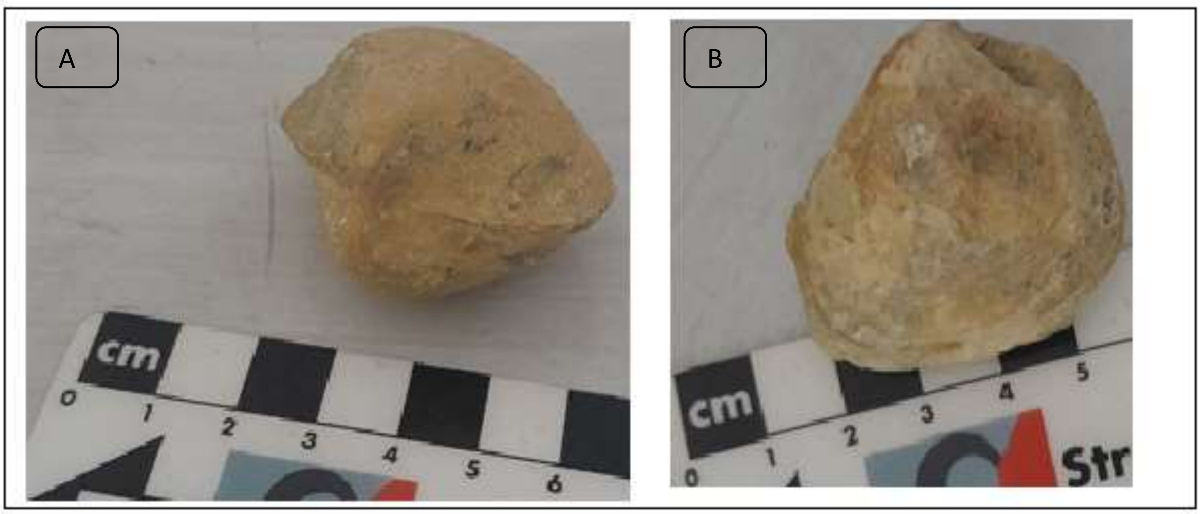


Figure 5. 4: Bivalve

Ostracode

A, *Cytheretta (Fleuxs) Trifurcata*

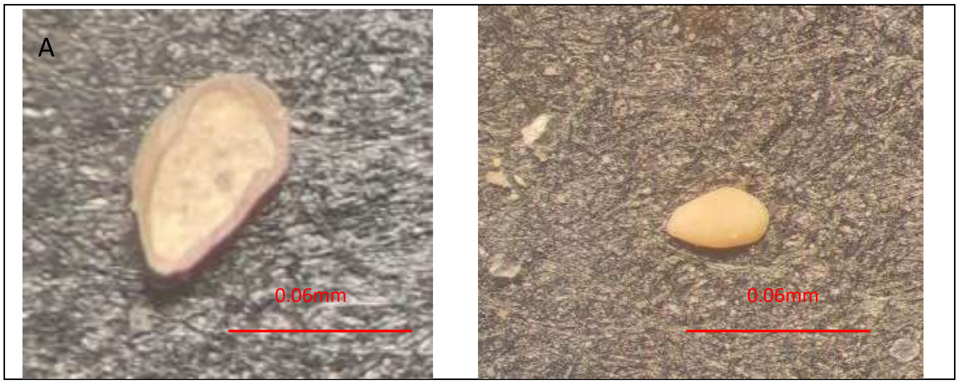


Figure 5. 5: Ostracods from marl sample A, from sample number S1K1

CHAPTER SIX

Microfacies analysis

Facies analysis, depositional environment and the age of carbonate unit can be identified by using by using microscopic data. It is difficult to conclude about an area by using only the field observation data that way microscopic data are so important to describe and know an area. Due sacristy of the microscopic data in the sheket section there is limited evidence of Microfacies analysis in the area. Because of that this study applies most Microfacies data's. There is detail thin section identification and analysis and naming by using Dunham (1962) later modified by Embry and Klovan (1972) and Folk (1959) classification.

Microfacies analysis

Microfacies are a set of all the paleontological and sedimentological criteria which can be classified in thin section (Flugel, 1982). It gives detail information about thin section companied with field observation. In sheket section the Microfacies of carbonate unit analysis is apply by using 20 samples. All each thin section carefully investigate in Petrographic microscope identify and describe including the fossils. After describe of the thin section from the result standard micro facies (SMF) classification Flugel (2004, 2010) and Wilson (1975) and ramp are studied.

The following are Microfacies that are identified

6.1 **Bioclastic packstones/floatstone microfacies type (MFT 1)**: this facies is found in sample number S1K13and S1S2 they have 52-52.5 percent of allochems. In this sample there is a lot of microfossil like gastropod with oblique section and highly spirl (Figure 5.1, A), some of bivalve (Figure 5.1 B) and also there is belemnite guard longitudinal sections rostrum. The open spaces of the fossil are field by calcites and between the grains there are matrixes.

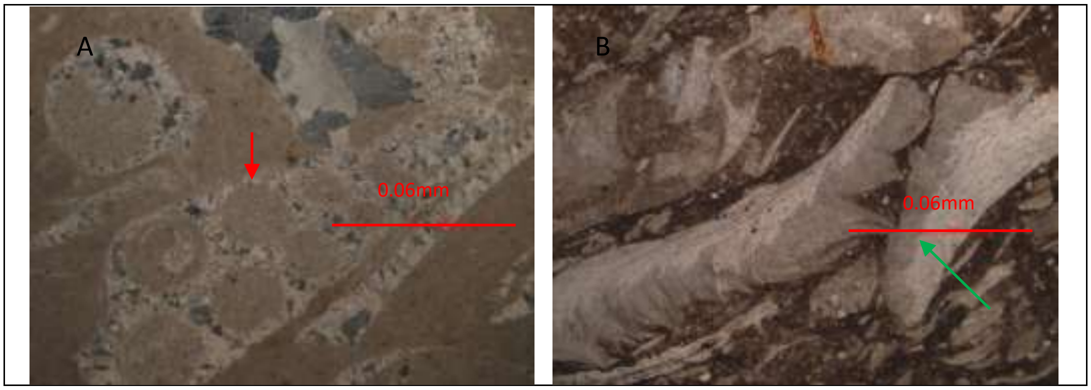


Figure 6. 1: Packstone/Floatstone from S1K13, A, under the XPL the red arrow shows the gastropoda fossil and S1S2 B from sample is under PPL the green arrow shows the bivalve fossil

Interpretation: The high degree of well sorting suggests that it is high energy environment (walker James, 1992). There are whole fossils and well preserved like gastropoda cephalopoda, bivalve and brachiopod with the micritic matrix. This corresponding with SMF 8 of flugel, (2010) and Wilson (1975). SMF 8 is common in deep open shelf (FZ 2) and open marine environment (FZ 7) (Flugel, 2010).

6.2 **Foraminifera bioclastic/ packstone microfacies type (MFT 2)**: this Microfacies is occurring in lower and middle part of the studied section in sample S1K5A, S1K5B, S1K10, S1K19 and S1K19B. There are different dense fossil like bivalve, gastropoda, brachiopod, and different type of foraminifera (Figure 6.2).

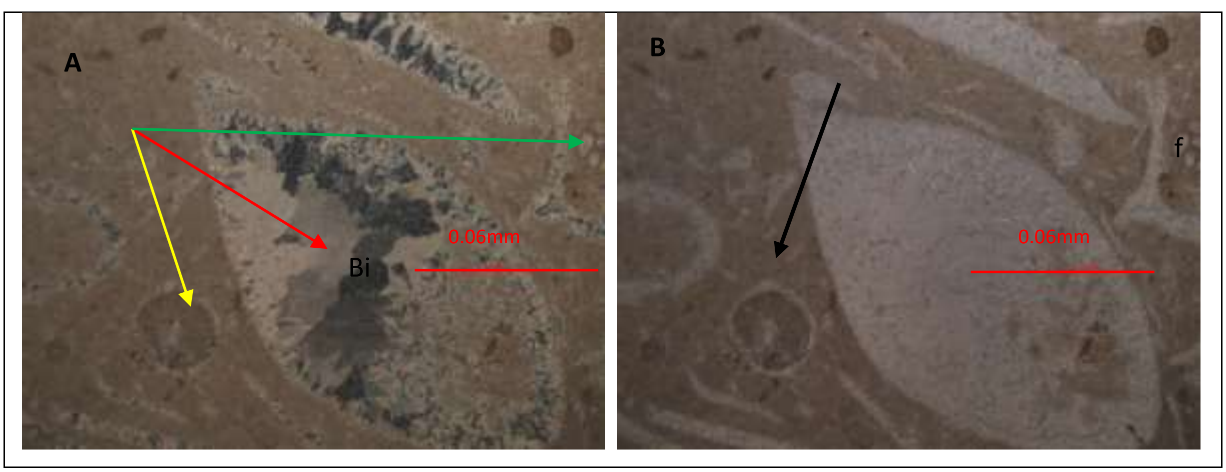


Figure 6. 2: Biomicritic/packstone from sample S1K19 A, sample under XPL these line shows a bioclast the yellow one is Gastropoda, the red one is bivalve and the grain one is foraminifera and B, sample under PPL the black one is shows the micritic under 4X magnification

Interpretation: There is dense of whole fossil and fossil fragments which is appear in disorder may be due to the various factor such as post-depositional alteration, incomplete preservation and bioturbation. It is an assemblage to SMF 5 of flugel (2010) and occurs in reef-flank facies (FZ 4) (Flugel, 1978).

6.3 **Oobiosparite/grainstones microfacies type (MFT 3)**: this facies is found in S1K7 it contains 80% bioclast, 2.5% ooids and 17.5% sparite. The bioclast are field by calcite cement and matrix cements. There is some bivalve, ostracode and some oblique section Gastropoda. There are also many unidentified bioclastic. There are few pore spaces.

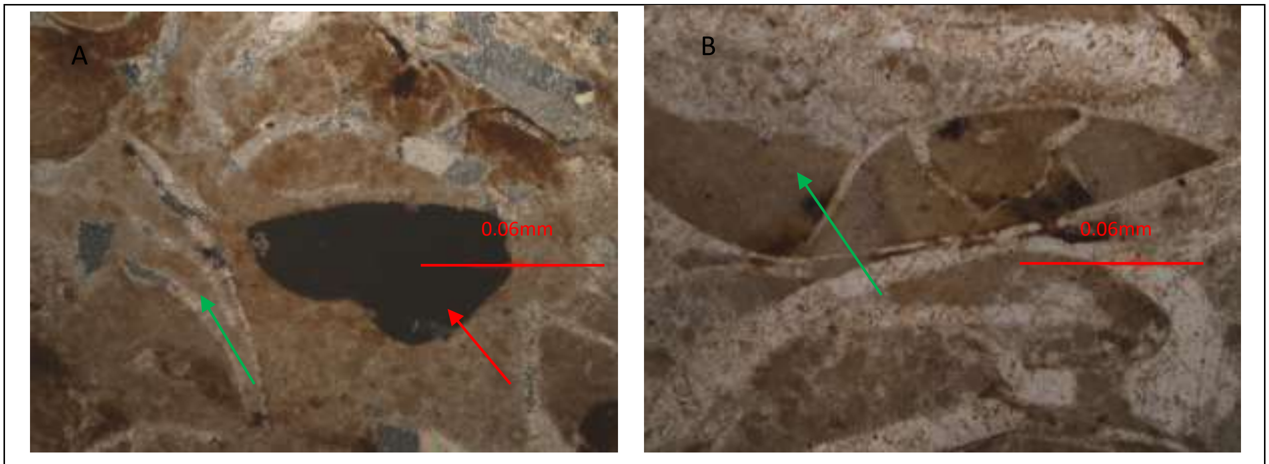


Figure 6. 3: Oobiosparite/greenstone in S1K7 A, the sample under XPL the red arrow is shown the open space (pores) and the green one is bioclast field by calcite cement B, the sample under PPL the green arrow shows bioclast field by matrix

Interpretation: This deposition shows the reworked platform material and pelagic admixtures with variable grain size. They are redeposited in deep water benthos. They have also very narrow facies belts (FZ 4) by corresponding to flugel 2010. It also assemblage to SMF 5 (Flugel, 2004).

6.4 **Oopelbiomicritic/wackestone micro facies type(MFT 4)**: this facies is find in a sample of S1K8 it consists 40% bioclast, 0.70% ooids, 0.80 peloids, 41% of micrite and 17.5% is sparite. There are a lot of bioclast like a long Brachiopoda with inner views, some ostracode, belemnite guards (cephalopoda) and some bivalves.

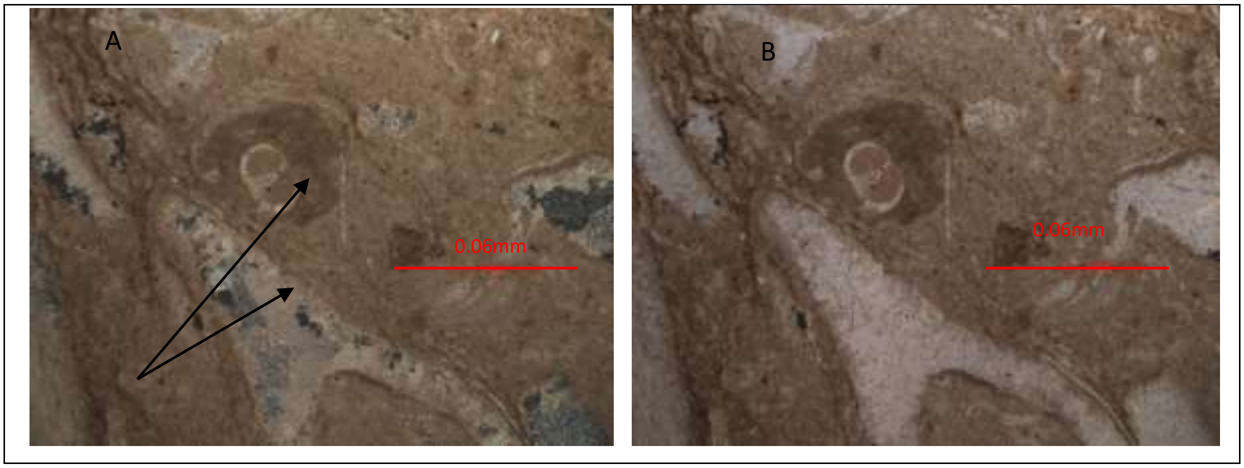


Figure 6. 4: Oopelbiomicritic/wackestone S1K8 A, the sample under XPL the black arrow is shown the grain cement B, the sample under PPL

Interpretation: burrowing organism mostly found in Mesozoic and tertiary like bivalve, gastropoda and Echinodermata are found living in shallow lagoon with open circulating or below the fair-weather wave base which is FZ 7 and deep shelf (FZ 2) (Flugel, 2004) or occur in the shelf facies-open circulation (facies belt 2 and 7) Wilson (1975).This is assemblage of SMF 9 Flugel, (2010).

6.5 **Bioclastic packstone microfacies type (MFT 5):** this facies found in the sample of S1K13B it has 51% bioclast, 34.25% calcite cement, 12.5% sparite and 2.7% of micritic. In this sample the bioclast are dominated there are also some sparite between the bioclast and there is also calcite cement. There are a lot of fossil gastropoda and some ostracode, foraminifera and others.

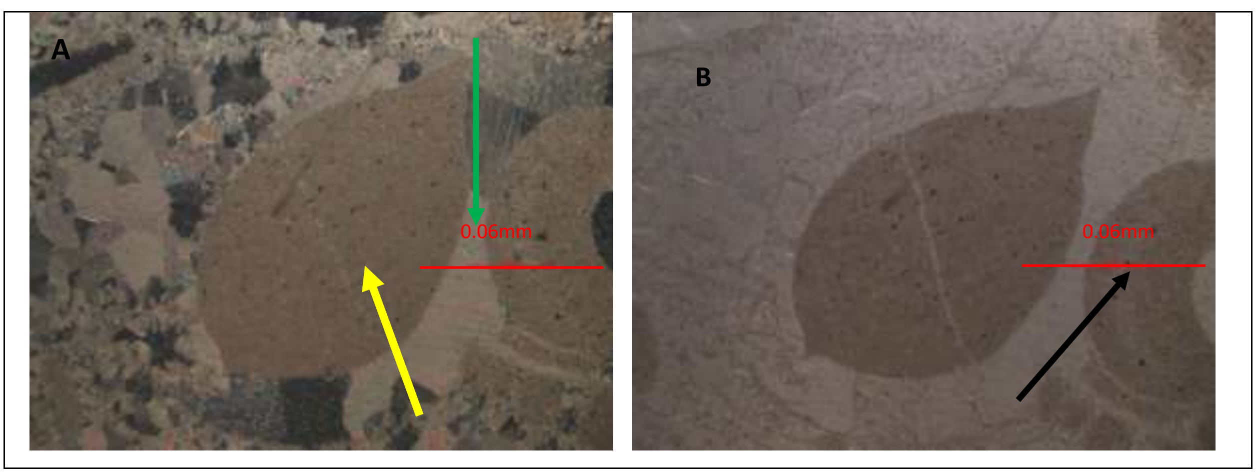


Figure 6. 5:Biosparite/packstone (S1K13B), A, sample under XPL, the yellow arrow shows the bivalve fossil that field by micritic and the green arrow shows the sparite between grain ,B, sample under PPL the black arrow shows the gastropoda fossil that field by micritic

Interpretation: There are coated, whole and fragment of fossils with fine grain of matrix. Like gastropoda, foraminifera, bivalve fragment. It is corresponding with flugel (2010) of SMF 10. There is inversion of texture between the particles and the fine grain matrix it means the large grain particle travel from high energy environment to the low energy environment And occur in open circular(FZ 2) and open sea shelf (FZ 7) Flugel, (2010) .

6.6 **Crinoid grainstones microfacies type (MFT 6)**: this facies is found at sample number of S1K10B, it has 65% bioclast, 13.25% sparite, 10.5% opaque and 11.5% porosity. In this sample is dominantly bioclast and have some sparite. There are dominantly echinodermata (Figure 6.6) and some brachiopod and bivalve shell.

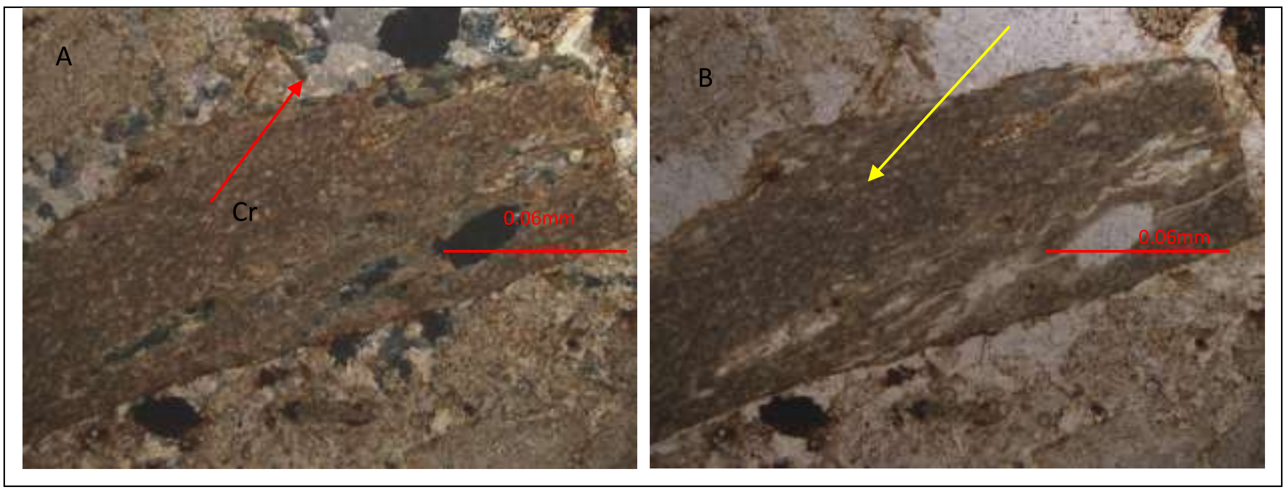


Figure 6. 6: Biosparite/grainstones S1K10B, A, sample under XPL the red arrow shows sparite B, sample under PPL the yellow arrow shows Brachiopoda fossil

Interpretation: limestone consist of abundant and dense packed Echinodermata represent a specific facies type formed in various setting including slope protecting plate form, reef and mounds(Flugel 2004). It is represent environment consist of wave and current action that is remove the carbonate mud by winnowing. It is associated with SMF 12.

6.7 **Bioclastic mudstone microfacies type (MFT 7)**: this facies is found in S1K16 and S1K5C. This is mud supported also have 4 to 5% bioclast like bivalve and other small grain. Micritic is dominantly found in this section.

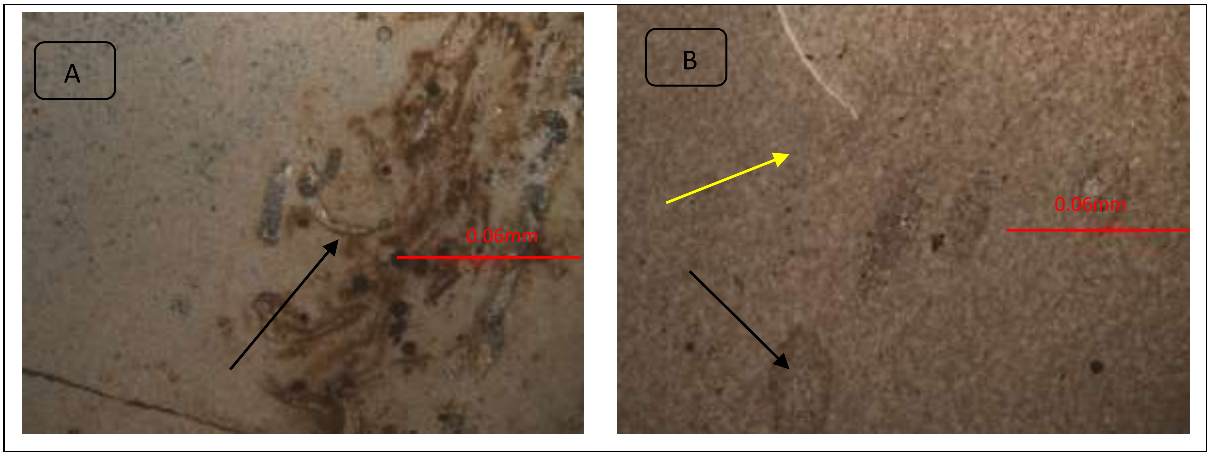


Figure 6. 7: Bioclastic Mudstone, A, from sample S1K16 and B, is from sample S1K5C the black arrow in A and B shows the bioclast and the yellow arrow shows the calcite mud

Interpretation: Dominate mud with some tiny bivalve and radiolaria and brown color of limestone is indicate that environment is corresponding with deep water basin below wave base (FZ1B) (Flugel, 2004).

6.8 **Bioclastic wackestone microfacies type (MFT 8**): this facies is found in S1K2, S1K14 and S1K4. They are mud supported with greater than 10% grain. Among them they gastropoda and bivalve. Some of the fossils are field by calcite and some are silicified. There is also some trace of opaque minerals.

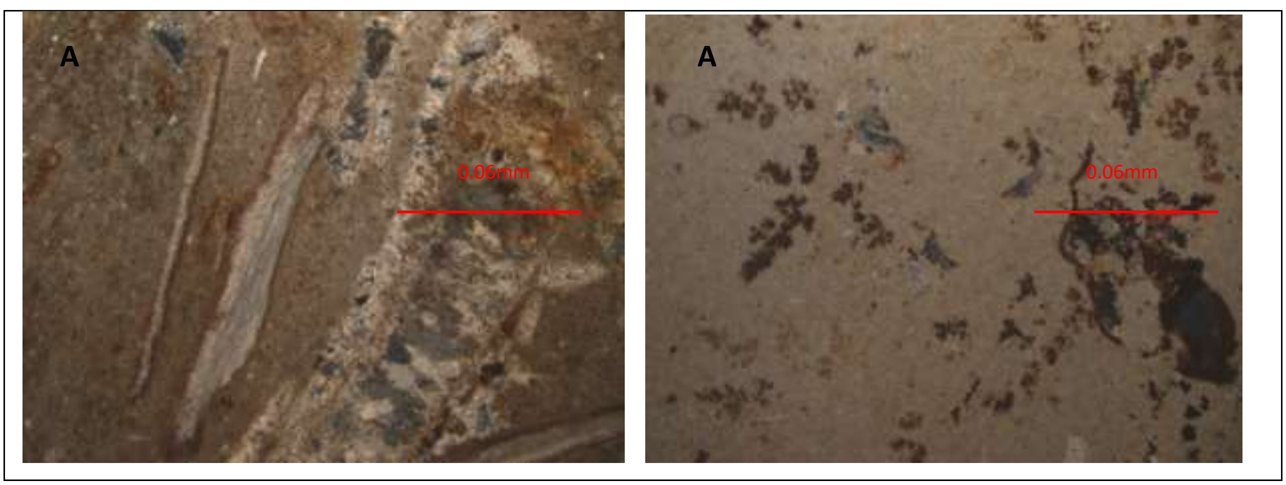


Figure 6. 8: Biomicritic /wackestone, A, Is from S1K14 and B from S1K2

Interpretation: The fossils that are found are Coated and worn bioclast in micrite. And they are common in the middle ramp. According to James L. 1975 it is assemblage with SMF 10.

6.9 **Bioclast spiculite /packstone microfacies type (MFT 9):** this facies is found in S1K18 has 48% micritic and 52% bioclast It consists small in size of some bivalve, radiolaria and calpionellids.

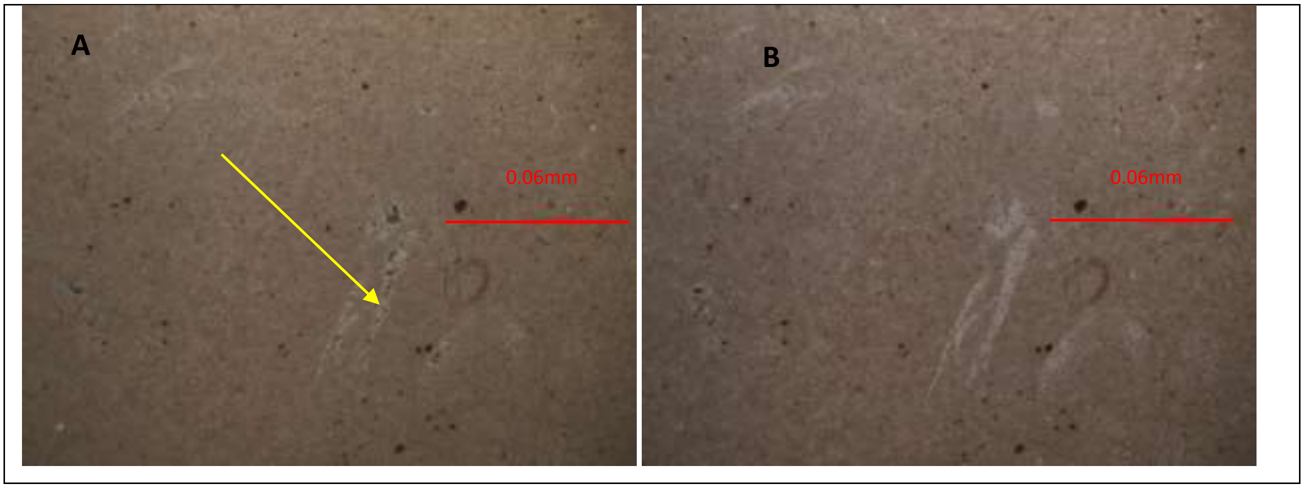


Figure 6. 9: Biomicritic/packstone (S1K18), A, sample under XPL, the yellow arrow shows the bioclast shell, B, sample under PPL

Interpretation: The bioclast packstone have dominantly radiolaria with some of sponge of spicules and also Calpionellids and some bivalve shells. this micro facies is similar with SMF 1 of Flugel ,(2010) which is corresponding with deep environment(FZ 1) and deep shelf carbonate(FZ 2) and outer ramp.

6.10 **Peloidal-bioclastic /wackestone micro facies type (MFT 10)**: this facies is found in S1K15 and S1K3. It has 30 to 37.5% of peloids (Figure 6.10). It is also mud supported. There is some bio clast grain which is covered by calcites.

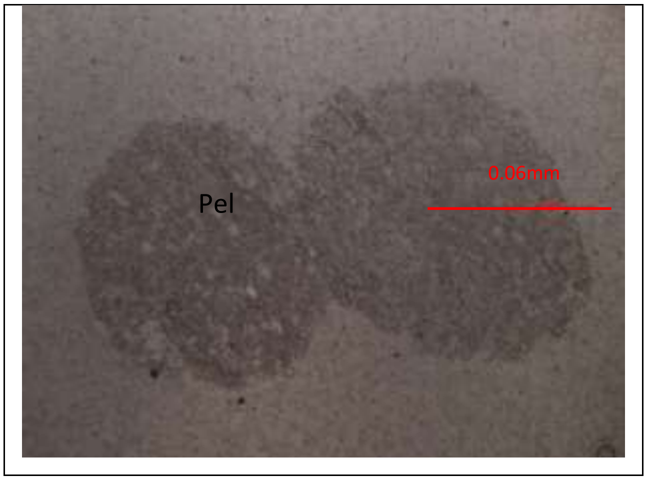


Figure 6. 10: Peloidal wackestone from S1k15

Interpretation: thin to medium limestone which is fine grain wackestone that consists dominated peloids grain and some Mollusca bioclast corresponded with SMF 2 of flugel (2004) and Wilson (1975). It is occur in deep basin (FZ 1), open marine shelf (FZ 2) and deep shelf-toe of slop position (FZ 3). Dominantly it found outer ramp specifically in RMF 4.

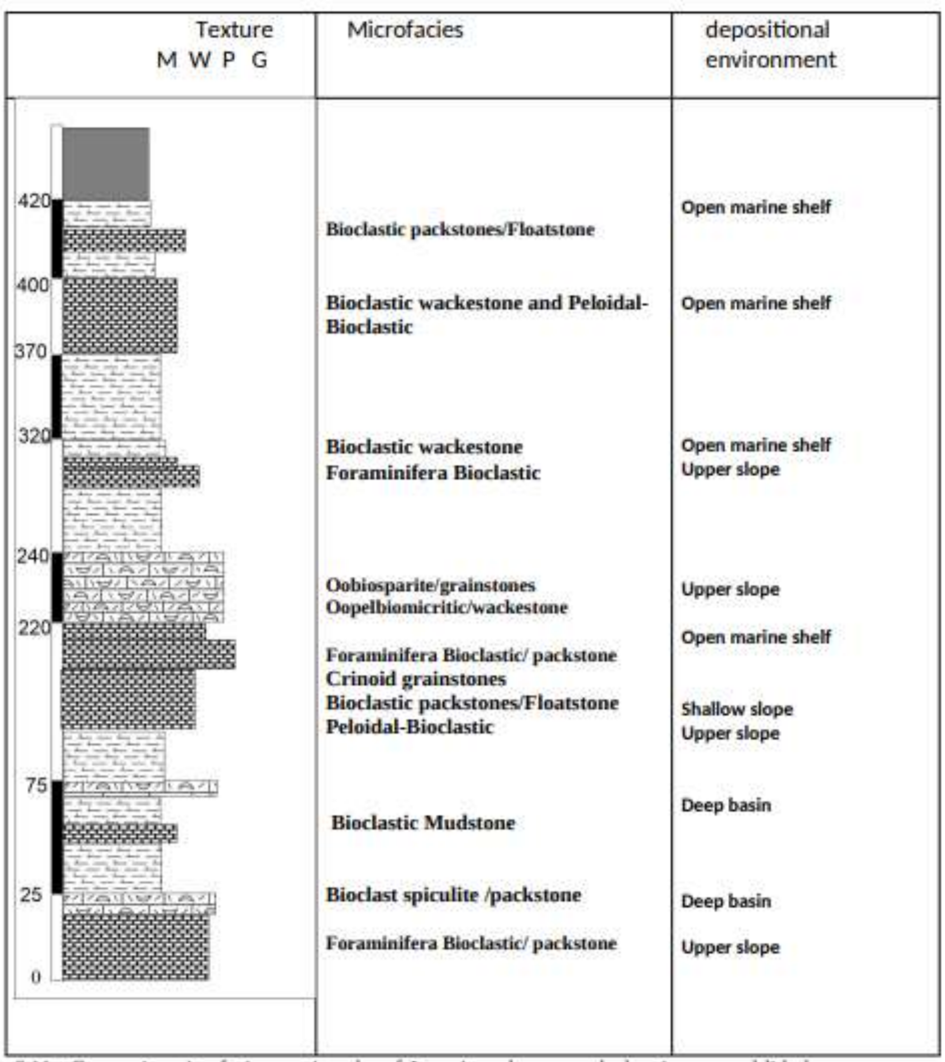


Figure 6.11 : Composite microfacies stratigraphy of Jurassic carbonate rock showing general lithology, microfacies distribution and interpretation of depositional environments

CHAPTER SEVEN

Discussion

7.1 Facies association and depositional environment

Introduction

Based on detail field investigation and thin section analysis or Petrographic analysis v of 20 thin section and 10 dray marl sediment in the sheket section the carbonate unit is characterized thick layer of limestone and marl with some shales. By carful investigation of those data the carbonate unit have various fossil grain with micritic or and sparite calcite cements and different grain ranging from mudstone to grain stone. Based on the varying sedimentological and paleontological investigation result are collecting for libratory describion and analysis, age determination and depositional environment interpretation.

Petrographic analysis and sedimentological interpretation help to identify the micro facies type and facies associations. Micro facies type and the facies associations play a crucial role in the development of models for carbonate depositional environment (Flugel, 2010). Based on identification of micro facies type and sedimentological characters there are four facies association have been illustrated.

7.1.1 Facies association FA1 (open marine shelf)

Deep shelf or open marine shelf is finding below FWWB but within the reach of extreme storm wave. The water depth is ten of meter to hundred meters. They have normal saline, oxygenate water and good current circulation. Most of the carbonate rock are fossiliferous and interbedded with marl and have gray to brown color. These facies associations have three micro facies as follow:

7.1.1.1 Oopelbiomicritic/wackestone (MFT4)

This is found in the middle part of the study area which is in the sample S1K8. It is consisting of ooids, peloids and dominantly of diverse fossil like Brachiopoda, belemnite, and some bivalve. This facies is corresponding with SMF 9 of Flugel, (2010) and Wilson, (1975). The sediments are fossiliferous limestone interbedded with marl.

7.1.1.2 Bioclastic packstone (MFT 5)

This is also found in the middle part of the study are from sample S1K13B which is having gastropoda foraminifera and the un identifiable fossils. Generally it consists 51% of bioclast and 2.75% of mud.

7.1.1.3 Bioclastic wackestone (MFT 8)

This facies found in the top and bottom part of the study area. From sample S1K2, S1K14. The bioclast undergoes silicification and micritization of diagenesis process.

7.1.1.4 Bioclast packstones/floatstone (MFT 1)

This facies found on the upper and middle part of the study area. It have 52-53% of bioclast with large fossil and fossiliferous and micritic limestone. This is similar with flugel (2010) of SMF 8.

7.1.2 Facies association II (slope)

They have distinct inclined sea floor seaward and very narrow facies belt (Flugel, 2010). Typically found between shallow water carbonate or ramps and deep marine basins. Sediments in this environment originated from erosion and breakdown of carbonate plate forms and ramps located up slope. There are foraminifers' bioclast /packstone (MFT 2) and Oobiosparite /grainstones (MFT 3) in this depositional environment.

7.1.2.1 Foraminifera bioclast /packstone (MFT 2)

Which is found in the dominantly found in the bottom of the study are but there are also in the middle and top part. It is from S1K5A, S1K5B S1K10, S1K19 and S1K19B. There are different type fossil foraminifera Brachiopoda gastropoda and bivalve. They have reworked sediments it is corresponding to SMF F flugel, (2010) and Wilson, (1975) and RMF 9 in the middle ramp.

7.1.2.2 Oobiosparite/grainstones (MFT 3)

Obtained in the middle part of the study area. From the sample of S1K7. This consisted 80% of the bioclast.

7.1.3 Facies association III

They have very narrow facies belt. It can be setting in stable mud mound on the upper slop or in the wave resists small barrier reef rimming form this consists massive limestone with brown to light color. This facies have the following micro facies type:

7.1.3.1 Crinoid /grainstones (MFT 6)

This is found in the middle part of the section with 65% abundant bioclast. It has dominated crinoid echinoderms which is assemblage with SMF 12 and RMF 27. Occur dominantly in inner ramp.

7.1.4 Facies association IV (deep basin)

It is found below the wave base which is having wide facies belt. It is about 30 to 100 meters deep. The lime mudstones with dark, brown and light color of limestone are common in this environment. There is different type biota in this area like radiolarians, thin-shelled bivalve and calpionellids. There are two Microfacies type under this depositional environment which is:

7.1.4.1 Bioclastic mudstone (MFT 7)

This is found in the top and bottom part of the section. From sample number S1K16 and S1K5C. They have thin-shelled bivalve with some radiolaria. In this facies the mud is dominate around 80 to 93.75%.

7.1.4.2 Bioclastic-spiculite packstone (MFT 9)

This is obtained on the bottom part of the study section. From sample number S1K18. It has dominated radiolarians but also have some thin bivalve and calpionellids. This assemblage with SMF 1 of Flugel, (2010) and Wilson, (1975). And RMF 1 of outer ramp.

7.2Depositional environment

A carbonate ramp is a gently sloping surface, gradients of the order of a few metres per kilometer, contrasting markedly with the steep slope up to a carbonate shelf. On a ramp, shallow-water carbonates pass gradually offshore into deeper water and then into basinal sediments. Therefore, on the basis of detailed sedimentological and paleontological information, the vertical and lateral distribution of the facies types, and comparison with similar modern facies, the carbonate successions indicate deposition in a shallow marine setting (Maurice Tucker, 1990).

7.2.1 Inner ramp

The distinctive sediments of the inner ramp are carbonate sands formed in the agitated shallow sub tidal shore face zone above FWWB and low intertidal. On a ramp, wave energy is not as intense as along a shelf margin where oceanic swell and storm waves are suddenly confronted with a shallow steep slope (Maurice Tucker, 1990). Inner ramp sediments are bedded, micro facially differentiated limestones and dolomites forming relatively thin sequences. Marls are of minor importance. The inner ramp comprises open-marine environments with good water circulation, protected environments with restricted water circulation, sand shoal and bank environments (Flugel, 2010). From sheket section carbonate unit is crinoid/ grainstones have been deposited in this environment.

7.2.2 Middle ramp

It is the zone between FWWB and SWB where the sea floor is affected by storm wave but not by fair weather wave (Burchett and wright, 1990).medium-bedded, fine-grained bioclastic limestones and marls, often burrowed. Skeletal grains often worn and Echinoderms common. Evidence shows storm reworking (Flugel, 2010). In the sheket section foraminifera – bioclast/packstone, Oobiosparite/grainstones and bioclast packstone and wackestone are deposited in this environment.

7.2.3 Outer ramp

The outer ramp environment refers to a specific zone within a carbonate ramp system, which extends from the outer edge of the continental shelf to the deeper parts of the basin. it is located in deeper water compared to the inner ramp. It typically begins at the shelf break, where the seafloor drops off steeply into deeper marine basins, and extends further into the basin. Thin to medium bedded, fine-grained, often burrowed limestones and marls. Laminated marls alternate with lime mudstones (Flugel, 2010). In the sheket section bioclast spiculite/packstone, Peloidal-bioclast/ wackestone are deposited in this environment.

7.3Biostratigraphic and the age of sheket section carbonate unit

Micropaleontology's significant practical application lies in utilizing microfossils for biostratigraphy. Additionally, since species do not reappear later in time, the presence of a specific species in rocks indicates deposition during its existence, regardless of location. Species evolve once, persist for a period, and then vanish. Therefore, a rock with such a fossil indicates deposition between the species' origination and extinction. By sequencing the appearance of various species over time, geologic time can be subdivided through biostratigraphy. Microfossils are particularly valuable for this purpose and for correlation studies. The prevalence of microfossils in biostratigraphy is attributed to their abundant presence in rock samples, owing to their small size, which results in numerous specimens per sample. Additionally, their rapid evolution, characterized by frequent speciation events, contributes to the creation of numerous potential biostratigraphic zones. Furthermore, microfossils commonly exhibit extensive geographic distributions, further enhancing their utility in biostratigraphy. The biostratigraphic of the studied are is due to the presence of the index foraminifer's fossil like *pfenderella Arabica (*late Bathonian) *and Pfenderina neoucomiensis* (Bathonian/ Callovian) the age of Jurassic section is from Bathonian to Callovian. But Due to the presence of genus praechrysalidina there is possibility this carbonate unit may be extended to Tithonian. *Pfenderella Arabica* found in Marl sample of S1K1 in the upper part of the section it suggests late Bathonian (Luca Buscaglione and Milvio Fazzuoli, 1987 and C.D. Redmond, 1964). *Pfenderina neoucomiensis* is found in the lower part of the section in sample S1K19 it suggest that Bathonian/ Callovian (H. smut and W.sugden, 1961)

7.4 Diagenesis

7.4.1 Introduction

The physical, chemical, and biological alterations that take place in sedimentary rocks following deposition but before to metamorphism are referred to as diagenesis. The term "carbonate diagenesis" describes the particular processes that have an impact on carbonate minerals such aragonite, dolomite, and calcite. There are two primary categories of carbonate diagenesis: early and late. At or near the surface, where the sediment is exposed to groundwater, ocean, or meteoric water, early diagenesis takes place. At higher temperatures and depths, late diagenesis takes place when the material is buried behind layers of sediment and undergoes cementation, dissolution, or compaction. Micritization, dissolution and cementation, compaction, neomorphism, dolomitization, and the substitution of non-carbonate mineralogy, such as silicification, for the carbonate grains and matrix, are the diagenetic processes that impact carbonate sediments and rocks (Flugel, 2010). Clyde, (2001) states that there are three main diagenetic habitats in which carbonate porosity can emerge or change: meteoric, marine, and subterranean. The sheket section contains many different diagenetic processes.

7.4.2 Compaction and pressure solution (stylolitization)

Refer to mechanical and chemical processes, triggered by the increasing overburden of sediments during burial and increasing temperature and pressure conditions (flugel, 2004) . Chemical compaction involves pressure solution at grain to grain contacts resulting in interpenetrating and/or sutured contacts between grains. In addition to grain to grain suturing, pressure-solution seams commonly develop approximately parallel to bedding. Presumably, the reason stylolite are usually parallel overall to bedding is that bedding surfaces are usually the paths of easiest flow of pore solutions (Adams and Mackenzie, 1998). In the sheket section stylolite is found in the upper portion in S1K4 (figure 7.1).

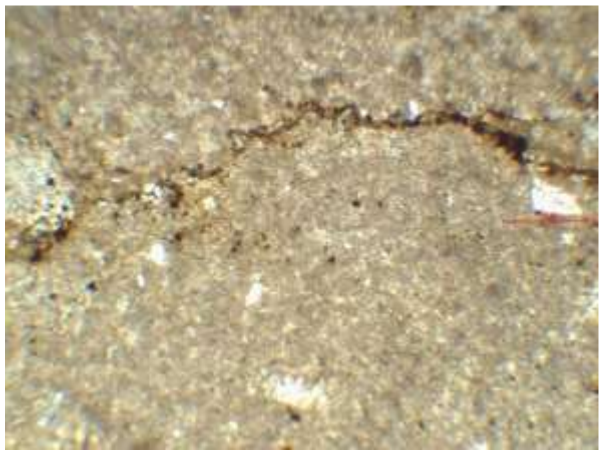


Figure 7. 1: Stylolite from the sample S1K4

7.4.3 Cementation

Cementation is a process in sedimentary rock formation where mineral cement fills the spaces between sediment grains and binds them together. This cementation occurs when minerals precipitate from pore fluids and fill the pore spaces between grains, forming a solid rock mass. Common cementing minerals include calcite, quartz, and iron oxides. The cementation process contributes to the lithification (conversion into rock) of loose sediment into coherent sedimentary rock. Cements represent an important record of the diagenetic history of carbonate rocks. Studies of thin sections are of paramount importance in recognizing diagenetic environments and determining paragenetic sequences in carbonate rocks (Flugel, 2004).

Calcite cements are commonly meniscus and pendant cements. In the water-saturated phreatic zone, they are isopachous, blocky or syntaxial rim cements. Syntaxial rims form by precipitation of optically continuous calcite around single-crystal fossil echinoderm fragments, in much the same way that cement overgrowths form around quartz grains. Calcite cementation may also take place during deep burial, although the conditions that control cementation at depth are poorly understood. Factors that have been cited to favor carbonate cementation during deep burial include unstable mineralogy (aragonite and high-magnesian calcite favors solution and reprecipitation); pore waters highly oversaturated in calcium carbonate; high porosity and permeability (which enable high rates of fluid flow); increase in temperature; and decree se in carbon dioxide partial pressure. The calcium carbonate needed for cementation at depth may be supplied, at least in part, by pressure solution of carbonate sediment in much the same way that pressure solution of quartz grains supplies silica to pore waters in siliciclastic sediment. Coarse mosaic calcite and bladed prismatic calcite are common kinds of deep-burial cements. These calcite cements are commonly coarse grained and clear or white in appearance. They are usually referred to as sparry calcite cement.

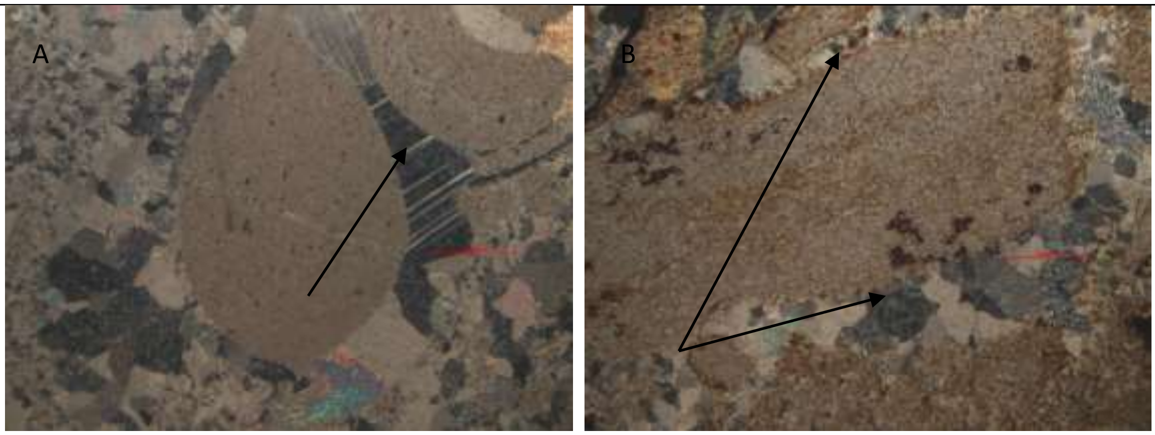


Figure 7. 2: Cementation in both A and B the black arrow shows as the cementation between grains

7.4.4 Dissolution

Dissolution refers to the chemical weathering and removal of carbonate minerals, such as calcite or aragonite, from carbonate rocks like limestone or dolomite. This process can result in the development of various features, including dissolution pores, vugs, caves, and karst topography, depending on factors such as the composition of the rock, the chemistry of the water, and the duration of dissolution (Flugel, 2010).

In this setting, there is significant dissolution of aragonite and high-magnesian calcite, and even calcite itself can dissolve if the pore waters are sufficiently aggressive. This dissolution tends to be concentrated along the water table, which marks the boundary between the vadose and phreatic zones, explaining the frequent occurrence of caves in carbonate rocks at this level. Dissolution is less pronounced in the deep burial realm compared to the meteoric realm for two main reasons. Firstly, in the meteoric realm, most aragonite and high-magnesian calcite may have already been converted to the more stable calcite form (refer to "Neomorphism" below). Secondly, the increase in temperature at depth reduces the solubility of all carbonate minerals. However, dissolution may still occur at depth if enough CO2 is added to pure waters due to the burial decay of organic matter, overcoming the decrease in solubility caused by higher temperatures. Additionally, the mixing of subsurface waters at depth can produce fluids that are under saturated with respect to calcite, thereby promoting the destruction of carbonate cements or other carbonate elements. When buried carbonate sediments are brought back into the meteoric zone after uplift, they may undergo extensive dissolution of both previously formed cements and other carbonate minerals under the influence of chemically aggressive, CO2-charged meteoric waters.

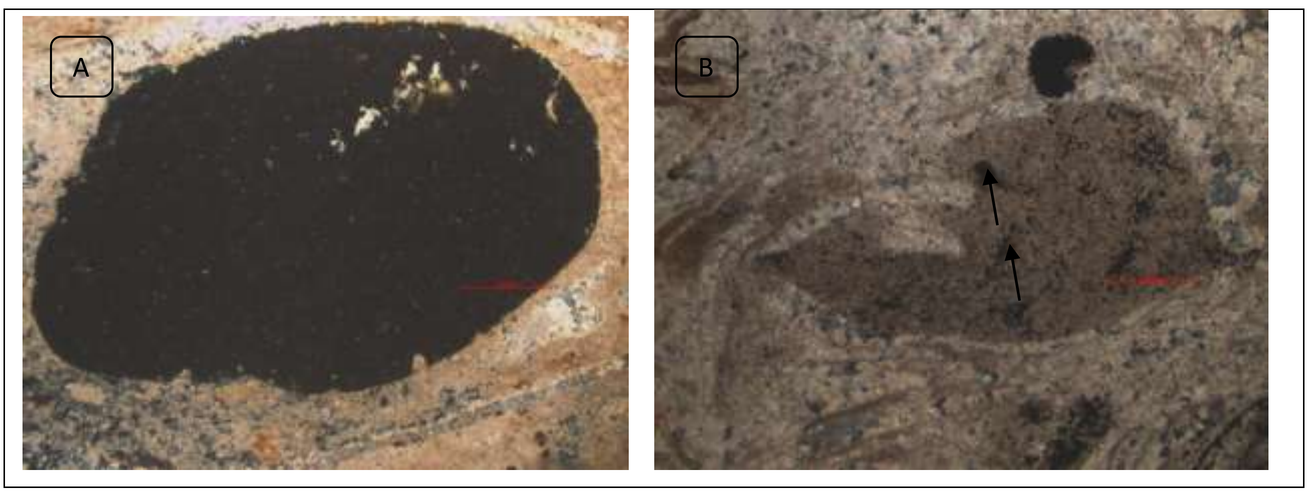


Figure 7. 3: Dissolution A, porosity B, the black arrow shows the dissolution in grain

7.4.5 Micritization

Micritization, a characteristic of marine environments, occurs before cementation, typically in the initial phases of diagenesis, as noted by Flugel in 2004. The process involves the transformation of original skeletal needles into mini micrite within organisms, likely due to the degradation of organic envelopes where the needles are formed and changes in internal chemical conditions. There are no mineralogical changes in the skeleton during this in vivo micritization. Microboring activity can significantly contribute to the micritization of carbonate grains. This process may involve either (A) the creation of open boreholes followed by the subsequent precipitation of infilling cement, as described by Bathurst, or (B) simultaneous infilling with minimal evidence of open boreholes. In the latter case, distinguishing micritization by Microboring from micritization by recrystallization becomes challenging. Bathurst (1996) suggested that the micritization of sediment grains could be caused by inorganic reduction in the free energy of crystal surfaces and biological change of pore-water chemistry.

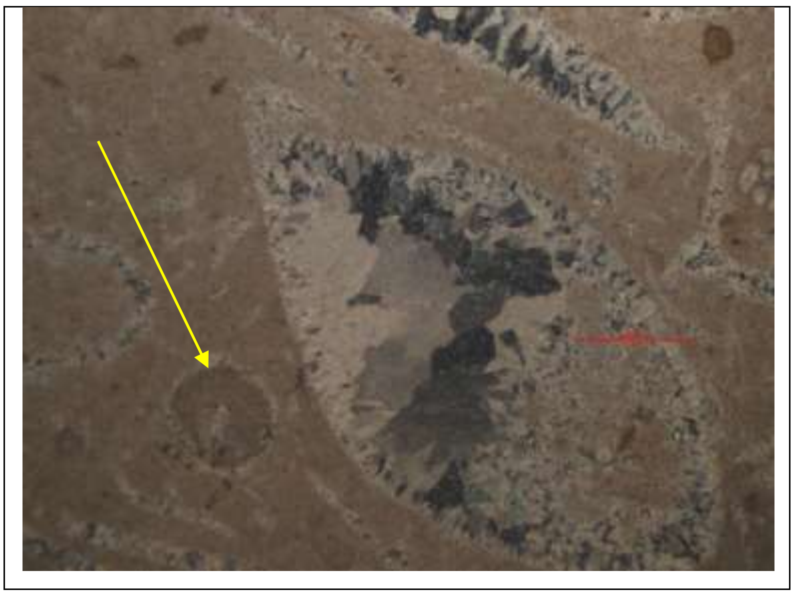


Figure 7. 4: Micritization the yellow arrow shows the micritization in the Gastropoda Grain

7.4.6 Silicification

Silicification involves the deposition of silica minerals, like quartz or chalcedony, which replace the original minerals in sedimentary rocks. This process plays a significant role in the diagenesis of sedimentary rocks, especially in altering biogenic or detrital components (Flugel 2004).

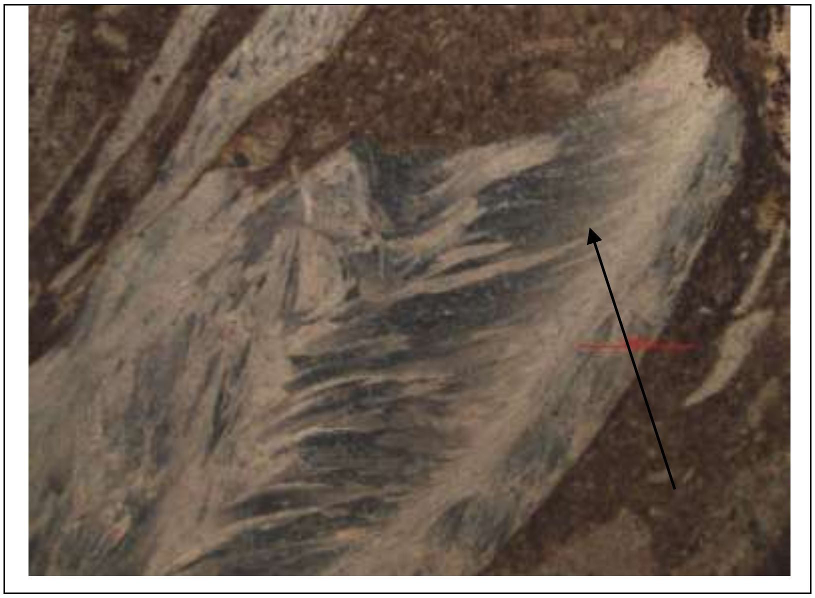


Figure 7. 5: Silicification

7.4.7 Neomorphism

Neomorphism, as defined by Folk in 1965, encompasses the processes of inversion (like aragonite change in to calcite) and recrystallization. It can occur across all three diagenetic realms but is particularly significant in meteoric and subsurface environments. Neomorphism affects both carbonate grains and micrite, often leading to an increase in crystal size. This process alters original textures and fabrics and, when extensive, can result in the complete recrystallization of the rock. For instance, a fine-grained (micritic) limestone may be transformed into a coarse-grained sparry rock. On a smaller scale, recrystallization yields large, clear calcite crystals resembling sparry calcite cement. Fossils composed of aragonite are dissolved and replaced by calcite during this process (Figure 7.6).

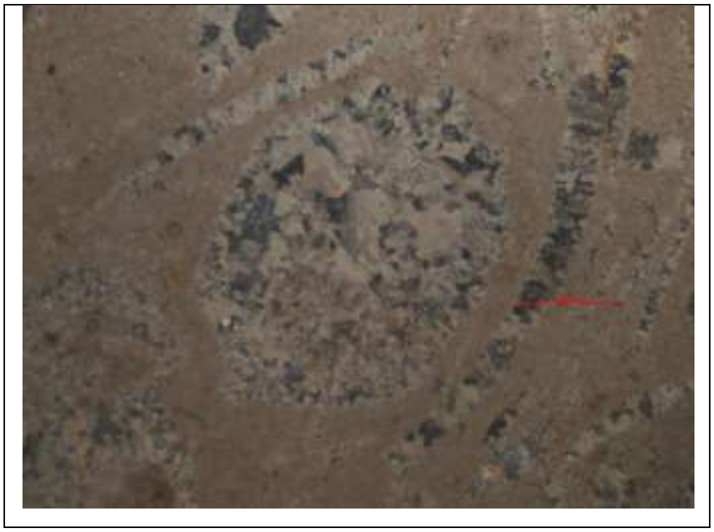


Figure 7. 6: The aragonite replaced by calcite in the bioclastic grain

7.4.8 Other sedimentary structures

Fractures are apparent under a microscope as fractures or cracks in the carbonate rock substance. Numerous geological processes, including tectonic stress, diagenesis, and weathering, can cause these cracks. Their existence can greatly affect the permeability, porosity, and general quality of carbonate reservoirs. They can vary in size, orientation, and morphology.

Within measured sections, fractures are often observed at varying intervals and result from compaction processes. Because carbonate rocks are naturally more brittle than the finer-grained, siliciclastic rocks they are commonly interlayered with, this characteristic is particularly noticeable and common in carbonate rocks (Longman, 1980).

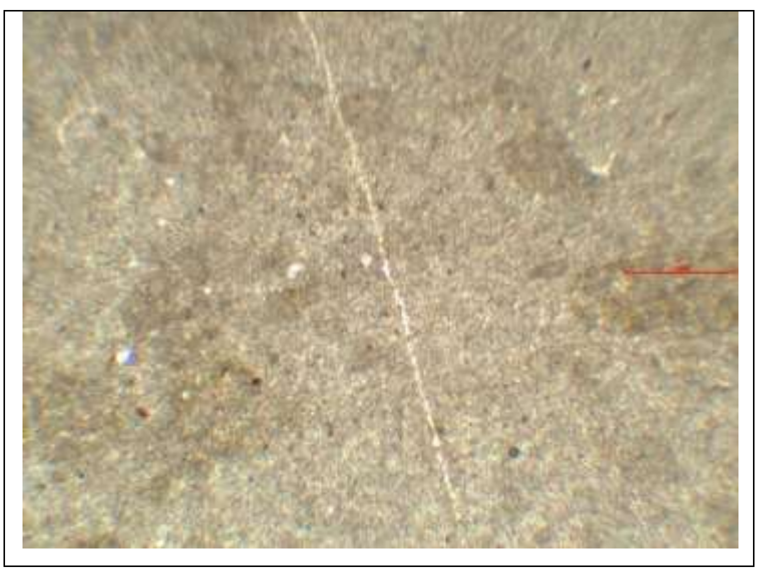


Figure 7. 7: Fracture

Vein: Within a rock, vein is a particular sheet-like body of crystallized material. Veins form when minerals carried by water within rocks settle and crystallize through precipitation (Schroeter, 2013).

Figure7. 8: veins that are filed by calcite from S1K9

Stalactites: Stalactites are a type of speleothems mineral deposits that develop inside caves as a result of the deposition of soluble minerals like limestone-forming calcium carbonate (White, W. B., 2019). Stalactites range in size from centimeters to meters and hang from the cave ceiling, gradually growing upward from the cave floor (Silvia F. and Jon D., 2012).

Figure 7. 9: Stalactite

7.5 Correlation

In the sheket section 420 m thickness of limestone has been studied. It is grouped in to 10 micro facies type based on Petrographic analysis and paleontological studied. This section is corresponding intra basinal with wekro section and hagereselam section of Mekelle basin.

The uppermost part of sheket section consist of dominantly 20 m thickness of Marl but it including some layers of micritic limestone and also it have 30 m thickness of Micritic

Limestone which have brown color and calcareous shale. This upper part has diverse bioclast like gastropoda, bivalve, peloids, ostracode and radiolaria. The middle of the section have 20 m thickness of fossiliferous limestone with brown color with some layer of micritic limestone and 80 m thickness of Marl they have gray color and have layers of fossiliferous limestone, micritic limestone and some shale and there is 120 m thickness of massive micritic limestone and have dark brown to dark color but including calcareous shale and marl. This part of the study area also consist bioclast like foraminifera, bivalve, cephalopoda, Brachiopoda and Echinodermata. The lower parts of the section have 20m thickness micritic and some layers fossiliferous limestone and 50 m of Marl and also with some layers fossiliferous limestone.

According to the Damenu Adefris et al., (2022) Hagere Selam section of Mekelle basin, Northern Ethiopia consists in the lower part of the section have the lower 120 m thickness consist marl intercalated with micritic limestone with different type of bioclast like foraminifera, Brachiopoda, and bivalve. Middle to upper part of the section consists of dominantly fossiliferous limestone but also have marl and micritic limestone. They have diverse bioclast like bivalve, gastropoda and foraminifera. The upper and the middle part of this section are corresponded with upper part of sheket section.

In the Wekro section two Mekelle Basin in Northern Ethiopia which is also studied by Damenu Adefris et al., (2022) it shows from the middle to the uppermost part of Antalo limestone. Interval between from 225 to 310 m comprise fine grain limestone (Fossiliferous and micritic), marl and shale layer with in limestone bed. The upper part of the wekro section two is limestone interbedded with shale. The middle part of this section is corresponding with middle part of sheket section.

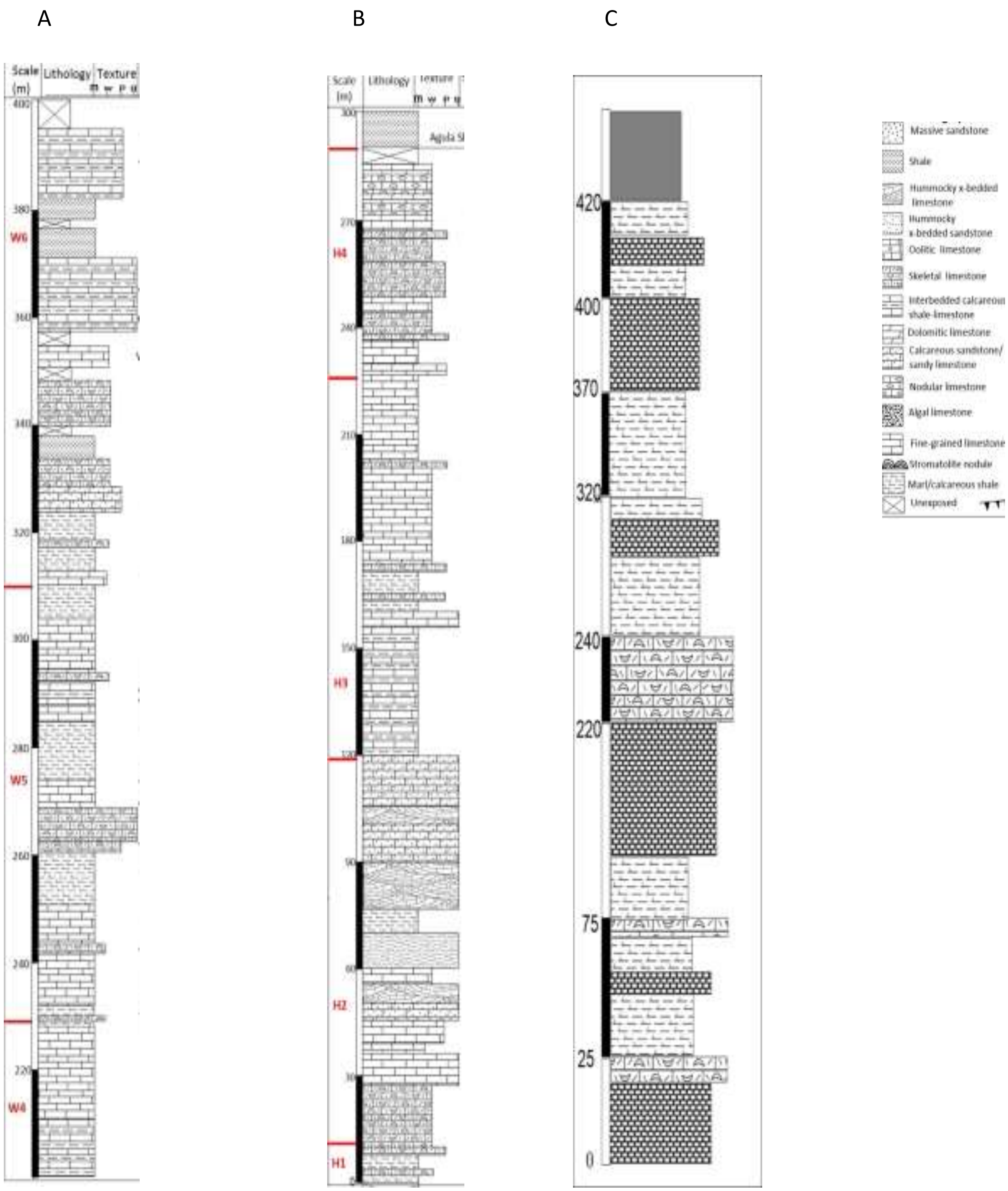


Figure 7. 10: Intrabasinal correlation of stratigraphic section A, wekro section (Damenu Adefris et al., 2022) and Hagereselam section Damenu Adefris et al.,2022 and C ,Sheket section present work

CHAPTER EIGHT

Conclusion and Recommendation

Conclusion

The study is located in North Ethiopia, Mekelle basin in the sheket section. Based on the detail field and Petrographic investigation the sheket section of Antalo limestone consisted calcareous mar and shale, marly limestone, micritic limestone and fossiliferous limestone. There are various Micro and Macro fossil are identified like from bivalve, *veneridea* Rafinesque 1815, *mesoderm* Deshayes 1832, from gastropoda *macluritidae* Ficher 1885, *Euomphalida*e de-koninck 1881. From foraminifera *Textularia* Detrace 1824, *Pfenderina neoucomiensis* and *miliolidae* Ehrenberg 1839, from ostracode *Cytheretta (Fleuxs)* Trifurcata Luembimova and Guna 1960 and more are recognized. Eight

Based on the Petrographic analysis of 20 thin section 10 Microfacies has been recognized such as Bioclastic packstones/floatstone, foraminiferal bioclastic/ packstone, oobiosparite/grainstones, Oopelbiomicritic/wackestone, bioclastic packstone, crinoid grainstones, bioclastic mudstone, bioclastic wackestone, bioclast spiculite /packstone and Peloidal-Bioclastic /wackestone. These microfacies grouped in to 4 facies association including open marine shelf, slop, plate form margin and deep basin. Fracture, cementation, dissolution, micritization neomorphism and silicification are diagenesis processes that are affected the carbonate unit of the study area.

The age of carbonate unit of sheket section indicates as: from Bathonian to Callovian due to the presence of *pfenderella Arabica*, *Pfenderina neoucomiensis* and but also Due to the presence of genus praechrysalidina there is possibility this carbonate unit may be extended to Tithonian.

The carbonate unit of sheket section are deposited from shallow to deep environment based on the field and Petrographic analysis it include inner ramp, outer and middle ramps. It has been correlated with previous stratigraphic section studied at Wekro and Hagere Selam of Mekelle Basin.

Recommendation

This study give understanding of the carbonate unit in Sheket section in Mekelle Basin, Northern Ethiopia in the terms of micro and macro fossils, paleoenvironment and the age. But better understanding of the carbonate unit of the area can be achieved by collecting of more samples for the Petrographic study and microfossil reorganization, prepare more thin section and strength of this study in the sheket section in order to obtain complete picture of the study area.

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Thin section

Thin no	Allochemes					Micritic	Cement			Poresty	Dunham	Folk	MFT	SMF
	Bioclast	Peloied	Ooide	Grain	Intraclast		Sparite	Calcite	Opaque					
S1K13	52	0.5	1	-	-	46.5	-	-	-	-	Packston/floatstone	Peloobiomicrtic	1	8
S1K10	82	-	-	-	-	13.75	-	-	-	-	Packston	Biomicrtic	2	5
S1k7	80	-	2.5	-	-	-	17.5	-	-	-	Grainstone	Oobiosparite	3	5
S1S2	52.5	-	-	-	-	31.25	16.25	-	-	-	Packston/floatstone	Biomicritic	1	8
S1K8	40	0.80	0.70			41	17.5	-	-	-	Wackestone/floatstone	Oopelbiomicrtic	4	9
S1K13B	49.5	-	-	-	-	3.75	12.5	34.25	-	-	Wackeston	Biosparite	5	10
S1K10B	65	-	-	-	-	-	13.5	-	10.5	11.25	Grainstone	Biosparite	6	12
S1K19	52	-	-	-	-	47.5	-	-	-	0.5	Packston	Biomcritic	2	5
S1K19B	53	-	-	-	-	29.5	11.25	4	0.25	2	Packston	Biomicrtic	2	5

S1K16	5	-	-	-	-	93.75	-	-	1.25	-	Mudstone	Biomicrtic	7	9
S1K5c	4	-	-	-	-	80		-	3	13	Mudstone	Biomicrtic	7	3
S1K15	3	30	-	-	-	40	-	17	10	-	Wackestone	Biopelmicrtic	10	2
S1K14	23	-	-	-	-	48	-	15	4.5	9.5	Wackestone	Biomicrtic	8	10
S1K5A	53	-	-	-	-	35	-	-	3.75	8.25	Packestone	Biomicrtic	2	
S1K2	24.5	-	-	-	-	48.5	-	8	1.5	17.5	Wackestone	Biomicrtic	8	10
S1K3	8.75	37.5	-	-	-	53.75	-		-	-	Wackestone	Biopelmicrtic	10	2
S1K4	7.5	-	-	35	-	50	-	7.5	-	-	Wackestone	Biomicrtic	8	10
S1K18	52	-	-	-	-	48	-	-	-	-	Packestone	Biomicrtic	9	1
S1K7B	51.25	-	-	-	-	35	-	10.25	-	3.5	Packestone	Biomicrtic	2	5
S1K5B	51.25	-	-	-	-	48.75	-	-	-	0.5	Packstone	Biomicrtic	2	5