

**ADDIS ABABA UNIVERSITY  
SCHOOL OF EARTH SCIENCES**

**SYSTEMATICS AND PALEOENVIRONMENT  
OF QUATERNARY CORALS AND  
OSTRACODS IN DALLOL CARBONATES,  
NORTH AFAR**

**ADDIS HAILU ENDESHAW**

**NOV., 2017**

**ADDIS ABABA, ETHIOPIA**

**Systematics and Paleoenvironments of Quaternary Corals and  
Ostracods in Dallol Carbonates; North Afar**

**Addis Hailu Endeshaw**

**Advisor – Dr. Balemwal Atnafu**

**A Thesis Submitted to**

**School of Earth Sciences**

**Presented in Partial Fulfillment of the Requirements for the Degree of  
Masters of Science in Earth Sciences (Paleontology and Paleoenvironment)**

**Addis Ababa University**

**Addis Ababa, Ethiopia**

**Nov., 2017**

**Addis Ababa University**

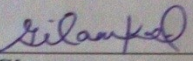
**Office of Graduate Studies**

This is to certify that the thesis presented by Addis Hailu, entitles: *Systematics and Paleoenvironment of Quaternary Corals and Ostracods in Dallol Carbonates, North Afar* and submitted in partial fulfillment of the requirements for the degree of Degree of Masters of Earth Sciences (Paleontology and Paleoenvironment) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

**Signed by Examining Committee**

Name – Gilamichael Kidanemariam (PhD)

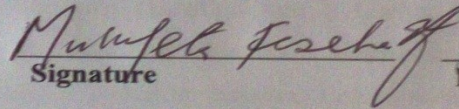
External Examiner

  
Signature

January 11, 2018  
Date

Name – Mulugeta Fisseha (PhD)

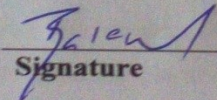
Internal Examiner

  
Signature

Jan 11, 2018  
Date

Name – Balemwal Atnafu (PhD)

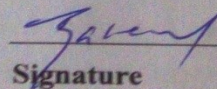
Advisor

  
Signature

11<sup>th</sup> January 2018  
Date

Name – Balemwal Atnafu (PhD)

Chairman of Thesis Defense Session

  
Signature

11<sup>th</sup> January 2018  
Date

## ABSTRACT

### Systematics and Paleoenvironment of Quaternary Corals and Ostracods in Dallol Carbonates, North Afar

Addis Hailu Endeshaw

Addis Ababa University, 2017

There are reef structures developed in Dallol during the Quaternary Period as a result of flooding of the area by the Red Sea at least two times. Dallol area is situated in the northern most part of the Eastern African Rift system. The studied coral outcrops are aligned along the northwestern margin of the Afar rift. This research focused on the investigation of systematics of corals and associated fossils of mollusca, echinoidea, ostracoda and foraminifera together with the reconstruction of past environmental conditions. Different scientific methods were followed in order to achieve the objectives of the study. These are detailed insitu morphological descriptions; field observations and measurements; laboratory preparations and microscopic examinations; comparison of the described specimens with type specimens; and paleoecological calculations using PAST-3 software. Total of 164 fossil and 9 sediment samples are collected from the field and examined. The Dallol corals are classified into 12 Families, 29 Genera and 60 Species. The most common species include massive *Porites*, *Porite lobata*, *Goniastrea pectinata*, *Goniastrea retiformis*, *Goniastrea stelligera*, *Echinopora hirsutissima*, *Echinopora gemmacea*, *Echinopora sp.*, *Caulastrea furcata*, *Caulastrea tumida*, *Pavona venosa*, *Stylopora wellsii*. Bivalvia classified into 9 Genera and 12 Species which are dominated by *Tridacna maxima*, *Tridacna crocia*, *Arca boucardi* and *Crossastrea sp.*; gastropoda classified into 6 Genera and 7 Species dominantly *Cerithideopsis cingulata*, *Canarium mutabile* and *Rhinoclavis sordidula*; and echinoidea classified into 6 Genera and 8 Species dominantly *Clypeaster humilis*, *Echinometra mathaei* and *Phyllacanthus imperialis*. Ostracoda grouped into 15 Genera and 27 Species most of them are monospecific and dominantly *Cyprideis torosa*, *Cyprideis longespina*, *Xestoleberis rotunda*, *Xestoleberis depressa*, *Leptocythere castanea*, *Loxoconcha carinata*, *Pontoparta salina*, *Keijia demissa* and *Cytherella sp.* are recognized. Most of them are euhaline ostracoda species. Foraminifera grouped into 9 Genera and 13 Species with dominant species *Trochammina sp.*, *Quinqueloculina oblonga*, *Quinqueloculina lamarckiana*, *Quinqueloculina sagamensis*, *Elphidium crispum*, *Amphistegina lenssonii* and *Ammonia tepida*. From paleoecological analysis of coral species 36% of total identified species are rare, 40% moderately abundant and 23% abundant. Shannon-Wiener index indicates that the older (MIS7) coral species are more diverse than the younger (MIS5) coral species. Paleoenvironmental interpretations are made from biofacies associations and paleoecological results. These are shallow open marine environments of two different phases with small sub – environments of shallow lagoon, brackish protected environment and lacustrine environment.

**Key words:** *Dallol, Corals, Ostracoda, Mollusca, Systematics, Reef, Paleoecology, Paleoenvironment*

## ACKNOWLEDGEMENT

I am thankful to LORD for everything that you made in my life and for your everyday blessings.

First of all I would like to give my sincere gratitude to Addis Ababa University School of Earth Sciences for giving me this opportunity of master's study and research funding.

I am above all deeply grateful to my supervisor Associate Professor Balemwal Atnafu for his wise guidance, advice, encouragement and introducing me to the scientific research. These will add valuable results and satisfactions throughout the research work.

I am grateful to Prof. Tesfaye Kidane (School of Earth Sciences, AAU); Prof. Anneleen Faubert and Dr. David Jaramillo Vogel (Carbonate sedimentologists from Fribourg University) for their great assistances during the fieldwork and bring me scanned reference literatures on corals. It is with great pleasure to express my thanks to SERENA project for covering fieldwork accommodations. I would like to express my deepest gratitude to Geological Survey of Ethiopia for providing me the geological reports of the area.

My gratitude extends to my colleagues and friend specially Mr. Wendwossen Sisay, School of Earth Sciences Petrology Laboratory expert; Mr. Ermiyas Filfilu and Mr. Haftom Hagos for their support during transect study in the field; and Dr. Seifu Kebede for his invaluable support and encouragement during the research work.

Finally, I am thankful to Mr. Tayachew Amsal, my husband, and my family members Reizana, Mariyamawit, Yeamlak, and Million for their patience and unforgettable support to see my success. The last but not least my gratitude goes to Mr. Hussen, Ahmedella local peoples and CIRCUM Company staffs for their help during the fieldwork.

# TABLE OF CONTENTS

<b>ABSTRACT</b> .....	<b>i</b>
<b>ACKNOWLEDGEMENT</b> .....	<b>ii</b>
<b>TABLE OF CONTENTS</b> .....	<b>iii</b>
<b>LIST OF FIGURES</b> .....	<b>VII</b>
<b>LIST OF TABLES</b> .....	<b>IX</b>
<b>LIST OF PLATES</b> .....	<b>IX</b>
<b>LIST OF ACRONYMS</b> .....	<b>X</b>
<b>1. INTRODUCTION</b> .....	<b>1</b>
1.1. Background.....	1
1.2. Previous Studies.....	4
1.3. Study Area Description.....	5
1.3.1. Location .....	5
1.3.2. Geology of Dallol.....	9
1.3.3. Tectonics and Structural Geology of the Area .....	11
1.4. Problem Statement .....	12
1.5. Objectives .....	12
1.5.1. General Objective .....	12
1.5.2. Specific Objectives .....	13
1.6. Significance of the Study .....	13
1.7. Thesis Outline .....	14
<b>2. METHODOLOGY AND MATERIALS</b> .....	<b>15</b>
2.1. Methodology .....	15
2.1.1. Background.....	15
2.1.2. Data Collection .....	15
2.1.2.1. Pre – fieldwork.....	15
2.1.2.2. Fieldwork .....	16
2.1.2.3. Post – fieldwork .....	16
2.1.3. Macrofossil Preparations and Descriptions.....	17
2.1.3.1. Coral Description and Comparison Approach .....	17
2.1.3.2. Other Associated Macrofossils .....	18
2.1.4. Microfossils Preparation and Description.....	18
2.1.4.1. Systematic Approach for Ostracoda Classification.....	19
2.1.4.2. Systematic Approach for Foraminifera Classification .....	20
2.1.5. Statistical Approach for Species Diversity and Abundance Calculation .....	21
2.2. MATERIALS .....	22
<b>3. LITERATURE REVIEW</b> .....	<b>23</b>
3.1. Background.....	23
3.2. Systematic Paleontology .....	23
3.2.1. Scleractinia Corals .....	23
3.2.2. Ostracoda and Foraminifera .....	27

3.3. Quaternary Corals and Ostracoda as Paleoenvironmental Proxies .....	31
<b>4. SYSTEMATIC PALEONTOLOGY .....</b>	<b>32</b>
4.1. Background .....	32
4.2. Systematics of Quaternary Corals of Dallol .....	32
4.2.1. Family Acroporidae Verrill, 1902.....	32
4.2.1.1. Genus <i>Acropora</i> Oken, 1815 .....	32
4.2.2. Family Agariciidae Gray, 1847.....	33
4.2.2.1. Genus <i>Leptoseris</i> Milne Edwards and Haime 1849 .....	33
4.2.2.2. Genus <i>Agaricia</i> Lamarck, 1801 .....	33
4.2.2.3. Genus <i>Pavona</i> Lamack, 1801 .....	34
4.2.3. Family Merulinidae Verrill, 1865 .....	34
4.2.3.4. Genus <i>Goniastrea</i> Milne Edwards and Haime, 1848.....	38
4.2.3.5. Genus <i>Hydnophora</i> Fischer von Waldheim, 1807 .....	38
4.2.3.6. Genus <i>Platygyra</i> Ehrenberg, 1834 .....	39
4.2.3.7. Genus <i>Leptoria</i> Milne Edwards and Haime, 1848.....	40
4.2.3.8. Genus <i>Mycedium</i> Milne Edwards and Haime, 1851 .....	41
4.2.3.9. Genus <i>Coelastrea</i> Verrill, 1866 .....	41
4.2.3.10. Genus <i>Paramontastraea</i> Huang and Budd, 2014 .....	42
4.2.3.11. Genus <i>Dipsastraea</i> Blainville, 1830 .....	42
4.2.3.12. Genus <i>Astrea</i> Lamarck, 1801 .....	44
4.2.4. Family Lobophylliidae Dani and Horng, 2009 .....	44
4.2.4.1. Genus <i>Lobophyllia</i> de Blainville 1830.....	44
4.2.5. Family Fungiidae Dana, 1849 .....	46
4.2.5.1. Genus <i>Fungia</i> Lamark, 1801 .....	46
4.2.6. Family Pocilloporidae Gray, 1842 .....	47
4.2.6.1. Genus <i>Pocillopora</i> Lamarck, 1816 .....	47
4.2.6.2. Genus <i>Seriatopora</i> Lamarck, 1816 .....	47
4.2.6.3. Genus <i>Stylophora</i> Schweigger, 1820 .....	48
4.2.7. Family Poritidae Gray, 1842.....	49
4.2.7.1. Genus <i>Porites</i> Link, 1807 .....	49
4.2.8. Family Scleractinia incertae sedis.....	51
4.2.8.1. Genus <i>Leptastrea</i> Milne Edwards and Haime, 1849.....	51
4.2.8.2. Genus <i>Pachyseris</i> Milne Edwards & Haime 1849.....	52
4.2.8.3. Genus <i>Blastomussa</i> Wells, 1968.....	53
4.2.9. Family Euphylliidae Alloiteau, 1952 .....	53
4.2.9.1. Genus <i>Galaxea</i> Oken, 1815 .....	53
4.2.10. Family Astrocoeniidae Koby, 1890 .....	54
4.2.10.1. Genus <i>Stylocoeniella</i> Yabe and Sugiyama, 1935.....	54
4.2.11. Family Coscinaraeidae Milne Edwards and Haime, 1848 .....	55
4.2.11.1. Genus <i>Coscinaraea</i> Milne Edwards and Haime, 1848 .....	55
4.2.12. Family Siderastreidae Voughan and Wells, 1943 .....	55
4.2.12.1. Genus <i>Pseudosiderastrea</i> Yabe and Sugiyama, 1935.....	55
4.3. Systematics of Other Invertebrate Fossils.....	56
4.3.1. Bivalvia Systematics .....	56
4.3.1.1. Genus <i>Spondylus</i> (Linnaeus, 1758).....	56
4.3.1.2. Genus <i>Arca</i> Linnaeus 1785 .....	57

4.3.1.3. Genus <i>Anadara</i> Gray, 1847 .....	57
4.3.1.4. Genus <i>Pronucula</i> Hedley, 1902 .....	58
4.3.1.5. Genus <i>Pitar</i> Romer, 1857 .....	58
4.3.1.6. Genus <i>Vasticardium</i> Iredale, 1927 .....	58
4.3.1.7. Genus <i>Tridacna</i> Bruguiere, 1797 .....	59
4.3.1.8. Genus <i>Pinna</i> Linnaeus, 1758 .....	59
4.3.1.9. Genus <i>Crassostrea</i> Sacco, 1897 .....	59
4.3.2. Gastropoda Systematics .....	60
4.3.2.1. Genus <i>Chicoreus</i> Montfort, 1810 .....	60
4.3.2.2. Genus <i>Nassarius</i> Dumeril, 1805 .....	61
4.3.2.3. Genus <i>Cypraea</i> Linnaeus, 1758 .....	61
4.3.2.4. Genus <i>Canarium</i> Schumacher, 1817 .....	61
4.3.2.5. Genus <i>Potamides</i> Brongniart, 1810 .....	62
4.3.2.6. Genus <i>Rhinoclavis</i> Swainson, 1840 .....	62
4.3.3. Echinoidea Systematics .....	62
4.3.3.1. Genus <i>Eucidaris</i> Pomel, 1883 .....	63
4.3.3.2. Genus <i>Phyllacanthus</i> Brandit, 1835 .....	63
4.3.3.3. Genus <i>Echinometra</i> Gray, 1825 .....	64
4.3.3.4. Genus <i>Jacksonaster</i> Lambert and Thiery, 1914 .....	64
4.3.3.5. Genus <i>Clypeaster</i> Lamarck, 1801 .....	64
4.3.3.6. Genus <i>Maretia</i> Gray, 1855 .....	65
4.4. Systematics of Quaternary Microfossils of Dallol .....	66
4.4.1. Systematics of Ostracoda .....	66
4.4.1.1. Genus <i>Cyprideis</i> Jones, 1857 .....	66
4.4.1.2. Genus <i>Neonesidea</i> Maddocks, 1969 .....	67
4.4.1.3. Genus <i>Xestoleberis</i> Sars, 1866 .....	68
4.4.1.4. Genus <i>Leptocythere</i> Sars, 1928 .....	69
4.4.1.5. Genus <i>Limnocythere</i> Brady, 1868 .....	70
4.4.1.6. Genus <i>Corallucythere</i> Hartman, 1974 .....	70
4.4.1.7. Genus <i>Loxoconcha</i> Sars, 1866 .....	70
4.4.1.8. Genus <i>Hemicypris</i> Sars, 1903 .....	71
4.4.1.9. Genus <i>Pontoparta</i> Vavra, 1901 .....	72
4.4.1.10. Genus <i>Cytherella</i> (Jones, 1849) .....	72
4.4.1.11. Genus <i>Keijcyoidea</i> Malz, 1981 .....	73
4.4.1.12. Genus <i>Bythocypris</i> Brady, 1880 .....	74
4.4.1.13. Genus <i>Bythocythere</i> Sars, 1866 .....	74
4.4.1.14. Genus <i>Hemicytheridea</i> Kingma 1948 .....	<b>Error! Bookmark not defined.</b>
4.4.1.15. Genus Keiji Teeter, 1975 .....	<b>Error! Bookmark not defined.</b>
4.4.2. Systematics of Other Microfossils .....	<b>Error! Bookmark not defined.</b>
4.4.2.1. Foraminifera Systematics .....	75
4.4.2.1.1. Genus <i>Trochammina</i> Parker and Jones, 1859 .....	75
4.4.2.1.2. Genus <i>Ammobaculites</i> Cushman, 1910 .....	75
4.4.2.1.3. Genus <i>Ammomarginulina</i> Wiesner, 1931 .....	76
4.4.2.1.4. Genus <i>Quinqueloculina</i> d'Orbigny, 1826 .....	76
4.4.2.1.5. Genus <i>Elphidium</i> de Montfort, 1808 .....	77
4.4.2.1.6. Genus <i>Amphistigina</i> d'Orbigny, 1826 .....	77
4.4.2.1.7. Genus <i>Baculogypsina</i> Saccor, 1893 .....	77

4.4.2.1.8. Genus <i>Globorotalia</i> Cushman, 1927 .....	78
4.4.2.1.9. Genus <i>Ammonia</i> Brunnich, 1772 .....	78
4.4.2.2. Micro-Mollusk and Charophycea .....	78
<b>5. PALEOECOLOGY AND PALEOENVIRONMENT .....</b>	<b>79</b>
5.1. Paleocology of Corals .....	79
5.1.1. Background .....	79
5.1.2. Species Richness .....	80
5.1.3. Diversity of Coral Species .....	85
5.1.4. Comparison of Species Diversity with Age .....	86
5.2. Paleoenvironmental Reconstruction .....	89
5.2.1. Background .....	89
5.2.2. Fossil Assemblages of Dallol .....	89
5.2.2.1. Corals Assemblages (CA) .....	89
5.2.2.2. Bivalvia, Gastropoda and Echinoidea Assemblages (BGEA) .....	90
5.2.2.3. Ostracoda Assemblage (OA) .....	91
5.2.3. Paleoenvironmental Interpretation .....	91
5.2.4. Comparison with Modern Classic Environment and Paleobiogeography .....	99
<b>6. CONCLUSION AND RECOMMENDATION .....</b>	<b>102</b>
6.1. Conclusion .....	102
6.2. Recommendation .....	103
<b>REFERENCE .....</b>	<b>104</b>
<b>ANNEX – I: PLATES .....</b>	<b>113</b>
<b>ANNEX – II: Estimated Diversity Indices Result from PAST Analysis .....</b>	<b>113</b>
<b>ANNEX – III: Percent Abundance of Species for Each Coral Outcrops and Transects .....</b>	<b>116</b>
<b>ANNEX – IV: Diversity Indices (PAST 3) Plots .....</b>	<b>122</b>

## LIST OF FIGURES

Fig.1.1. Sea level fluctuation curves of Quaternary glacial cycles.....	3
Fig.1.2. Location map of the study area.....	7
Fig.1.3. Landsat image of the study area and coral outcrop .....	8
Fig.1.4. Coral outcrop with <i>Potaminid</i> , <i>Pina</i> from CO2 site.....	9
Fig.1.5. (a) CO2 section ooids and at the top corals and (b) CO4 coral and echinoidea.....	10
Fig.1.6. (a) Gypsified corals at CO21 and coral outcrops at CO7.....	11
Fig.1.7. (a) CO1 road cut coral exposure and (b) CO20 laminated gypsum .....	11
Fig.1.8. a) CO4 left of river cut section and b) Dallol sulfur and salt deposit.....	12
Fig.1.9. Geological structures at CO1 and CO27.....	13
Fig.2.1. Materials used for microfossil preparation.....	24
Fig.3.1. Phylogenetic relationships among sclerectinia corals.....	28
Fig.3.2. Shell morphology of ostracoda.....	30
Fig.3.3. Principal Types of (a) chamber arrangement and (b) aperture types.....	31
Fig.3.4. Classification of foraminifera.....	32
Fig.5.1. Geographical distribution of group coral outcrop sites.....	90
Fig.5.2. Variation of specimen, genera and species numbers with coral outcrops.....	91
Fig.5.3. CO1R transect one and two (a) - (b).....	92
Fig.5.4. CO1RF transect (a) transect 1 (b) transect 2 (c) transect 3 and (d) transect 4.....	93
Fig.5.5. CO1RF coral exposures.....	94
Fig.5.6. CO7 transects from bottom (transect one) to top (transect four) of the exposure.....	95
Fig.5.7. CO27 transects: one (T1) and two (T2).....	96
Fig.5.8. CO20 transect and species variation.....	96
Fig.5.9. Calculated Shannon index for the dataset of each outcrop and transects.....	97
Fig.5.10. Calculated Simpson index for the dataset of each outcrop and transects.....	98
Fig.5.11. Relationship of age of coral outcrops with Shannon diversity of corals.....	99
Fig.5.12. Shannon-Weiner diversity variation in the coral outcrops for MIS5 and MIS7.....	99
Fig.5.13. Diversity values of Shannon Index variation during MIS5.....	100
Fig.5.14. Diversity values of Shannon Index variation during MIS7.....	100
Fig.5.15. Schematic representation of CO21 and CO18 exposures.....	104
Fig.5.16. Schematic representation of the stratigraphic units for CO28 and CO29.....	105
Fig.5.17. Schematic representations of stratigraphic sections at CO6, CO24 and CO27 .....	106
Fig.5.18. Schematic representations of stratigraphic sections: CO4 and CO20.....	107

Fig.5.19. Schematic representations of stratigraphic sections at CO2 and CO7 .....108  
Fig.5.20. Schematic representations of stratigraphic sections monospecific fauna at CO2.....109  
Fig.5.21. Schematic representations of stratigraphic sections at CO1R and CO1RC .....110  
Fig.5.22. A cross section through zoned marginal reef (fringing reef) illustrating different reef zones, limestone facies in each zone and environment of different reef building organisms in the modern environment (After James, 1979).....111  
Fig.5.23. Schematic representation of reef facies distribution and environmental setting.....113

## LIST OF TABLES

Table 2.1 Sieve size used for microfossil extraction.....	20
---	----

## LIST OF PLATES

Plate A1 Sclerectinia species .....	126
Plate A2 Sclerectinia species .....	129
Plate A3 Sclerectinia species .....	132
Plate A4 Sclerectinia species .....	135
Plate A5 Sclerectinia species .....	138
Plate B – Bivalvia species.....	141
Plate C – Gastropoda species.....	143
Plate D – Echinoidea species .....	145
Plate E1 – Ostracoda species .....	147
Plate E2 – Ostracoda species .....	149
Plate E3 – Ostracoda species .....	152
Plate F – Foraminifera species .....	154
Plates G – Microbivalvia and Microgastropda species.....	157

## LIST OF ACRONYMS

AAU: Addis Ababa University  
AM: Anterior Margin  
BGEA I: Bivalvia Gastropoda Echinoides Assemblage One  
BGEA II: Bivalvia Gastropoda Echinoides Assemblage Two  
CA I: Coral Assemblage One  
CA II: Coral Assemblage Two  
CO III: Coral Assemblage Three  
CO: Coral Outcrop  
CO1R: Coral Outcrop one Road cut  
CO1RF: Coral Outcrop one Reef Face  
CO4LA: Coral Outcrop Four Lacustrine  
CO4MA: Coral Outcrop Four Marine  
DEM: Digital Elevation Model  
DM: Dorsal Margin  
Fig.: Figure  
GPS: Global Positioning System  
GSE: Geological Survey of Ethiopia  
LIT: Line Intercept Transect  
LU: Lacustrine Unit  
MIS5: Marine Isotope Stage Five  
MIS7: Marine Isotope Stage Seven  
MU: Marine Unit  
OA 1: Ostracoda Assemblage One  
OA II: Ostracoda Assemblage Two  
PAST: Paleontological Statistics  
PIT: Point Intercept Transect  
PM: Posterior Margin  
Pl.: Plate  
RLM: Reflected Light Microscope  
SERENA: Sedimentary Research in Northern Afar  
VM: Ventral Margin  
WoRMS: World Registration of Marine Species

## CHAPTER ONE

### 1. INTRODUCTION

#### 1.1. Background

Cnidaria are exclusively aquatic and the majority of them are marine organisms. They could be sessile or freely swimming. Sessile forms occur as individuals called solitary or they could be united with each other to form groups called colony. Fossil cnidaria first occur in late Precambrian and they were uncommon until Ordovician in which the coral reef ecosystem started. Phylum Cnidaria contains three classes. These are Hydrozoas, Scyphozoa and Anthozoa. Reef building corals are grouped under Class Anthozoa, Subclass Zoantharia with three Orders of Rugosa, Tabulata and Scleractinia (Verrill, 1901).

Scleractinia are solitary or colonial corals with aragonite skeleton in which septa form cycles of six or multiples of six during their growth. They first appeared during mid – Triassic Aisian stage (237Ma) and they became as important reef formers in tropical seas today (Stanley, 2003). Reef building scleractinia contain symbiotic algae called zooxanthallae and require light which are called hermatypic however non zooxanthallae scleractinia are not reef building and they are called ahermatypic.

Based on the morphology of the reef coral reef zones are classified as fringing reef, barrier reef, and atolls. Barrier reefs cover large areas and form linear reef developments which are separated by a lagoon environment from the shore environment. Atolls are circular to semicircular structures developed around the center of a lagoon on the volcanic substrate. Fringing reefs develop in recent shore environments with increased thickness towards the sea. Fringing reefs are attached to the carbonate substrate above the basement and form forereef, reef crust and back reef. Patch reefs are small isolated coral outcrops occur together with the main types of reefs without defined boundaries. The morphology of scleractinian, the corallum, is secreted by the outer wall of the body and it is formed by fusion of minute fibers of aragonite. Each polyp is sited inside the U – shaped structure, the calice, from which the septa radiate between the pairs of mesenteries which classify the enteron (Verrill, 1901). Classification of corals is done based on the different methods applied for the extant and extinct specimens. Scleractinia classifications were carried out on the basis of the growth form, the corallite wall structure, the arrangement of corallite structure, coenosteum properties and other characteristics (Veron and Pichon, 1976 and 1980). These classifications of corals are the oldest and most commonly used classification.

Scleractinia form modern and past fossil reefs in the tropical and sub – tropical water bodies. These scleractinia corals incorporate isotopic composition and trace element compositions in their skeleton from the water bodies they were live. This compositional characteristic is used as an indicator of the past environment and environmental variables. Therefore they could be used as good proxies compared to other paleoclimatic archives (Felis et al., 2004).

Ostracoda are complex and challenging organisms which are grouped under the Phylum Arthropoda. Ostracoda are micro – crustaceans with bivalved shells, the carapace, and inhabit all aquatic environments. Arthropods and ostracoda share the characteristic of symmetry of their body form which is bilateral symmetry. The shell of ostracoda is very small in size and range from 0.2 to 30mm (Brasier, 1980). The Class Ostracoda are different from other crustaceans by their laterally compressed body, undifferentiated head, seven or less thoracic limb, bivalved perforated carapace and absence of growth lines. According to Horne et al. (2002) the ostracoda have been divided into two subclasses of Podocopa and Myodocopa. The five Orders are Podocopida, Myodocopida, Phosphatocopida, Leprediticopida and Palaeocopida. From these Orders the Podocopida and the Myodocopida are extant ostracoda.

Ostracoda are calcareous microfossils which secrete different ions during their growth. These ions could provide reliable information about the past climatic and past environmental condition. Analyses of stable isotopes of oxygen and stable isotopes of carbon from ostracoda shell is the most common method applied to determine past climate variables (Holms and Chivas, 2002).

Foraminifers are exclusively marine Protists consisting of a hard calcium carbonate test. They have benthic or planktonic mode of life. Based on Loeblich and Tappan (1964) classification of the foraminifera, it belongs to Kingdom Protista; Subkingdom Protozoa; Phylum Sarcomastigophora; Subphylum Sarcodina; Superclass Rhizopoda; Class Granuloreticulosa and Order Foraminifera. However, according to recent studies of benthic and planktonic foraminifera which is accepted by WoRMS (2017) the foraminifera taxonomy is changed to Kingdom Chromista; Subkingdom Harosa; Infrakingdom Rhizaria; Phylum Foraminifera. Foraminifera have a geological range from late Cambrian to present. All the studied fossils of foraminifera, ostracoda, bivalvia, gastropoda, echinodermata and scleractinia belongs to the Quaternary period.

Quaternary period is the last 2.7 million years of earth's history which includes Pliocene and Holocene Epochs. This period is unique by its fluctuating climates, glacial and interglacial events, and change in species number and species types of different organisms.

Over 30 glacial and interglacial cycles are logged in deep sea sediments and these have been applied to reconstruct past temperature, climate and atmospheric composition. According to Raymond (1999) the earth's surface temperature was 10 °c colder in middle latitude and 10 °c colder in the tropical areas. Isotopic composition of index fossils for example the scleractinia corals and foraminifera is used to reconstruct sea level fluctuation. This marine isotope stages indicate the period of higher sea level and lower sea level stands relative to the depletion and enrichment of stable isotopes of oxygen.

There are seven MIS stages (Fig. 1.1) and from these MIS 2, MIS 4 and MIS 6 were period of cooler climatic temperature however the MIS 5 have five sub-stages (MIS 5a-e) with variable sea level fluctuation episodes. Sub-stages 5a, 5c and 5e had relatively warm temperature and higher sea level than sub-stage 5b and 5d which were relatively cooler temperature and lower sea level.

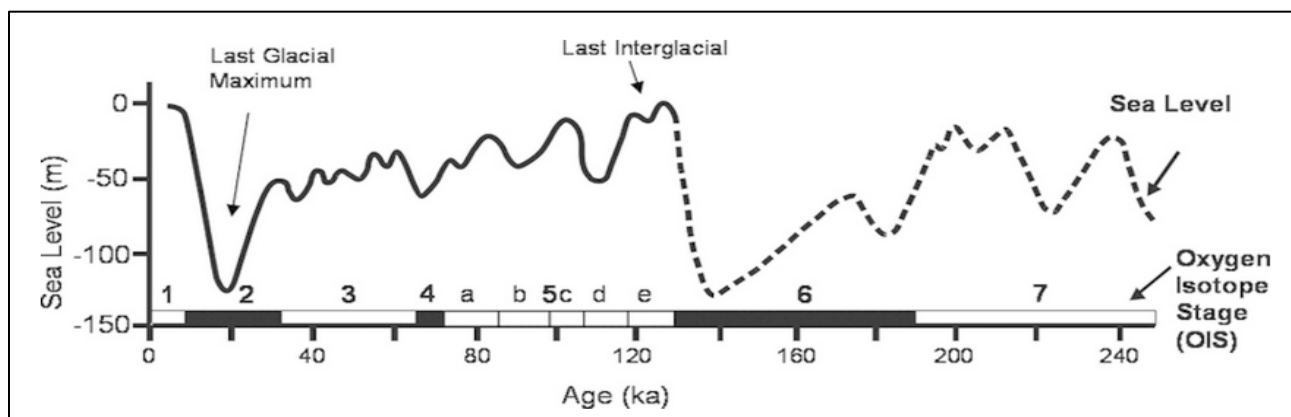


Fig.1.1. Sea level fluctuation curves of Quaternary glacial cycles (Source: Chappell et al, 1996).

According to Balemwal Atnafu et al. (2015) due to sea level fluctuation of Red Sea the northern part of Danakil Depression were flooded twice during Late Pleistocene and Middle Pleistocene. During these periods fringing coral reefs, coralline algae, oolitic carbonate rocks and microbial unit are deposited. Therefore coral reefs of Dallol area correspond to MIS 7 and MIS 5. From field observations the coral fossils of today in Dallol area, thick gypsum units and salt deposit are good implication for the flooding of northern part of Ethiopia by Red Sea and spend thousands of years.

This research is focused on the systematics of corals and ostracoda together with the paleoenvironmental interpretations of Dallol. These invertebrate fossils were living during the glacial – interglacial time of the Quaternary Period and most of the fossils are very well-preserved.

Systematic studies are carried out by comparing the collected representative coral samples with the type specimens described by Veron (1976, 1977, 1982, 1984, 1990, 2000, 2013 and 2015); Budd et al. (2009); and Benzoni et al., (2011). The systematic studies for bivalvia, gastropoda and echinoidea were used by the different parts of “Treatise on Invertebrate Paleontology” Moore (1960, 1966 and 1969). For the extracted microfossils from the collected sediment samples comparisons have been made with type specimens described by recent taxonomic studies of Munef et al. (2012), Marthens and Horne (2009), Gupta (1997), Hartmann and Puri (1974) and Moore (1961). Paleoenvironmental interpretation is carried by following the fossil assemblages (biofacies) and paleoecological results.

## 1.2.Previous Studies

Paleontological researchs in the northern Afar started earlier (Johanson and Taieb, 1976). Vertebrate fossil studies were done since 1960's mainly focused on hominid fossil discoveries. Hadar, Awash, Woranso – Mille and Danakil depression are common sites of the investigation. From the studies Lucy, Ardi and Selam are the most known discoveries which play a great role in understanding of human evolution (Walter, 1994; Kalb, 1995 and Yohannes Haile-Selasse et al., 2010). However the invertebrate fossils are poorly known and only limited studies which are cited below are done in the northern Afar.

Most of the invertebrate fossils of Ethiopia were done by Italians' since 1930s'. The studies mainly focused on documentation and reporting of Jurassic fossil including ammonoidea, brachiopoda, bivalvia, echinoidea, belminitidae, gastropoda, spong and corals from the Blue Nile Basin, Dire Dawa, Hararri, Northern Afar and Mekelle Outlier (Merla and Minucci, 1938; Zuffardi-Comerci, 1932; Blanford, 1870; and Kiessling et al., 2011).

According to Lalou et al. (1970) and Bonatti al. (1971), corals and bivalvia are identified from afar carbonates of Zariga Formation for radiometric dating using  $^{230}\text{Th}/^{234}\text{U}$  and  $^{14}\text{C}$ . The result indicates 80,000yrs, 100,000 – 120,000 and 200,000yrs. This indicates the Red Sea penetrates the Gulf of Zula and flood the Danakil depression two or three times during the upper Pleistocene (Garland, 1972).

According to Bannert et al. (1971) the mega-fossils found in Pliocene and Quaternary sediments of Danakil depression include Lamellibranciata and Gastropoda. The age and biotope of Danakil sediments were determined and interpreted.

According to Abell and Williams (1989) paleoenvironmental studies were done for the northern afar area from gastropoda shell by using stable isotopic ratios of oxygen and carbon. The result indicates the arid condition at the end of Pleistocene; the wet condition during early Holocene and the arid condition of today.

According to Kiessling et al. (2011) morphological descriptions, taxonomic studies and paleobiogeographic pattern of corals, brachiopoda and bivalvia were done from Antallo limestone of Mekele Outlier. From the result their age is Oxfodian; they were living in the shallow sub – tidal environment in small patch reefs. Paleobiogeographic pattern and delineation of the Ethiopian province were done by multi – dimensional scaling analysis for the Callovian to Kimmeridgian stages.

Recent studies done by a joint project of School of Earth Science (AAU) and Fribourg University Department of Geology since 2013 describes Pleistocene coralgall and microbial reef deposits. From this study sedimentological and stratigraphical units are identified for six marine and two lacustrine localities on western and southern side of Danakil depression (Balemwal et al., 2015). Quaternary invertebrate fossil study will have two fold importances. The first is directly related to understanding of the species distribution and paleobiogeographic pattern of the area and secondly it will provide reference data to aid assessment of the ecosystem response to the environmental change for the future.

Therefore, in this research detailed morphological analysis and statistical methods are applied to provide a clear understanding of the Northern Afar Quaternary corals and ostracoda occurrence, species types, taxa assemblages, and the reconstruction of the paleoenvironment of Dallol area.

### **1.3.Study Area Description**

#### **1.3.1. Location**

The area is located in the Northern Afar, Ethiopia 1000km from Addis Ababa. The area is geomorphologically characterized by rugged and desiccated rift escarpments in the west; flat lying plane at the center; and Tertiary Danakil ridges in the east. It is the lowest area with the approximate elevation of 146m below the present sea level (Tesfaye et al., 2003). Dallol is the area with the warmest climatic condition. The average annual rainfall ranges from 50 to 100mm and the annual temperature ranges from 25 to 45°C. The drainage pattern is mainly defined by intermittent small scale rivers which commonly flow from the western plateaus towards the afar depression and the Red Sea (Garland, 1972).

The coral outcrops are located in the two different localities Ahmedela and Bada found in Berahle woreda and Dallol woreda respectively. Coral outcrops which are located in Ahmedela locality include CO1R, CO1RF, CO2, CO4, CO7, CO20, CO24, and CO27. The coral outcrops found in Bada area include the coral outcrops of CO6, CO18, CO19, CO21, CO28 and CO29. Detailed transect data collection and sampling is done for CO1R, CO1RF, CO7, CO20 and CO27.



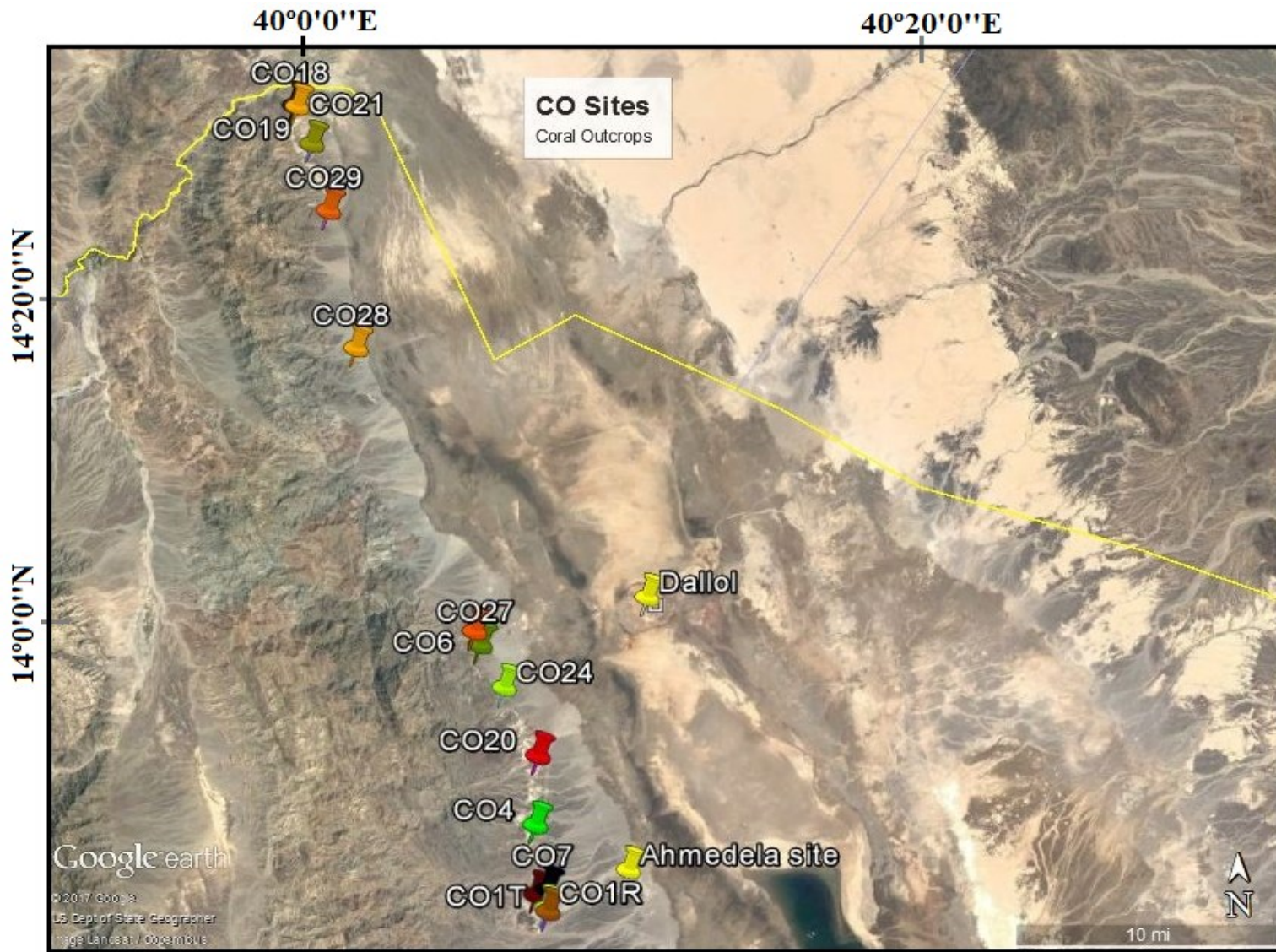


Fig.1.3. Modified coral outcrop sites and Landsat 7 image of the study area

### 1.3.2. Geology of Dallol

The geology of Dallol area comprises of Neoproterozoic basement complex which occupy the entire upper part of Dallol, western margin and partly the lower margin (Redfield et al., 2003). Central part of Dallol is covered by Mesozoic sedimentary successions which include Adigrat Sandstone, Antallo limestone, and the shale unit. The Miocene – Pliocene volcanic and sedimentary sequence comprises the red series sandstone unit (Red Beds of Zariga Formation), greater than one kilometer thick Pliocene to recent lacustrine sediment, evaporate beds, younger volcanic dike and sill (Mirutse Hagos, 2011). Quaternary evaporate deposits, gypsum and halite, diatomites, and alluvial deposits are clearly exposed on the western and southwestern part of Dallol (Meruts Hagos and Konka, 2016). From field observations most of the coral outcrops comprises of carbonate sediments rich in fossils (Fig. 1.4.); laminated evaporates with variable thickness (Fig. 1.7b); alluvial fan conglomerates and volcano-clastic rocks with various geological structures (Fig. 1.9); thick bed of fossil corals, oolitic beds and coralline algae (Fig. 1.5); marvelous dallol sulfur deposit (Fig. 1.8b); and fossils of bivalvia, gastropoda, and echinoidea are common.



Fig.1.4. Coral outcrop with potaminid, pina from CO2 site

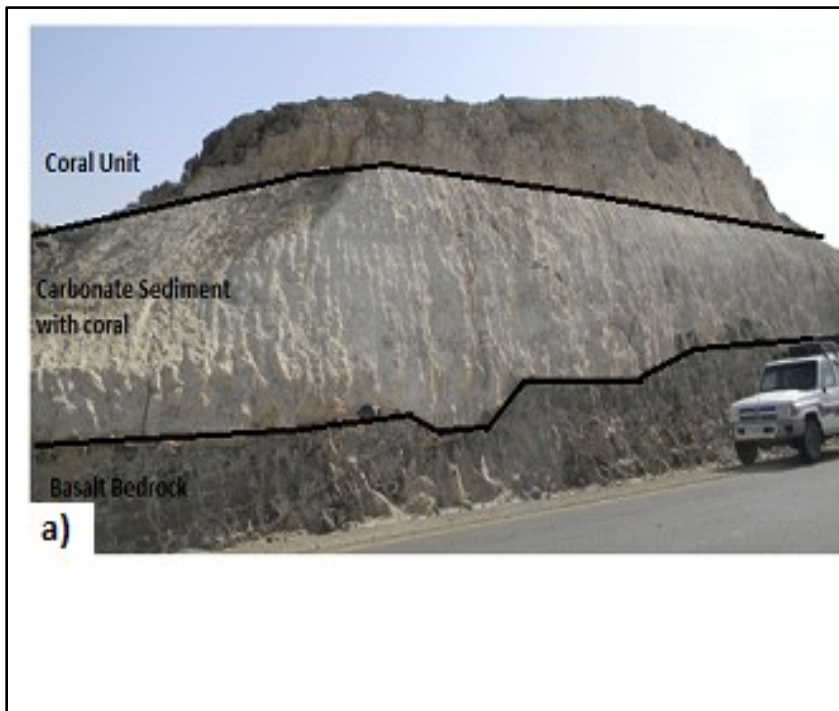


Fig.1.7. a) CO1 road cut coral exposure and b) CO20 laminated gypsum unit and gypsified corals

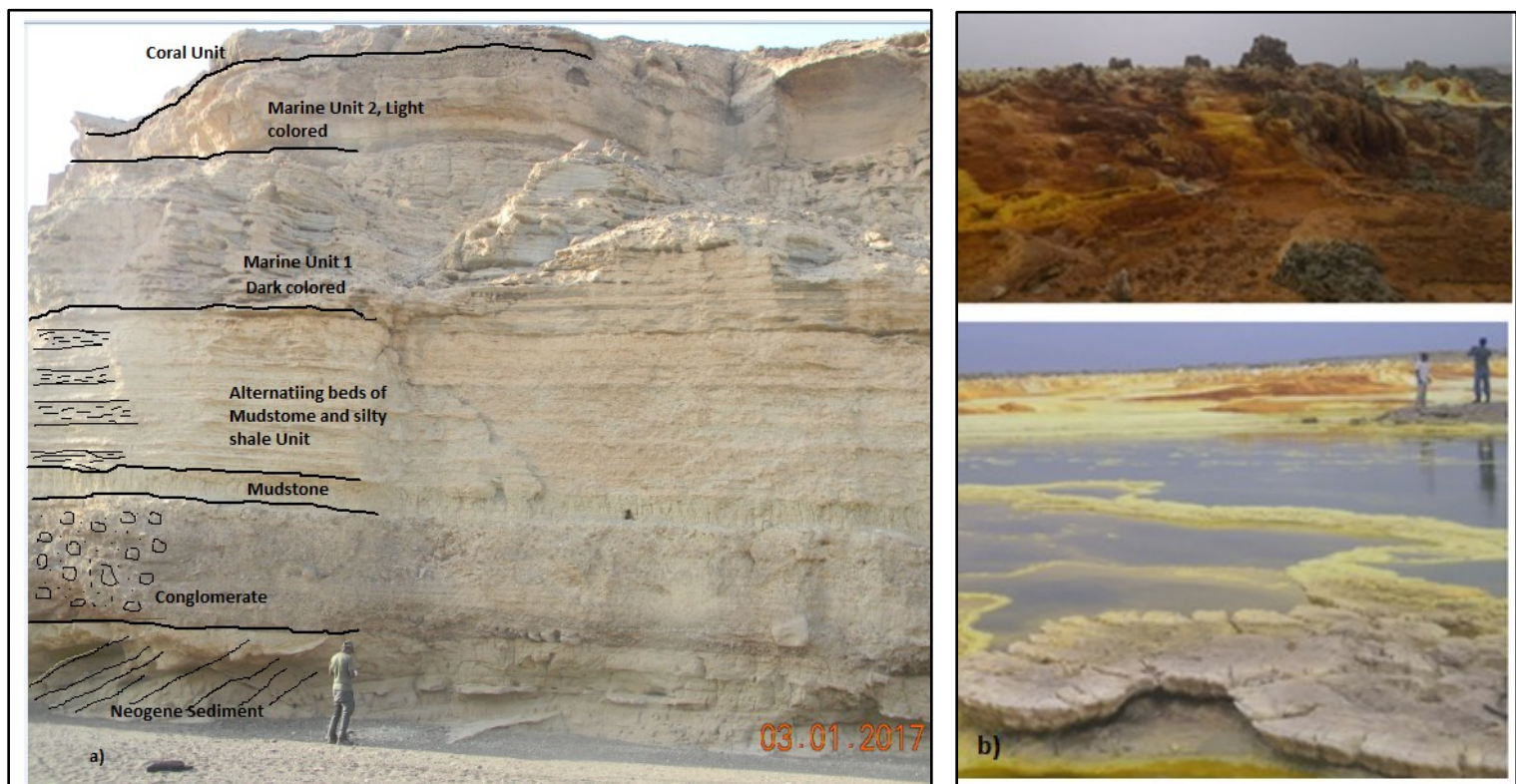


Fig.1.8. a) CO4 left of river cut section and corals b) Dallol sulfur and salt deposit

### 1.3.3. Tectonics and Structural Geology of the Area

Dallol area is tectonically active. The tectonic development of the Afar depression is largely associated with tectonics and development of Red Sea rift and Gulf of Aden rift. The development of the rifting is associated with arching and doming tectonics in Late Eocene followed by extension and rifting with subsequent sea floor spreading that separate the continental plates. This tectonic activity will lead to the development of the basin. The altitude drops radically from the rift border to the center of Dallol and it ranges from 2300 to 146 meter below present sea level (Beyene and Abdsalam, 2005; Hagos, 2011; Tesfaye et al., 2003). The area is affected by major and minor fault systems. The area shows similar fault system with major afar fault which is trending NW – SE, NE – SW and E – W direction (Boccaletti et al., 1998). This tectonic activity will lead to the formation of different topographic highs with distinct coral outcrops in addition to the localized patches of coral deposits. Field measurement of fault orientation in CO21 gives between conglomerate unit and volcanoclast 354/73E.

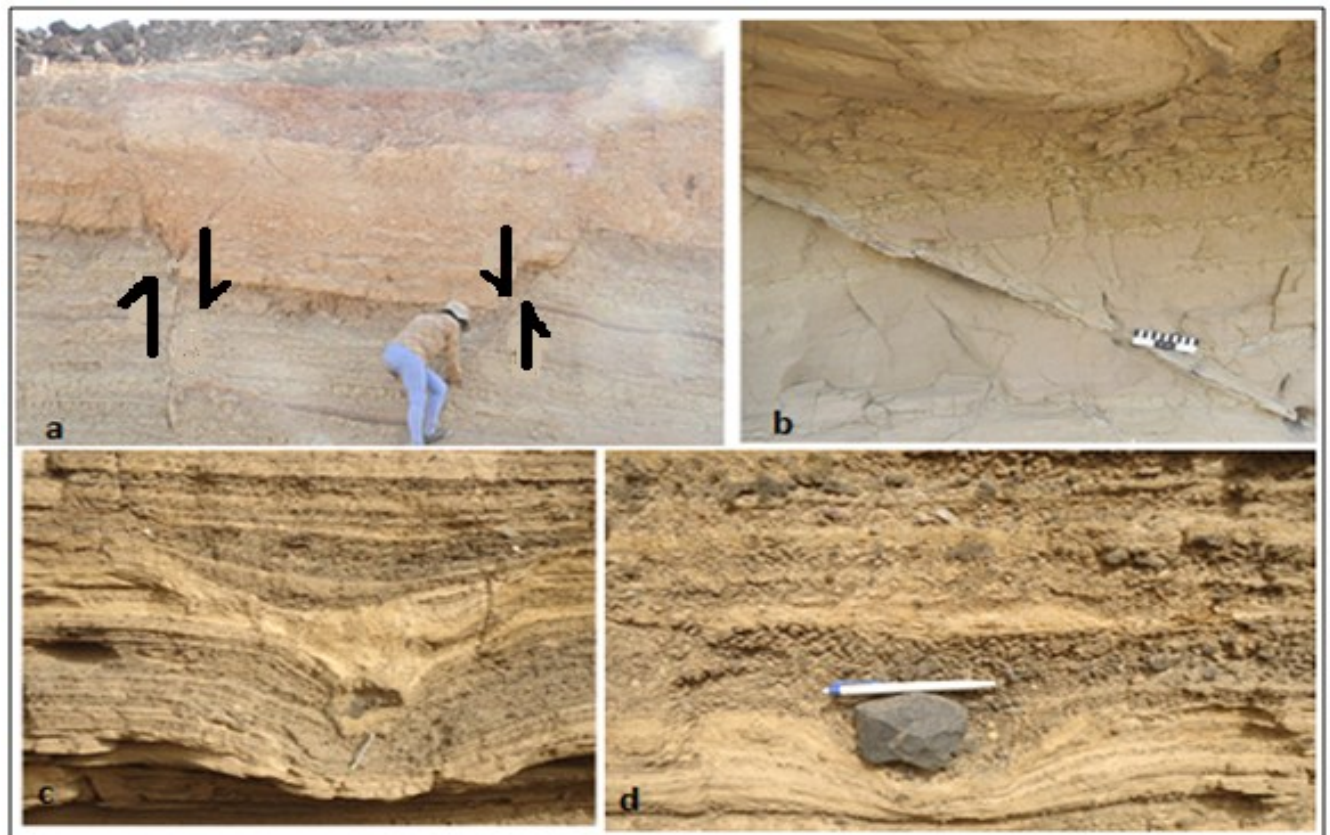


Fig. 1.9 Geological structures at CO1 and CO27

#### **1.4. Problem Statement**

Marine invertebrate fossils are poorly known from the Ethiopian Quaternary sedimentary deposits. Most of the studies are focused on description, documentation, paleobiogeographic studies and systematics of Jurassic invertebrate fossils. However, Quaternary corals and ostracoda systematics is not studied before. Therefore, this study specifically works on the species level identification, fossil assemblage analysis, and reconstruction of the paleoenvironment of the area in order to fill the gap.

#### **1.5. Objectives**

##### **1.5.1. General Objective**

The main objectives of this research are investigation of the systematics of Quaternary corals and ostracods based on the detailed descriptions of macro – morphological and micro –

morphological features and reconstruction of the paleoenvironment of Dallol using fossil assemblages and paleoecology results.

### **1.5.2. Specific Objectives**

The specific objectives of this research are:-

- To identify different invertebrate fossil and fossil assemblages;
- To analyze macro-morphological and micro-morphological features;
- To investigate systematics of corals;
- To investigate systematics of ostracoda;
- To determine abundance and diversity of species; and
- To reconstruct paleoenvironment of Dallol.

### **1.6. Significance of the Study**

Understanding species morphological characteristics, names, types of different marine invertebrate fossil assemblages, and paleoenvironmental conditions in which they were live will help to recognize response of the ecology for environmental variation in different scale, and for understanding of paleobiogeographic pattern of the area.

Therefore, this research contributes scientific outputs on Quaternary corals and ostracoda of Dallol. The main significances of this study are the following:-

- Corals and Ostracoda are proxies for any environmental variation. Therefore, the detail result of the research can be used as primary data to understand past climate condition and predict the future;
- The result is important data source for different researchers who are working in Afar Quaternary geology and paleoenvironment; and
- The result of the research can be used as the primary data source for studies on paleobiogeography of Afar and evolutionary history of Red Sea corals.

### **1.7.Thesis Outline**

This thesis is compiled by six chapters. Chapter one is introduction about the overview of the study area location, geology, tectonics, objectives, previous studies, and significance of the study. The second chapter states different methodology and approaches used to achieve the objectives of the research and it includes the different materials used for the research. Chapter three is compilation of different literatures which are used to create conceptual framework for the study and referencing. The systematic paleontology result is clearly described under chapter four and chapter five contains paleoecological analysis and paleoenvironmental interpretations. Final conclusions and recommendations are done under chapter six.

## CHAPTER TWO

### 2. METHODOLOGY AND MATERIALS

#### 2.1. Methodology

##### 2.1.1. Background

Appropriate research methodology is a core for solving the stated problems and gain qualified result. For this study primary and secondary data collection is done on the framed time period. After collection of primary data, samples preparation is followed for extraction of microfossils and microscopic examinations. Macro-morphological and micro-morphological descriptions are the main approaches to identify generic level and species level classification for the systematics.

The species abundance and diversity calculations are made from the data collected by line transect technique and random sampling. Various diversity indexes applied to estimate paleoecological parameters. Diversity index is quantitative measurement that reflects the number of different types of species present in the community and concurrently considers how the individuals distributed between those types. Shannon diversity index is the frequently used diversity index and it is applied for this study. Distribution of species is variable from one coral outcrop to another coral outcrop. Therefore, separate analysis is carried out for each outcrop. Graphical representations and statistical examination is applied to avoid biases in the estimations using PAleontological STatistics PAST-3 software (Hammer et al., 2001). Fossil assemblages and paleoecological analysis used to interpret past environmental conditions of the area during Quaternary period and qualitative determination of paleoclimatic parameters for example temperature and salinity with their depositional environments.

##### 2.1.2. Data Collection

###### 2.1.2.1. Pre – fieldwork

Secondary data collection was started from July-2016. The coral and the sediment samples were collected by field crews from School of Earth Sciences, AAU and Fribourg University on Jan. 2016. These collected samples were stored in the School of Earth Science Paleontology laboratory. From these samples a total of twenty coral samples are used as secondary data source for this research. Organizing the field equipment and literature review is carried out to understand the concepts and reef ecologies of the modern and past reef environments before the fieldwork.

The number of samples collected during the fieldwork and the sampling sites to get representative sample for the area; and in order to identify and choose appropriate sampling technique for the systematics of reef communities various literatures reviewed.

#### **2.1.2.2. Fieldwork**

According to the Sedimentary Research in Northern Afar project (SERENA) this research area (Dallol) is classified in to 29 different coral outcrop sites (CO1 – CO29) based on existence of the randomly exposed reef building corals and carbonate platforms. In the fieldwork insitu description of stratigraphical sections, logging and sampling is done for the selected coral outcrops. A total of 164 fossil samples and 9 sediment samples were collected from Feb. 3/2017 to Feb. 16/2017.

All other faunas and lithological constituents that intercept the points along transect were recorded including marine carbonate sediment, clastic sediments, calcareous algae, mollusk (bivalvia and gastropoda), echinoidea and echinoid spines.

The number of transect for a single outcrop is depending on the thickness and the length of the exposure and the presence of coral colonies in that specific area. The separation distance between transects for single outcrop range from 1m to 1.5m depending on the height of the outcrop exposure.

#### **2.1.2.3. Post – fieldwork**

Literature review continues to gather information about the geologic and tectonic histories of the area; different taxonomy studies of living as well as fossil corals of Red Sea and surrounding areas; and selection of guide used as reference material for the contrast in the species recognition process. Sample preparation of macrofossil includes primarily washing the specimens by tape water and let them dry to make the morphological features visible for description and identification of the specimens. The collected sediment sample prepared for extraction of microfossil by following steps on Brasier (1980). Input data compiled on Excel software for further statistical calculations and analysis of different ecological parameters.

### **2.1.3. Macrofossil Preparations and Descriptions**

#### **2.1.3.1. Coral Description and Comparison Approach**

The taxonomic classification is done based on descriptions of macro and micro morphologies of the type specimen. In the post fieldwork, detail morphological description of the collected coral specimen is carried out. From the collected samples, well preserved and poorly preserved specimens are identified; well preserved fossils are identified, selected and washed by running water to clean the sediment from the surfaces; and detail description of the preserves structures and measurements were taken. The main morphological features are corallite wall structure; corallite form; living condition (colonial or solitary); arrangement, size of septa either it is exsert or not and shape of the septa; presence or absence of costae and columella appearance; valley width and length; shape and diameter of calices; coenosteum appearance; and type of budding (Intratentacular or Extratentacular).

The World Registration of Marine Species (WoRMS) website is used to access original naming, accepted taxa, synonymized taxa and recent updates in the taxonomic classification. For coral systematics comparison with different literatures are used. Wells (1956) is widely accepted scleractinian phylogeny based on morphological features of extinct and extant scleractinian and co-occurrence of genera in the fossil record. Vaughan and Wells (1843) divide the order to five suborders and revised several families which reflect current taxonomic organizations.

Veron (1990; 2000; 2013; and 2015) provides the most recent descriptions of the orders of scleractinian based on insitu observation and macro – morphological characteristics of extant taxa. He evaluates some families to suborders and result 24 extant families in seven suborders and the biogeography of different corals species.

Recent studies on taxonomy and phylogeny of scleractinia are focused on the relationships between families and between genera. The studies are applying the molecular phylogenetic analysis and macro and micro – morphological characteristics. Recent literatures are used for the identification of corals of Dallol includes Fukami et al. (2004); Daly et al. (2007); Budd and Stolaski (2011); Arrigoniet al. (2012); Budd et al. (2012); Huang et al. (2014a; b) and Raza et al. (2015). Literatures reviewed from previous studies on the Red Sea corals are Dullo (1990); Kleeman (1992); Lemmens (1993); El-Sorogy (2002); and Kora et al. (2014).

### 2.1.3.2. Other Associated Macrofossils

In the research area, corals are not the only preserved organisms. However, from Phylum Mollusca various types of bivalvia, gastropoda; and from Phylum Echinodermata the echinoidea and their spines with diverse morphology and variable abundance preserved. Some exposures are rich in mollusca families and others rich in echinoidea. Field description and logging is done for selected outcrops and genera level identification is done by comparing the described properties with the accepted classification scheme for each fossil specimen.

### 2.1.4. Microfossils Preparation and Description

Sediment samples collected for the extraction of the calcareous microfossils. Ostracod and foraminifera microfossils are concentrated and extracted depending on durability and hardness of the rock or the sediment. The collected samples are unconsolidated sediments which are easily disintegrated by water and hydrogen peroxide during extraction process. The calcareous microfossils are easily extracted from the 50gm of sediments by mixed with the 100ml of distilled water. The 50ml amount of 30% concentrated hydrogen peroxide added to the mixture of sediment and distilled water inside the gridded beaker. The mixed sediment, distilled water and hydrogen peroxide are remained for three days to clean the surface of the microfossil free of surfaced sediment (Thomas and Murney, 1985). The mixture is washed by running water using variable mesh size sieve of USA standard (Table 2.1).

After washing the mixed sediment by running water it was air dried at least for 24 hours. The dry sediment sample in each sieve is separately stored and labeled in plastic bottles.

Table 2.1 Sieve size used for microfossil extraction

Sieve No.	Size (mm)	Size ( $\mu\text{m}$ )	Remark
No. 35	0.5	500	Used to extract larger size ostracoda and foraminifera
No. 60	0.25	250	Used to extract medium size ostracoda and foraminifera
No. 120	0.123	123	Used to extract small size ostracoda and foraminifera
No. 450	0.032	32	Very fine foraminifera and mineral grains

Ostracoda and Foraminifera fossils are separated and counted under binocular reflecting microscope (Leica EZ4) by carefully observing through the residue and picking out the microfossils from the sediment and mineral grains. From the sieve sizes only sieve number 35,

60 and 120 are chosen for the extraction and species description of ostracoda and foraminifera due to specimen visibility under the microscope.

The dried sediments are sprinkled in small amount thinly on to a black tray which is divided into four parts by line which is equivalent to the field of view observed at a time. The tray is placed beneath the reflected light microscope with magnification range from 8 to 35. According to the size of the sediment the microfossil is picked into another container (cavity slide) using fine artists paint brush by trap the fossil between the hairs or slightly reduce the brush tip in order to temporarily stick the microfossil to it. But the fossils may spring away and will lose this way. Some samples were very rich in fossils and hundreds are collected in half an hour others may not have so many fossils and require few hours to spend to pick out representative samples.

The microfossils are collected according to the difference in fauna or type of fossil and variation in shape and size. The maximum amount of fossil collected from each sieve size is 100 and minimum 10. Those sediments with microfossils below 10 in number are excluded to avoid biases. Separate cavity slides used for storing the microfossils based on the sieve size and the microfossil type.

The cavity slide is made of card with dark colored card base, gridded by numbers, white thin top card and a glass cover slip under to keep the fossils inside. Other microfossils of micro – gastropoda, micro – bivalvia and calcareous algae fossil (charophyta) are found together with the foraminifera and ostracoda on 0.5mm sieve size.

#### **2.1.4.1. Systematic Approach for Ostracoda Classification**

Classification of ostracoda is complex because of absence of diagnostic characteristics which is equally applicable for taxonomic differentiation of each group. Therefore, the character that would be diagnostic at the ordinal level for one group of ostracoda would be used at the lower level taxonomy. According to Pokorny (1998) unique morphology of muscular scar groups in Leprediticopids is a good diagnostic criterion for this order whereas in the Mydocopids muscular scars are very variable and they cannot be used as unique criteria for the group.

In certain groups of Podocopids ostracoda adductor muscular scar is invariable and in others it varies considerably even with in the same species. For Paleozoic ostracoda sexual diamorphism is the main taxonomic criteria.

Family level classification is done based on descriptions of features of marginal zones for example the extent of calcification, the characteristics of fused areas, the sequence of inner margin, form of the margin, and shape of radial pore canals. Genus level classification is based on shape of the carapace, basic pattern of gross sculpture, character of the hinge, presence or absence of eyespot, detail of muscular scars, line of concrescence, shape, position and number of pore canals and structure and width of the marginal zones. For recognition of species different modification of the shape of the carapace, sculpture, hinge type, number and position of pore canals, development of vestibula, presence or absence of opaque spots in the valve walls, shape of spots and other minor features. Diagnostic features of species evolved repeatedly in different evolutionary lines (Boersma, 1998). Classification of ostracoda follows detail descriptions of Bowman and Abele (1982); Boersma (1998); Horn et al. (2002); Balemwal Atnafu and Russo (2004) and Ikeya et al. (2005).

#### **2.1.4.2. Systematic Approach for Foraminifera Classification**

Foraminifera live on the bottom and floating in the water column from 5 to 5000 meter depth. Bottom dwellers appear during Cambrian and planktonic since Mesozoic period. Foraminifera are grouped into three different wall structures. These are the agglutinated, the calcareous and the microgranular. Microgranular wall structure is formed by microscopic particles of calcite cemented by calcareous material and the wall of the foraminifera appears sugary. Calcareous wall structure of foraminifera composed of either high or low Mg – calcite or aragonite. Hyaline test composed of a single calcite crystal with calcareous lamination.

According to Loeblich and Tappan (1964) the shape of foraminifera chambers could be spherical, lobate, tabular, or ovate. Chamber arrangement in a single row, uniserial; curved row, arcuate; spirally arranged around an axis of coiling planispiral arrangement. When spiral arrangement progress up to the axis of coiling with helicoidal arrangement, the chamber arrangement is called trochospiral. Therefore, type of coiling and plane of coiling is primary criteria for classification of foraminifera.

According to Boersma (1998) there are nine criterias used for the classification of foraminifera. The criterias are wall composition and microstructures; overall coiling and shape; chamber arrangement and septal addition; apertureal characteristic and position; chamber form; ornamentation and suture properties; presence or absence of spines; keel structure and lip/teeth;

and geologic range. In addition to this criterion the works of Parker (1962) for planktonic foraminifera is applied.

### **2.1.5. Statistical Approach for Species Diversity and Abundance Calculation**

All transect data are applied to estimate the coral coverage with in transects, between transects and coral outcrop terraces. The gaps produced by the marine sediments, soil, gravel, rubbles and rare taxa are excluded from the data set and diversity, abundance and percentage of the coral species are calculated. Abundance and diversity is determined for each outcrop in the study area. The number of species observed in a given area or volume is referred to as species diversity. The number of species in each assemblage, S, is highly sensitive to sample size. It is a function of the number of individuals, N, counted.

The species that characterize any natural community differ in relative abundance, usually with a few species quite common and most species much less so. Another way of looking at it is that most individuals belong to the few common species in a typical community. One way to plot such species abundance data is a rank-abundance curve in which each species is represented by a vertical bar proportional to its abundance (Harper, 1999).

A community with such striking disparities in abundance among species is said to have low evenness. A rank – abundance plot for a hypothetical community with perfect evenness would be flat instead of declining, indicating that every species had the same abundance. The simplest non parametric estimator, Chao1, augments the number of species observed ( $S_{obs}$ ) by a term that depends only on the observed number of singletons (a, species each represented by only a single individual) and doubletons (b, species each represented by exactly two individuals):-

$$S_{est} = S_{obs} + a^2/2b$$

According to Chao (2004, as cited in Balakrishnan, 2000) the simplest measure of species diversity is species richness, but a good estimation can be made for giving some weight to evenness as well. Diversity indices are mathematical functions that combine richness and evenness in a single measure, although usually not explicitly. The most commonly used diversity indices in ecology/paleoecology are Shannon diversity, Simpson diversity, and Fisher's  $\alpha$ . If species i comprises proportion,  $p_i$  of the total individuals in a community of S species, natural logarithm of the proportion,  $\ln p_i$ .

Shannon-Wiener diversity is,

$$H = - \sum_{i=1}^s p_i \ln p_i \text{ or, } e^H \text{ and,}$$

Simpson diversity is,

$$D = 1 - \sum_{i=1}^s p_i^2 \text{ or preferably, } D' = (\sum_{i=1}^s p_i^2)^{-1}$$

Simpson diversity range from 0 to 1, high score close to 1 indicates high diversity and low score close to 0 indicate low diversity. Both Shannon and Simpson diversities increase as richness increases, for a given pattern of evenness, and increase as evenness increases, for a given richness, but they do not always rank communities in the same order. Simpson diversity is less sensitive to richness and more sensitive to evenness than Shannon diversity, which, in turn, is more sensitive to evenness than is a simple count of species (richness, S).

Because rare species tend to be missing from smaller samples, the sensitivity of these indices to sampling effort depends strongly on their sensitivity to richness. Selection of diversity index depends on determination of richness and evenness, relative abundance pattern of the data, comparison with previous studies and interpretation of the result. Therefore based on the objective of this research work Shannon – Weiner index is applied in order to compare results of abundance and diversity between coral outcrops and get meaningful result which will help to reconstruct the paleoenvironment of the study area. PAleontological STatistics (PAST) is used for diversity and abundance calculations and representations (Hammer et al., 2001).

## 2.2. Materials

The materials employed on this study includes topographic map of 1:50,000 scale, geological map of Northern Afar from GSE; stratigraphic logs and tectonic histories of the area from GSE; satellite images and DEM of the study area from Google Earth; GPS, Plastic sample bag; Reflected Light Microscope (RLM); Dil. HCl and H<sub>2</sub>O<sub>2</sub>; Sieves with variable mesh size and Beakers (Steel or pyrex) from School of Earth Science Paleontology laboratory. Softwares used during the research work are Arc GIS, Ms. Excel, PAST 3 and Surfer 10.

## CHAPTER THREE

### 3. LITERATURE REVIEW

#### 3.1. Background

Taxonomic classification of fossil is crucial for identification of species which occur within specific geographical location and environmental condition. Taxonomic studies will be done based on previously identified and accepted classifications. There is a database for recording the newly identified species under its taxonomic grouping which is world record of marine species (WoRMS). According to WoRMS (2017) the accepted or valid hierarchy and synonymized groups are mentioned in detail including the revised and original works on systematics of marine species. Therefore, different literatures are used as reference comparison material for the systematics of corals and ostracoda.

#### 3.2. Systematic Paleontology

##### 3.2.1. Scleractinia Corals

According to Veron and Pichon (1967) part I, the three families which belong to suborder Astrocoeniina Vaughan and Wells, 1943 which is taxonomically isolated group of scleractinian corals with known fossil record from middle Triassic is explained. The families are Thamnasteriidae with only one Genus *Psammocora* Dana, 1846; Family Astrocoeniidae with one Genus *Stylocoenia* Yabe and Sugiyama 1935; and Family Pocilloporidae which contains five genera namely Genus *Pocillopora* Lamarck 1816, Genus *Seriatopora* Lamarck 1816, Genus *Calouastrea* Schweigger 1819, and Genus *Madracis* Edwards and Haime 1849. Distinct morphological characteristics of the species under the above mentioned genera are clearly explained including their bathymetry and biogeography.

According to Veron and Pichon (1977) the Family Faviidae are described in detail. There are fifteen genera together with their respected species descriptions. The description includes the different morphological features of species, unique characteristics and their geographic distribution. Out of 63 species of this family, half of them are extended from Red Sea to western Pacific and there are some restricted species only for eastern Indian Ocean and western Pacific. *Echinopora gemmacia*, *Montastrea annuligera* and *Cyphastrea microphthalma* are more abundant in Red Sea and Indian Ocean than *Echinopora lammelosa*, *Montastrea curta* and *Cyphastrea sterailia* (Crossland, 1952).

According to Veron (2000) the new species in the corals of the world are described. A total of 794 species of zooxanthillate scleractinian are described based on skeletal characteristics for the taxonomic study. This study describes new species for the Family Acroporidae, Family Pocilloporidae, Family Euphyllidae, Family Occulinidae, Family Agariciidae, Family Fungiidae, Family Pectiniidae, Family Mussidae, Family Faviidae and Family Poritidae. The description of species includes the morphological features of the colony skeleton, abundance, habitat and geographic distribution.

According to Lemmens (1993) the reef building corals from the Wetamu Marine National Reserve, Kenya cost a total of 113 species and 45 genera of corals are identified. Kora et al. (2014) study Pleistocene scleractinian from Marsa Alam area, Egyptian Red Sea cost. This study recognizes 61 scleractinian coral species belongs to 25 genera. *Acropora stoddarti*, *Acropora sperifera*, *Acropora squarrosa*, *Stylopora wellis*, *Pseudosiderastrea tayamai*, *Psammocora haimeana*, *Favites Chinensis*, *Favites vasta*, *Plesiastrea devantieri*, *Leptastrea Purpurea*, *Leptastrea pruinosa*, *Echinopora hirsutissima* and *Porites lobata* are described for the first time from Pleistocene Samadi Formation of Red Sea fossil corals.

According to Veron et al. (2015) the northern part of Red Sea contains consolidated coral reefs in the world. Red Sea has similar diversity to the ecological regions of the south with the highest level of endemism in the Indian Ocean region. There are around 340 species found in Red Sea and out of these 333 occurring elsewhere and the remaining are endemics. Eastern Somali cost, the Socotra islands and Yemen are affected by monsoonal upwelling through the northern cost of Socotra and has relatively high diversity of corals.

According to Kalus (2015) study the living coral colonies of the Red Sea and it contains highly diverse fringing coral reefs along the cost of Sudan, Eritrea, Djibuti and Yemen. The area is transitional zone where shallow marine communities exposed to more marginal conditions.

Sudanese Red Sea Coastline extends over 750km from the border with Egypt in the north to Eritrean border in the south. Different types of coral reefs exist with in Sudanese coast including the fringing reefs and barrier-type reefs. The fringing reefs occur along the Mainland cost of Sudan which contains massive and sub-massive *Porite spp.*, *Galaxea fascicularis*, *Galaxea astreata*, *Favidea*, *Mycedium*, *Fungiidae* and *Acropora* at a depth of <10m (Kalus, 2015).

Eritrean Red Sea coast extends over 1350km from border of Sudan in the north to border of Djibouti in the south. Fringing reefs developed along the mainland and islands of Gulf of Zula, Massawa, Dahlak Archipelago and Buri Peninsula. The dominant coral cover includes massive *Porites*, *Acropora*, *Galaxea* and *Stylopora* (Kalus, 2015).

Republic of Djibouti coast covers 370km comprises both Red Sea and Gulf of Aden, however it situated with deeper triangular coast of Gulf of Tajura. Mainland and island fringing reefs and patchreefs are common along the coast of Djibouti and comprise abundant *Porite spp.*, *Acropora spp.* and *Pocillopora* developed on hard substrate (Kalus, 2015).

Yemen coast extends 735km from Saudi Arabia to Straits of Bab-Al-Mandab with submerged patch reefs and fringing reefs. The maximum depth of the mainland fringing reef ranges from 4 to 6m and the coral colonies of *Porite sp.*, *Stylopora pistillata*, *Montipora spp.*, and *Favids* present. The reef flat width ranges from 10 to 100m and contains solid rock pavements supporting coral growth and red coralline algae. Massive *Porites* provides the dominant framework together with *Stylopora pistillata*, *Platygyra daedalea*, *Pavona cactus*, *Goniastrea retiformis*, *Leptastrea purpurea*, *Echinopora gemmacea* and *Galaxea fascicularis* (Kalus, 2015).

According to Buffler et al. (2010) the geological setting of the Abdur archaeological site, Red Sea coast of Eritrea, described in detail. The study describes the presence of the shallow marine reefal limestone contains extensive buildups of molusca, echinoidea and coral deposits. These are dated to the last glacial high stand (MIS5e).

Zufardi Comersi (1932) describes the coral species from the Mesozoic formations of Ogaden, Somali land and Arsi Plateau. These are *Astrocoenia subornata var. Africana*; *Stromatopora daurillei*; *Orbicella lifdensis*; *Stylina ogadensis*; *Milleporidouem somaliensis* and *Burgundia tertia*. There is no previous study and description of Quaternary corals from Ethiopia.

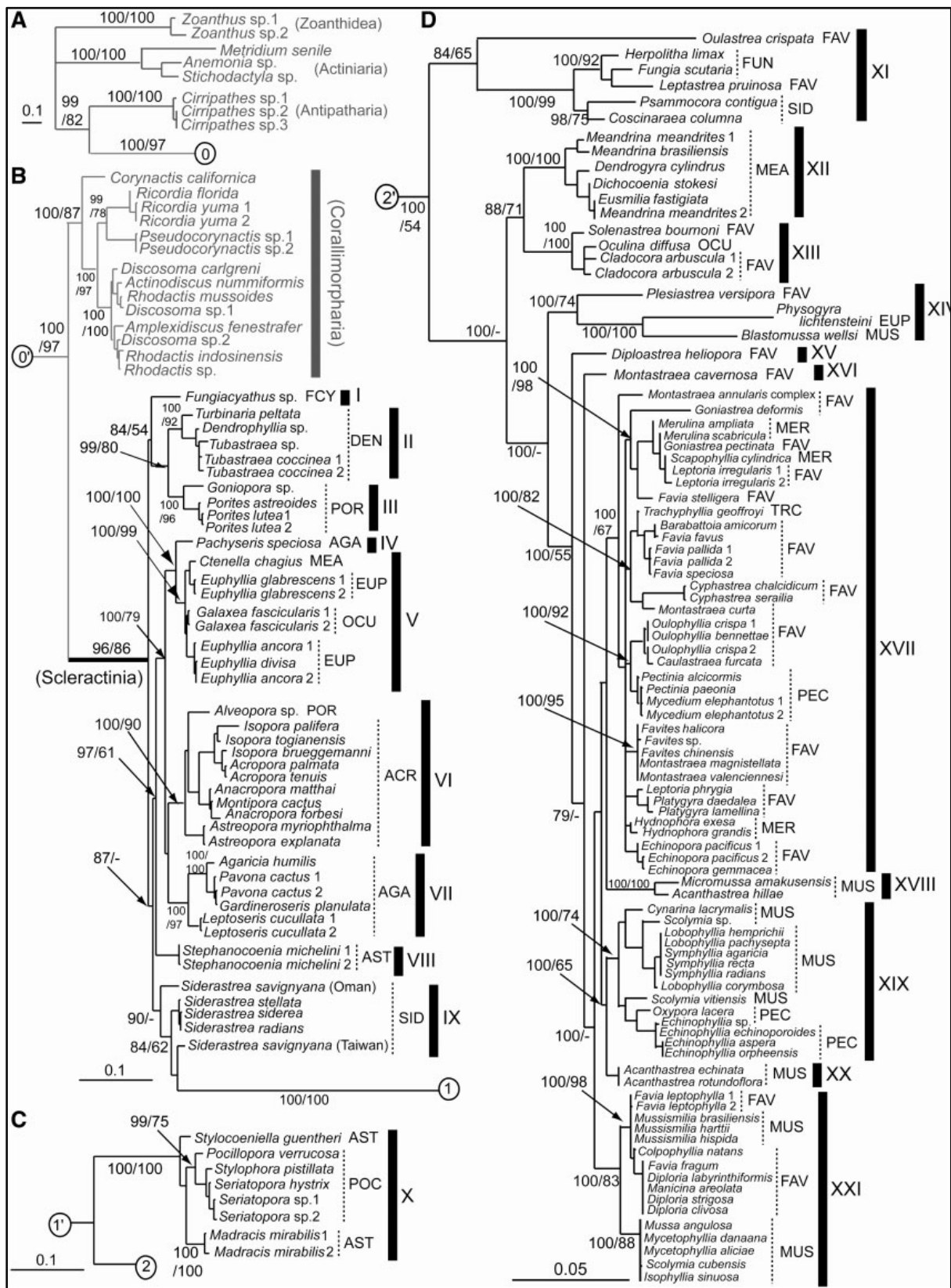


Fig.3.1. Phylogenetic relationships among scleractinia corals (source: Fukamin et al., 2008)

### 3.2.2. Ostracoda and Foraminifera

Important introduction about taxonomy of major ostracoda groups is given by Horn et al. (2002). The Class Ostracoda (Bowman and Abele, 1982) is divided into two subclasses the Myodocopa and the Podocopa. All Myodocopans are marine ostracoda and have weakly calcified valves which are poorly preserved in the fossil record. The carapace of Myodocopa characterized by typically subovate shape and ventral margin would never have concave shape; minimum valve overlap; weak adont hinge type; narrow marginal zone. Myodocopa have two orders which are Order Myodocopida which is marine and nektobentic and Order Halocyprida marine nektobentic and pelagic. Podocopa ostracoda carapace characterized by sub-quadrate, sub-triangular and reniform shape; concave ventral margin; minimum to strong valve overlap; adont to complex hinge type; simple to complex marginal zone which is broad or narrow. Podocopans are divided into three orders and these are Order Platycopida bentic and marine, Order Podocopida bentic or nektobentic with marine, non-marine and some terrestrial species and Order Palaeocopida marine and bentic which are mostly extinct during Paleozoic. Review of ostracoda systematics is carried out by Ikeya et al. (2005) and the 65,000 ostracoda species have been described.

According to Balemwal and Russo (2004) Late Quaternary lacustrine ostracoda are controlled by salinity changes in Lake Langano and Lake Zwiay, Central Rift Valley of Ethiopia. The species recognized includes *Limnocythere thomasi thomasi*, *Limnocythere aff. Tudoranceai*, *Darwinula stevensoni*, *Gompgocythere angulate*, *Cyprides torosa*, *Ilyocypris gibba*, *Zonocypris costata*, *Candonopsis sp.*, and *Hetrocypris sp.* Environmental interpretation is done based on C<sup>13</sup> analysis and ostracode assemblage. From this study lower salinity correspond to periods of high humidity and higher salinity indicates dry periods and lake level fluctuations.

Ostracoda species level identification is based on the morphological features of CaCO<sub>3</sub> carapace and sieve selection of the species; type of muscular scars; calcified inner lamella and vestibules; hinge morphology along the dorsal margin; carapace surface ornamentation; and intra and inter-population morphological variability. These morphological variations will depend on environmental conditions of physical parameters for example the salinity, water chemistry, and temperature (Cronin, 2015).

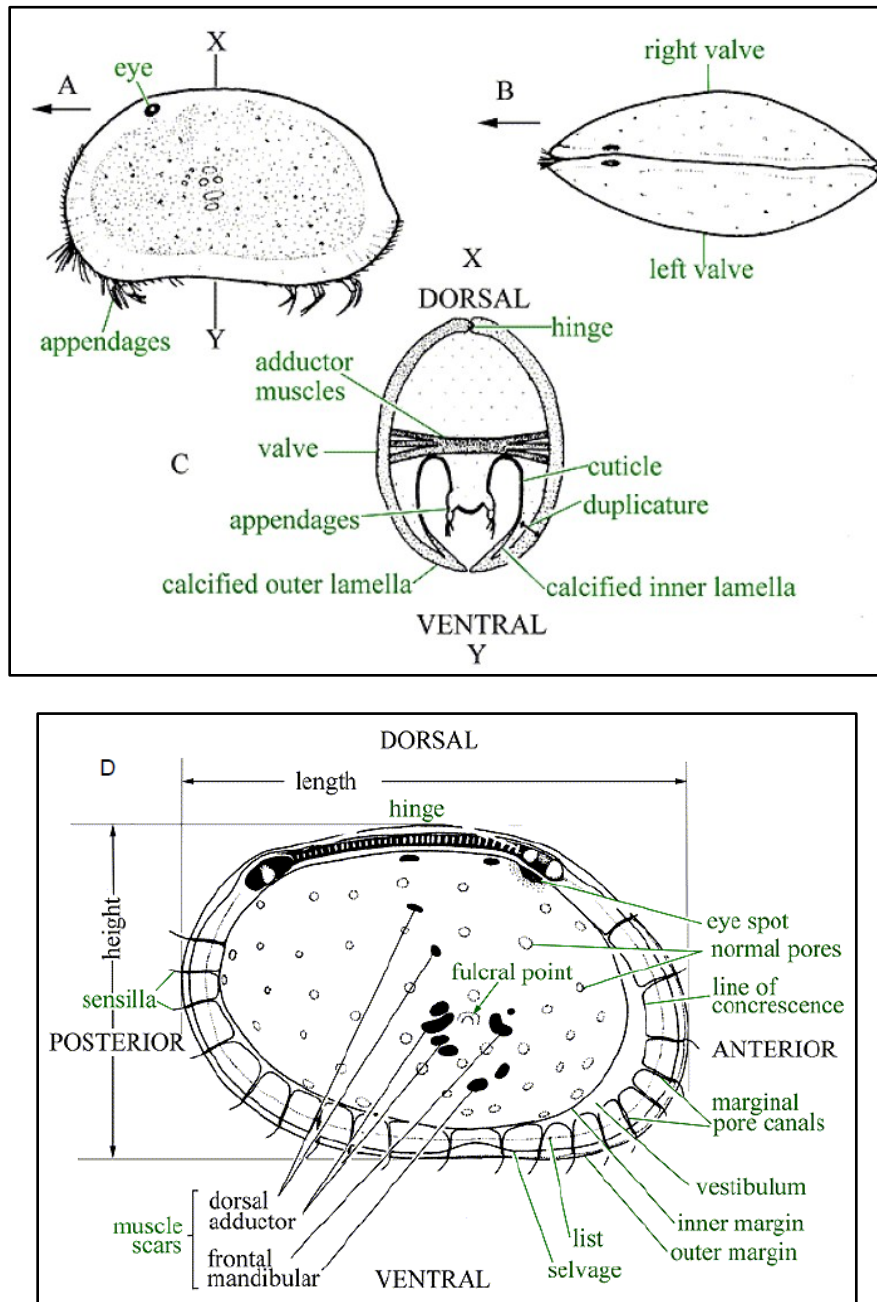


Fig.3.2. Shell morphology of ostracoda external view of left valve (A), the dorsal view (B), dorso – central section (C), and internal view of left valve (D) after Athersuch et al. (1989).

Classification and species concept of foraminifera is entirely based on their mode of life as planktonic and benthic and the different morphological features of their shell. Planktonic foraminifera generally have globular chamber often with spines. Their proportion from shallow marine environment to deep marine environment increases from 0 percent to 90% (Boersma, 1998).

Benthic foraminifera can be agglutinated or calcareous. Calcareous species are divided into hyaline shells with clear or translucent appearance; pores with tiny perforations; and porcelaneous white and opaque shells with no perforation. Proportion of these three types of shell is characteristic of particular environment in modern sea and oceans. Species level classification of Quaternary planktonic foraminifera follows concepts of Parker (1962).

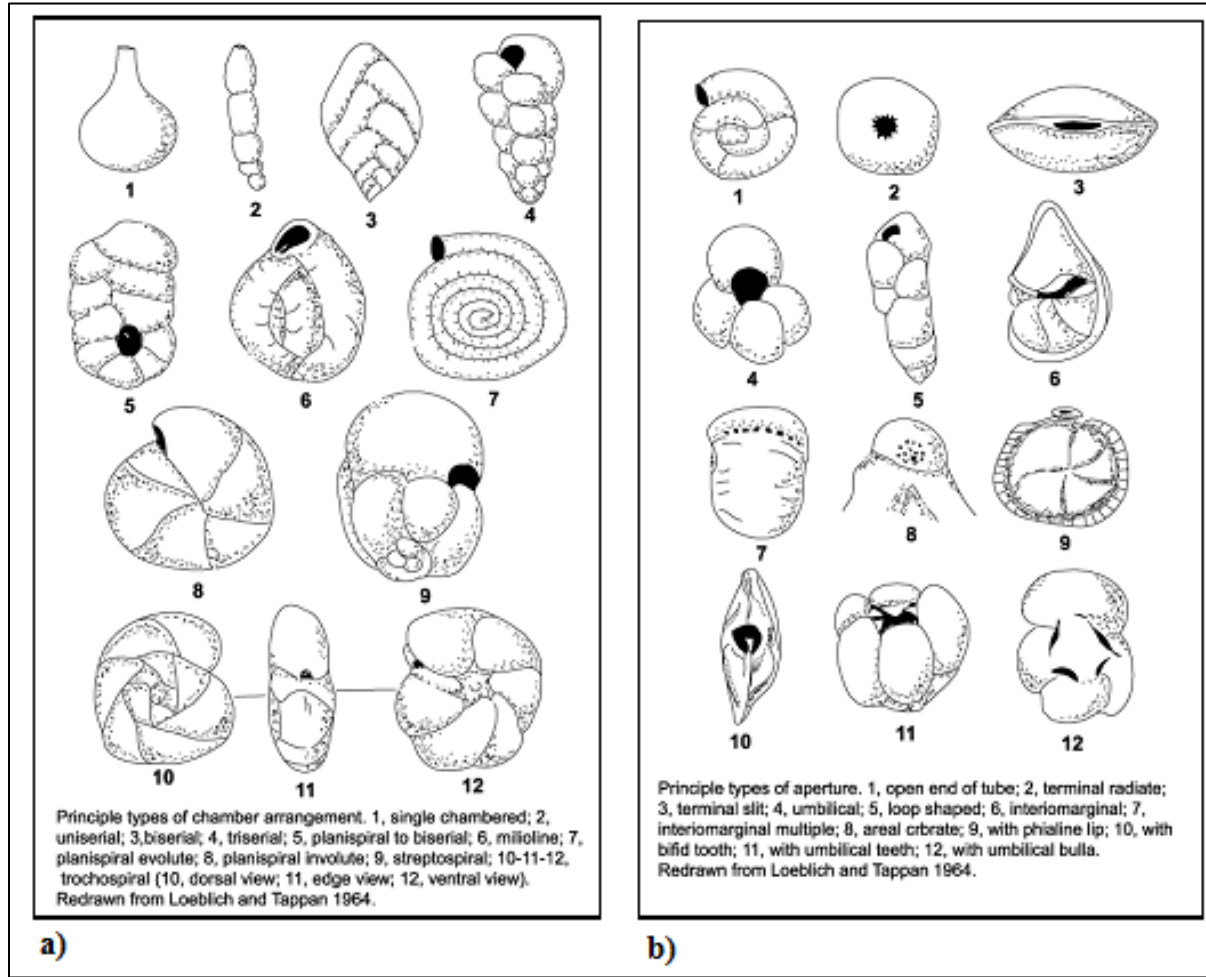


Fig.3.3. Principal Types of (a) chamber arrangement and (b) aperture types after Loeblich and Tappan (1964)

Loeblich and Tappan (1964) identify 12 Suborders, 74 Superfamily, 296 Family, and 302 Subfamily, 2,455 Genera based on principal types of chamber arrangement and aperture primary position and its shape. Out of the 2455 genera 628 suborder Rotalina, 624 Texturalina, 412 Fusulinina, 279 Miliolina, 221 Lagenina, 135 Globigerina, 56 Allogromina, 58 Robertinina briefly described in his book. For identification of the collected samples selected chapters are used for comparison.

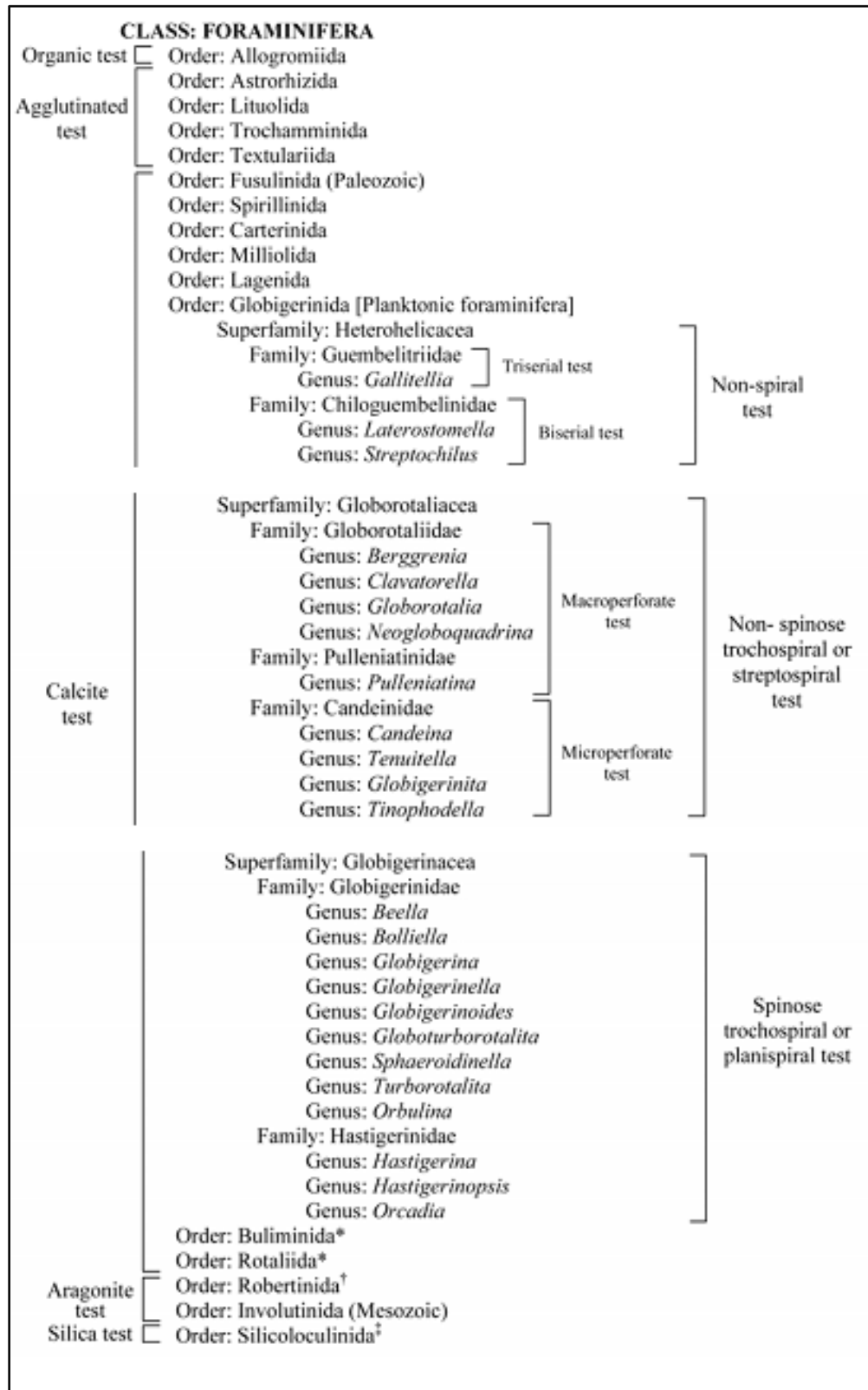


Fig.3.4. Classification of foraminifera based on morphological characteristics of the test after Loeblich and Tappan (1964)

### **3.3. Quaternary Corals and Ostracoda as Paleoenvironmental Proxies**

Massive hermatypic corals are more important than branching varieties for application of paleoenvironmental reconstruction. Massive corals form round, wave resistant structures that can grow hundreds of years and activity of zooxanthllar leads to higher accretion rate of calcium carbonate (Goreau, 1959).

Assemblage of coral is good indicator of the environment which is reflected by coral morphologies. According to Crame (1980) studied the Kenyan coral assemblages and sediment tolerance corals form dome shaped and commonly massive forms and platy/encrusting and branching coral colonies show relatively quiet environment and sediment free.

Analysis of ostracoda fossils allows the reconstruction of paleoenvironmental parameters associated with the assemblage and individual species. Common environmental factors are salinity, water depth, dissolved ion composition and the changes in these factors are determined from biogeochemical analysis of ostracoda valves (Griffiths and Holmes, 2000).

According to Cronin (2015) the climate variability during the medieval climate anomaly and little ice age is determined from shell geochemistry and faunal assemblage of ostracoda. The ostracoda assemblages indicate various salinity ranges from oligohaline - polyhaline - euhaline.

## CHAPTER FOUR

### 4. SYSTEMATIC PALEONTOLOGY

#### 4.1. Background

Coral taxonomy is challenging because of the high degree of morphological variation between species and within single species (Fukamin et al., 2004). Systematic classification of fossil corals is currently done according to criterias, terminologies, descriptions of macro and micro – morphological characteristics done by different researchers. This study applies principles of classifications of Wells (1956); Veron (1976, 2000, 2013, 2015); Sheer and Pillai (1983); Sheppard and Sheppard (1991); Benzoni et al. (2011); Budd et al. (2012); and Hugan et al. (2014) for the coral specimens of Dallol.

This study species level identification is done from selected coral outcrops for ostracoda and foraminifera excluding other microbivalves, microgastropods and charophyta. This study recognizes a total of 15 Genera and 27 Species ostracoda and 9 Genera and 13 Species of foraminifera. The detailed systematic description summarized as below.

#### 4.2. Systematics of Quaternary Corals of Dallol

**Phylum** Cnidaria Hatschek, 1888

**Class** Anthozoa Ehrenberg, 1834

**Subclass** Hexacorallia Haeckel, 1866

**Order** Scleractinia Bourne, 1900

##### 4.2.1. Family Acroporidae Verrill, 1902

###### 4.2.1.1. Genus *Acropora* Oken, 1815

**Type Species** *Acropora hayacinthus* (Dana), 1846

***Acropora hayacinthus* (Dana, 1846) (Pl. A1, Fig. 1)**

1983 *Acropora hayacinthus* (Dana). — Scheer and Pillai: pp. 39, pl. 6, fig. 7 and pl. 7 fig. 4

1976 *Acropora reticulata* (Dana). — Pillai and Scheer: pp. 28, pl. 7a

1954 *Acropora conferta* (Quelch). — Wells: pp. 116, pl. 1 and 2

**Material** Three specimens from CO7

**Diagnosis** Colony encrusting and branching with axial corallite; branch length range from 5 to 8mm; the colony have thick tapering branches with rounded cup – shaped tips; calice is rounded and have inner calice width of 0.15 to 0.2mm in diameter; U – Shaped calicullar platform shape with less defined septa; evenly distributed corallite along the lower surface of the branch and corallites are crowded on the top surface of the colony with distinct but not exsert axial corallite.

**Geographic Distribution** The species is found in Red sea cost of Marsa Alam area (Kora et al., 2014) and Northern Safaga Bay, Egypt and South Western Australia (Veron, 2000).

**Habitat** The species is common in sheltered water 5 – 25m depth and reef slopes (Sheppard and Sheppard, 1991).

#### 4.2.2. Family Agariciidae Gray, 1847

##### 4.2.2.1. Genus *Leptoseris* Milne Edwards and Haime 1849

**Type species** *Leptoseris explanata* (Yabe & Sugiyama, 1941)

*Leptoseris explanata* (Yabe & Sugiyama, 1941) (Pl. A1, Fig. 2)

1980 *Leptoseris explanata* Yabe & Sugiyama. — Veron and Picon: pp. 42, fig. 71-82

1948a *Leptoseris scabra*. — Matthai: pp. 192, fig. 4, pl. 11

**Material** One specimen from CO6

**Diagnosis** Platy colony with smooth continues septocostae; the septocostae are unequal and primary septa are more exsert; corallites are inclined towards the edge of the colony; colony wall is thickened with dissepiments; colony formed by intratentacular type of budding.

**General Remark** The family is largely monophyletic (Fukamin et al., 2008). *Leptoseris* is endemic to Indo – Pacific genera (Veron, 2000).

**Geographic Distribution** The species found in Kenya, Indian Ocean, Red Sea (Sheppard, 1998).

**Habitat** Very shallow environment (Sheppard, 1998)

##### 4.2.2.2. Genus *Agaricia* Lamarck, 1801

**Type species** *Agaricia agaricites* Linnaeus, 1758

*Agaricia agaricites* Linnaeus, 1758 (Pl. A1, Fig. 3)

**Material** One specimen from CO6

**Diagnosis** Colonies are thick, raised and platy with ceroid to submeandroid corallite wall; calice is rounded to polygonal and some of the parts show a series of centers 2 – 3 center per series; calice width range from 2 – 4mm in diameter; costea run regularly between the centers of the calices; intratentacular type of budding and the corallite skeleton is solid.

**General Remarks** The species is found within the depth range of 1 to 75 meters (Veron, 1976c)

**Geographic distribution** Carrabin Sea, Cuba, Gulf of Mexico (Veron, 1976c; 2000)

**Habitat** Common in shallow reef environment (Veron, 2000)

#### 4.2.2.3. Genus *Pavona* Lamack, 1801

**Type species** *Pavona bipartita* Nemenzo, 1979

*Pavona bipartita* Nemenzo, 1979(Pl. A1, Fig. 4)

**Material** One specimen from CO20

**Diagnosis** It is platy colonial coral with well - developed septocostea with no granular texture. The species form large septa and rounded calice 1-1.5mm diameter without defined wall. The corallites are evenly distributed and crowded on the surface.

**Geographic Distribution** The species is found from Central Indo-pacific to Japan including Comoros, Eritrea, India and Red Sea (Veron, 1976c).

**Habitat** Shallow water reef slope environment with the depth limit of 3 to 20m (Veron, 1976c)

#### 4.2.3. Family Merulinidae Verrill, 1865

##### 4.2.3.1. Genus *Caulastrea* Dana, 1846

**Type species** *Caulastrea tumida* Matthai, 1928

*Caulastrea tumida* Matthai, 1928 (Pl. A1, Fig. 9)

1928 *Caulastrea tumida* Matthai. — pp. 275, pl. 72/5 and 72/6

1977 *Caulastrea tumida* Yabe and Sugiyama. — Veron et al.: pp. 18, fig. 13 - 15

1983 *Caulastrea tumida* Matthai. — Scheer and Pillai: pp. 102, pl. 26, fig. 1 and 2

**Material** Four specimen from CO1

**Diagnosis** Colonies are branching and shared at the base; phaceloid; corallites are short and solid with calice width range from 10 – 12mm in diameter, corallite rounded to elongate; poorly developed costea and very defined septa. The corallite wall is smooth and solid.

**Geographic Distribution** The species is a commonly found in Red Sea cost of Sudan; Indian Ocean; Madagascar; Mozambique; (Veron, 2000)

**Habitat** The species grow in depth limit from 2 to 30 meter (Veron, 1976c).

**Type species *Caulastraea furcata* Dana, 1846**

***Caulastraea furcata* Dana, 1846 (Pl. A1, Fig. 10)**

1976b *Caulastrea furcata* Dana.— Veron: pp. 16, fig. 6-10

**Material** Five specimens from CO1 and CO20

**Diagnosis** Colonies are distinctly phaceloid; corallites diverge at the colony base; the calice is 5 – 8mm in diameter; less spiky, thick and prominent septa radiating towards the center of the corallite; colony shows mono to polycentric calices and intratentacular type of budding; corallite wall is well developed and skeleton is solid; the species covers an area 6 to 8.5 meters on the study area exposures.

**General Remarks** The species occur in protected reef slope where the substrate is partly sandy. It forms extensive single species stands and cover large area over 5 meters (Veron, 1986).

**Geographic Distribution** The species found in East Africa and Indian Ocean (Veron, 1986)

**Habitat** Sheltered reef slopes with low energy and very shallow environment (Veron, 2000).

**4.2.3.2. Genus *Echinopora* Lamark, 1816**

**Type species *Echinopora gemmacea* (Lamark), 1816**

***Echinopora gemmacea* (Lamark, 1816) (Pl. A1, Fig. 11)**

1983 *Echinopora gemmacea* (Lamark). — Scheer and Pillai: pp. 136-137, pl. 32, fig. 6-9

1914 *Echinopora gemmacea* (Lamark). — Matthai: pp. 54, pl. 14/9 and 15/5

1879 *Echinopora carduus* Klunzinger. — pp. 57, pl. 6/6

**Material** One specimen from CO2

**Diagnosis** The colony is laminar with controlled branches; plocoidal; and have exsert primary septa; corallites are rounded and have a calices width of 3 – 5 mm in diameter; the corallite have poorly developed and large columella; paliform lobes are weakly developed and calices separated by granular septocostea.

**General Remarks** Colonies are usually found in the reef flat and in several environmental conditions for example in turbid reef slope environment at all depth over 30m (Sheppard, 1998 and Veron 1986).

**Geographic Distribution** Central Red Sea (Veron, 1986; 2000)

**Habitat** Shallow protected reef environment (Veron, 2000)

**Type species *Echinopora hirsutissima* Edwards and Haime, 1849**

***Echinopora hirsutissima* Edwards and Haime, 1849(Pl. A1, Fig. 12)**

1977 *Echinopora hirsutissima* Edwards and Haime. — Veron et al.: pp. 192, fig. 383-387

1997 *Echinopora hirsutissima* Edwards and Haime. — Riegl and Piller: pp. 40-41, fig. 18b

2000 *Echinopora hirsutissima* Edwards and Haime. — Veron 3, pp. 260-261, fig. 1-7

**Material** Six specimens from CO6, CO7 and CO27

**Diagnosis** The colony is thick and well defined corallites with platy to sub-massive colony; calices are rounded to sub-rounded; plocoid; calice width range from 1 to 2mm in diameter; unevenly distributed calice; septa emerge from the periphery of the corallite to the center; costea is beaded and the coenosteum covered by fine spinule septocostea.

**Geographic Distribution** Very rare species, found in Red Sea, Indian Ocean, Kenya (Sheppard, 1998 and Veron 1986).

**Habitat** Shallow reef environment (Riegl and Piller, 1997)

**4.2.3.3. Genus *Favites* Link, 1807**

**Type species *Favites pentagona* (Esper, 1794)**

***Favites pentagona* (Esper, 1794) (Pl. A2, Fig. 3)**

1983 *Favites pentagona* (Esper). — Scheer and Pillai: pp. 118, pl 29, fig. 4

1877 *Favites pentagona* (Esper). — Veron, Pichon and Wijsman-Best: pp. 68, fig. 122-127

1972 *Favites pentagona* (Esper). — Wijsman-Best: pp. 27, pl. 5/1-2

**Material** Two specimens from CO4 and CO27

**Diagnosis** Colonies are massive, ceroid and with thin corallite wall; calices are polygonal; U-shaped deep calicular platform; calice width range from 4.5 to 5 mm in diameter; septa regularly arranged; paliform lobes distinct; corallite wall is perforated; colonies are large; cover wider area.

**Geographic Distribution** Kenya, Egypt, Central Red Sea (Veron, 2000)

**Habitat** Shallow reef slope environment (Veron, 2000)

**Type Species *Favites chinensis* (Verrill, 1866)**

***Favites chinensis* (Verrill, 1866) (Pl. A2, Fig. 4)**

1977 *Favites chinensis* (Verrill). — Veron et al.: pp. 53-54, fig. 83-85

1991 *Favites chinensis* (Verrill). — Sheppard and Sheppard: pp. 127, fig. 139

2000c *Favites chinensis* (Verrill). — Veron 3: pp. 143, fig. 5-8

**Material** Two specimens from CO1R and CO1RF

**Diagnosis** The colony is massive with ceroid corallites; calices are polygonal with calice diameter of 8 – 10 mm in diameter; septa well developed 25 – 49 per calice and well elongated; thick epitheca developed with endothecal dissepiments; paliform lobes absent.

**Geographic Distribution** It is common in Red Sea, Somalia, Kenya, Indo – West Pacific and East Africa (Sheppard and Sheppard, 1991; and Veron et al., 1977).

**Habitat** The species is uncommon but it occurs in a wide range of habitat (Veron, 1986).

**Type species *Favites abdita* (Ellis and Solander, 1786)**

***Favites abdita* (Ellis and Solander, 1786) (Pl. A2, Fig. 5)**

1983 *Favites abdita* (Ellis and Solander). — Scheer and Pillai: pp. 114, pl. 28, fig. 6

1834 *Astraea abdita* Ehrenberg. — pp. 321

1972 *Favia abdita* Ellis and Solander. — Wijsman-Best: pp. 33, pl. 7/1-2

**Material** Three specimens from CO7 and CO20

**Diagnosis** The colony is massive and large dome shaped; corallite is rounded to elongated; calices width range from 2 to 4mm in diameter; corallites 9.5 – 11.5mm in length; have shared walls (ceroid) and V – shaped calice with fine to medium teeth; septa are alternating short and long; exsert and irregularly arranged on the hillocky side with 2 to 3 centers per series.

**Geographic Distribution** Indo – West Pacific, Red Sea, Gulf of Aden, South West and North West Indian Ocean (Veron, 1986)

**Habitat** Reef slope, shallow environment and sheltered reef environments (Veron, 1986).

#### 4.2.3.4. Genus *Goniastrea* Milne Edwards and Haime, 1848

**Type species *Goniastrea retiformis* (Lamarck, 1816)**

***Goniastrea retiformis* (Lamarck, 1816) (Pl. A2, Fig. 6)**

1816 *Astrea retiformis* Lamarck 2. — pp. 265

1977 *Goniastrea retiformis* (Lamarck). — Veron and Pichon: pp. 79, fig. 145-150

1983 *Goniastrea retiformis* (Lamarck). — Scheer and Pillai: pp. 119, pl. 29, fig. 5-6; pl. 30, fig. 1

**Material** Three specimens from CO1R, CO1RF and CO7

**Diagnosis** It is dome shaped and massive; exposure covers more than 1 meter in the field; calices are small and polygonal; ceroid; calices width range from 4 – 5 mm in diameter; three cycle septa; paliform lobes are well-developed.

**Geographic Distribution** Common in all reef exposures from Indo-Pacific, Red Sea to Samoa (Veron, 2000; and Scheer and Pillai, 1983)

**Habitat** The species occur on reef slope preferring shallow waters. It is always found on reef flat and in areas where water temperature and salinity is elevated (Sheppard, 1998)

#### 4.2.3.5. Genus *Hydnophora* Fischer von Waldheim, 1807

**Type species *Hydnophora microconos* (Lamarck, 1816)**

***Hydnophora microconos* (Lamarck, 1816) (Pl. A2, Fig. 10)**

1983 *Hydnophora microconos* (Lamarck). — Scheer and Pillai: pp. 128, pl. 31, fig. 2 and 3

1977 *Hydnophora microconos* (Lamarck). — Veron et al.: pp. 135, fig. 255-256

**Material** Four specimens from CO1, CO2 and CO27

**Diagnosis** Massive colony with rounded calice containing neat regular monticules; calice width range from 2 to 3.5mm in diameter; densely packed rounded calices. Monticules present and slightly weathered in some specimens.

**Geographic Distribution** Gulf of Aqaba, Northern and Central Red Sea (Veron, 2000)

**Habitat** The species found in shallow exposed water and rarely found under 10m depth and common in reef flat from 2 – 5meter (Sheppard, 1998; Veron, 1986).

#### 4.2.3.6. Genus *Platygyra* Ehrenberg, 1834

**Type species** *Platygyra daedalea* (Ellis and Solander, 1786)

***Platygyra daedalea* (Ellis and Solander, 1786) (Pl. A2, Fig. 11)**

1983 *Platygyra daedalea* (Ellis and Solander). — Scheer and Pillai: pp. 123, pl. 30, fig. 6

1972 *Platygyra daedalea* (Ellis and Solander). — Wijsman-Best: pp. 46, pl. 11/1-2

1928 *Coeloria lamellina* Matthai.— pp. 37, pl. 6/2-6 and pl. 7/1-8

**Material** Four specimens from CO7, CO19, CO24 and CO28

**Diagnosis** Meandroid colony with wider valley and thin separating walls; dome shaped with narrow and perforated wall; sharp angular walls with valley length range from 10 to 54 mm; valley width range from 2.5 to 5 mm; exsert septa arranged in parallel to each other; and weakly developed columella.

**Geographic Distribution** Red Sea, Indian Ocean (Veron 1986; Veron 2000)

**Habitat** Found in mid depth for reef slope (Sheppard, 1998); common in back reef margin and diverse reef areas (Veron, 1986)

**Type species** *Platygyra lamellina* Ehrenberg, 1834

***Platygyra lamellina* Ehrenberg, 1834 (Pl. A2, Fig. 12)**

1976 *Platygyra lamellina* Ehrenberg.— Veron: pp. 104, fig. 197-200

**Material** Six specimen from CO1, CO19, CO20 and CO27

**Diagnosis** Massive, thick walled and dome shaped colony; meandroid; septa are emerged from the wall of the calice towards the center of the valley and evenly spaced; septa regularly arranged and equal in size; valley length 10 – 52mm; valley width 10.2 mm; paliform lobes absent.

**Geographic Distribution** Widely distributed in the Indo-Pacific and Red Sea (Veron, 1976b)

**Habitat** It develops on reef slopes and form large colonies (Sheppard, 1998)

**Type species** *Platygyra sinensis* (Edwards and Haime, 1849)

***Platygyra sinensis* (Edwards and Haime, 1849) (Pl. A3, Fig. 1)**

1976b *Platygyra sinensis* (Edwards and Haime).— Veron: pp. 107, fig. 201-202

1977 *Platygyra sinensis* Edwards and Haime. — Veron et al.: pp. 105, fig. 201-206

1983 *Platygyra sinensis* (Edwards and Haime).— Scheer and Pillai: pp. 125, pl. 30, fig. 7

**Material** Two specimens from CO2 and CO4

**Diagnosis** Massive colony; meandroid; valley width range from 3 – 5mm; unevenly distributed septa; thin septa and ridges; fine granulose dentations present on the margins of the septa; valley length range from 5 – 25mm; 2 – 3 centers per series; solid epithelial wall.

**Geographic Distribution** Widely distributed from Red Sea, East Africa, Pacific (Veron, 2000).

**Habitat** It develops on reef slopes (Sheppard, 1998)

#### 4.2.3.7. Genus *Leptoria* Milne Edwards and Haime, 1848

**Type species** *Leptoria phrygia* (Ellis and Solander, 1786)

***Leptoria phrygia* (Ellis and Solander, 1786) (Pl. A3, Fig. 2)**

1928 *Platygyra phrygia* Ellis and Solander. — Matthai: pp. 112, pl. 1/3 and pl. 10/5-7

1983 *Leptoria phrygia* (Ellis and Solander). — Scheer and Pillai: pp. 126, pl. 30, fig. 10 – 11

2016 *Leptoria phrygia* (Ellis and Solander). — Zuschin et al.: pp. 5, fig. 3c

**Material** Five specimens from CO2, CO7 and CO27

**Diagnosis** The colony is massive, meandroid and dome shaped with long and straight valleys; valleys are narrow, zipper like and have valley width of 0.2mm; very shallow valley width; septa

are systematically arranged; long and short meanders with average length range from 13 – 30mm.

**Geographic Distribution** Gulf of Aqaba, Central Red Sea, El Quseir Egypt, Japan (Veron, 2000 and Zuschin et al.,2016)

**Habitat** Species is restricted to depth of 6m on the seaward facing reef slopes and less turbid water (Veron, 1986; Sheppard, 1998)

#### 4.2.3.8. Genus *Mycedium* Milne Edwards and Haime, 1851

**Type species** *Mycedium elephantotus* (Pallas, 1766)

***Mycedium elephantotus* (Pallas, 1766) (Pl. A3, Fig. 3)**

1980 *Mycedium elephantotus* Pallas . — Veron and Pichon: pp. 230, fig. 564 and 811

1983 *Mycedium elephantotus* (Pallas). — Scheerand Pillai: pp. 151/152, pl. 36, fig. 1 and 2

**Material** Three specimens from CO6, CO20 and CO24

**Diagnosis** Colonies are laminar, subplocoid rounded calices; calice width 2 – 5mm in diameter; corallites are nose – shaped and inclined to the edge of the colony; septa well developed and outward radiate ribs costae with no spines; corallite wall protruding with vertical wall; coenosteum septocostea.

**Geographic Distribution** Red Sea, Gulf of Suez, Gulf of Aqaba, Madagascar, Great Barrier Reef, New Caledonia (Veron, 2000)

**Habitat** In many reef environments with broader range of depth on fore and back reef slope (Sheppard, 1998 and Veron 2000)

#### 4.2.3.9. Genus *Coelastrea* Verrill, 1866

**Type species** *Coelastrea aspera* (Verrill, 1866)

***Coelastrea aspera* (Verrill, 1866) (Pl. A3, Fig. 4)**

1976b *Goniastrea aspera* (Verrill). — Veron: pp. 83, fig. 157-159

**Material** Eight specimens from CO2, CO4, CO7, CO24 and CO28

**Diagnosis** Colonies are massive with angular calice shape and thick wall; calice diameter range from 2 – 5mm; polycentric; perforated skeleton; alternating clear septa are well developed; septa

project from the periphery to the center of the corallite; more elongate paliform lobes present; intratentacular.

**General Remarks** According to Budd et al., 2014 phylogenetic study the species name changed from *Goniastrea aspera* to *Coelastrea aspera* Verrill, 1866 and accepted by WoRMS.

**Geographic Distribution** Indonesia, New Caledonia and Great Barrier Reef (Veron 2000)

**Habitat** Occur in protected turbid water and shallow intertidal habitat (Veron, 1998 and 2000)

#### 4.2.3.10. Genus *Paramonastrea* Huang and Budd, 2014

**Type species** *Paramonastrea persi* (Faure and Pichon, 1978)

***Paramonastrea persi* (Faure and Pichon, 1978) (Pl. A3, Fig. 5)**

1983 *Favites persi* Faure and Pichon. — Scheer and Pillai: pp. 113, pl. 28, fig. 4 and 5

1978 *Goniastrea persi* (Faure and Pichon). — Faure and Pichon: pp.107, pl. 1 - 5

**Material** Seven specimen from CO1, CO2, CO6, CO7, CO27

**Diagnosis** The colony is massive; ceroid; calice rounded to sub-meandroid; calice width range from 2 – 6mm in diameter; corallite wall is acute; septa are equal in size and length; paliform lobes present; intratentacular.

**General Remarks** The species name changed from *Goniastrea persi* (Faure and Pichon, 1978) according to Budd et al., 2014 and accepted by WoRMS as *Paramonastrea peresi* (Faure and Pichon, 1978).

**Geographic Distribution** Gulf of Aqaba, Central and Northern Red Sea, Indian Ocean (Veron, 1976; 2000)

#### 4.2.3.11. Genus *Dipsastraea* Blainville, 1830

**Type species** *Dipsastraea favus* (Forsk., 1775)

***Dipsastraea favus* (Forsk., 1775) (Pl. A3, Fig. 6)**

1983 *Favia favus* (Forsk.). – Scheer and Pillai: pp. 110, pl. 27, fig. 8 and 9

1857 *Favia aspera* Milne Edwards. — pp. 439

1775 *Madripora cavernosa* Forskal. — pp. 132

**Material** Two specimens from CO6 and CO29

**Diagnosis** The colony is massive plocoid corallites with conical to cylindrical shape at the base of the colony; inward sloping dentition of septa; well-developed dentition of septa; paliform lobes absent; septa exsert, calice width range from 5 – 8mm in diameter; rounded calice; well-developed septocostea; intratentacular.

**General Remarks** According to Huang et al., (2014b) the species *Favia favus* Forskal, 1775 taxonomic classification reclassified as *Dipsastraea favus* (Forskal, 1775)

**Geographic Distribution** Red Sea Cost of Egypt, Gulf of Aqaba, Arabian Gulf (Scheer and Pillai, 1974)

**Habit** Dominant species on the reef back margins (Scheer and Pillai, 1974)

**Type species** *Dipsastraea helianthoides* (Wells, 1954)

***Dipsastraea helianthoides* (Wells, 1954) (Pl. A3, Fig. 7)**

2008 *Favia helianthoides* Wells.— El-Sorogy: pp. 63

1983 *Favia helianthoides* Wells.— Scheer and Pillai: pp. 107, pl. 26, fig. 9 and 10

1954 *Favia helianthoides* Wells.— pp. 458, pl. 174/2 – 6

**Material** One specimen from CO1RF

**Diagnosis** The colony is massive with nodular not dense corallite; plocoidal; calice width range from 3 to 9mm in diameter; neat costae; three cycle septa reach to the columella and form paliform lobes; regular costea well-developed and have equal size.

**General Remarks** *Favia helianthoides* Wells, 1954 changed to *Dipsastraea helianthoides* (Wells, 1954) after Budd et al., (2012)

**Geographic Distribution** Red Sea, Solomon Islands (Veron, 2000)

**Habitat** Shallow reef slope and reef crust (Veron, 1986)

**Type species** *Dipsastraea laxa* (Klunzinger, 1879)

***Dipsastraea laxa* (Klunzinger, 1879) (Pl. A3, Fig.8)**

1983 *Favia laxa* (Klunzinger, 1879).— Scheer and Pillai: pp. 106, pl. 26, fig. 7 and 8

1914 *Favia laxa* (Klunzinger, 1879).— Matthai: pp. 99, pl. 24/5 and 24/6

1974 *Favia laxa* (Klunzinger, 1879).— Wijsman-Best: pp. 256, pl. 4/2

**Material** Two specimen from CO1R and CO1RF

**Diagnosis** Colony is sub-massive to hemispherical; ceroid; calice range from 3 to 6mm in diameter; septa emerge from the periphery to the center and fused with the columella; septa range from 28 to 32; visible intercorallite grooves; well-developed costea and merge each other at the middle of coenosteum; both intra and extratentacular type of budding.

**General Remarks** WoRMS accept the species name changed from *Favia laxa* to *Dipsastrea laxa* after Budd et al., (2012).

**Geographic Distribution** Common in Red Sea (Veron, 2000)

**Habitat** Shallow reef environment (Veron, 2000)

#### 4.2.3.12. Genus *Astrea* Lamarck, 1801

**Type species** *Astrea curta* Dana, 1846

*Astrea curta* Dana, 1846 (Pl. A3, Fig. 11)

1846 *Astrea curta* Dana. — pp. 209, pl.10, fig. 3a-c

**Material** Four specimens from CO1, CO6 and CO27

**Diagnosis** The colony is spherical; widely spaced corallites with rounded calices; variable calice diameter range from 0.5 to 3mm in diameter; alternating thick, long and short septa present; extratentacular type of budding.

**General Remarks** After Huang et al., (2016) taxonomic classification study the species *Montastrea curta* Dana, 1846 accepted by WoRMS as *Astrea curta* Dana, 1846

**Geographic Distribution** Indo-Pacific; Red Sea (Veron et al., 1977)

**Habitat** Common in shallow reef flat environments (Veron, 2000)

#### 4.2.4. Family Lobophylliidae Dani and Horng, 2009

4.2.4.1. Genus *Lobophyllia* de Blauville 1830

**Type species** *Lobophyllia hemprichii* (Ehrenberg, 1834)

*Lobophyllia hemprichii* (Ehrenberg, 1834) (Pl. A4, Fig. 1)

1983 *Lobophyllia hemprichii* (Ehrenberg). — Scheer and Pillai: pp. 146-147, pl. 34, fig. 9

1980 *Lobophyllia hemprichii* (Ehrenberg). — Veron and Pichon: pp. 266, fig. 457 – 471

1928 *Lobophyllia hemprichii* (Ehrenberg). — Matthai: pp. 221, pl. 54/8 and 71/4

**Material** Five specimens from CO1, CO20 and CO29

**Diagnosis** Colonies are hemispherical; phaceloid to semi-flabelloid and flabelo-meandroid; septa well developed and emerge from the wall of the corallite to the center of the valley with sharp teeth; corallites have 2 centers per series; septa thickened from the periphery to the center with sharp and exert teeth. It covers wider area in the coral outcrops of the study area.

**Geographic Distribution** Red Sea and Samoa (Veron, 1986).

**Habitat** Very common in the upper reef slopes with monospecific stands (Veron 1986).

**Type species** *Lobophyllia radians* (Milne Edwards and Haime, 1849)

*Lobophyllia radians* (Milne Edwards and Haime, 1849) (Pl. A4, Fig. 2)

**Material** One specimen from CO2

**Diagnosis** Colonies are hemispherical in shape; meandroid; valley width range from 15 to 23mm; irregularly arranged septa; ridge is thick and well defined; sinuous valley length range from 10 to 18mm; septa cross the margin of the ridge and form wider valley.

**Geographic Distribution** Indian Ocean, Great Barrier Reef of Australia and Red Sea (Veron and Pichon, 1980)

**Habitat** Common in upper reef slopes of fringing reefs (Veron and Pichon, 1980)

**Type species** *Lobophyllia corymbosa* (Forsk., 1775)

*Lobophyllia corymbosa* (Forsk., 1775) (Pl. A4, Fig. 3)

1983 *Lobophyllia corymbosa* (Forsk.). — Scheer and Pillai: pp. 146, pl. 34, fig. 7 and 8

1980 *Lobophyllia corymbosa* (Forsk.). — Veron and Pichon: pp. 274, fig. 472-475

**Material** Two specimens from CO1 and CO29

**Diagnosis** Colonies are branching at the top by sharing at the base of the colony and corallites form massive dome shape; Septas are tall and blunt at the corallite wall and becoming smaller in

size towards the center; Calice are elongate to sub rounded and their size range from 3 to 4mm in diameter and 3 - 4cm long with well-defined walls.

**Geographic Distribution** Red Sea and Tahiti; in the Red Sea the species covers more than 2 meters (Veron, 2000)

**Habitat** Diverse reef environment (Veron, 1986)

#### 4.2.5. Family Fungiidae Dana, 1849

##### 4.2.5.1. Genus *Fungia* Lamark, 1801

##### Type species *Danafungia horrida* (Dana, 1846)

##### *Danafungia horrida* (Dana, 1846) (Pl. A4, Fig. 4)

1983 *Fungia danai* Milne Edwards and Haime.— Scheer and Pillai: pp. 82, pl. 19, fig. 1 and 2

1976 *Fungia dana* Dana.— Pillai and Scheer: pp. 43

1889 *Fungia dana* Dana.— Veron and Pichon pp. 134, fig. 214-217

**Material** Three specimens from CO2, CO20 and CO24

**Diagnosis** Solitary coral; disc like shaped and weakly domed at the center; 30cm diameter, knobby like dentition tips; septa are very unequal; septa are exert around the central fossa and primary septa very large; the margin of the coral is regularly dentate.

**General Remarks** Weak preservation of the solitary corals is observed on the outcrops. The specimen from CO21 and CO24 is gypsified.

**Geographic Distribution** Red Sea, Zanzibar, Philippines, Japan, Soma and Great Barrier Reef of Australia (Veron, 2000)

**Habitat** Occur in most of reef slopes and lagoon (Veron, 2000)

##### Type species *Pleuractis granulosa* (Klunzinger, 1879)

##### *Pluractice granulosa* (Klunzinger, 1879) (Pl. A4, Fig. 5)

1980 *Fungia granulosa* Klunzinger. — Veron and Pichon: pp. 156, fig. 257 - 260

1983 *Fungia granulosa* Klunzinger. — Scheer and Pillai: pp. 80, pl. 18, fig. 2

**Material** Four specimens from CO1 and CO6

**Diagnosis** Solitary coral with wavy appearance of septa and finely granulated margin; fine costea developed; the diameter range from 12 to 13cm; lower surface is solid and smooth; well-developed epitheca.

**Geographic Distribution** South Pacific; Indian Ocean; Red Sea (Veron, 2000)

**Habitat** Mainly occur in the reef slopes (Veron, 2000)

#### 4.2.6. Family Pocilloporidae Gray, 1842

##### 4.2.6.1. Genus *Pocillopora* Lamarck, 1816

**Type species** *Pocillopora grandis* Dana, 1846

***Pocillopora grandis* Dana, 1846 (Pl. A4, Fig. 6)**

1987 *Pocillopora eudouxi* Milne Edwards.—Sheppard: pp. 21, Fig. 1

1986a *Pocillopora corconata* Gardiner, — Veron: pp. 251, Fig. 3

**Material** Two specimen from CO1

**Diagnosis** Colonies are branching thick and flattened at the tip of the branches; ceroid; calice width range from 0.5 to 2mm in diameter; branch length range from 15 -70cm; widely separated branches.

**General Remarks** WoRMS accepted *Pocillopora eudouxi* Milne Edwards, 1960 as *Pocillopora grandis* Dana, 1846 after Sheppard, (1991)

**Geographic Distribution** Red Sea and East Africa (Veron, 2000)

**Habitat** Common in upper reef slopes and exposed reef fronts where there is strong current (Veron and Pichon, 1976)

##### 4.2.6.2. Genus *Seriatopora* Lamarck, 1816

**Type specie** *Seriatopora hystrix* Dana, 1846

***Seriatopora hystrix* Dana, 1846 (Pl. A4, Fig. 7)**

1976 *Seriatopora hystrix* Dana. — Veron and Pichon: pp. 58, fig. 99 – 118

1971 *Seriatopora spinosa* Dana. — Loya and Slobodkin: pp. 122

1983 *Seriatopora hystrix* Dana. — Scheer and Pillai: pp. 28 – 29, pl. 4, fig. 7 and 8

**Material** Two specimen from CO2 and CO27

**Diagnosis** Colonies are branching and cover wider area; the branch thickness range from 1.5 to 3.5mm; calice diameter range from 1 to 1.5mm in diameter; top of the colony partly covered by red algae at CO2 and the branches are exposed at the lower part cover wider area; septa poorly preserved.

**General Remarks** Easily recognizable by their fine branches and tapering tips (Veron, 1986)

**Geographic Distribution** Gulf of Suez, Gulf of Aqaba, Northern Red Sea and Central Red Sea (Scheer and Pillai, 1983)

**Habitat** Shallow reef area and sheltered inner algal and intertidal environments (Veron and Pichon, 1976)

#### 4.2.6.3. Genus *Stylophora* Schweigger, 1820

**Type species** *Stylophora wellsii* Scheer, 1964

***Stylophora wellsii* Scheer, 1964 (Pl. A4, Fig. 8)**

1983 *Stylophora wellsii* Scheer.—Scheer and Pillai: pp. 25-26, pl. 3, fig. 5-7

2000 *Stylophora wellsii* Scheer.—Veron: pp. 64, fig. 1-3

2014 *Stylophora wellsii* Scheer.—Kora et al.: pp. 6, fig.4, pl. a1-a2

**Material** One specimen from CO4

**Diagnosis** The colony has thick, short and blunt branches with of 12 – 25mm thick; branching surfaces are irregular and they develop verrucae; calices are closely spaced, rounded and diameter of 0.1-0.6mm; septa arranged in two cycles; fused primary septa to the columella; spiny coenosteum between the calices; and hoods are absent.

**General Remarks** This species is endemic to red sea and common in the northern and central parts (Sheppard, 1998).

**Geographic Distribution** Previously recorded from northern and central parts of Red Sea, Egyptian Red Sea Coast and Madagascar (Kora et al., 2014, Veron, 2000 and Sheppard and Sheppard 1991).

**Habitat** The species only exist in very shallow water environments exposed to wave action and very rare below the depth of 3m (Veron, 2000 and Sheppard and Sheppard 1991).

**Type species** *Stylophora pistillata* Esper, 1797

*Stylophora pistillata* Esper, 1797 (Pl. A4, Fig. 9)

1974 *Sideropora mordax* Dana. — Scheer and Pillai: pp. 11

1976 *Stylophora pistillata* Esper. — Veron and Pichon: pp. 66, fig. 133-150

1983 *Stylophora pistillata* Esper. — Scheer and Pillai: pp. 23, fig. 3-5

**Material** Three specimens from CO27

**Diagnosis** Colonies are branching, the tip of the branch is blunt, smooth and thick to sub-massive; calices are rounded and 0.5mm in diameter; no verrucae; colonies are well developed in a layered branching structure and anastomosed branches cover wider areas 1.5 – 2.5 meters; hoods present between corallites.

**Geographic Distribution** Occurs in Red Sea and Central Indo – Pacific (Veron, 2000)

**Habitat** Occupy enormous habitat upto 50m in extreme conditions of turbidity (Veron, 2000).

#### 4.2.7. Family Poritidae Gray, 1842

##### 4.2.7.1. Genus *Porites* Link, 1807

**Type species** *Porites furcata* Lamarck, 1816

*Porites furcata* Lamarck, 1816 (Pl. A4, Fig. 10)

**Material** Two specimen from CO2

**Diagnosis** Thin finger coral colony with branching and flat topped corallite; ceroid; calice width 0.5 – 2mm in diameter; smooth coenosteum; porous skeleton; costea absent; v- shaped deeply excavated calicular depth.

**Geographic Distribution** Caribbean Sea, Western Atlantic Ocean, Red Sea (Veron 2000)

**Habitat** Found in shallow to mid slope reef environment at 0 - 50m depth range (Veron 2000)

**Type species** *Porites lobata* Dana, 1846

*Porites lobata* Dana, 1846 (Pl. A4, Fig. 11)

1991 *Porites lobata* Dana. — Sheppard and Sheppard: pp. 68, pl. 39

2000c *Porites lobata* Dana. — Veron 3: pp. 284, fig. 1-5

2007 *Porites lobata* Dana. — Glynn et al.: pp. 82, fig. 7A-7G

**Material** Five specimens from CO1, CO6 and CO29

**Diagnosis** It is characterized by massive, develop drooping lobes; ceroid, rounded to sub-angular calice with calice width 0.5 – 1mm in diameter. Very fine but distinct septa range from 8 to 12, styliform columella and spinules occur all over the corallite surface. Occur together with microbialite crust at the base.

**Geographic Distribution** Red Sea and Gulf of Aden (Sheppard and Sheppard, 1991) and Egypt Marsa Alam area (Kora et al., 2014)

**Habitat** Forming huge colonies in clear water to about 15m depth (Sheppard, 1998). Found in back reef margins, lagoons and some fringing reefs (Veron, 1986).

**Type species *Porites lutea* Milne Edwards and Haime, 1851**

***Porites lutea* Milne Edwards and Haime, 1851 (Pl. A4, Fig. 12)**

1983 *Porites lutea* Milne Edwards and Haime. — Scheer and Pillai: pp. 98, pl. 24, fig. 5 and 6

1918 *Porites lutea* Vaughan.— pp. 198, pl. 88/1a and 1b

1846 *Porite conglomerata* Dana. — pp. 561, pl. 55/3a

**Material** One specimen from CO2

**Diagnosis** Massive and thickly developed colonies, ceroid; corallites develop vertically projected columns and septa two cycles; calices width range from 1 to 1.5mm in diameter; rounded calice; septa with smooth surface texture and radial.

**Geographic Distribution** Red Sea Cost Egypt (El Sorogy, 2008); Gulf of Aden, Djibouti, Yemen (Veron 2000).

**Habitat** Shallow lagoon, they may form in fringing reefs by cover large area between the depth of 10 to 15m (Richmond, 1997; Veron 2000; Sheppard, 1998)

**Type species *Porites* sp.**

***Porites* sp. (Pl. A5, Fig. 1)**

2017 *Porites sp.* Casazza.— pp. 12, fig. 4, pl. A and E

2017 *Porites sp.* Casazza. — pp. 13, fig. 5, pl. A and C

**Material** Fourteen specimens from CO1R, CO1RF, CO7, CO20 and CO27

**Diagnosis** Massive and branching porites which covers larger area range from 1.5 to 2.3m in each coral outcrops; highly weathered and altered; only concentric circles and wavy surfaces exist on the exposure; calices not preserved.

**Geographic Distribution** Recent studies indicate that this species of *Porites* found in Egyptian Red Sea and Gulf of Aqaba in the localities of Middle Pleistocene Wadi Gawasis and Late Pleistocene Wadi Wizr (Casazza, 2017).

**Habitat** *Porites* mainly occur in intertidal and reef flat environment (Veron, 1976d).

#### 4.2.8. Family *Scleractinia incertae sedis*

##### 4.2.8.1. Genus *Leptastrea* MilneEdwards and Haime, 1849

###### Type species *Leptastrea purpurea* (Dana, 1846)

*Leptastrea purpurea* (Dana, 1846) (Pl. A5, Fig. 2)

1991 *Leptastrea purpurea* (Dana). — Sheppard and Sheppard: pp. 138-139, fig. 159

2000 *Leptastrea purpurea* (Dana). — Veron 3: pp. 236, fig. 1-5

2007 *Leptastrea purpurea* (Dana). — Glynn et al.: fig. 8G

**Material** Four specimens from CO1, CO7, CO24 and CO29

**Diagnosis** Colonies are encrusting and flattened with angular calice; calice width range from 2 to 3.5mm in diameter; ceroid to subceroid; septa radiate from the center to the periphery of the corallite wall and primary septa are thick and long.

**Geographic Distribution** Common from Red Sea to Hawaii; Arabian Sea and Arabian Gulf; and Somoa and Fiji Islands (Scheer and Pillai, 1983; and Sheppard and Sheppard 1991).

**Habitat** Commonly in shallow water environment and according to Frick and Schuhmacher (1983) it is recorded at depth of 2 to 28m in Sinai coast of Northern Red Sea.

###### Type species *Leptastrea pruinosa* Crossland, 1952

*Leptastrea pruinosa* Crossland, 1952 (Pl. A5, Fig. 3)

1977 *Leptastrea pruinosa* Crossland, 1952: Veron et al., Pp. 163, Fig. 319 – 326

1980 *Leptastrea pruinosa* Crossland, 1952: Wijsman – Best Pp. 250, Pl. 2, Fig. 1

2000c *Leptastrea pruinosa* Crossland, 1952: Veron 3; Pp. 237, Fig. 9-11

**Material** Three specimens from CO6 and CO18

**Diagnosis** The colony is encrusting with 10 – 15mm length; thick walled rounded to oval calices with ceroid edge; the calice diameter range from 2 to 6mm and have U – shaped shallow depth; some pinnules at the columella; well-developed epitheca; univenly distributed corallite; costea developed.

**Geographic Distribution** The species is recorded from Marsa Alam; Vanuatu and Sinai Peninsula in Egypt; and Calamian Island in Philippines (Kora et al., 2014 and Veron, 2000).

**Habitat** It occurs in shallow and clean water (Veron 1986 and 2000).

#### 4.2.8.2. Genus *Pachyseris* Milne Edards & Haime 1849

##### Type species *Pachyseris gemmae* Nemenzo, 1955a

*Pachyseris gemmae* Nemenzo, 1955a (Pl. A5, Fig. 4)

**Material** One specimen from CO6

**Diagnosis** Large foliaceous colony with no wall; calices developed parallel in the valley and polycentric. Septocostea is wavy and fused with columella. Parallel and alternating septa are developed along the ridge and the colonies have thick long and short ridges. Skeleton is imperforated.

**Geographic Distribution** Rare species and occur in Japan; Indonesia and Western Indian Ocean

**Habitat** Semi protected reefs (Veron, 2000)

##### Type species *Pachyseris foliosa* Veron, 1990

*Pachyseris foliosa* Veron, 1990 (Pl. A5, Fig. 5)

**Material** One specimen from CO24

**Diagnosis** Colony is platy unifacial fronds; septa project from the center and form shallow valley parallel to the margin of the frond; valley width is 0.2mm; columella absent; the fronds are thin and septa form regular rib.

**Geographic Distribution** South Africa, North Western Pacific (Veron, 2000)

**Habitat** Lagoon and protected reef slopes (Veron, 1990).

#### 4.2.8.3. Genus *Blastomussa* Wells, 1968

**Type species** *Blastomussa merleti* (Wells), 1961

***Blastomussa merleti* (Wells, 1961) (Pl. A5, Fig. 7)**

1983 *Blastomussa merleti* (Wells). —Scheer and Pillai: pp. 149-150, pl. 5,6, 10 and 11

1980 *Blastomussa merleti* Wells. — Veron and Pichon: pp. 234, fig. 393 and 394

1976 *Bantamia merleti* Wells. — Veron: pp. 235, fig. 393-394

**Material** One specimen from CO20

**Diagnosis** Colony is massive; corallites are plocoid to sub-phaceloid; calice diameter range from 4 to 4.5mm in diameter; two cyclesepta and projecting towards the columella; and coenosteum is smooth.

**Geographic Distribution** Red Sea; South Africa; Great Barrier Reef (Sheppard, 1998)

**Habitat** It commonly occur onreef slopes and slightly sediment rich (turbid) areas to the depth of 50m in fairly dark and cryptic conditions (Sheppard, 1998).

#### 4.2.9. Family Euphylliidae Alloiteau, 1952

##### 4.2.9.1. Genus *Galaxea* Oken, 1815

**Type species** *Galaxea cryptoramosa* Fenner and Veron, 2000

***Galaxea cryptoramosa* Fenner and Veron, 2000 (Pl. A5, Fig. 8)**

2000 *Galaxea cryptoramosa* Fenner and Veron. — Veron 2: pp. 114, fig. 1 and 2

**Material** One specimen from CO2

**Diagnosis** Colonies are branching with irregularly arranged fused corallites; plocoid; calice width range from 3 to 5mm in diameter; septa are less exsert and short with smooth margins; Columella absent; smooth coenosteum; and costea present.

**Geographic Distribution** Red Sea and Central Indo Pacific (Veron, 2000)

**Habitat** Shallow protected reef environment, with depth limit of 5m (Veron, 2000)

**Type species *Galaxea fascicularis* (Linnaeus), 1767**

***Galaxea fascicularis* (Linnaeus), 1767 (Pl. A5, Fig. 9)**

1983 *Galaxea fascicularis* (Linnaeus). — Scheer and Pillai: pp. 142, pl. 34, fig. 1 and 2

1976 *Galaxea aspera* Quelch. — Veron 3: pp. 207, fig. 343

1976 *Galaxea lawisiana* Nemenzo. — Veron 3: pp. 208, fig. 345

**Material** Two specimen from CO1 and CO2

**Diagnosis** Columnar corallite with cellular coenosteum and large protruding septa; well-spaced, tall and thin walled corallite; circular calice with calie width range from 2 to 5mm in diameter; extratentacular type of budding; well-developed corallite wall and loosely interconnected; columnar corallite length range from 5 to 9cm.

**Geographic Distribution** Arabian Sea, Red Sea; Eastern Madagascar, Mauritius Islands, North and East Cost of Australia (Raza et al., 2015 and Veron, 1976c)

**Habitat** Dominant on inshore fringing reefs and shallow water at the depth of 5 – 20m (Veron, 1989; Sheppard, 1998)

**4.2.10. Family Astrocoeniidae Koby, 1890**

**4.2.10.1. Genus *Stylocoeniella* Yabe and Sugiyama, 1935**

**Type species *Stylocoeniella guentheri* (Bassett-Smith, 1890)**

***Stylocoeniella guentheri* (Bassett-Smith, 1890) (Pl. A5, Fig. 10)**

1966a *Stylocoeniella guentheri* (Bassett-Smith). — Wells: pp 230, Fig. 1 - 10

1976 *Stylocoeniella sp.* Wells. —Veron: pp. 38, fig. 45-49

1983 *Stylocoeniella guentheri* (Bassett-Smith). — Scheer and Pillai: pp 21, pl. 2, fig. 2

**Material** One specimen from CO6

**Diagnosis** The colony is thin encrusting to knobby; plocoid; calices equal in size and rounded; calice width is 0.05mm in diameter; solid skeleton bore by bivalvia; smooth coenosteum; well-developed two cycle septa 12 – 16 septal teeth.

**Geographic Distribution** Commonly distributed in Red Sea, Madagascar, Taiwan and Great Barrier Reef (Scheer and Pillai, 1983).

**Habitat** The species mostly occur in shallow reef environment at the depth range from 0 to 15 meters (Veron and Pichon, 1976).

#### 4.2.11. Family *Coscinaraeidae* Milne Edwards and Haime, 1848

##### 4.2.11.1. Genus *Coscinaraea* Milne Edwards and Haime, 1848

**Type species** *Coscinaraea columna* (Dana, 1846)

*Coscinaraea columna* (Dana, 1846) (Pl. A5, Fig. 11)

1976 *Coscinaraea fossata* (Dana). — Veron 3: pp. 97, fig. 157

1976 *Psammocora fossata* Dana. — Veron 3: pp. 96, fig. 155-156

**Material** Four specimens from CO6 and CO29

**Diagnosis** The colonies are platy; randomly arranged calices with ceroid surfaces; contineous septocostea; sugary and granular surface texture of coenosteum; corallites have calice width of 2mm in diameter and crowded calices with elongate septa; solid skeleton.

**Geographic Distribution** Fiji, Samoa and Tuamoru Archipelago; Japan; Egypt (Veron and Pichon, 1980)

**Habitat** Shallow water habitat, found at the depth of above 90m (Veron and Pichon, 1980).

#### 4.2.12. Family *Siderastreidae* Vaughan and Wells, 1943

##### 4.2.12.1. Genus *Pseudosiderastrea* Yabe and Sugiyama, 1935

**Type species** *Pseudosiderastrea tayamai* Yabe and Sugiyama, 1935

*Pseudosiderastrea tayamai* Yabe and Sugiyama, 1935 (Pl. A5, Fig. 13)

1976c *Anomastraea tayamai* Yabe and Sugiyama, 1953: Veron, pp. 87, Fig. 146-147

2000 *Pseudosiderastrea tayamai* Yabe and Sugiyama: Veron, pp. 134, Fig. 1-4

2014 *Pseudosiderastrea tayamai* Yabe and Sugiyama: Kora et al., pp. 7, Fig. 4b1-b4

**Material** Three specimens from CO7 and CO21

**Diagnosis** Colonies are massive with ceroid calices and the polygonal to sub-circular calice diameter range from 2 to 3.5mm in diameter; septa equally radiated towards the center of the corallite; columella present, calice unevenly distributes.

**Geographic Distribution** Indo West Pacific, Gulf of Kutch; Arabian Gulf and Arabian Sea; Great Barrier reef of Australia (Pillai and Patel, 1988; Sheppard and Sheppard, 1991).

**Habitat** The species is uncommon (Sheppard and Sheppard, 1991) and in shallow water reef slopes (Veron, 1986).

#### **4.3. Systematics of Other Invertebrate Fossils**

##### **4.3.1. Bivalvia Systematics**

There are abundant species of bivalvia in most of the coral outcrop sites with diverse species as monospecific and associations with other mollusca. All of these Quaternary bivalvia are completely preserved with their morphological features. For the classification of bivalvia a total of 26 samples are examined. The main characteristic features applied to distinguish the species type are nature of dentition which is shape, size and arrangement; growth lines shape and dimension; type of muscular scar and position of ligament; and presence or absence of pallial line.

For the systematics of bivalvia, “Treatise on Invertebrate Paleontology”, (Moore, 1969), Gosling (2004) and literatures done on the Red Sea mollusca for example Grill and Zuschin (2001) and Farag et al. (1999) are used.

**Phylum** Mollusca Linnaeus, 1758

**Class** Bivalvia Linnaeus, 1758

**Order** Pectinida Gray, 1854

**Family** Spondylidae Gray, 1826

##### **4.3.1.1. Genus *Spondylus* (Linnaeus, 1758)**

***Spondylus squamosus* Schreibers, 1793 (Pl. B, Fig. 1)**

**Material** Three specimens from CO2

**Diagnosis** Valves are well preserved; long and flattened spines are developed on the right and left valves; umbo is thick; width of ventral side is 30mm and length of posterior border is 45mm.

***Spondylus* sp. (Pl. B, Fig. 2)**

**Material** Four specimens from CO2 and CO7

**Diagnosis** Monomyarian with single adductor muscular scar; large and groove dentitions; no palial line; highly bored by borer organisms and become perforated outer surface; thick umbo at dorsal margin; oval shape from dorsal to ventral.

**Order** Arcida Stoliczka, 1871

**Family** Arcidea Lamarck, 1809

#### 4.3.1.2. Genus *Arca* Linnaeus 1785

***Arca boucardi* Jousseume, 1894 (Pl. B, Fig. 3)**

**Material** Five specimens from CO6 and CO27

**Diagnosis** The shell is elongate and very irregular in shape; anterior end is deeper than posterior end; umbo is prominent with two sharp raised ridges running from the posterior margins; cardinal area has chevron lines with taxodont dentition; ventral margin is irregular and variable; median area flattened, inner margin weakly crenulated, anisomyarian. It is a salt water genus common in intertidal and shelf environment (Farag et al., 1999).

***Arca ventricosa* Lamarck, 1819 (Pl. B, Fig. 4)**

**Material** Eight specimens from CO6 and CO27

**Diagnosis** Anisomyarian, taxodont dentition; left valve is folded; concentric and radiating growth lines are banded and form sinus ventral margin; longer posterior part; sinus palial line present.

#### 4.3.1.3. Genus *Anadara* Gray, 1847

***Anadara kagoshimensis* (Tokunaga, 1906) (Pl. B, Fig. 5)**

**Material** Eleven specimens from CO2

**Diagnosis** The valve is well preserved, smooth umbo and domed dorsal margin; concentric growth lines well developed; anterior to posterior length is 4mm; heterodont dentition with well developed cardinal teeth; anisomyarian; palial line absent.

**Order** Nuculida Lamarck, 1799

**Family** Nuculidae Gray, 1824

#### 4.3.1.4. Genus *Pronucula* Hedley, 1902

##### *Pronucula tenuis* Powell, 1927 (Pl. B, Fig. 6)

**Material** Eight specimens from CO2

**Diagnosis** The shell is composed of imbricated sculpturing and smooth surfaces; hetrodont dentition with cardinal teeth; equivalve with closed margins; isomiarean; concentric growth lines; ligament form triangular area with thick shell at the dorsal margin.

**Remark** The species found on muddy deposits and edge of the continental shelf (Farak et al., 1999)

**Order** Venerida Gray, 1854

**Family** Veneridae Rafinesque, 1815

#### 4.3.1.5. Genus *Pitar* Romer, 1857

##### *Pitar fulminatus* (Menke, 1828) (Pl. B, Fig. 7)

**Material** Seven specimens from CO2, CO4

**Diagnosis** The valve is well preserved; right valve outer surface is colored by varies lines; brown color marks; dentition is hetrodont; anisomyarian; sinus palial line; wider anterior to posterior area and 5mm in length.

**Order** Cardiida Ferussac, 1822

**Family** Cardiidae Lamarck, 1809

#### 4.3.1.6. Genus *Vasticardium* Iredale, 1927

##### *Vasticardium elongatum* (Bruguiere, 1789) (Pl. B, Fig. 8)

**Material** Five specimens from CO4, CO21 and CO27

**Diagnosis** The valves preserved as single and both attached right and left valves; ventral border is smaller with 15mm than anterior border 45mm length; valve is elongate from dorsal to ventral with oval shape; radial growth lines on outer surface; internal surface is smooth; well-developed cardinal teeth; thick in the umbo region; anisomyarian.

**Remark** Lives in marine and brackish environments (Zuschin and Piller 1997b)

#### 4.3.1.7. Genus *Tridacna* Bruguiere, 1797

##### *Tridacna maxima* (Rodng, 1798) (Pl. B, Fig. 9)

**Material** Seven specimens from CO1, CO2, CO4, CO7, CO20, CO21 and CO27

**Diagnosis** The species is characterized by thick shell and thickened at the dorsal margin of umbo area; right and left valves are form curved border along the anterior margin; thick comcentric growth lines form on outer surface both on the depressed and folded area; 4 depresses and 5 folded areas present; hetrodont; anterior to posterior width is 25cm and dorsal to ventral is 15cm.

##### *Tridacna crocea* Lamarck, 1819 (Pl. B, Fig. 10)

**Material** Nine specimens from CO1, CO2, CO4, CO6, CO7, CO19 and CO20

**Diagnosis** The species is characterized by thick shell and thickened at the dorsal margin of umbo area; the right and left valves are form curved border along the anterior margin; thick comcentric growth lines form on outer surface and dominant on the folded area; depressed area is relatively smooth; 5 folded and 6 depressed areas found on the outer surface; inner surface is smooth; dentition is hetrodont with cardinal teeth elongate towards the posterior margin.

**Remark** The species is a boring calm, found in Indo – Pacific reefs in large aggregation and marine environments; saltwater bivalve (Zuschin and Piller, 1997b).

**Order** Ostreidea Ferussac, 1822

**Family** Pinnidae Leach, 1819

#### 4.3.1.8. Genus *Pinna* Linnaeus, 1758

##### *Pinna rudis* Linnaeus, 1758 (Pl. B, Fig. 11)

**Material** Eight specimens from CO2

**Diagnosis** The shell is pen shaped with pointed anterior end; radial ribs present; anterior to posterior length range from 10 to 15cm; sediment fill the opening at the top part; it only occur in CO7 and it is monospecies by forming single layer.

**Family** Ostreidea Rafinesque, 1815

#### 4.3.1.9. Genus *Crassostrea* Sacco, 1897

##### *Crassoastrea* sp. (Pl. B, Fig. 12)

**Material** Five specimens from CO7 and CO27

**Diagnosis** The valve is iomyarian, smooth internal surface and external surface of the right valve is covered by concentric growth layers and projecting like structures; well-defined palial line without sinus present; dentition only in dorsal margin of the umbo and looks same size 7 in number; ventral margin is thick and smooth boundary inner surface; ponderous shell.

**Remark** The superfamily includes the marine and brackish water species which are attached and sessile animals. Under this taxon there are 80 species with widespread distribution (Zuschin and Piller, 1997b).

#### **4.3.2. Gastropoda Systematics**

There are abundant species of gastropoda in most of the coral outcrop sites with varied type of species and associations with other fossils. All of these Quaternary gastropoda have excellent preservation with their morphological features. For the classification of gastropoda a total of 24 samples are selected and species level identification is carried out to infer the past environmental conditions. The main morphological features of gastropoda which are distinct to each species are not easily recognized due to similarity in ornamentation of ribs however the coiling axis, presence or absence of siphonal canal; shape and size of aperture; number of coiling; growth line pattern and coiling direction; dentitions; presence or absence of cyphonal canal; presence or absence of spines and shape of aperture are used. Literatures used for gastropoda classification includes Bouchet and Rocroi (2005) and “Treatise on Invertebrate Paleontology” Moore (1960) applied for gastropoda classification.

**Phylum** Mollusca Linnaeus, 1758

**Class** Gastropoda Cuvier, 1795

**Order** Neogastropoda, Wenz, 1938

**Family** Muricidae, Rafinesque, 1815

##### **4.3.2.1. Genus *Chicoreus* Montfort, 1810**

***Chicoreus vergineus* (Roding, 1798) (Pl. C, Fig. 1)**

**Material** Three specimens from CO2, CO6 and CO20

**Diagnosis** The shell is large and coiled to the right; protoconch is smooth and have small whorls; aperture is oval and not fully closed due to the presence of siphonal canal; columella is well developed and show in one of the preserved samples exposed due to preservation; posterior to anterior length is 100mm with 4 teleoconch and 2 protoconch whorls; the teleoconch whorl contain 14 to 16 axial ribs; varices developed on the fourth whorl and on outer lip; three open spines present at the third teleoconch.

**Family** Nassariidae Iredale, 1916

**4.3.2.2. Genus *Nassarius* Dumeril, 1805**

***Nassarius glans* (Linnaeus, 1758) (Pl. C, Fig. 2)**

**Material** Five specimens from CO2, CO4 and CO20

**Diagnosis** The shell is characterized by 8 coils on the spire which are classified to dome and sulcus along each keeled suture margins; convex whorls; body whorl is larger with smooth inner lip which extends towards last whorl; siphonal canal present; thin outer lip.

**Order** Littorinimorpha Golikov and Starobogatov, 1975

**Family** Cypraeidae Linnaeus, 1758

**4.3.2.3. Genus *Cypraea* Linnaeus, 1758**

***Cypraea pantherina* Lightfoot, 1786 (Pl. C, Fig. 3)**

**Material** Two specimen from CO1, CO20 and CO21

**Diagnosis** It is pyriform shell characterized by rounded dorsal margin; anterior margin is pointed and narrower; posterior is bent upward; length is 7mm and width is 4mm; common name cypraea cowry and it is marine gastropoda.

**Family** Strombidae Rafinesque, 1815

**4.3.2.4. Genus *Canarium* Schumacher, 1817**

***Canarium mutabile* (Swainson, 1821) (Pl. C, Fig. 4)**

**Material** Seven specimen from CO2, CO4, CO6 and CO20

**Diagnosis** Turbinate shape with 6 – 7 whorls; suture is smooth and whorl surface bumpy; inner lip is thin and smooth; outer lip is thin and zigzag; anterior margin is sinus and siphonal canal

present; aperture is oval in outline; length of the shell range from 3 – 4mm. Verry shallow environment from intertidal to 40m depth (Janssen et al., 2011).

***Canarium erythrinum* (Dillwyn, 1817) (Pl. C, Fig. 5)**

**Material** Five specimen from CO2, CO4, CO6 and CO20

**Diagnosis** Turbinate shape with 4 to 5 whorls; suture is smooth and whorl surface bumpy; inner lip is thick; outer lip is thick, smooth and curved; anterior margin is sinus and syphonal canal present; aperture is oval in outline; length of the shell range from 3mm.

**Order** Caenogastropoda

**Family** Potamididae

**4.3.2.5. Genus *Potamides* Brongniart, 1810**

***Cerithideopsilla cingulata* (Gmelin, 1791) (Pl. C, Fig. 6)**

**Material** Five specimen from CO2, CO4, CO7 and CO27

**Diagnosis** It is soleniscus shell with variable number of whorl range from 6 to 10; aperture is basal and rounded at the last whorl; narrow and 0.5mm long siphonal canal present; apex is rounded; well defined suture lines present; length of the shell range from 4 – 6mm.

**Remark** It is brackish water snail lives in intertidal zone - mud flat (Bouchet and Rocroi, 2005).

**Family** Cerithiidae Fleming, 1822

**4.3.2.6. Genus *Rhinoclavis* Swainson, 1840**

***Rhinoclavis sordidula* (Gould, 1849) (Pl. C, Fig. 7)**

**Material** Eight specimen from CO2, CO7 and CO20

**Diagnosis** The shall is elongate with length range from 0.5 to 15mm; shall surface is composed of prominent rounded beades and there is no defined suture between consecutive whorls; aperture is small and oval to sub-rounded; concentric ribs connect the beads throughout the surface of the whorls; siphonal canal present.

**4.3.3. Echinoidea Systematics**

Echinoidea are common in two outcrops of the area, CO1, CO4, CO6 and CO27. Their preservation is medium and difficult to collect the samples due to lithification of the rocks on

CO4 but medium in CO1 which are preserved together with their spines. From these Quaternary echinoidea the good preserved ones are selected for the systematic study and a total of 14 samples are considered in the classification. "Treatise on Invertebrate Paleontology", (Moore, 1966) and recent literatures done on the Red Sea coast of Egypt, Eretria and Kenya (Clark and Rowe, 1971) applied.

**Phylum** Echinodermata Bruguiere, 1791

**Class** Echinoidea Leske, 1778

**Order** Cidaroida Claus, 1880

**Family** Cidaridae Gray, 1825

**4.3.3.1. Genus *Eucidaris* Pomel, 1883**

***Eucidaris metularia* (Lamarck, 1816) (Pl. D, Fig. 1)**

**Material** Two specimens from CO1, CO4 and CO6

**Diagnosis** A regular echinoidea with large primary tubercles in the interambulacra on oral view; sinuate ambulacra; ambulacral pores are fine and arranged in line; diameter of the test is 4mm; aboral view is smooth and contain periproct; interambulacral plates contain 6 to 8 beads; peristome width is 3mm in diameter; pair pores plate on outer ambulacral margin.

**Remark** It is recent echinoidea distributed in China, Japan, Philippines, tropical Indo-Pacific and Red Sea to Hawaii. Ecologically the species prefers inshore tidal environments and unexposed coral reach areas with 0 – 125m depth range (Tortonese, 1980; Samyn, 2003 and Sloan et al., 1979).

**4.3.3.2. Genus *Phyllacanthus* Brandit, 1835**

***Phyllacanthus imperialis* (Lamarck, 1816) (Pl. D, Fig. 2)**

**Material** Two specimens from CO1 and CO4

**Diagnosis** Only the spine is preserved; have longitudinal ribs with large and platy appearance; length of spine range from 4 - 5mm; proximal end of the spine is articulated with primary tubercles; rounded collar and neck have 0.2mm width; no thorns present along the shaft.

**Remark** Recent species described from type locality in Red Sea (Samyn, 2003)

**Order** Camarodonta Jackson, 1912

**Family** Echinometridae Gray, 1855

**4.3.3.3. Genus *Echinometra* Gray, 1825**

***Echinometra mathaei* (Blainville, 1825) (Pl. D, Fig. 3)**

**Material** Three species from CO1, CO4 and CO6

**Diagnosis** The test is oval in outline, denuded and partly covered by sediment and lithophaga; apical system is not visible; test width is 2.5mm in diameter; apical disc is 0.25mm in diameter; one large two rows of tubercle present in each ambulacral and interambulacral plates.

**Remark** Distributed in North Africa, Kenya, Mediterranean, Red Sea and Indo-Pacific with depth 0 – 45meters (Samyn and Burghe, 2000).

**Order** Clypeasteroidea Agassiz, 1872

**Family** Laganidae Link, 1807

**4.3.3.4. Genus *Jacksonaster* Lambert and Thiery, 1914**

***Jacksonaster depressum* (L. Agassiz, 1841) (Pl. D, Fig. 4)**

**Material** Three specimen from CO4 and CO27

**Diagnosis** Well preserved test; pentagonal to sub-ovate in outline; thick margin; petals well developed; elongate periproct at the oral view close to posterior margin; straight and simple food grooves present on aboral veiw; 3 goniopors present around the peristome; 5 ambulacral plates with longer petals; surface is smooth with normal pores.

**Remark** Miocene to Recent of Indo – Pacific

**Family** Clypeasteridae L. Agassiz, 1835

**4.3.3.5. Genus *Clypeaster* Lamarck, 1801**

***Clypeaster reticulatus* (Linnaeus, 1758) (Pl. D, Fig. 5)**

**Material** One specimen from CO4

**Diagnosis** Test is oval; well defined five goniopores present on the apical system; aboral view is domed at the center with ambulacral plates; interambulacral plate divided by pentagonal sub-plates.

**Remark** Benthic and deposit feeder and irregular echinoids which are geographically distributed around tropical Indo-West Pacific Ocean; occur with depth range 0 – 125m (Clark and Rowe, 1971)

***Clypeaster humilis* (Leske, 1758) (Pl. D, Fig. 6)**

**Material** Two specimens from CO4

**Diagnosis** Test is flat at the oral view; closed frontal ambulacra and small petals; food grooves present; periproct is close to the posterior margin and rounded in shape; center of oral surface is depressed.

***Clypeaster sp.* (Pl. D, Fig. 7)**

**Material** Two specimens from CO4

**Diagnosis** Test is oval; differs from *Clypeaster reticulatus* by having peg like internal pillars around the interambulacral plates; domed shape central aboral surface.

**Order** Spatangoida L. Agassiz, 1840

**Family** Maretidae Lambert, 1905

**4.3.3.6. Genus *Maretia* Gray, 1855**

***Maretia sp.* (Pl. D, Fig. 8)**

**Material** One specimen from CO4

**Diagnosis** Irregular echinoid with bilateral symmetry; elongated apical disc with ocular plate 2 and 5 in contact with anterior genital plate; periproct is open towards the anterior margin with oval to elongated shape; peristome is on posterior margin; spine attachment areas gives grainy surface for the test.

#### **4.4. Systematics of Quaternary Microfossils of Dallol**

##### **4.4.1. Systematics of Ostracoda**

Extractions of microfossils from the collected sediments were carried out as per the methodology set in the chapter two. The systematic identification and recognition of ostracoda to species level is done by using reflected light microscopes LEICA EZ4 with 35x magnification. Classification is following “Treatise on Invertebrate Paleontology”, Moore (1961); Hartmann and Puri (1974); Marthens and Horne (2009); Munef et al. (2012).

**Phylum** Arthropoda Margulis, 1998

**Subphylum** Crustacea Brunnich, 1772

**Superclass** Oligostraca Zrzavy, 1998

**Class** Ostracoda Latreille, 1802

**Subclass** Podocopa Sars, 1866

**Order** Podocopida Sars, 1866

**Suborder** Cytherocopina Baird, 1850

**Superfamily** Cytheracea Baird, 1850

**Family** Cytherideidea Sars, 1925

##### **4.4.1.1. Genus *Cyprideis* Jones, 1857**

***Cypridis torosa* (Jones, 1850) (Pl. E1, Fig. 1 - 3)**

2002 *Cypridis torosa* (Jones).— Wouters: pp. 131-137, pl. 137, fig. 1a - 4d

2004 *Cypridis torosa* (Jones).— Mohammed: pp. 73, pl. 2, fig. 1 and 2

2012 *Cypridis torosa* (Jones).— Munef et al.: pp. 155, pl. 2, fig. 22

**Material** Thirty specimens from CO4, CO27 and CO20

**Diagnosis** This species occur in many forms which have pits, tubercles and sometimes smooth surfaces; carapace occur in three shapes as reniform, sub-trapezoid and trapezoid; dorsal view carapace is sub-elliptical with rounded AM and nearly strait to slightly sinus PM; pitted carapace contain many radial pore canals; crenulated tooth and socket present on DM of the carapace; antero-ventral and mid dorsal muscular scars present.

**Remark** It occurs in various salinity ranges from freshwater to hyper-saline and tolerates water temperature, oxygen and substrate conditions. According to Deckker and Lord (2017) the species *C. torosa* is model organism which tolerates salinity range from 0 to 150‰.

***Cyprideis longespina* (Purper, 1979) (Pl. E1, Fig. 4)**

1979 *Cyprideis longespina*.—Purper: pp. 230-231, pl. 3, fig. 10-21

2010 *Cyprideis longespina*.—Wesseligh and Ramos: pp. 308, fig. 18, pl. 5a and 5b

**Material** Eight specimens from CO6 and CO27

**Diagnosis** Larger and elongated carapace; extended flange present at PM in lateral view; only one spine present around PM; PM is more inflated than the AM; surface is slightly ornamented; dorsomedian surface is slightly sinus.

***Cyprideis australensis* Hartmann, 1978 (Pl. E1, Fig. 5)**

**Material** 16 specimens from CO20 and CO27

**Diagnosis** The carapace is small; carapace shape is sub-triangular; strongly tumid DM; antero-dorsal and postero-dorsal margin form curved shape; broadly rounded AM; PM is slightly arched.

***Cyprideis* sp. (Pl. E1, Fig. 6)**

**Material** Five specimens from CO6 and CO27

**Diagnosis** Carapace elongate to ovate in lateral view; DM is slightly arched; VM concave; rounded PM and AM however the PM is oblique; no marginal pore canal; surface is macro punctate.

**Suborder** Bairdicopina Grundel, 1967

**Superfamily** Bairdioidea Sars, 1865

**Family** Bairdiidae Sars, 1865

**4.4.1.2. Genus *Neonesidea* Maddocks, 1969**

***Neonesidea schulzi* Hartman, 1964 (Pl. E1, Fig. 7)**

1970 *Neonesidea schulzi* Hartman.—Bate: pp. 246, pl. 1, fig. 1(i)

**Material** Fifteen carapaces from CO4MA and CO27

**Description** Carapace is mediumly calcified; found on 0.372mm sieve size; oval in lateral view; surface with lower degree of reticulation; seven to eight dorso-median muscular scar present; PM zone is broader; AM is curved and relatively small; dorsal side is nearly straight with simple adduct hinge; and inner lamella and radial pore canal present.

**Remark** The species occur in diverse habitats with salinity range 5 - 41‰ and depth 25 – 34 meters (Bate, 1970).

***Neonesidea villosa* Brady, 1880(Pl. E1, Fig. 8)**

1880 *Bairdia villosa* Brady.— pp. 50, pl.3, fig. 3a and 3b

1964 *Bairdia villosa* Brady.— Benson and Maddocks: pp. 14, pl. 1, fig. 3 and 6

**Material** 12 specimens from CO4 and CO27

**Diagnosis** The valve is from sieve size 0.25mm; it is more elongate and oval shape; the surface is smooth and thick walled; margins are thick; normal pores absent; PM is broader than AM and less caudate posterior end; duplicature wide and vestibule present; muscular scar near center of carapace.

**Family** Xestoleberididae Sars, 1928

#### 4.4.1.3. Genus *Xestoleberis* Sars, 1866

***Xestoleberis rotunda* Hartman, 1964 (Pl. E2, Fig. 1)**

1970 *Xestoleberis rotunda* Hartman.—Hartman and Bate: pp. 246, pl. 1, fig. 1c

2004 *Xestoleberis rotunda* Hartman.—Abd El-Wahab and Helal: pp. 14, pl. 1, fig. 18

**Material** Eighteen specimens from CO4 and CO27

**Description** Carapace is oval to tumid; DM is nearly straight; VM is curved with thick surface; AM is slightly curved and PM is slightly curved; surface of carapace is pitted by normal pores; mid-dorsal area is curved; muscular scar placed along the median surface.

**Remark** The species occurs from 5 to 34 meters depth and tolerate salinity 28 - 41‰. Geographically it founds in Red Sea, Persian Gulf and Indian Ocean (Bate, 1970 and Hartman, 1964).

***Xestoleberis rhomboidea* Hartman, 1964 (Pl. E2, Fig. 2 - 3)**

1964 *Xestoleberis rhomboidea* Hartman. \_\_ pp.71-73, pl. 12

2012 *Xestoleberis rhomboidea* Hartman. \_\_ Mohammed and Keyser: pp.29, Fig. 13, Pl. 209-210

**Material** Twenty three carapace from CO4, CO6 and CO27

**Description** Shape of carapace is semi-oval; the PM width greater than AM; anterio-dorsal margin is sloppy; VM form rounded curvature; surface dentate by pores; relatively larger size which range from 0.375 to 0.25mm sieve size.

**Remark** Shallow marine ostracod (Hartman, 1964)

***Xestoleberis depressa* Sars, 1866 (Pl. E2, Fig. 4)**

**Material** Twenty carapaces from CO4, CO27 and CO20

**Diagnosis** Carapace is tumid narrow in front view; VM flattened behind; unequal valves with smooth surface; PM distinctly depressed; continues arch form at DM and pass through both anterior and posterior margins; slightly sinus VM; AM tapered and deflexed; PM broad and ovate in outline.

**Superfamily** Cytheracea Baird, 1850

**Family** Leptocytheridae Hanai, 1957

**4.4.1.4. Genus *Leptocythere* Sars, 1928**

***Leptocythere castanea* (Sars, 1866) (Pl. E2, Fig. 5)**

**Material** Thirty specimens from CO20 and CO27

**Diagnosis** The valve is oval with depressed VM, surface is punctate by normal pores; dorsal hinge area is crenulated; snap pit is absent at the VM but sinus; wide vestibulum and double furcate PM; width of PM is greater than the AM and strongly convex.

**Remark** The species is brackish water species found in Eurithermal (0 - 22°C) and Euhaline (2 - 32‰) environments in restricted areas (Bate, 1970 and Sars, 1866).

**Family** Limnocytheridae Klie, 1938

#### 4.4.1.5. Genus *Limnocythere* Brady, 1868

##### *Limnocythere* sp. (Pl. E2, Fig. 6 - 7)

**Material** Twelve specimens from CO4, CO19 and CO27

**Diagnosis** Lateral view of the carapace is sub-reniform in shape; DM is straight and VM is slightly curved; centro-ventral region have higher concavity; AM is broadly rounded than the PM; surface of the carapace is pitted; flattened margin contains radial pore canals; moderately calcified carapace; muscular scar is not visible.

**Superfamily** Cytheroidea (Baired, 1850)

**Family** Cytheridae Baired, 1850

#### 4.4.1.6. Genus *Corallucythere* Hartman, 1974

##### *Corallucythere* cf. *dianiensis* Jellinek, 1993 (Pl. E2, Fig. 8 – 9)

1993 *Corallucythere dianiensis* Jellinek.— pp. 111, pl. 8, fig. 175

2012 *Corallucythere* cf. *dianiensis* Jellinek.— Munef et al.: pp. 155, pl. 1, fig. 18

**Material** Nineteen carapaces from CO27 and CO20

**Diagnosis** The carapace is strongly ornamented and moderately calcified; sub-triangular to ovate shape; AM are curved and PM is slightly angular; antero-dorsal margin is slightly straight; muscular scar close to postero-ventral margin and five are visible; pore occurrence dominate along the anterior part.

**Family** Cytheridae Bard, 1850

**Subfamily** Loxoconchinae Sars, 1825

#### 4.4.1.7. Genus *Loxoconcha* Sars, 1866

##### *Loxoconcha carinata* (Pl. E2, Fig. 10)

1976 *Loxoconchia cerenata* Bonaduce et al.: pp.394, pl. 11, fig.6-9

2012 *Loxoconcha carinata* Munef et al.: pp162, pl. 5 fig. 80

**Material** Seventeen carapaces from CO4MA and CO27

**Diagnosis** The valve is found on the 0.25mm sieve size characterized by sub- rectangular to oval shape; surface is ornamented by reticulations; Medium carapace calcification; VM is straight and DM is curved; PM is arched and broaded than AM; vestibule weakly developed; three alligned muscular scars present.

***Loxoconcha* sp. (Pl. E2, Fig. 11)**

**Material** Eleven carapaces from CO4MA and CO27

**Diagnosis** The valve is found on the 0.375mm sieve size characterized by sub- rectangular to oval shape; surface is ornamented by reticulations; carapace is larger in size than *Loxoconcha carinata*; VM is straight and DM is curved; PM is arched and broaded than AM; vestibule weakly developed; muscular scar is not visible.

**Superfamily** Cypridoidea Baird, 1845

**Family** Cyprididae Baird, 1845

**4.4.1.8. Genus *Hemicypris* Sars, 1903**

***Hemicypris* sp. 1 (Pl. E2, Fig. 12)**

**Material** Eleven carapaces from CO4LA and CO20

**Diagnosis** Strongly calcified unequal carapace; sub-rectangular in outline with AM rounded and broad and PM truncated; postereo-dorsal area is slopped; postereo ventral surface is concave; VM is slightly straight; and maximum curvature is along the median of the carapace.

***Hemicypris* sp. 2 (Pl. E2, Fig. 13)**

**Material** Ten carapaces from CO4LA and CO20

**Diagnosis** Strongly calcified unequal carapace; sub-rectangular in outline with AM slightly curved to straight and PM nearly rounded; antereo-dorsal area is slopped and flattened; postereo ventral surface is convex; collected from 0.375mm sieve size and anterior radial pore canal present.

***Hemicypris* sp. 3 (Pl. E2, Fig. 14)**

**Material** Fourteen carapaces from CO4LA and CO20

**Diagnosis** Strongly calcified unequal carapace; juvenile and small in size; collected from 0.25mm sieve; sub-rectangular in outline with AM slightly to curved and PM rounded; antero-dorsal spine present; postereo ventral surface is convex.

**Family** Eucandonidae Baird, 1845

**4.4.1.9. Genus *Pontoparta* Vavra, 1901**

***Pontoparta salina* Harding, 1954 (Pl. E2, Fig.15)**

1954 *Pontoparta salina* Harding.—pp. 63, fig. 1-13

2012 *Pontoparta salina* Harding.—Mohammed and Keyser: pp. 5, fig. 2, pl. 11-14

**Material** Two carapaces from CO4LA and CO20

**Diagnosis** Medium thick carapace; AM curve and PM broad curve; carapace surface is smooth; well-developed vestibule and inner lamella thickly calcified; curved to straight DM and VM is slightly sinus. Brackish water species occur in Lybia and Egypt (Mohammed and Keyser, 2012).

***Pontoparta* sp. (Pl. E2, Fig. 16)**

**Material** Twenty three carapaces from CO4 and CO6

**Diagnosis** Oval in outline; medium thick carapace; AM and PM curve; carapace surface is smooth to slightly reticulate; well-developed inner lamella; curved to straight DM and VM is slightly sinus.

**Order** Platycopeida (Sars, 1866)

**Suborder** Platycopeina (Sylvester-Bradley, 1961)

**Superfamily** Cytherelloidea (Alexander, 1929)

**Family** Cytherellidae (Sars, 1866)

**4.4.1.10. Genus *Cytherella* (Jones, 1849)**

***Cytherella brettegi* Mohammed and Keyser, 2012 (Pl. E3, Fig. 1)**

2012 *Cytherella brettegi*.— Mohammed and Keyser: pp. 5, fig. 2, pl. 4-6

**Material** Thirteen specimens from CO4 and CO20

**Diagnosis** The carapace is elongated and medium calcification; posterior end is rounded; small pore ornamented surface; half of the posterior-dorsal margin is angular; ventral to mid carapace is broadly rounded; muscular scar are in two rows of small scars at the dorso-median position; half of the PM of the carapace is more inflated than AM.

***Cytherella sp.1* (Pl. E3, Fig. 2)**

**Material** Ten specimens from CO4, CO20 and CO27

**Diagnosis** The carapace is elongated and medium thickness; Straight PM and AM; asymmetrically curved AM; median convex shape; dorsal – ventral length is shorter than the anterior – posterior length; muscular scar close to middorsal and five straightly aligned and two scattered scars present.

***Cytherella sp.2* (Pl. E3, Fig. 3)**

**Material** Twenty five carapaces from CO4MA and CO27

**Diagnosis** The carapace is sub-ovate to sub-rectangular and heavily calcified; simple adont hinge; eight to ten posterior-dorsal muscular scars which are aligned in pair; inner lamella thin and anterior normal pore canals developed at AM; denticles present at median surface; and the species is marine and benthic.

**4.4.1.11. Genus *Keijcyoidea* Malz, 1981**

***Keijcyoidea dissimilis* Malz Abd Jellinek, 1989 (Pl. E3, Fig. 4)**

1998 *Cytherelloidea praecipua* (Van Den Bold).— Hussain: pp. 2-3, pl. 1, fig. 2-3

2002 *Keijcyoidea praecipua* (Van Den Bold).— Sridhar et al.: pp. 17-39, pl. 1, fig. 3

**Material** Eighteen specimens from CO20 and CO27

**Diagnosis** Open and closed carapace is well preserved; sieve size 0.25; carapace is ornamented; elongated shape with rounded PM and AM; in lateral view anterior end is wider than posterior end; dorso-ventral width is smaller than anterior-posterior width.

**Subclass** Podocopa Sars, 1866

**Order** Podocopida Sars, 1866

**Suborder** Baidiocopina Grundel, 1967

**Family** Bythocyprididae Maddocks, 1961

**4.4.1.12. Genus** *Bythocypris* Brady, 1880

***Bythocypris eskeri* Bassiouni and Luger, 1990 (Pl. E3, Fig. 5)**

1990 *Bythocypris eskeri* Bassiouni and Luger.— pp. 781, pl. 2, fig. 2-3

2005 *Bythocypris eskeri* Bassiouni and Luger.— Shahn: pp. 756, pl. 1, fig. 18

**Material** Sixteen specimens from CO20 and CO4

**Diagnosis** The carapace shape is oval and depresses at the VM and curved at the DM; the inner surface is smooth with well-developed duplicature; AM is slightly curved and smaller in size than the PM.

**Remark** The species is recorded in Egypt and Tunisia (Shahn, 2005).

**Suborder** Cytherocopina Baird, 1850

**Superfamily** Cytheroidea Baird, 1850

**Family** Bythocytheridae Sars, 1866

**4.4.1.13. Genus** *Bythocythere* Sars, 1866

***Bythocythere minima* Bounaduce, Ciampo and Masoli, 1976 (Pl. E3, Fig. 6)**

2009 *Bythocythere minima* Bounaduce, Ciampo and Masoli.— Morssi: pp. 8/156, pl.,1 fig.18

**Material** Twenty eight carapace from CO4 and CO27

**Diagnosis** Carapace is ovate; anterior end caudata and less symmetrical dorsal margin; AM is nearly rounded; PM is curved; carapace surface is smooth; thickly calcified carapace; valve overlap absent; median surface domed; straight VM and domed DM.

#### 4.4.1.14. Foraminifera Systematics

The Foraminifera of Dallol coral outcrops are dominantly benthic foraminifera and classification is done at species level. For the classification works of Cushman (1928); Gupta (1997) and Boersma (1998) are applied.

**Phylum** Foraminifera Eichwald, 1830

**Class** Globothalamea Pawlowiski, Holzmann and Tyszka, 2013

**Subclass** Textulariia Mikhalevich, 1980

**Order** Lituoida Saidova, 1981

**Superfamily** Trochamminoidea Schwager, 1877

**Family** Trochamminidae Schwager, 1877

##### 4.4.1.14.1. Genus *Trochammina* Parker and Jones, 1859

*Trochammina* sp. (Pl. F, Fig. 1)

**Material** Eleven specimens from CO20

**Diagnosis** Test is trochospiral growth with globular to ovate chambers; basal aperture; extra-umbilical to umbilical shape of aperture; numbers of chambers range from 6 to 8. The genus *Trochammina* is the dominant species in the brackish zone of continental shelf (Gupta, 1997; Boersma, 1998).

**Superfamily** Lituoloidea Parker, 1982

**Family** Lituolidae Blainville, 1827

##### 4.4.1.14.2. Genus *Ammobaculites* Cushman, 1910

*Ammobaculites* sp. (Pl. F, Fig. 2)

**Material** Seven specimens from CO6, CO20 and CO27

**Diagnosis** Early chambers are coiled involutely and later form inverted V-shaped chambers; linear series chambers present after the last whorl; simple aperture at the center of the chambers with rounded shape.

#### 4.4.1.14.3. Genus *Ammomarginulina* Wiesner, 1931

##### *Ammomarginulina* sp. (Pl. F, Fig. 3)

**Material** Eight specimens from CO4 and CO6

**Diagnosis** Planispiral shape of test; test has narrow linear terminal aperture; planispiral evolute coiling; normal pore develop on the surface of the test; thick calcified test; three coiled surface with number of chambers range from 6 on the last whorl to 3 on the first whorl.

**Class** Tubothalamea

**Order** Miliolida Delagn and Herouard, 1896

**Suborder** Milliolina Delagn and Herouard, 1896

**SuperFamily** Milioloidea Ehrenberg, 1839

**Family** Hauerinidae Schwagner, 1876

#### 4.4.1.14.4. Genus *Quinqueloculina* d'Orbigny, 1826

##### *Quinqueloculina disparillis* d'Orbigny, 1826 (Pl. F, Fig. 4)

**Material** Seven specimens from CO4MA and CO27

**Diagnosis** Terminal aperture; tubular elongated chambers; wall is imperforate; aperture is commonly with tooth plate; three chambers are visible in one side of the test and four in the opposite side; wall is smooth with distinct sutures. The genus *Quinqueloculina* dominates in the inner shelf environment (Gupta, 1997; Boersma, 1998).

##### *Quinqueloculina oblonga* Ehrenberg, 1840 (Pl. F, Fig. 5)

**Material** Twelve specimens from CO4 and CO6

**Diagnosis** Test is planispiral to sub-tubular; number of chambers range from 4 to 6; simple terminal or umbilical aperture; central chamber is small and depresses; size is small and identified from 0.123 and 0.25 sieve sizes.

##### *Quinqueloculina lamarckiana* d'Orbigny, 1839 (Pl. F, Fig. 6)

**Material** Nine specimens from CO4 and CO6

**Diagnosis** Test is planispiral to sub-tubular; whorl with 4 to 6 chambers arranged in defined order; side view show three chamber arrangements; simple terminal or umbilical aperture at the last chamber; central chamber is small and depresses.

***Quinqueloculina sagamiensis* Asano, 1936 (Pl. F, Fig. 7)**

**Material** Six specimens from CO4 and CO6

**Diagnosis** Test is planispiral to sub-tubular; whorl with 4 to 6 chambers; simple terminal or umbilical aperture; central chamber is small and domed with smooth surface.

**Family** Elphidiidae Galloway, 1933

**Subfamily** Elphidiinae Galloway, 1933

**4.4.1.14.5. Genus *Elphidium* de Montfort, 1808**

***Elphidium crispum* (Linne, 1758) (Pl. F, Fig. 8)**

**Material** Thirteen specimens from CO4, CO6, CO20 and CO27

**Diagnosis** Multilocular test with planispiral involute coiling; calcareous wall; retral processes with canal openings between aperture; involute, edium size umbulacral region, chambers 20 to 26 long and narrow, wall is finely perforate around the aperture and the other smooth; 0.375mm sieve size.

**4.4.1.14.6. Genus *Amphistigina* d'Orbigny, 1826**

***Amphistigina lessonii* d'Orbigny in Guerin-Meneville, 1832 (Pl. F, Fig. 9)**

**Material** More than 50 specimens from CO6, CO20 and CO27

**Diagnosis** Rounded test; pores arranged in involute pattern on the surface of the test; test divide to chambers range from 4 to 6; simple aperture present on last chamber.

**4.4.1.14.7. Genus *Baculogypsina* Saccor, 1893**

***Baculogypsina* sp. (Pl. F, Fig. 10)**

**Material** Five specimens from CO20 and CO4

**Diagnosis** Rounded test with lines arranged in involute pattern; test is divided from 4 to 7 chambers; simple aperture on last chamber; pitted surface; radial connecting roads reticulate the appearance of the test.

**Family Globorotaliidae Cushman, 1927**

**4.4.1.14.8. Genus *Globorotalia* Cushman, 1927**

***Globorotalia menardii* (d'Orbigny in Parker et al., 1865) (Pl. F, Fig. 11)**

**Material** Eleven specimens from CO4 and CO6

**Diagnosis** Rounded shape of test; number of chambers range from 6 to 7; smooth peripheral keels present; dextral involute coiling; aperture present on the central chamber.

**Order** Rotaliida Ehrenberg, 1839

**Family** Ammoniidae Saidova, 1981

**4.4.1.14.9. Genus *Ammonia* Brunnich, 1772**

***Ammonia tepida* Cushman, 1926 (Pl. F, Fig. 12)**

**Material** Ten specimens from CO6 and CO27

**Diagnosis** Benthic foram with biconvex rounded test; last whorl is larger; trochospiral coiled two whorl; 7 – 9 chambers in the last whorl; umbilical side sutures are depressed and umbilicus open; aperture on the last chamber has slit; salinity tolerate 0-35‰ and temperature 15 – 20 °C (Cushman, 1950).

***Ammonia Sp.* (Pl. F, Fig. 13)**

**Material** Nine specimens from CO6 and CO27

**Diagnosis** Benthic foram with biconvex rounded test; trochospiral coiled two whorl; chambers range from 4 to 6; umbilical side sutures are not depressed; aperture on the last chamber has slit.

**4.4.1.15. Micro-Mollusk and Charophycea**

The micro-mollusks are found on 0.5mm sieve size and characterized by well-developed morphological features. The microbivalvia have smooth surface with concentric growth lines and taxodont dentition. The microgastropoda are diverse. These species require detail taxonomic study and together with their environmental implication (Pl. G, Fig. 1 – 4).

## CHAPTER FIVE

### 5. PALEOECOLOGY AND PALEOENVIRONMENT

#### 5.1. Paleocology of Corals

##### 5.1.1. Background

Paleocology deals with past distribution and abundance of organisms based on their preserved parts in the fossil record. These patterns recorded on the fossil over time used as inferences for identification and interpretation of the past environmental conditions as well as interaction between the environment and the organism. The processes occurred during the past reflected by the index fossils or proxies that once lived within that environment.

According to Hatcher (1997) reefs occur in many forms and contain diverse community of marine organisms such as mollusca, scleractinia and crustose coralline algae which record the environmental conditions and reflected by their response on the species abundance and diversity. Paleocology of reef is important for understanding of the modern ecological crisis by the current environmental degradation and it is also possible to identify the degree of environmental impact on the reef ecosystem.

Coral growth is controlled by five main factors which are local factors, regional factors, latitudinal range limit, biotic factor and autecology. The local factors include wave energy of the area, water quality of the basin, turbidity, salinity and light intensity of the area. The regional factors are sea level fluctuation, sea surface temperature, sea water chemistry and global atmospheric CO<sub>2</sub> level (Kiessling, 2009).

According to Kiessling (2004; 2012) living corals are confined to the latitudinal limit of 30°N and 30°S. This latitudinal limit determines the local factors and geographic distribution of the different coral species. Microfossils are used as indicator of past environment and environmental changes. Studies done by various authors indicate ostracoda and foraminifera are good environmental proxies (Balemwal and Russo, 2004; Gupta and Thomas, 2003).

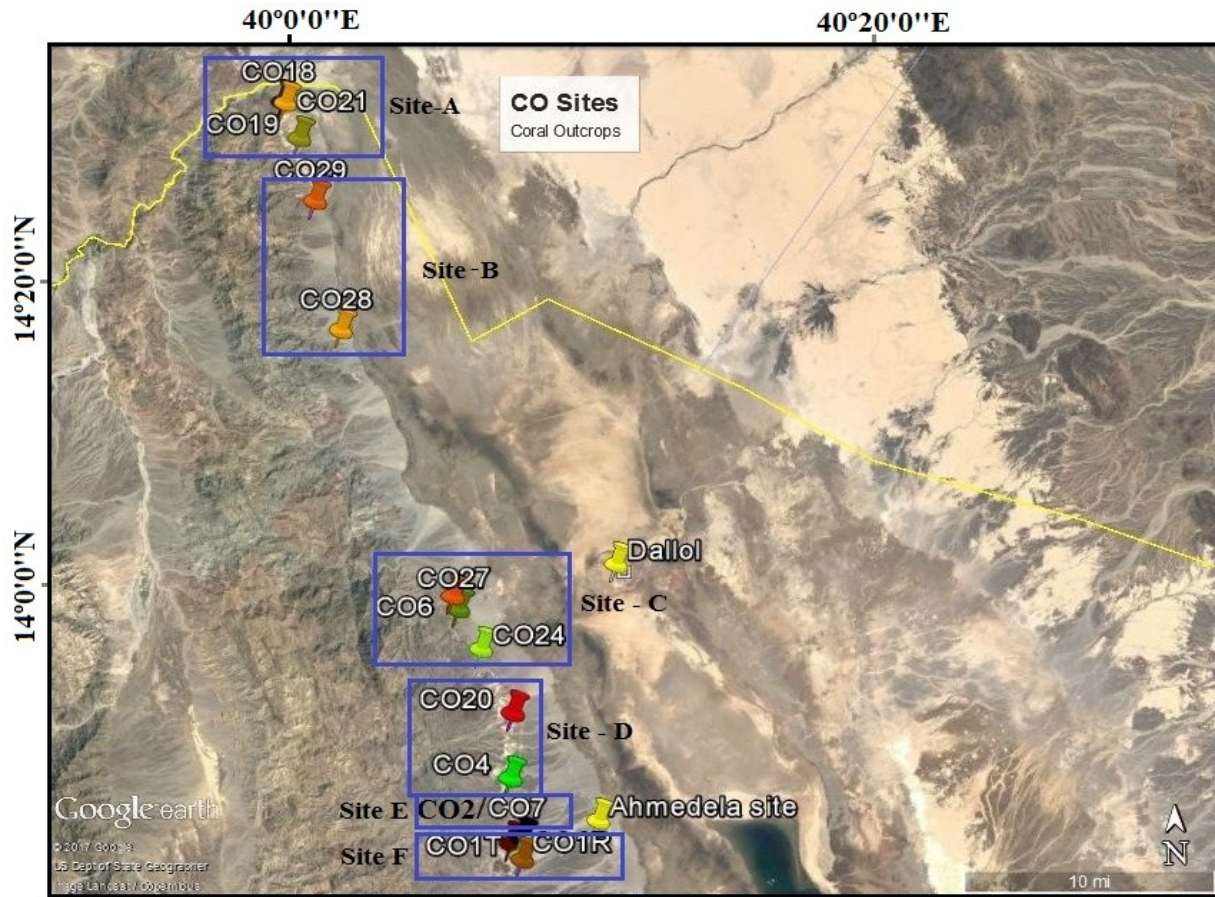


Fig.5.1. Geographical distribution of grouped coral outcrop sites

### 5.1.2. Species Richness

In the study area there are numerous types of coral species associated invertebrate taxa. The total of 181 numbers of individuals examined and 60 species are recognized. CO1 both road cuts and reef face (fore reef), CO2, CO6, CO27, CO20 and CO24 comprises the large number of genera range from 8 to 14 and CO18, CO19 and CO21 shows the minimum number of genera range from 1 to 3. Taxonomic composition (Fig. 5.2) shows variation in abundance of individual species between the coral outcrop sites and similarity within one outcrop transects.

).

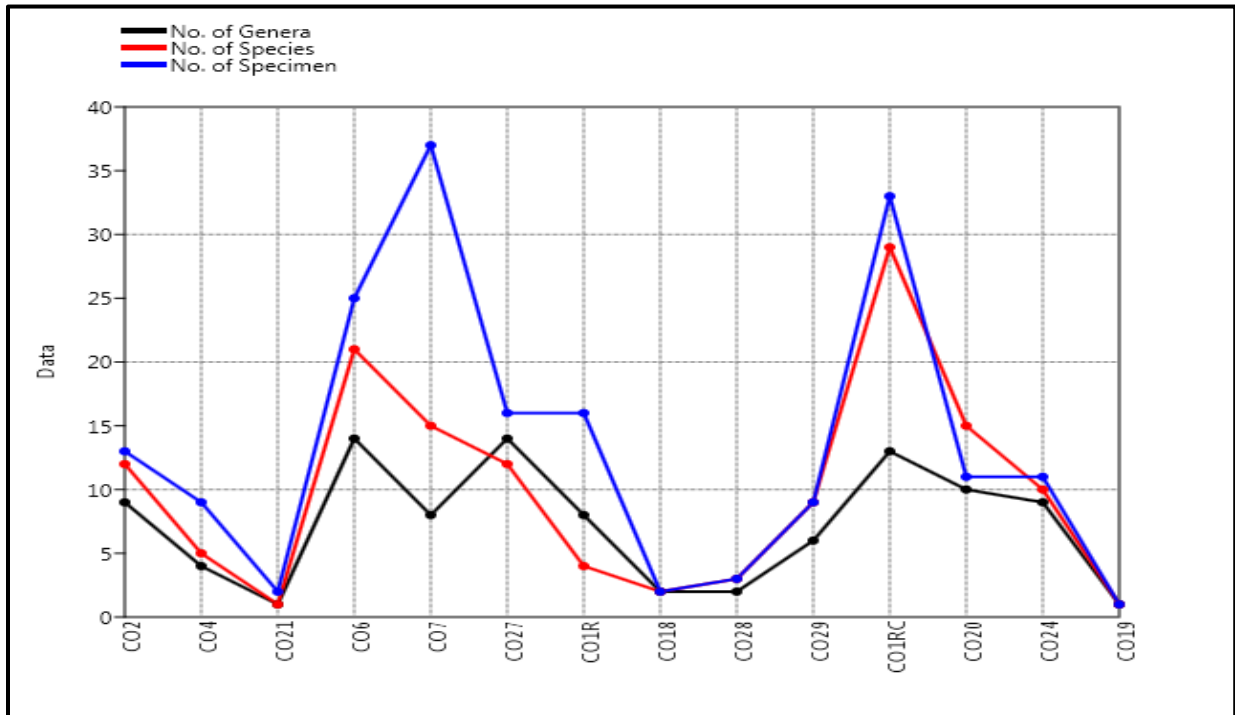


Fig.5.2. Variation of specimen, genera and species numbers with coral outcrops

From all coral outcrop sites a total 60 species are identified. Based on the presence absence data analysis rare species, moderately abundant species and abundant species percentage are identified. The result indicates 36% of the total species are rare species which exist only in single site; 40% of species are moderately abundant and 23% of the total species are abundant.



Fig.5.3. CO1R transect one and two (a) - (b)

CO1RF exposure is more than 1Km and four transects are done with transect one length 24m, transect two 18m length, transect three 30m and transect four 18m (Fig.5.4). The abundance of coral species is variable from one transect to another. Transect one comprises varies species of

corals dominated by Massive and branching *Porite* 43%; *Favite chinensis* 13%; *Caulastrea furcata*, *Echinopora sp.* and *Hydnopora microconos* each have 8% and *Echinopora hirsutissima*, *Goniastrea stelligera*, *Goniastrea pectinata*, and *Platygyra lamellina* each have 4% of the total species.

Transect two have relatively similar proportion of species distribution along all transects except repeatedly presence of the Massive *Porite*. It constitutes 47% of the total identified species of the site; *Dipsastrea favus*, *Echinopora hirsutissima* and *Lobophylia hemprichii* 42%; *Caulastrea tumida*, *Leptastrea purpurea*, *Platygyra lamellina* and *Echinopora sp.* have 11% abundance.

The third transect coral species are dominated by Massive *Porite* 24%; *Caulastrea furcata* 13.5%; Branching *Porite*, *Goniastrea pectinata* and *Caulastrea tumida* each have 10%; *Dipsastrea laxa* and *Platygyra lamellina* each contains 8%; *Platygyra daedalea* and *Echinopora mammiformis* contains each 5%; and *Astrea curta*, *Echinopora sp.*, *Goniastrea retiformis*, *Pocilopora grandis* and *Porite lobata* have each 2.7% from the total species.

The fourth transect coral species dominated by Massive *Porite* 28.5%; Branching *Porite* 14%; *Gonistrea favulus* 14%; *Caulastrea tumida*, *Dipsastrea helianthoids*, *Dipsastrea maritime*, *Pocilopra grandis*, *Platygyra daedalea* and *Porite lobata* have each 7% of the total species. Therefore, the species abundance vary in the four transects but dominance of Massive *Porite* is observed in all of the four transects. The second dominant species is *Caulastrea furcata* followed by *Caulastea tumida*.

CO7 exposure is gentle slope with flat topped topography and four transects are done from bottom to top. The transect length is 27m for transect one, 18m for transect two, 18m for transect three and 16m for transect four (Fig.5.6). The abundance of species decreases from the transect one to transect four however the dominant species is the same through out the exposure. The first transect is dominated by *Echinopora hirsutissima* and *Echinopora sp.*, each have 21% of the total species. Massive *Porite* and *Goniastrea favulus* each have 10% abundance; *Coelastrea aspera*, *Pseudosiderastrea tayami*, *Platygyra daedalea*, *Acropora hayacinthus*, *Leptorya phrygia*, *Goniastrea pectinata* and *Favite abdita* contribute each 5% of the total species. Transect two dominated by *Echinopora sp.*, with 43%; *Goniastrea retiformis* 28.5% and *Echinopora hirsutissima* and *Leptastrea purpurea* each 14% of the total identified species of the site.

Transect three is dominated by *Echinopora sp.*, and Massive *Porite* with 30% of the total species followed by *Goniastrea pectinata* with 20%; *Echinopora hirsutissima* and *Echinopora gemmecea* each 10%. On the fourth transect Massive *Porite* contribute 62% of the identified species followed by each 12% of *Goniastrea pectinata*, *Paramontastrea persi* and *Coelastrea aspira*.

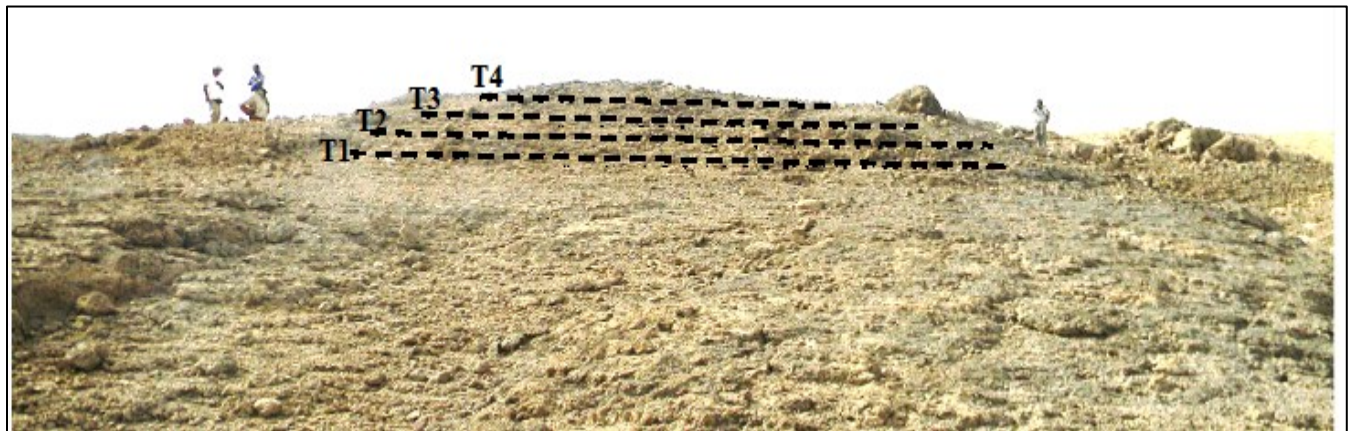


Fig.5.6. CO7 transects from bottom (transect one) to top (transect four) of the exposure

CO27 exposure is occupying gentle slope terrain surrounded by alluvial fan deposits and basaltic debris. The corals of this outcrop are collected along two transects with 20m length of the first transect and 19m length of the second transect (Fig. 5.7). Transect one is dominated by Massive *Porite* with 36% cover followed by 18% *Platygyra lamellina*; and *Hydnophora microconos*, *Stylopora pistillata*, *Leptorya phrygia*, *Echinopora sp.*, and *Pachyseris speciosa* each 9% of the total species. Transect two dominated by *Goniastrea pectinata* and Massive *Porite* with 20% followed by *Stylopora pistillata* 13% and *Echinopora sp.*, Branching *Porite*, *Platygyra lamellina*, *Favites pentagona*, *Astrea curta*, *Seriatopora hystrix* each contains 6%.

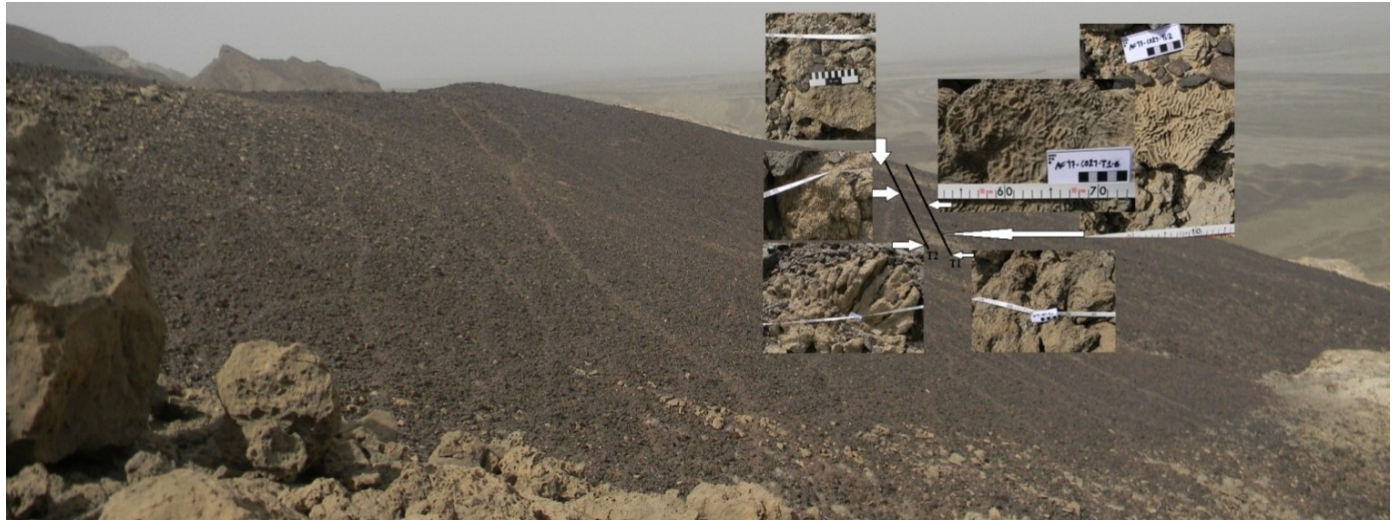


Fig.5.7. CO27 transects: one (T1) and two (T2)

CO20 exposure is a site with well - preserved ecosystem of the corals together with *Tridacna maxima* and *Tridacna crocea* (Fig.5.8). The coral colonies cover wider area and the majority of identified species have equal dominance except *Pavona venosa*, *Goniastrea pectinata*, *Favite abdita*, *Lobophyllia hemprichii*, *Pavona bipartita*, *Mycedium elephantotus* and *Blastomusa merleti* which have each 11% of the total species. The dominant species includes *Echinopora mammiformis*, *Caulastrea furcata*, *Platygyra lamellina* and branching *Porite* each have 22% of the total species.



Fig.5.8. CO20 transect and species variation

CO24 dominated by *Coscinarea crassa* and *Danafungia horrida* by 18% each and the other species of *Pachysieris foliosa*, *Mycedium elephantotus*, *Pavina frondifera*, *Coelastrea aspera*, *Leptastrea purpurea*, *Favite maritima* and *Platygyra daedalea* each have 9% of the total identified species. The detail abundance bar charts and calculated Dominance curves are attached in the annex (See [Annex - II](#) and [Annex - III](#)).

### 5.1.3. Diversity of Coral Species

Diversity indices are used to see the effects of the number of individual, presence/absence of species in all outcrops and to calculate the diversity values. When Shannon value (Fig. 5.9) compared with Simpson value the Shannon value is relatively higher because of the proportion of individual species considered from the total number of individual in the community. It is slightly sensitive to the number of samples.

However, Simpson diversity value indicates the evenness of the community to infer the presence of equal number of species in the community or the dominance of the community by a single species. Therefore from Simpson analysis the dominant species is identified for each site.

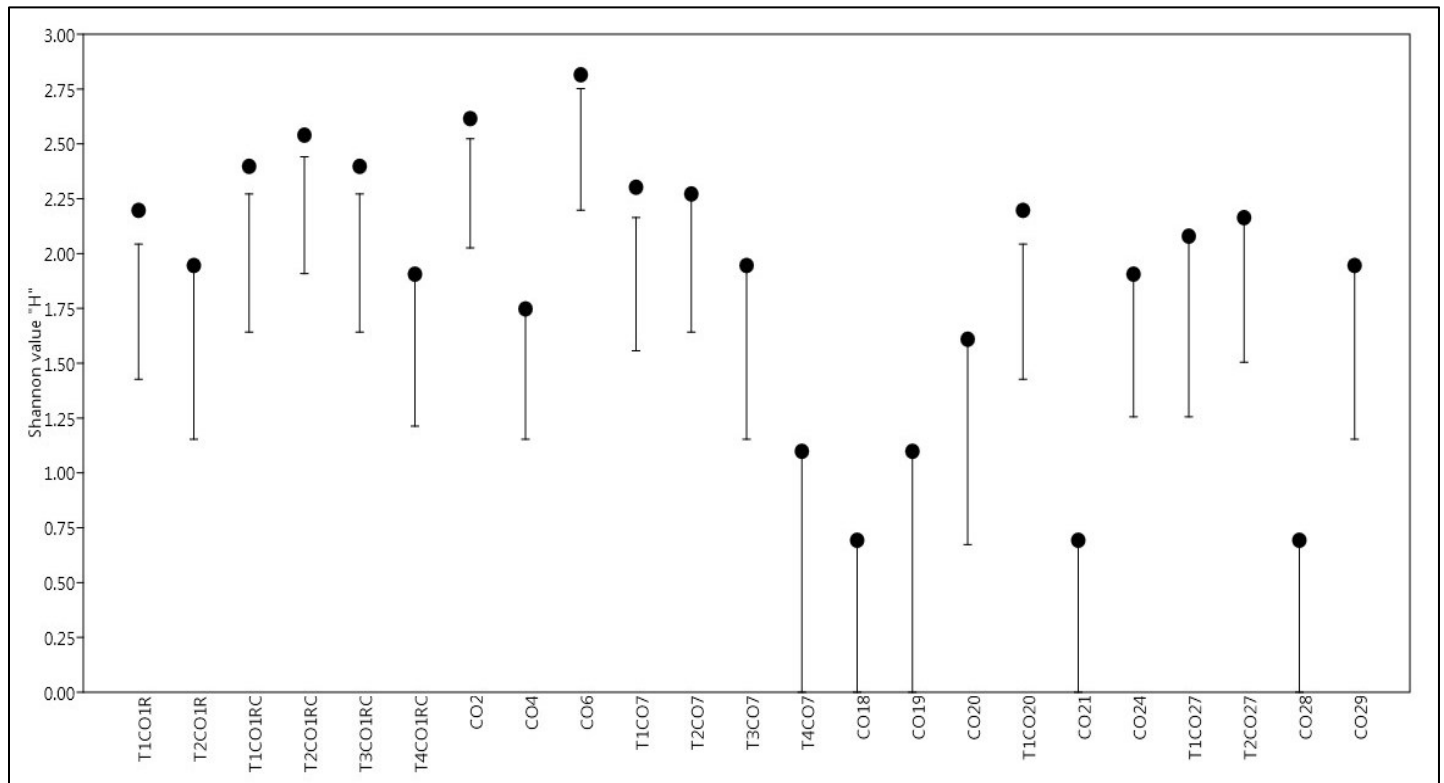


Fig.5.9. Calculated Shannon index for the dataset of each outcrop and transects

From the plot the Simpson value for CO6 (Fig. 5.10) is close to one which means the outcrop is dominated by single taxon and the Shannon value for the site is 2.76 which indicate the presence of diverse group of individual species. Simpson index is sensitive for the presence of rare taxa and CO6 is the distinct outcrop which comprises species which are not common in all outcrop sites. On the other side, CO18, CO21 and CO28 Simpson value is 0.55 which indicates the presence of all taxa in relatively equal proportion and Shannon value (Fig. 5.10) is 0.62 resulted from the presence of homogenous community in the outcrop.

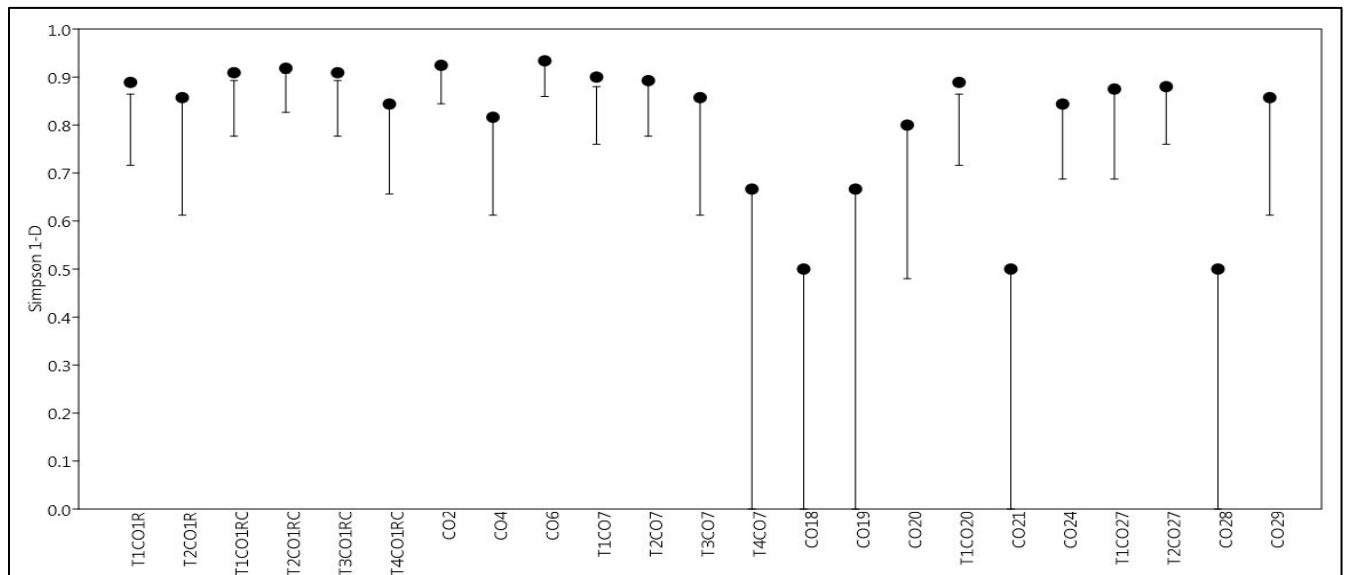


Fig.5.10. Calculated Simpson index for the dataset of each outcrop and transects

#### 5.1.4. Comparison of Species Diversity with Age

Diversity could be varying due to the change in both biological and physical factors with time. In order to see these variations of diversity with time, Shannon diversity index compared with the two different marine isotope stages occurred in the area (Fig. 5.11). The value of MIS stages for each coral outcrop is used from secondary data done by SERENA project and the calculated diversity values analyzed using PAleontological STATistics (PAST-3).

The result shows that the older corals of MIS7 are diverse and show higher value of Shannon diversity index which range from 2 to 2.5. The diversity of corals of MIS5 slightly changed and show decreasing of Shannon diversity values (Fig. 5.12). The transition between MIS7 and MIS5 creates discontinuities in the diversity value.

The first reason is the time span of MIS7 which is greater than that of MIS5. Therefore the corals have sufficient growth time with space and their response for the various factors of variation in temperature, sunlight, salinity, substrate type, wave energy, and eutrophic or oligotrophic conditions leads to have more diverse community than the corals of MIS5. Secondly, the sea level variation during MIS7 and MIS5 creates sub-stages which have an influence on the diversity of corals. Thirdly, preservability and diagenesis creates bias in species sampling especially in transitional corals of MIS5 which is observed during fieldwork. From the field observation most of the corals of MIS5 are poorly preserved due to gypsification and weathering processes. For instance there are gypsified solitary corals in the outcrops of CO2 and CO21 which are highly fragmented and poorly preserved.

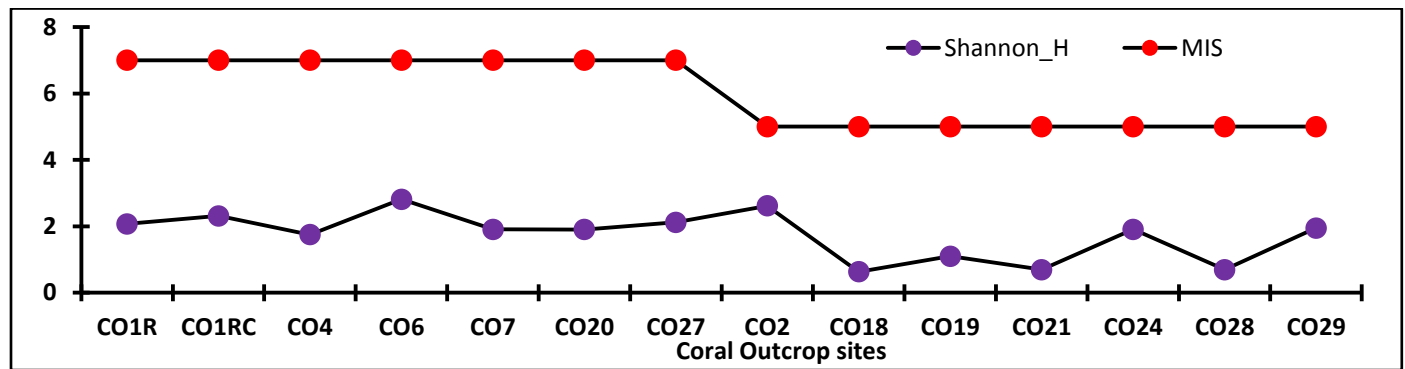


Fig.5.11. Relationship of age of coral outcrops with Shannon diversity of corals

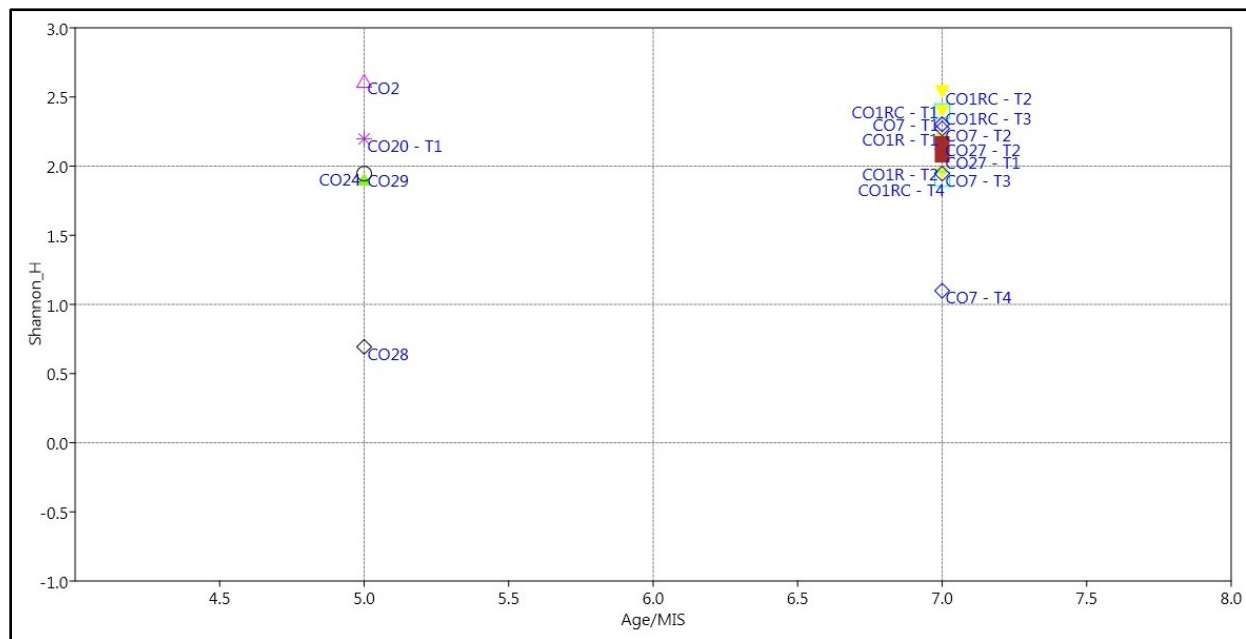


Fig.5.12. Shannon-Weiner diversity variation in the coral outcrops for MIS5 and MIS7

The diversity value of sites of the MIS5 (Fig. 5.13) are relatively close to 2 with some exceptions of the CO28 exposure which constitutes the single species and CO2 with diversity value above 2.5 resulting from the large number of identified species. There is an increasing of diversity for coral species within sites of MIS7 (Fig. 5.14) and they concentrate in the range of 2 to 2.5 except one transect of CO7.

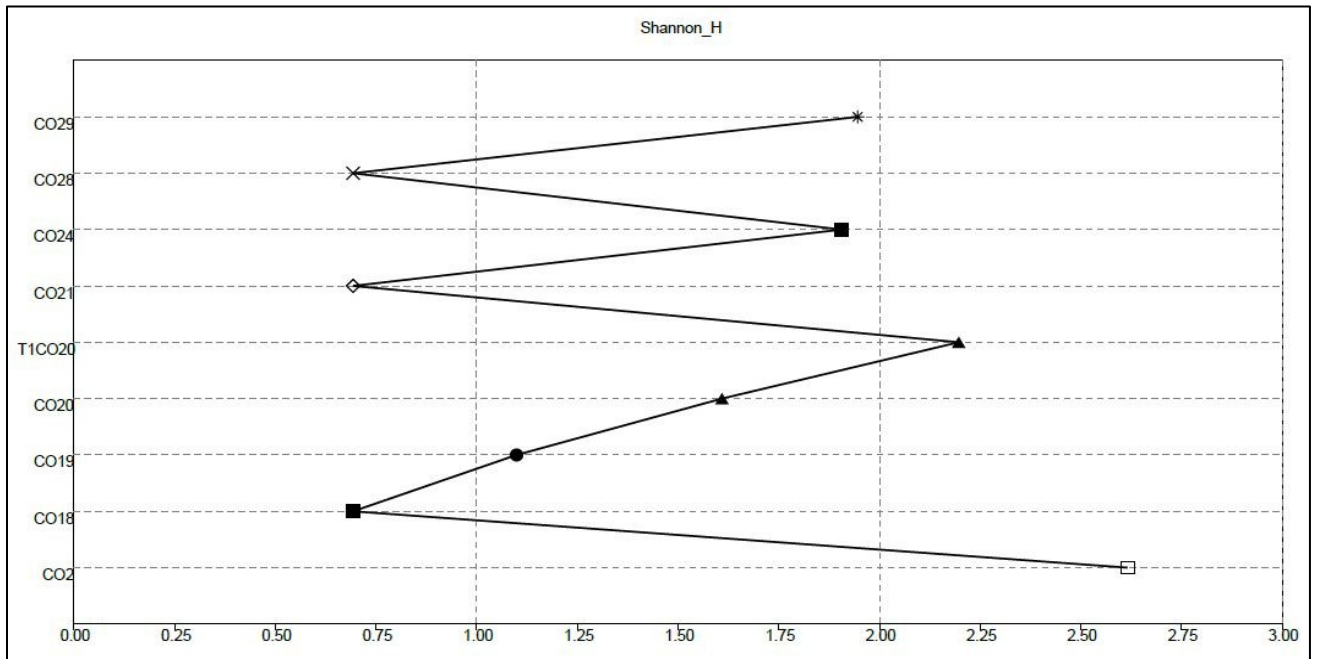


Fig.5.13. Diveristy values of Shannon Index variation during MIS5

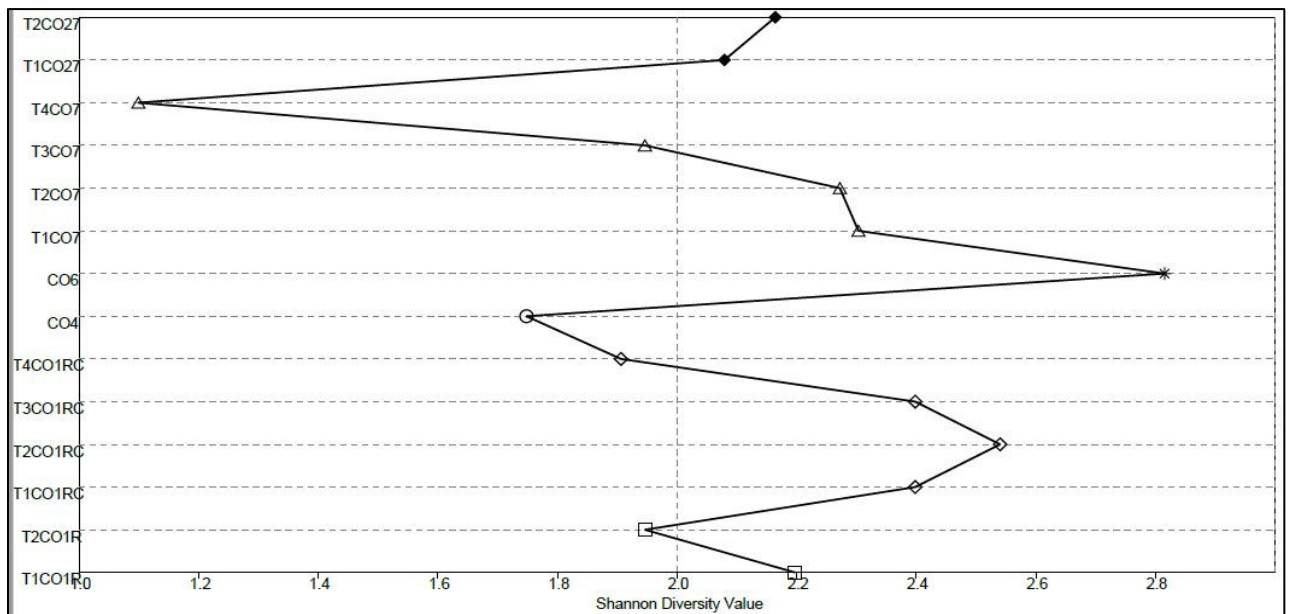


Fig.5.14. Diveristy values of Shannon Index variation during MIS7

## **5.2. Paleoenvironmental Reconstruction**

### **5.2.1. Background**

Paleoenvironmental interpretations of the area is carried out from the existence of the indicator species within biofacies studies and sequence stratigraphy of sedimentary deposits. Sclerectinia and Ostracoda are good indicators of past environmental conditions because of their sensitivity and preference of environment during their life time. Sclerectinia corals require specific physical and biological environment. The physical environment includes 25-31°C temperature; 34 - 37‰ salinity and sunlight predominantly passes in the top of 30m of water depth. The biological factors includes oligotrophic and highly stratified water column (Stanley, 2003).

Ostracoda can be influenced ecologically by various physical factors. These are: **Type of the substrate**: Swimmers have smooth, thin, bean-shaped carapace. Fine-grained (mud) dwellers have flattened ventral, wing-shaped carapace. Coarse-grained (sand) dwellers have thick carapace with coarse ornamentation. Interstitial ostracoda are small, long and robust. **Salinity**: Ostracoda carapace morphology tends to vary in surface features based on the variation in the salinity. Ostracoda occurs in fresh water (0.0-0.5‰) of rivers and estuaries, brackish water (0.5-30‰) of lagoons and marshes, normal sea water (35-45‰) and hypersaline water bodies (up to 57‰) of the closed seas, lakes, lagoons and marginal bays. **Depth**: Populations of living pelagic forms increase with increasing the water-depth, whereas benthic forms show highest diversity near shallow waters. Psychospheric forms occurred around 500 m depth. Thermospheric forms are restricted to the photic zone (0.0 – 150 m). **Temperature**: Latitudinal temperature controls the shallow water forms (Pokorney, 1998). At tropical regions, faunas are more abundant and diverse than at the higher latitudes (Ikeya et al., 2005).

### **5.2.2. Fossil Assemblages of Dallol**

#### **5.2.2.1. Coral Assemblages (CA)**

Dallol constitutes diverse ecosystem associated with the corals reefs of the outcrops. Depending on the morphological variation of the corals there are three dominant morphological features made by the coral colony. These morphological features are results of the response of the colony for variations in wave action, warm temperature situation, shallow depth, and substrate type. There are three types of colony morphology made by the corals which indicates the energy of the environment and depth. These morphologies are massive/encrusting, branching and platy/leafy (Kalus, 2015; Lemmens, 1993 and Crame, 1980).

**CA – I:** This assemblage includes massive and/or encrusting corals of massive *Porite*, *Echinopora sp.*, *Astrea curta*, *Dipsastrea maritime*, *Goniastrea pectinata*, *Lobophyllia radians*, *Platygyra sinensis*, *Platygyra daedalea*, *Dipsastrea speciosa*, *Paramontastrea persi*, *Porite lutea*, *Coelastrea aspera*, *Favite pentagona*, *Leptastrea pruinosa*, *Dipsastrea laxa*, and *Goniastrea stelligera*.

**CA – II:** Branching corals includes branching *Porite*, *Pocilopora grandis*, *Acropora hayacinthus*, *Galaxea cryptoramosa*; *Galaxea fascicularis*, *Stylopora wellsi*, *Caulastrea tumida*, *Caulastrea furcata*, *Echinopora hirsutissima*, *Lobophyllia hemprichii*, and *Lobophyllia corymbossa*.

**CA – III:** Platy and/or leafy corals includes *Pavona frondifera*, *Pavona cactus*, *Pavona venosa*, *Pavona duerdieni*, *Echinopora mammiformis*, *Echinopora gemmacea*, *Pachyseris foliosa*, *Pachyseris speciosa*, *Mycedium elephantotus*, *Coscinarea columna*, and *Leptoseris explanata*.

#### **5.2.2.2. Bivalvia, Gastropoda and Echinoidea Assemblages (BGEA)**

The mollusca and echinoidea species form distinct assemblages in the studied outcrops. This association of fossils in specific outcrop indicates specific environmental conditions. Most of the marine bivalvia live in temperature range from -3 to 44°C and salinity tolerance range from 4 to 40‰. Most bivalvia species show preference for specific substrate condition. The hard substrate mostly occupied by the oysters and soft substrate dominated by the calms with their burrowing life styles. Feeding types of the bivalvia, suspension feeders or deposit feeders, controls their geographic distribution within a specific environment. This indicates the energy of the water where they live (Gosling, 2004). Therefore two BGEA are identified based on tolerance of the species for specific salinity condition and the energy of the environment which is reflected on the substrate conditions of the coral outcrops.

**BGEA – I:** Brackish water fauna which contains species of bivalvia *Vasticardium elongatum*, *Arca ventricosa*, *Arca boucardi*, and *Pitar fulminatus*; species of gastropoda *Cerithideopsis cingulate*; and no Echinoidea. These species prefer the muddy and sandy sediment substrates together with saline waters condition. Most of the time they are associated with *Porites* and algae on the exposure sections of the outcrops.

**BGEA – II:** Normal shallow marine environment which contains bivalvia species of *Tridacna crocea*, *Tridacna maxima*; gastropoda species of *Crassoastrea sp.*, *Spondylus squamosa*,

*Cypraea pantherina*, *Canarium mutabile*, and *Caranium Erthrinium*; and echinoidea species of *Eucidaris metularia*, *Phyllacanthus imperialis* and *Jacksonaster depressum*.

### 5.2.2.3. Ostracoda Assemblage (OA)

Ostracoda are very sensitive for variation of salinity and temperature from other physical environments. Salinity will control the osmotic pressure of their body (Keyser et al., 2004). From the dominant identified species of ostracoda *Cyprideis torosa* lives in wide range of salinity from oligohaline to hyperhaline (0.3 - 140‰) and it is extremely productive, model organism (Deckker and Lord, 2017). Generally the ostracoda assemblages are classified into polyhaline (OA-I) and euhaline (OA-II) ostracods based on the presence of salinity indicator species identified from the specimens. Here, all species are not included in the assemblage because of the absence of habitat preference and salinity range information for all identified species.

**OA – I:** Comprise the polyhaline ostracoda with salinity range of 18 - 30‰ and the species prefers brackish water environment at a depth range from 0 to 20m (Shahin, 2005). These species includes *Cyprideis torosa*, *Hemicypris sp.*, *Limnocythere sp.*, *Pontoparta salina*, *Bytocypris eskeri*, *Bythocythere minima* and *Leptocythere castanea*.

**OA – II:** Comprise the euhaline ostracoda with salinity range of 30 - 45‰ and depth range from 0 – 34m. These species infer the normal shallow marine environment (Helal and Abdel Wahab, 2004). The species are *Xestoleberis rotunda*, *Xestoleberis rhomboidea*, *Xestoleberis depressa*, *Neonesidea schulzi*, *Hemicytheridea paki*, *Keijia demissa*, *Cypredeis torosa*, *Loxoconcha carinata*, *Corallocythere cf. daniensis* and *Cytherella sp. 2*.

### 5.2.3. Paleoenvironmental Interpretation

The paleoenvironmental interpretations are done for six sites of the grouped outcrops. These six sites are grouped based on the proximity of the geographical locations of the coral outcrops determined during field observations (Fig. 5.1). Site – A comprises the outcrops of CO18, CO19 and CO21; Site – B includes coral outcrops of CO28 and CO29; Site – C includes coral outcrops of CO6, CO24 and CO27; Site – D contains outcrops of CO4 and CO20; Site – E includes coral outcrops of CO2 and CO7; and Site – F contains coral exposures of CO1R and CO1RF. The biofacies assemblages, indicator foraminifera species, paleoecology results and stratigraphic sections are used as paleoenvironmental indicators. The presence of two separate phases (MIS7 and MIS5) of flooding the area by the Red Sea is discussed in the environmental interpretations.

**Site – A:** This is the northern boundary of the basin, around Bada locality, contains CO18, CO19 and CO21. This site is considered as MIS5. CO18 dominated by gypsified corals, gypsum deposits, lacustrine laminated silty rocks and shale. CO21 is tectonically uplifted site from the others and channel deposits of conglomerate, volcanoclastic rocks and the corals are exposed (Fig. 5.15). The corals developed as massive colony morphology and exposed at the eastern side of Dahara River.

From this site *Platygyra daedale*, *Danafungia horrida*, *Leptastrea pruinosa* and *Pseudosiderastrea tayamai* are the dominant coral species with diversity value range from 0.69 to 1; from bivalvia species *Triducna maxima* is common in CO19 and CO21; and *Vasticardium elongatum* is common in CO21. *Limnocythere sp.* ostracoda species occur in CO19. Generally, site-A characterised by 41.1% of CA-I; 29.4% of CA – II and 29.4% of CA – III. BGEA – II is dominant and OA – I present in the site.

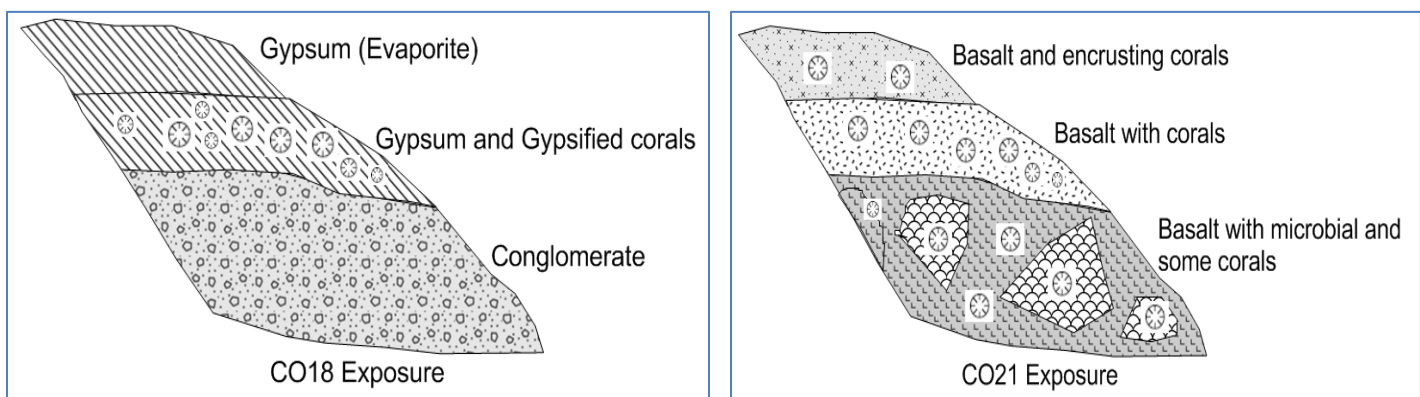


Fig.5.15. Schematic representation of CO21 and CO18 exposures (Not to scale)

From paleoenvironmental point of view, these areas were covered by sea level and currently uplifted by tectonic activity. The coral association indicates the presence of higher water energy. The polyhaline ostracoda species (*Limnocythere sp.*) indicates the presence of sandy substrate from the marginal marine environment with some fresh water input. Bivalvia species (*Vasticardium elongatum*) indicates the presence of brackish environment and the interaction of saline sea water with coastal freshwater bodies. Therefore, the area was flooded by late sea level rises during MIS5 (Sea level high stand) and form estuaries.

**Site – B:** This site includes coral outcrops of CO28 and CO29 which are exposed inline with the first site. Clastic matrix (conglomerates and sandy materials) are the substrate for the corals in both sites and at the top of the coral there is gypsum unit (Fig. 16). Abundance study indicates

the dominant species of *Lobophyllia hemprichii*, *Platygyra daedalea*, *Coelastrea aspera*, *Dipsastrea favus* and *Porite lobata*. The biofacies assemblage is CA – I. There is no OA.

The sequence of stratigraphic units is dominated by gypsum unit, gypsified corals and clastic unit. The age of corals corresponds to MIS5. The corals of this exposure are restricted to small exposed areas and mostly associated with clastic sediments.

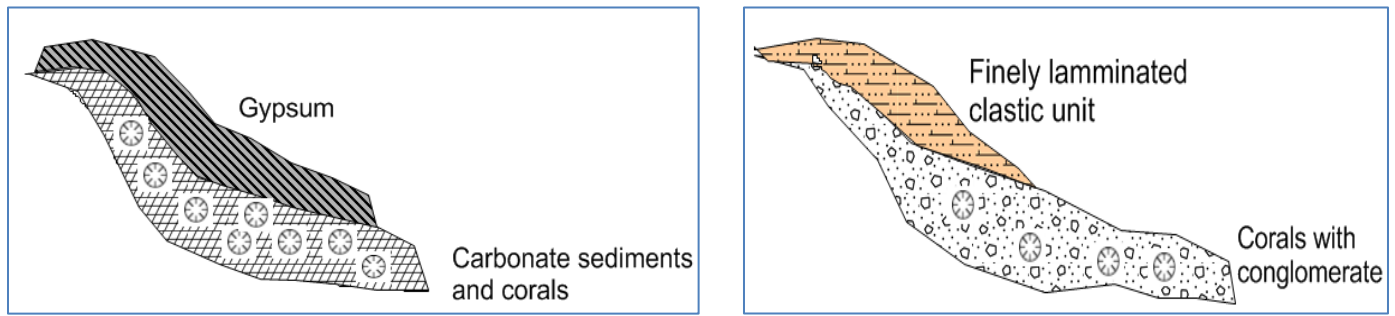


Fig.5.16. Schematic representation of the stratigraphic units for CO28 and CO29 (Not to scale)

Generally, from the above assemblage and stratigraphic sequence most of the coral colonies of the site are developed under shallow marginal marine environment as fringing reefs which are developed on the hard substrate.

**Site – C:** Contains the coral outcrops of CO6, CO24 and CO27. They occur in the central part of the studied area. CO6 contains both marine and lacustrine faunas above the older red beds. Monospecific bivalvia occurs by intercalated with the coral species (Fig.5.17). The corals of this area are categorized under CA – II. Bivalvia species of *Arca ventricossa*, *Arca boucardi*, *Triducna crocea*; gastropoda species of *Chicoreous verginus*, *Caranium mutabeli*, *Caranium erythrium*; and echinoidea species of *Eucidaris metularia* and *Echinometra mathaie* are dominant in CO6 site and grouped under BGEA – II. From identified microfossils the ostracoda species are dominated by three genera of *Cyprideis*, *Xestoleberis* and *Keijia* and grouped under OA – II. Foraminifera also associated with the extracted ostracoda and most of the identified genera of foraminifera exist from the sediments collected from CO6. These are *Ephidium*, *Amphistegina* and *Quinculocolina*. There are also micro-bivalvia and micro-gastropoda. Shannon diversity index of CO6 is 2.85 and indicates higher diversity of coral species.

Most of the gypsified solitary corals and platy coral colonies occur in CO24. The platy corals are *Pachyseris speciosa*, *Pachyseris foliosa*, *Mycedium elephantotus*, *Leptastrea purpurea*; and the solitary coral species *Danafungia horrida*. In this site the corals diversity is low.

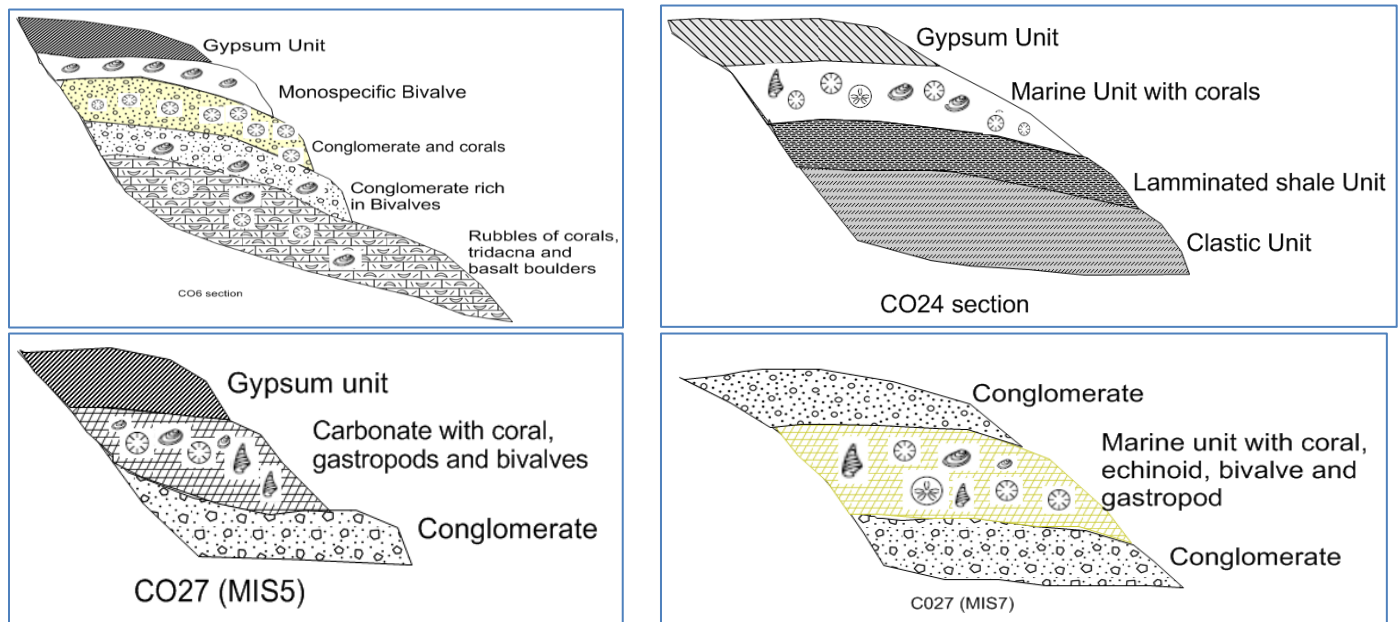


Fig.5.17. Schematic representations of stratigraphic sections at CO6, CO24 and CO27 (Not to scale)

CO27 is the third outcrop under site C and two sections are examined with two different ages. Under the first section (Fig.5.17) deposits of echinoids and echinoid spines, corals and bivalvia occur on the top of the gypsum unit and these are considered as younger fossils. The second exposure contains well preserved corals inhabiting the slope area separated by incised channels and alluvial fan deposits. This outcrop is characterized by CA – II, BGEA – II and OA – II which indicates open marine environment with small sub environments.

Generally the corals deposited during the MIS7 are underlain by the older conglomerate unit and develop diverse coral species especially in CO27 which correspond with coral species of CO6 except localized shallow lagoon area of the backreef exist in the CO6. Deposits of CO24 are MIS5. The facies pattern indicate the presence of an open marine environment with sea level fluctuation during MIS7 which is reflected on the occurrence of more massive and platy coral colonies on CO27 and CO6. During the periods of sea level fall the shallow lagoon faunas, algal deposits and evaporite deposits are developed. Therefore, the environment was open marine environment with small sub-environments of shallow lagoon and again open marine as a result of sea level fluctuations during sub-stages of the MIS7 and MIS5.

**Site – D:** It contains CO4 and CO20 outcrops reflecting MIS7 and MIS5 deposits. The distinct feature exist in this site is occurrence of oolite beds and red algae which clearly demonstrate the changes from one environment to another. CO4 exposure stratigraphy comprises lacustrine unit

which comprises the bioturbated fine grained sediment underlain by older inclined clastic unit and conglomerate unit with erosional surface on the Red beds. The lacustrine unit is overlain by the thick marine unit which is rich in echinoid fossils without time gap (Fig. 5.18a). Previously this unit is described as a white marine sediment or Zariga Formation. The sequence is not similarly exposed everywhere in the area and all the beds thin towards the ancient shoreline (Garland, 1972).

CO4 dominated by 90% of BGEA-II, 65% of CA – II and 63% of OA – II. The CO4 exposure lacks corals and contains ooids except in some the transitional environment from lacustrine to marine. However in exposures of CO20 which corresponds to MIS5, the ooids disappeared and the coral bed becomes the dominant unit. There is *Pontoparta salina* and *Hemicypris sp.* in both specimens of CO4LA and CO20. OA – I is the dominant assemblage in CO4LA and CO20. The Foraminifera species of *Trochammina sp.* and *Ammobaculite sp.* occur in CO20 indicates brackish zone of continental shelf (Boersma, 1998).

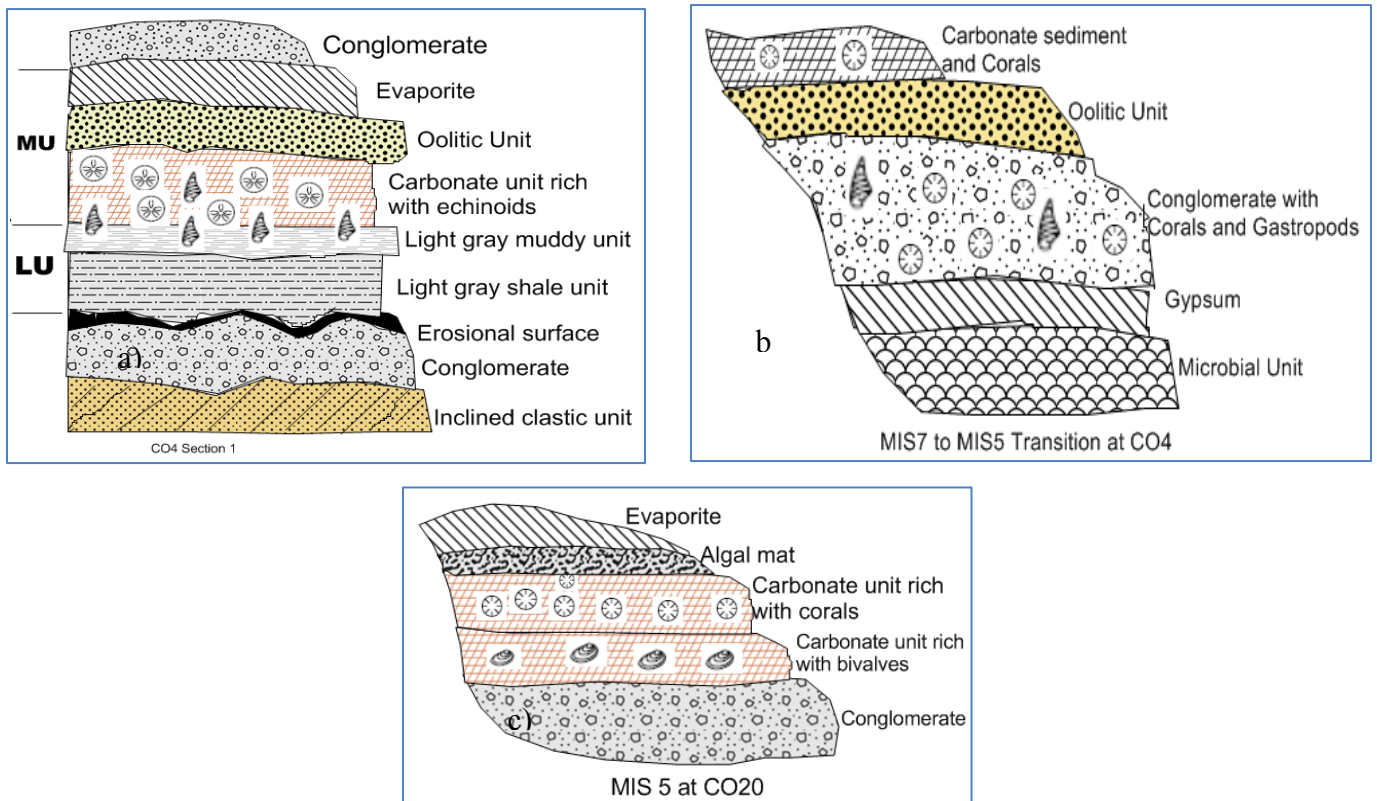


Fig.5.18.Schematic representations of stratigraphic sections: a) and b) CO4; and section c) CO20 (Not to scale)

Generally, the environment of this site is interpreted as presence of lacustrine environment along the margin of the basin and transition to an open marine environment due to later sea level rise. The marine deposits start to accommodate over the lacustrine deposits without any time gap and very shallow marine environment occurred. Small protected brackish water environments exist along the margin of the shallow marine environment.

**Site – E:** This site includes coral outcrops of CO2 and CO7. On CO2 exposure recent alluvial deposits cut the lacustrine deposit, coral unit and gypsum unit. The red algae deposits, oolitic carbonaceous deposits and bivalvia and gastropoda intercalations occur below the coral unit (Fig. 19). In terms of environment this indicates the protected environment which is not good for corals as a result of the energy of the environment. The corals of CO2 are dominated by the genera of *Porite*, *Leptorya*, *Galxea* and *Goniastrea*. Transects of CO7 indicates the diversity variation of corals which decrease from the bottom (transect-1) to top (transect-4) of the outcrop. The first three transects of CO7 dominated by genus *Echinopora* and the fourth transect is dominated by massive *Porites*.

In some areas there are repeated sequences of corals and red algae beds (Fig. 5.19) which indicates the sea level fluctuation and temperature variation which leads to domination of the algae over the corals and corals development on the red algae by making them substrate material. The monospecific *Pina rudis*, *Anadara kagoshimensis*, and *Cerithideopsisilla cingulata* occurrence in between the red algae unit typically indicates small protected area of back reef shallow lagoon. Therefore, the assemblage for site E is generalized as BGEA-I comprise 78% and BGEA – II comprises 22%; CA – I contains 66% of the total coral species of the site, CA – II 21% and CA – III is 13%; there is no OA.

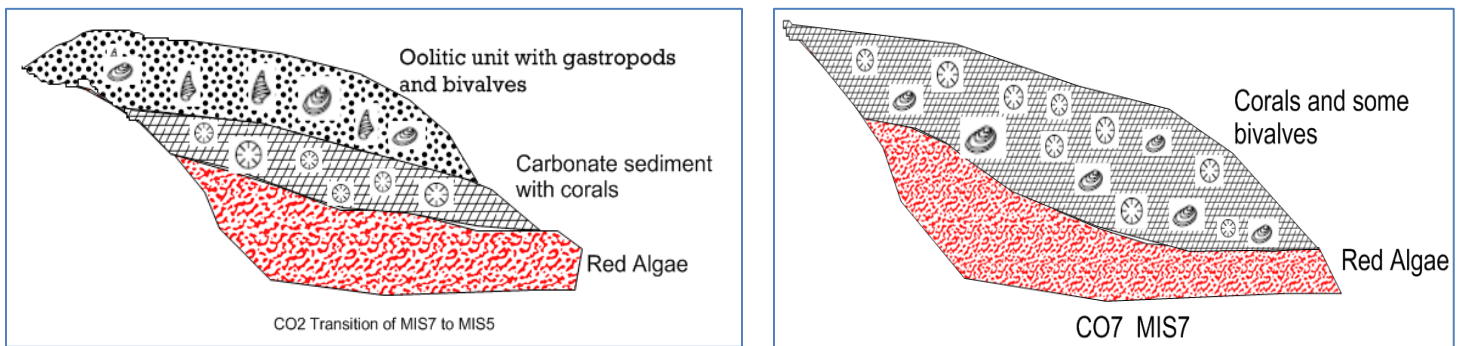


Fig.5.19.Schematic representations of stratigraphic sections at CO2 and CO7 exposures (Not to scale)

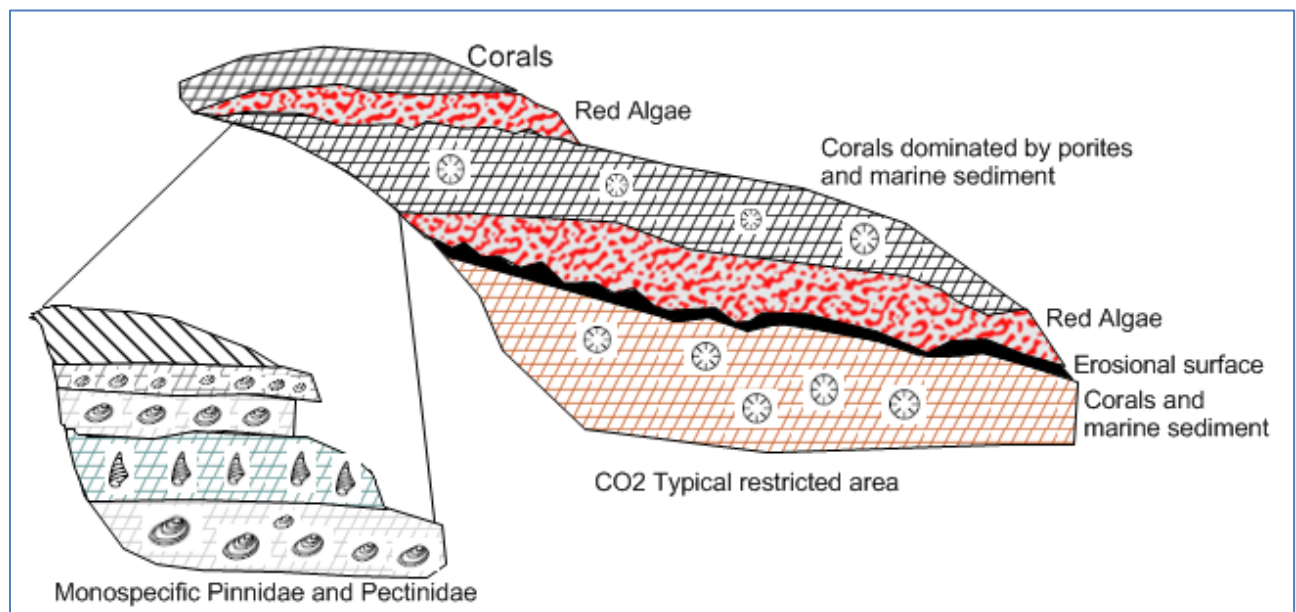


Fig.5.20.Schematic representations of stratigraphic sections at CO2 (Not to scale)

The presence of red algae at the bottom of the section indicates environmental change from near shore to open marine or sea level rise towards the shore (Fig. 5.20) with various hydrodynamic factors of change in the energy of the water and increasing the water temperature. Red algae dominate in the near shore of an open shallow marine environment and warm depositional temperature (Studencki, 1999).

Generally, site E paleoenvironment interpreted as reef front and reef crust deposits of coral species and *Tridacna* exposed on CO7 which correspond to MIS7 and small shallow lagoon of back reef margin fauna exist on CO2 which is related to MIS5. From the above biofacies association the paleoenvironment of the site is concluded as the back reef margin with small protected lagoon (Fig. 5.20). Later sea level rise develop the coral colonies along the margin of the open marine environment.

**Site – F:** This site contains coral exposures of CO1R and CO1RF. CO1R exposed along the road section to Ahmedela and CO1RF is the lateral extension of the reef crust (Fig.5.21). CO1R unit indicates the presence of two different episodes of sea level fluctuation by its lower coral unit and upper coral units divided by erosional surface. The lower unit is correspond to MIS7 and the upper unit is deposited during MIS5. Transects are carried out on the lower coral unit which is correspond which developed on the basaltic substrate.

CO1R characterized by carbonate sediments rich in echinoid spines of *Phyllacanthus imperialis*, coral rubbles, massive coral frameworks and red algae at the top. The corals are altered and poorly preserved, dominated by *Porite sp.* and *Platygyra daedalea*.

The CO1 corals diversity is low and the coverage of the carbonate sediment is larger than the coral colonies. This will indicate the reef crust environmental deposits during MIS7. CO1RF typically represent the reef face coral species with noticeable morphological change from lower part of platy, to branching and to massive coral colonies at the top. Four transects are carried out and species *Tridacna crocea*, *Tridacna maxima*, *Cyprea phantherina* and *Phyllacanthus imperialis* occur in between the coral colonies.

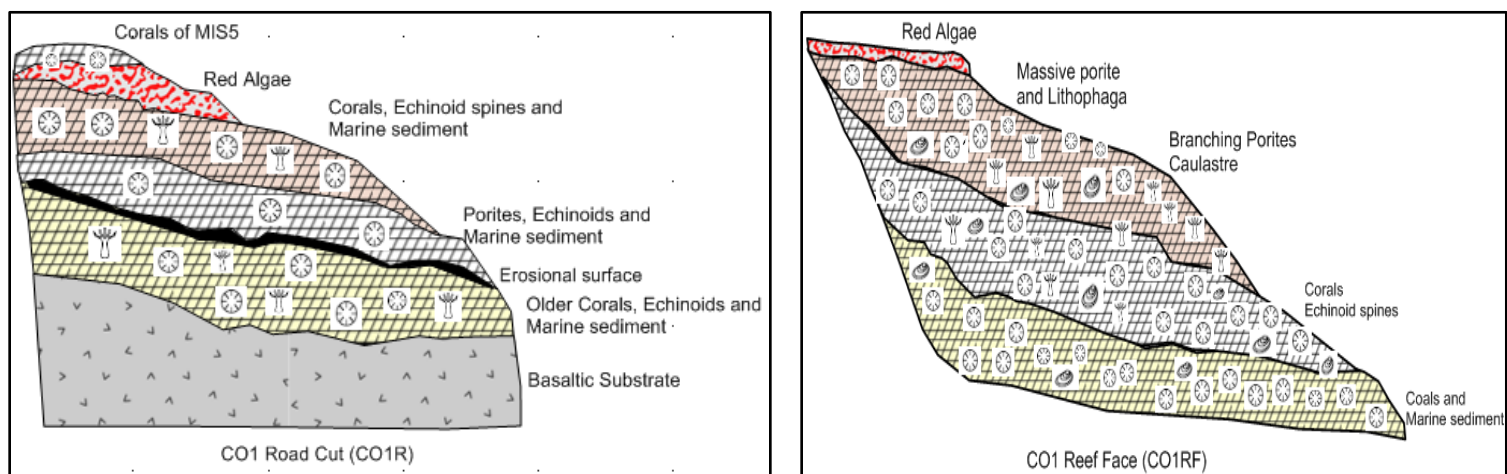


Fig.5.21. Schematic representations of stratigraphic sections at CO1R and CO1RC (Not to scale)

The dominant coral species is *Porite sp.* followed by *Caulastrea furcata* and *Caulastrea tumida*. This is typical reef face facies developed during MIS7. The biofacies assemblage for the site F is generalized as BGEA-I comprise 85% and BGEA-II comprises 15%; CA – I comprises 59% of the total coral species of the site; CA – II: 28% and CA – III contains 12% of the total coral species of the site. There is no OA.

Therefore, the environment of the site is interpreted as an open marine environment which develops partly reef crust and complete reef face facies of the fringing reef.

#### 5.2.4. Comparison with Modern Classic Environment and Paleobiogeography

The reefs of the study area are fringing reefs which develop close to the shore line of the past ocean (Balemwal et al., 2015). Most of the modern fringing reefs are geomorphologically divided into three main zones: fore reef, reef crest and back reef (Fig. 5.22).

The majority of fringing reefs tend to be relatively narrow reefs if the submarine slope is steeper and they become broader if the area is gentle (James, 1979). Therefore, the reef width is controlled by the geomorphological situation of the area and the substrate conditions.

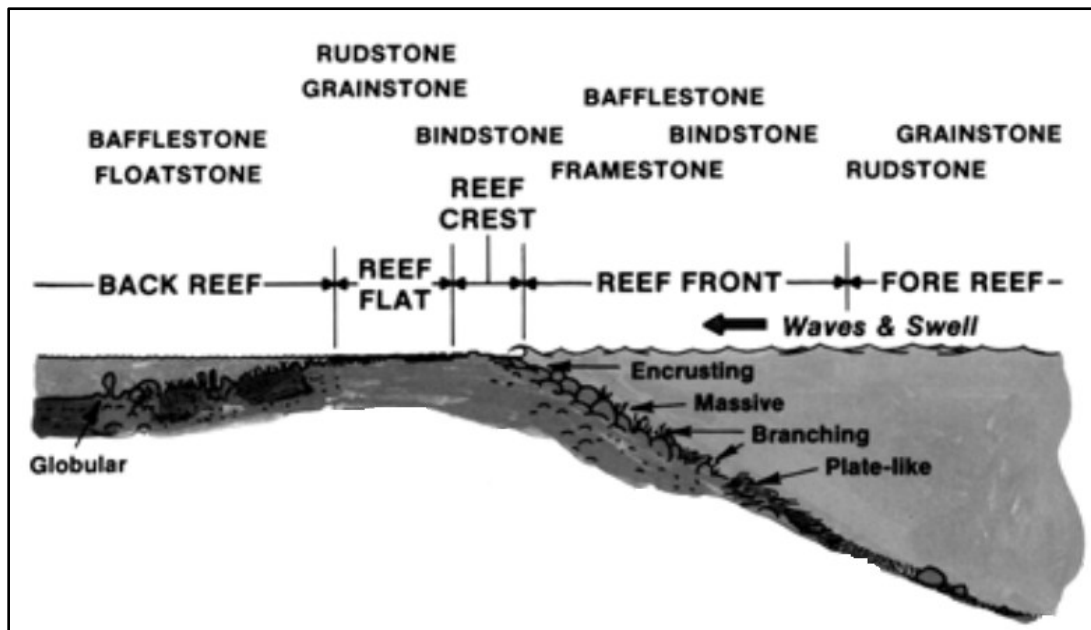


Fig.5.22. A cross section through zoned marginal reef (fringing reef) illustrating different reef zones, limestone facies in each zone and environment of different reef building organisms in the modern environment (After James, 1979)

The studied area encounters two different episodes of flooding by the Red Sea and as a result the coral colonies, bivalvia, gastropoda, and echinoidea developed along the western margin of the northern Dallol. From geographical distribution of the exposures the southern part, central part and northern part of the study area; from field observations of the morphology of the reef platforms; and associated invertebrate fossil taxa the schematic representations of the sites constructed using Surfer 10 software (Fig. 5.23). The sections are compared with the classic modern fringing reef zones.

From the comparison result reflects that the sites of CO18, CO19, CO28, CO29, CO6 and CO20 correspond to partial part of the modern reef cross section and sites of CO1R, CO1RF, CO7 and CO27 reflect comprehensive picture of the fringing reef facies. To identify the age of the coral deposits coloring of the line is used and areas having both MIS7 and MIS5 indicated as black line and areas with only MIS7 and only MIS5 indicated as red and green respectively.

Most of the deposits of MIS7 corresponds to the reef crust and reef front coral facieses as indicated on sections of CO1R, CO1RF, CO7 and CO27; and exposures of CO6 and CO20 corresponds to shallow lagoon of back reef environment (Fig. 23). MIS5 deposits reflect the start of reef development towards the shore with minor sea level fluctuations indicated by gypsification of corals; thick evaporate deposits and another phase of coral colony developments on the top of evaporates and red algae units.

Dallol coral assemblages have been compared with the paleobiogeographical distribution in the Red Sea coast of Egypt, Sudan, Eritrea, Somalia, Djibouti, Kenya and Yemen Pleistocene coral reef habitats (Crame, 1980; El-Sorogy, 2002, 2008; Kore et al., 2014; Zuschin et al., 2016; Buffler et al., 2010; and Casazza, 2017). In addition attempts have been made with comparison of some of the living invertebrate fauna (Kalus, 2015). From these studies the corals of the areas exhibit a clear trend of increasing taxonomic richness and diversity from reef flat towards the reef slope at about 10m depth. Therefore the most abundant genera of the Dallol coral outcrops are closely comparable to both the Pleistocene and the present coral communities of the Red Sea coast.

The paleoenvironmental situation of Dallol coral outcrops are results of the two different phases of flooding of the area by Red Sea and generalized as an open marine environment together with small sub – environments of shallow lagoon; brackish – protected environment; and lacustrine environment.

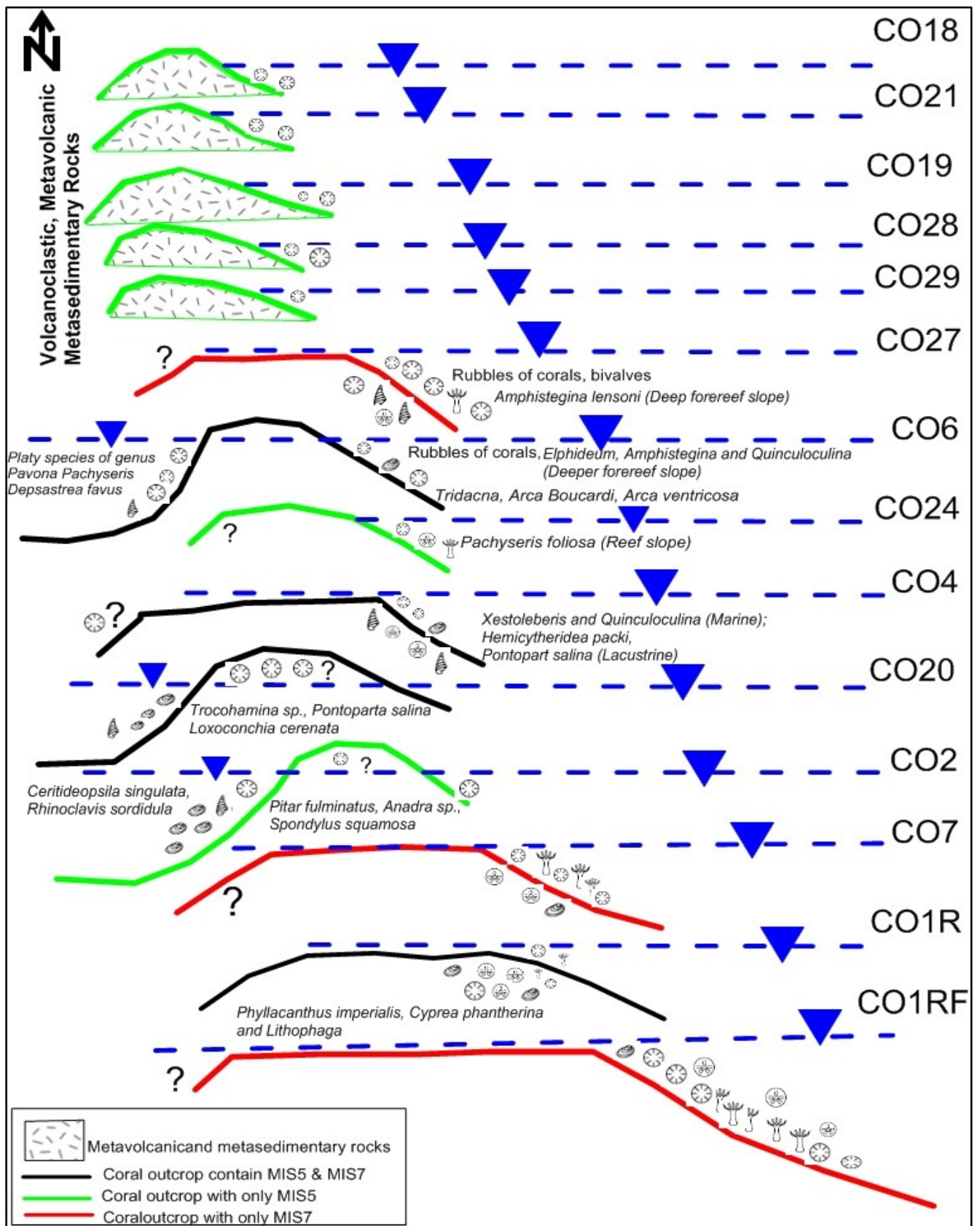


Fig.5.23. Schematic representation of reef facies distribution and environmental setting (Not to scale)

## CHAPTER SIX

### 6. CONCLUSION AND RECOMMENDATION

#### 6.1. Conclusion

The Dallol area was flooded at least two times during Pleistocen. As a result of these marine transgression and regression the area comprises dominant species of marine faunas. This study focused on the systematic study of reef building corals and ostracoda; paleoecological analysis; and paleoenvironmental interpretations for 13 coral outcrop sites of Dallol (western margin) which are deposited during the Quaternary Period.

The systematic description is done for the first time from this Quaternary carbonates of Ahmedela and Bada localities. There are diverse species of bivalvia, echinoidea and gastropoda together with the corals. Detail morphological features descriptions are made for the selected specimens to study the systematics. A total of 12 Families, 29 Genera, 60 Species of scleractinia; 9 Genera and 12 Species of bivalvia; 6 Genera and 7 Species of gastropoda; and 6 Genera and 8 Species of echinoidea recognized from the study.

Systematic classification of microfossils is done and species level identification is conducted for ostracoda and foraminifera. From this study a total of 15 Genera and 27 Species of ostracoda and total of 9 Genera and 13 Species of foraminifera recognized. There are micro-bivalvia, micro-gastropoda and charophyta in the extracted sample.

Paleoenvironmental interpretations indicates that during the first transgression of the Red Sea (MIS7) the older corals were living in an open marine environment (CO1R, CO1RF, CO7, CO27 and CO6); lacustrine environments (CO4 and CO20) which are changed progressively to marine environment (CO4) as a result of later sea level rises; and small shallow lagoons or small protected brackish environments (CO6 and CO20). During MIS5 the younger corals deposited in the environment which is the same as environment of MIS7 except sea level fluctuations reflected on depositions of gypsum, gypsified corals, repeated units of algae units – coral colonies – algae units. Transitional environments observed in both MIS7 and MIS5 deposits.

Paleoenvironmental interpritations are generalised by the presence of an open marine environment and small sub – environments of shallow lagoon; brackish – protected environment; and lacustrine environment.

## **6.2.Recommendation**

This study is the first work to conduct species and generic level identifications of scleractinia, ostracoda, bivalvia, gastropoda, echinoidea and foraminifera. Paleoenvironmental interpretations are carried out from macrofossils and microfossils assemblages in addition to paleoecological results.

The area is a model for the Quaternary Period and contains numerous fossils with good preservation. Therefore, the following recommendations are made to have more detailed picture of the environment of the area. These are identification and systematics of corals and other invertebrate fossils for the eastern margin of the North Afar, detail geochemical analysis on ostracoda species and dating of the corals.

## REFERENCE

- Abell, P. & Williams, M. (1989). Oxygen and Carbon Isotope Ratios in Gastropod shells as indicators of Paleoenvironments in the Afar Region of Ethiopia. *PALAEO*. **74**: 278 – 265.
- Arrigoni, R., Benzoni, F., Stefani, F., Pichon, M. & Galli, P. (2012). Molecular phylogeny of the Robust Clade (Faviidae, Mussidae and Pectiniidae): An Indian Ocean perspective. *Molecular Phylogenetics and Evolution*. **65**: 183-193.
- Athersuch, J., Horne, D.J. & Whittaker, J.E. (1989). Marine and brackish water ostracods (Superfamilies Cypridacea and Cytheracea). *Synopsis of British Fauna*. **43**: 1–370.
- Balemwal Atnafu & Russo, A. (2004). Late Quaternary lacustrine ostracoda of Ziway-Shalla Basin (Ethiopia) as paleoenvironmental indicators. *Bollettino della Societa Paleont. Ital.* **43**(1-2): 235 – 266.
- Balemwal Atnafu, Tesfaye Kidane, Foubert, A., Jarmaillo-Vogel, D., Schaegis, J-C. & Henriët, J-P. (2015). Reading history from Afar. EOS, *Earth and Space Science News*, **96**: 1-2.
- Bannert, D., Brinckmann, J., Jordan, R., Kursten, M., Ochse, G., Rise, H., & Schmid, F. (1971). Beitrage zur Geologie der Danakil-Senke (NE-Athiopien). *Behi. Geol. Jahrb.*, **116**: 1 – 199.
- Bate, R.H. (1970). *The distribution of recent ostracoda in the Abu Dhabi Lagoon, Persian Gulf*. (Oertli, H.J. ed.): 239 – 256.
- Benzoni, F., Arrigoni, R., Stefani, F. & Pichon, M. (2011). Phylogeny of the coral genus *Plesiastrea* (Cnidaria, Scleractinia). *Zoolog.*, **80**, 231-249.
- Beyene. A, & Abdelsalam, M.G. (2005). Tectonics of the Afar Depression: A review and synthesis. *Journal of African Earth Sciences*. **41**: 41–59.
- Blanford, W.T. (1870). *Observations on the Geology and Zoology of Abyssinia made during the British Expedition to that country in 1867-68*: Macmillan & Co. London
- Boccaletti, M., Bonin, M., Mazzuoli, R., Bekele Abebe, Piccardi L. & Tortorici L. (1998). Quaternary oblique extensional tectonics in the Ethiopian Rift (Horn of Africa). *Tectonophysics*. **287**: 97-116
- Boersma, A. (1998). *Introduction to marine micropaleontology*. (Haq, B.U. and Boersma, A. eds). 2<sup>nd</sup> ed., Elsevier Science Singapore Pte Ltd. 19 - 77.
- Bonatti, E., Emiliani, G., Ostiund, G. & Rydell, H. (1971). Final dessication of the Afar Rift, Ethiopia. *Science*. **172**: 468 – 469

- Bouchet, P. & Rocroi, J.P. (2005). Classification and nomenclature of gastropoda families. *Malacologia*. **47**: 1–397.
- Brady, G.S. (1880). Report on the Ostracoda dredged by HMS challenger during the years 1873–1876. *Zoology* **1**(3): 1 – 184.
- Brasier, M.D. (1980). *Micropaleontology*. Bill and Sons Ltd., London.
- Buffler, R.T., Bruggimann J.H., Brhane Gebretensae, Walter, R.C., Guillaume, M.M., Seife Berhe, McIntosh W. & Park, L.E. (2010). Geoficalsetting of the Abdur Archaeological sites in the Red Sea coast of Eritrea. *Gloplacha*. **72**:429 – 450.
- Budd, A.F. & Stolarski, J. (2009). Searching for new morphological characters in the systematics of scleractinian reef corals: comparison of septal teeth and granules between Atlantic and Pacific Mussidae. *Acta Zoologica*. **90**: 142 – 165.
- Budd, A.F. & Stolarski, J. (2011). Corallite Wall and Septal Microstructure in Scleractinia Reef Corals: Comparison of Molecular Clades within the Family Faviidae. *Journal of Morphology*. **272**: 66–88.
- Budd, A.F., Fukami, H., Smith, N.D. & Knowlton N. (2012). Taxonomic classification of the reef coral family Mussidae (Cnidaria: Anthozoa: Scleractinia) *Zool. J. Linn. Soc.*, **166**: 465-529.
- Casazza, L.R. (2017). Pleistocene reefs of the Egyptian Red Sea: environmental change and community persistence. *PeerJ*. **5**:e3504
- Chao, A. (2004). *Species richness estimation*. In: Balakrishnan, N., Read, C.B. & Vidakovic, B. eds., 2000. A comprehensive review of the statistical methods for estimating richness. *Encyclopedia of Statistical Sciences*, pp. 354 – 359.
- Chappell, J., Omura, A., Esat, T., McCulloch, M., Pandolfi, J., Ota, Y. and Pillans, B. (1996). Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. *Earth and Planetary Science Letters*. **141**: 227–236.
- Clark, A.M. & Rowe, F.W.E. (1971). *Monograph of shallow water Indo-West Pacific echinoderms*. Trustees of the British Museum (Natural History). **1-7**: 1-238 pp. London.
- Crame, J.A. (1980). Succession and Diversity in the Pleistocene coral reefs of Kenya coast. *Paleoecology*. **24** (3): 609-646

- Cronin T.M. (2015). *Ostracods and Sea level*. (Shennan I., Long, A.J. and Horton, B.P. eds) Handbook of Sea Level Research. 1<sup>st</sup> ed., John Wiley & Sons, Ltd. American Geophysical Union. 249 – 257.
- Cushman, A.J., (1928). *Foraminifera their Classification and Economic use*, 1st ed., Sharon, Cambridge, Massachusetts, USA, 424 pp.
- Cushman, A.J. (1950). *Foraminifera their Classification and Economic use*, 4<sup>th</sup> ed. Sharon, Cambridge, Massachusetts, USA. 605 pp.
- Daly, M., Brugler, M.R., Cartwright, P., Collins, A.G., Dawson, M. N., Fautin, D.G., France, S.C., Mc-Fadden, C.S., Opresko, D.M., Rodriguez, E., Romano, S.L., & Stake, J.L. (2007). The phylum Cnidaria: A review of phylogenetic patterns and diversity 300 years after Linnaeus. *Zootaxa*. **1668**: 127–182.
- Deckker, D.P. & Lord, A. (2017). *Cyprideis torosa*: a model organism for Ostracods? *Journal of Micropaleontology*. Geological Society of London: 100 pp.
- Dullo, W.C. (1990). Facies, Fossil Record and Age of Pleistocene reefs from the Red Sea (Saudi Arabia). *Facies*. **22**: 1-46.
- El-Sorogy, A. S. (2002). Palaeontology and depositional environments of the Pleistocene coral reefs of the Gulf of Suez, Egypt. *Neues Jahrbuch für Geologie und Palaeontologie*. **225**(3): 337–371.
- El-Sorogy, A. S. (2008). Contributions to the Pleistocene coral reefs of the Red Sea coast, Egypt. *Arab Gulf Journal Scientific Research*. **26**(1/2): 63–85.
- Farag, E.A., Dekinesh, S.I. & El-Odessy, H. M. (1999). Taxonomical studies on the Edible Bivalve Molluscs inhabiting the costal zones of Alexandria, Egypt. *Pakistan Journal of Biological Sciences*. **2**(4): 1341 – 1349.
- Felis, T., Lohmann, G., Kuhnert, H., Lorenz, S.J., Scholz, D., Patzold, J., Al-Rousan, S.A. & Al-Moghrabi, S.M. (2004). Increased seasonality in Middle East temperatures during the last interglacial period. *Nature*. **429**:164–168.
- Fukami, H., Budd, A.F., Paulay, G., Sole-Cava, A., Chen, C.A., Iwao, K. & Knowlton, N. (2004). Conventional taxonomy obscures deep divergence between Pacific and Atlantic corals. *Nature*. **427**: 832–835.
- Fukami, H., Chen, C.A., Budd, A.F., Collins, Wallace, C., Chuang, Y.Y., Chen, Dai, C.F., Iwao, K., Sheppard, C. & Knowlton, N. (2008). Mitochondrial and nuclear genes suggest that

- stony corals are monophyletic but most families of stony corals are not (order Scleractinia, class Anthozoa, phylum Cnidaria). *PLoS ONE*. **3**: e3222
- Garland, C.R. (1972). Report on the geology of sheet MD37-7, 1:250,000 scale Dallol area northern Ethiopia. Regional mapping division Ministry of Mines. Unpublished report, GSE, I.C. 0544/403.1 – 120 pp.
- Goreau, T.F. (1963). Calcium carbonate deposition by coralline algae and corals in relation to their roles as reef builders. *Ann. N.Y. Academy of Science*. **109**: 127 – 167.
- Gosling, E. (2004). *Bivalve Molluscs: Biology, Ecology and Culture*. Blackwell Science, UK. 1 – 443.
- Griffiths, H.I. & Holmes, M.C. (2000). Non-Marine ostracods and Quaternary paleoenvironments. *Quaternary Research Association*. **8**: 188.
- Grill, B. & Zuschin, M. (2001). Modern shallow to deep water bivalve death assemblage in the Red Sea – ecology and biogeography. *PALAEO*. **168**: 75 – 96.
- Gupta, A.K. (1997). Paleooceanographic and paleoclimatic history of the Somali Basin during the Pliocene–Pleistocene: Multivariate analyses of benthic foraminifera from DSDP Site 241 (leg 25). *Journal of Foraminiferal Research*. **27**: 196–208.
- Gupta, A.K. & Thomas, E. (2003). Initiation of Northern Hemisphere glaciation and strengthening of the northeast Indian monsoon: Ocean Drilling Program Site 758, eastern equatorial Indian Ocean. *Geology*. **31**: 47–50.
- Hammer, O., Harper D.A.T., & Ryan, P.D. (2001). Paleontological statistics software package for education and data analysis. *Paleontologia Electronica*. **4**(1): 1 – 9.
- Harper, D.A.T. (1999). *Numerical Paleobiology*. PAST manual 1999 – 2009. John Wiley and Sons, 103 pp.
- Hartmann, G. (1964). Zur Kenntnis der Ostracoden des Roten Meeres. *Kieler Meeresforsch* **20**:35–127.
- Hartmann, G. & Puri, H. (1974). Summary of Neontological and Paleontological Classification of Ostracoda. *Mitteilungen Hamburgisches Zoologisches Museum und Institut*. **7**: 7–73.
- Hatcher, B.G. (1997). Coral reef ecosystems: How much greater is the whole system than the sum of the parts? *Coral Reefs*. **16**: S77 – S91.
- Helal, S.A. & Abd El-Wahab, M. (2004). Recent Ostracodes from marine sediments of Safaga Bay, Red Sea, Egypt. *Egypt J. of Paleo*. **4**:75–93.

- Hill, J. & Wilkinson, C. (2004). *Methods for ecological monitoring of coral reefs*. Australian Institute of Marine Science. **1**: 1 – 117 pp.
- Hoeksema, B. & Cairns, S. (2015). Scleractinia. Accessed through: World Register of Marine Species at <http://www.marinespecies.org/aphia.php?p=taxdetails&id=1363> on 2017-2-23.
- Holmes, J.A. & Chivas, A.R. (2002). The Ostracoda. Applications in Quaternary Research. American Geophysical Union, Washington, DC. *Geophysical Monograph*. **131**: 5-36.
- Horne, D.J., Cohen, A. & Martens, K. (2002). Taxonomy, morphology, and biology of Quaternary and living Ostracoda. American Geophysical Union. *Geophysical Monograph*. **131**: 5–36.
- Huang, D., Arrigoni, R., Benzoni, F., Fukami, H., Knowlton, N., Smith, N.D., Stolarski, J., Chou, L.M. & Budd, A.F. (2016). Taxonomic classification of the reef coral family Lobophylliidae (Cnidaria: Anthozoa: Scleractinia). *Zool. J. Linn. Soc.*, **178**(3): 436-481.
- Huang, D., Benzoni, F., Arrigoni, R., Baird, A.H., Berumen, M.L., & Bouwmeester, J. (2014a). Towards a phylogenetic classification of reef corals: the Indo-Pacific genera *Merulina*, *Goniastrea* and *Scapophyllia* (Scleractinia, Merulinidae). *Zool. Scr.* **43**: 531–548.
- Huang, D., Benzoni, F., Fukami, H., Knowlton, N., Smith, N.D. & Budd, A.F. (2014b). Taxonomic classification of the reef coral families Merulinidae, Montastraeidae, and Diploastraeidae (Cnidaria: Anthozoa: Scleractinia). *Zool. J. Linn. Soc.*, **171**: 277–355.
- Ikeya, N., Tsukagoshi, A. and Horne, D. J. (2005). Preface: The phylogeny, fossil record and ecological diversity of ostracod crustaceans. *Hydrobiologia*. **538**: 7 – 13.
- James, N.P. (1979). *Reefs*. (Walker, R.G, ed.) Facies models. Geosci. Canada, Reprint series. **1**: 121 – 132.
- Janssen, R., Zuschin, M., & Baal Ch. (2011). Gastropods and their habitats from the northern Red Sea (Egypt: Safafga) Part 2: Caenogastropoda: Sorbioconcha and Littorinimorphia. *Annalen des Naturhistorischen Museums in Wien*. **113**(A): 373 – 509.
- Johanson, D.C. & Taieb, M. (1976). Plio – Pleistocene Hominid Discoveries in Hadar, Ethiopia. *Nature*. **260**: 293 – 298.
- Kalb, J.E. (1995). Fossil Elephantoids, Awash Paleolake Basin, and the Afar Triple Junction, Ethiopia. *PALAEO*. **114**: 357 – 368

- Kalus, R. (2015). *Coral reefs communities of the Central and Southern Red Sea: Sudan, Eritrea, Djibouti and Yemen*. (Rasul, N.M.A. and Stewart, I.C.F., eds). The Red Sea. Springer. Earth System Sciences. 409 – 451.
- Keyser, D., Aladin, N. & Plotnikov I. (2004). Ostracods and their adjustment to saline environments. *Mitt. Hamb. Zool. Mus. Inst.* **101**: 157 – 167.
- Kiessling, W. (2009). Geologic and Biologic Controls on the Evolution of Reefs. *Annu. Rev. Ecol. Evol. Syst.*, **40**: 173 – 192.
- Kiessling, W. & Baron-Szabo, R.C. (2004). Extinction and recovery patterns of scleractinian corals at the Cretaceous – Tertiary boundary. *PALAEO*. **290**: 11 – 19.
- Kiessling, W., Pandey, D., Gregory, S.M., Mewis, H. & Aberhan, M. (2011). Marine benthic invertebrates from the Upper Jurassic of northern Ethiopia and their biogeographic affinities. *J. African Earth Sci.*, **59**: 195–214.
- Kiessling, W., Simpson, C., Beck, B., Mewis, H. & Pandolfi, J.M. (2012). Equatorial decline of reef corals during last Pleistocene interglacial. *Proc. Natl. Acad. Sci.*, **109**: 21378–21383.
- Kleemann, K., 1992. Coral communities and coral- bivalve associations in the northern Red Sea at Safaga, Egypt. *Facies*. **26**:1 - 9.
- Kora, M.A., Ayyad, S.N. & El-Desouky, H.M. (2014). Pleistocene scleractinian corals from Marsa Alam area, Red Sea Coast, Egypt: systematics and biogeography. *Swiss J. Palaeontol.*, **133**: 77–97.
- Lemmens, J. (1993). Reef building corals (Cnidaria: Scleractinia) from the Watamu Marine National Reserve, Kenya; annotated species list. *Zool. Med. Leiden*. **67**(32): 453-465.
- Loeblich, A.R. & Tappan, H. (1964). Foraminifera of Sahul shelf and Timor Sea. *Cushman foundation for foraminiferal research special publication*, **31**:1 – 166.
- Martens, K., & Horne, D.J. (2009). *Ostracoda*. (Gene, E., ed.) Encyclopedia of Inland Waters. Elsevier, Oxford. **2**: 405–414.
- Merla, G. & Minucci, E. (1938). Mission geologica nel Tigray, Roma: *Regia Accademia Italiana*. 419 pp.
- Miruts Hagos, Bheemalingeswara, K., and Jemal Ahmed (2016). A preliminary Geological and Generalized Stratigraphy of Western Margin of Northern Afar Depression, Dallol Area, Northern Ethiopia. *Momona Ethiopian Journal of Science*. **8**(1):1-22.

- Mirutse Hagos (2011). Geochemical and Petrographic Studies of the Volcano-Tectonic Evolution of Northern Afar: Implications for the Structural Setup of the Actively Expanding Erta' Ale. Ph.D thesis, University of Vienna, Vienna, Austria. 239 pp.
- Mohammed, M., & Keyser, D. (2012). Recent ostracods from the tidal flats of the coast of Aden City, Yemen. Senckenberg, Gesellschaft für Naturforschung and Springer. *Mar Biodiv.* 1 – 35.
- Moore, R.C. (1956). *Treatise on Invertebrate Paleontology. Coelenterata. Part F.* Geological Society of America & University of Kansas Press. 498 pp.
- Moore, R.C. (1960). *Treatise on Invertebrate Paleontology, Mollusca 1. Part I.* Geological Society of America & University of Kansas Press. 351 pp.
- Moore, R.C. (1961). *Treatise on invertebrate Paleontology, Arthropoda, (Ostracoda). Part Q.* Geological Society of America & University Kansas Press. 422 pp.
- Moore, R. C. (1966). *Treatise on Invertebrate Paleontology, Echinodermata. Part U.* Geological Society of America and University of Kansas Press. **3**(1): 358 pp.
- Moore, R.C. (1969). *Treatise on Invertebrate Paleontology.* Part N. Geological Society of America & University of Kansas Press. **1**: 489 pp.
- Munef, M.A., Al-Wosabi M.A., Keyser D. & Al-Kadasi W. M. (2012). Distribution and taxonomy of shallow marine ostracods from northern Socotra Island (Indian Ocean)-Yemen. *Revue de Micropaleontologie.* **55**: 149 – 170.
- Paik, K.H. (1976). Rezente Ostracoden aus Oberflächen sedimenten des Persischen Golfs und des Golfs von Oman. PhD Thesis, University of Kiel. 406 pp.
- Parker, L.F. (1962). Planktonic Foraminiferal species in Pacific sediments. *The Micropaleontology Project Inc.* **8**(2): 219 – 254.
- Pillai, C.S.G., & Patel, M.I. (1988). Scleractinian corals from the Gulf of Kutch. *Journal of Marine Biological Association.* **30**(1-2): 54 –74.
- Pokorny, V. (1998). *Ostracoda.* (Haq, B.U. and Boersma, A. eds). Introduction to marine micropaleontology. Elsevier Science Singapore Pte Ltd. 109 - 149.
- Raymond, S. (1999). *Quaternary Paleoclimatology: Reconstructing Climates of the Quaternary,* 2<sup>nd</sup> ed. Academic Press. 613 pp.
- Raza, A., Bramanti, L., Perveen, R., & Shaukat, S.S. (2015). A new record of hard coral species *Galaxea fascicularis* (Linnaeus, 1767) of Sclerectinia, Family Occulinidae (Gray, 1847)

- collected from Paradise Point, Arabian Sea, Sindh Coast, Pakistan. *International Journal of Fauna Biology Study*. **2**: 12 – 15.
- Redfield, T.F., Wheeler, W.H & Often, M. (2003). Kinematic model for the development of the Afar Depression and its paleogeographic implications. *Earth and Planetary Science Letters*. **216**: 383–398.
- Riegl, B., & Piller, W.E. (1997). Distribution and environmental control of coral assemblages in Northern Safaga Bay (Red Sea, Egypt). *Facies*. **36**:141–162.
- Samyn, Y. (2003). Shallow water regular echinoids (Echinodermata: Echinoidea) from Kenya. *African Zoology*. **38**(2): 193 – 212.
- Samyn, Y., & Vanden-Burghe, E., (2000). Annotated checklist of Echinoderms from the Kiunga Marine National Reserve, Kenya. Part I Echinoidea and Holoturoidea . *Journal of East African Natural History*. **89**: 1 – 36.
- Scheer, G. & Pillai, C.S.G. (1983). Report on the stony Corals from the Red Sea. *Zoologica*. **133**: 198 pp.
- Shahin, A., (2005). Maastrichtian to Middle Eocene ostracodes from Sinai, Egypt: systematics, biostratigraphy and paleobiogeography. *Revue de Paléobiologie*. **24**(2): 749 – 779.
- Sheppard, C.R.C. (1998). Biodiversity patterns in Indian Ocean corals, and effects of taxonomic error in data. *Biodiversity and Conservation*. **7**: 847–868.
- Sheppard, C.R.C. & Sheppard, A.L.S. (1991). Corals and coral communities of Arabia. *Fauna Arabia*. **12**: 3 – 170.
- Sloan, N.A., Clark A.M. & Taylor, J.D. (1979). The echinoderms of Aldabra and their habitats. *Bulletin of the British Museum of Natural History (Zoology)* **37**:81-128.
- Stanley, G.D. (2003). The evolution of modern corals and their early history. *Earth Science reviews*. **60**: 195 – 225.
- Studencki, W. (1999). Red-algal limestones in the Middle Miocene of the Carpathian Fore deep in Poland: facies variability and palaeoclimatic implications. *Geological Quarterly*. **43**(4): 395 – 404.
- Tesfaye, S., Harding, D.J and Kusky, T. (2003). Early continental break-up boundary and migration of the Afar Triple Junction, Ethiopia. *Geological Society of America Bulletin*. **115**:1053 –1067.

- Thomas, F.C. and Murney, M.G. (1985). Techniques for Extraction of Foraminifers and Ostracods from Sediment Samples. *Canadian Technical Report of Hydrography and Ocean Sciences*. **54**: 45 – 52.
- Tortonese, P. (1980). Researchers on the coast of Somalia. Littoral Echinodermata. *Monitore Zoologico Italiano, N.S. Supplementi*. **13**: 237 – 250.
- Vaughan, T.W. & Wells, J.W. (1943). Revision of the suborders, families and genera of the Scleractinia. *Spec. Pap. Geol. Soc. Am.*, **44**: 1 – 363.
- Veron, J.E.N. & Pichon, M. (1976). Scleractinia of Eastern Australia. Families Thamnasteriidae, Astrocoeniidae, Pocilloporidae. Australian Institute of Marine Science. *Monograph Series*. **1**(1): 1 – 86.
- Veron, J.E.N. (1986). *Corals of Australia and the Indo-Pacific*. Angus and Robertson. Australian Institute of Marine Science. 644 pp.
- Veron, J.E.N. (1990). Checklist of the hermatypic corals of Vanuatu. *Pacific Sci.*, **44**: 51 – 70.
- Veron, J.E.N. (2000). *Corals of the world*. Australian Institute of Marine Science, Townsville. **3**: 1 – 324.
- Veron, J.E.N. (2013). Overview of the taxonomy of zooxanthellate Scleractinia. *Zool. J. Linn. Soc.*, **169**: 485 – 508.
- Veron, J.E.N. (2015). The potential type species to destabilize the taxonomy of zooxanthellate Scleractinia. Magnolia press. *Zootaxa*. **4048** (3): 433 – 435.
- Veron, J.E.N. & Pichon, M. (1980). Scleractinia of Eastern Australia. Part III. Families Agaraciidae, Siderastreidae, Fungiidae, Oculinidae, Merulinidae, Mussidae, Pectiniidae, Caryophylliidae, Dendrophylliidae. Australian Institute of Marine Science. *Monograph Series*. **4**: 1 – 471.
- Veron, J.E.N. & Pichon, M. (1982). Scleractinia of Eastern Australia Part V, Family Acroporidae. Australian Institute of Marine Science (AIMS) in association with Australian National University Press Canberra, London and New York. *Monograph Series*. **6**: 1 – 485.
- Veron, J.E.N. & Wallace, C. (1984). Scleractinia of Eastern Australia. Part IV, Family Poritidae. Australian Institute of Marine Science (AIMS). *Monograph Series*. **5**: 1 – 159.

**ANNEX – I: PLATES**

[addisshaiu.geo@gmail.com](mailto:addisshaiu.geo@gmail.com) or [Addis.Hailu@aaau.edu.et](mailto:Addis.Hailu@aaau.edu.et)

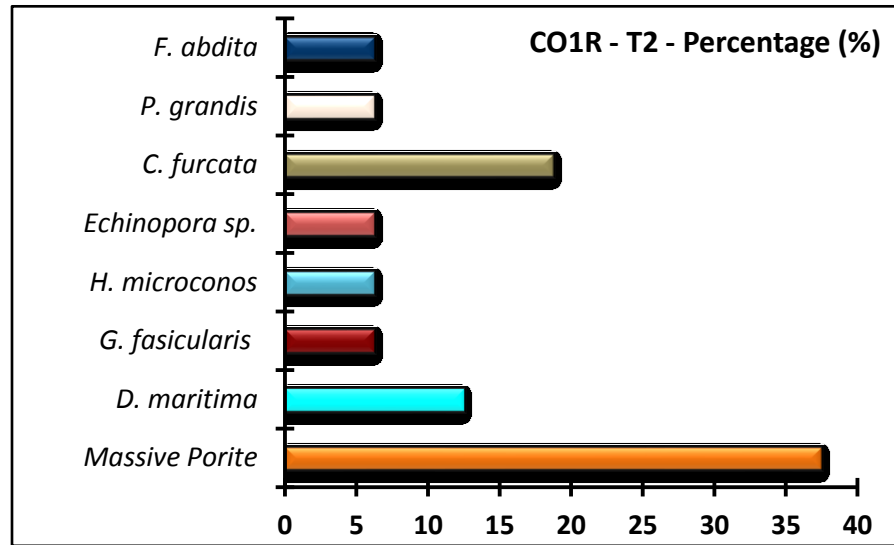
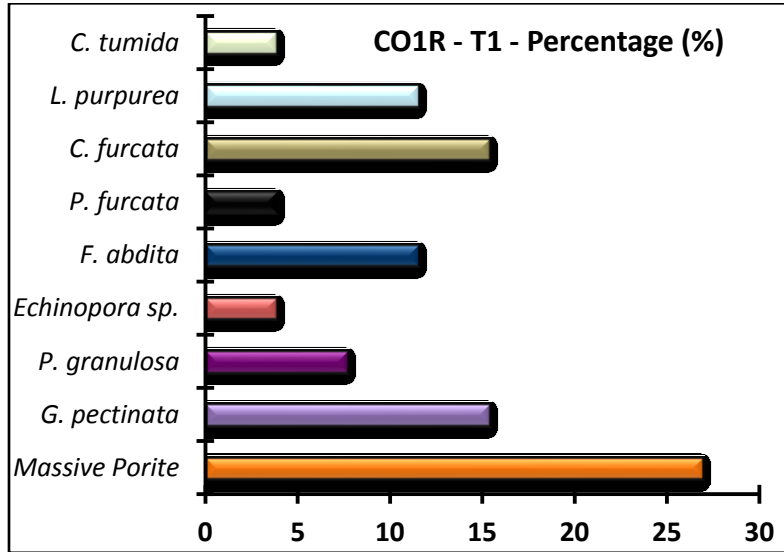
**Annex – II: Estimated diversity indices result from PAST analysis**

	Taxa_S	Individuals	Dominance_D	Simpson_1-D	Shannon_H	Evenness_e^H/S	Equitability_J	Fisher_alpha	Chao-1
<b>T1CO1R</b>	9	9	0.1111	0.8889	2.197	1	1	0	45
<b>Lower</b>	5	9	0.1358	0.716	1.427	0.81	0.8824	4.632	5.333
<b>Upper</b>	8	9	0.284	0.8642	2.043	0.9721	0.9826	34.61	22
<b>T2CO1R</b>	7	7	0.1429	0.8571	1.946	1	1	0	28
<b>Lower</b>	4	7	0.1429	0.6122	1.154	0.8668	0.8699	3.878	4
<b>Upper</b>	7	7	0.3878	0.8571	1.946	1	1	0	28
<b>T1CO1RC</b>	11	11	0.09091	0.9091	2.398	1	1	0	66
<b>Lower</b>	6	11	0.1074	0.7769	1.666	0.8306	0.9084	5.403	7
<b>Upper</b>	10	11	0.2231	0.8926	2.272	0.9698	0.9867	53.28	37
<b>T2CO1RC</b>	13	14	0.08163	0.9184	2.54	0.9754	0.9903	88.78	46
<b>Lower</b>	8	14	0.09184	0.8265	1.909	0.8272	0.9137	7.757	8.6
<b>Upper</b>	12	14	0.1735	0.9082	2.441	0.9571	0.9823	39.9	46
<b>T3CO1RC</b>	11	11	0.09091	0.9091	2.398	1	1	0	66
<b>Lower</b>	6	11	0.1074	0.7769	1.642	0.8368	0.9084	5.403	6.25
<b>Upper</b>	10	11	0.2231	0.8926	2.272	0.9698	0.9867	53.28	37
<b>T4CO1RC</b>	7	8	0.1563	0.8438	1.906	0.961	0.9796	26.78	14.5
<b>Lower</b>	4	8	0.1563	0.6563	1.213	0.8	0.8614	3.184	4
<b>Upper</b>	7	8	0.3438	0.8438	1.906	0.961	0.9796	26.78	16
<b>CO2</b>	14	15	0.07556	0.9244	2.616	0.9768	0.9911	102.6	53
<b>Lower</b>	9	15	0.08444	0.8444	1.991	0.8428	0.9222	9.5	10.2
<b>Upper</b>	13	15	0.1556	0.9156	2.523	0.9591	0.9837	46.48	47
<b>CO4</b>	6	7	0.1837	0.8163	1.748	0.9571	0.9755	19.95	11
<b>Lower</b>	4	7	0.1837	0.6122	1.154	0.7925	0.8322	3.878	4
<b>Upper</b>	6	7	0.3878	0.8163	1.748	0.9661	0.9755	19.95	11
<b>CO6</b>	18	22	0.06612	0.9339	2.815	0.9276	0.974	46.3	53

<b>Lower</b>	11	22	0.07025	0.8595	2.197	0.7739	0.8978	8.755	13.5
<b>Upper</b>	17	22	0.1405	0.9298	2.752	0.9436	0.9785	34.33	55
<b>T1CO7</b>	10	10	0.1	0.9	2.303	1	1	0	55
<b>Lower</b>	5	10	0.12	0.76	1.557	0.8262	0.8982	3.98	6.2
<b>Upper</b>	9	10	0.24	0.88	2.164	0.9673	0.9849	43.45	29
<b>T2CO7</b>	10	11	0.1074	0.8926	2.272	0.9698	0.9867	53.28	28
<b>Lower</b>	6	11	0.1074	0.7769	1.666	0.8306	0.9084	5.403	7
<b>Upper</b>	10	11	0.2231	0.8926	2.272	0.9698	0.9867	53.28	37
<b>T3CO7</b>	7	7	0.1429	0.8571	1.946	1	1	0	28
<b>Lower</b>	4	7	0.1429	0.6122	1.154	0.8668	0.8699	3.878	4
<b>Upper</b>	7	7	0.3878	0.8571	1.946	1	1	0	28
<b>T4CO7</b>	3	3	0.3333	0.6667	1.099	1	1	0	6
<b>Lower</b>	1	3	0.3333	0	0	0.9449	0	0.5252	1
<b>Upper</b>	3	3	1	0.6667	1.099	1	1	0	6
<b>CO18</b>	2	2	0.5	0.5	0.6931	1	1	0	3
<b>Lower</b>	1	2	0.5	0	0	1	0	0.7959	1
<b>Upper</b>	2	2	1	0.5	0.6931	1	1	0	3
<b>CO19</b>	3	3	0.3333	0.6667	1.099	1	1	0	6
<b>Lower</b>	1	3	0.3333	0	0	0.9449	0	0.5252	1
<b>Upper</b>	3	3	1	0.6667	1.099	1	1	0	6
<b>CO20</b>	5	5	0.2	0.8	1.609	1	1	0	15
<b>Lower</b>	2	5	0.2	0.48	0.673	0.8621	0.865	1.235	2
<b>Upper</b>	5	5	0.52	0.8	1.609	1	1	0	15
<b>T1CO20</b>	9	9	0.1111	0.8889	2.197	1	1	0	45
<b>Lower</b>	5	9	0.1358	0.716	1.427	0.8333	0.8824	4.632	5.333
<b>Upper</b>	8	9	0.284	0.8642	2.043	0.9721	0.9826	34.61	22
<b>CO21</b>	2	2	0.5	0.5	0.6931	1	1	0	3
<b>Lower</b>	1	2	0.5	0	0	1	0	0.7959	1
<b>Upper</b>	2	2	1	0.5	0.6931	1	1	0	3
<b>CO24</b>	7	8	0.1563	0.8438	1.906	0.961	0.9796	26.78	14.5

<b>Lower</b>	4	8	0.1563	0.6875	1.255	0.8	0.8614	3.184	4.5
<b>Upper</b>	7	8	0.3125	0.8438	1.906	0.961	0.9796	26.78	16
<b>T1CO27</b>	8	12	0.1806	0.8194	1.907	0.8418	0.9172	10.49	15.5
<b>Lower</b>	5	12	0.1389	0.6806	1.358	0.6999	0.8166	3.218	5.5
<b>Upper</b>	8	12	0.3194	0.8611	2.023	0.9449	0.9728	10.49	23
<b>T2CO27</b>	9	14	0.1429	0.8571	2.069	0.8798	0.9417	10.88	16.5
<b>Lower</b>	6	14	0.1327	0.7143	1.489	0.7333	0.8406	3.978	6
<b>Upper</b>	9	14	0.2857	0.8673	2.107	0.9481	0.9758	10.88	23
<b>CO28</b>	2	2	0.5	0.5	0.6931	1	1	0	3
<b>Lower</b>	1	2	0.5	0	0	1	0	0.7959	1
<b>Upper</b>	2	2	1	0.5	0.6931	1	1	0	3
<b>CO29</b>	7	7	0.1429	0.8571	1.946	1	1	0	28
<b>Lower</b>	4	7	0.1429	0.6122	1.154	0.8668	0.8699	3.878	4
<b>Upper</b>	7	7	0.3878	0.8571	1.946	1	1	0	28

**Annex – III: Percent abundance of species for each coral outcrops and transects**



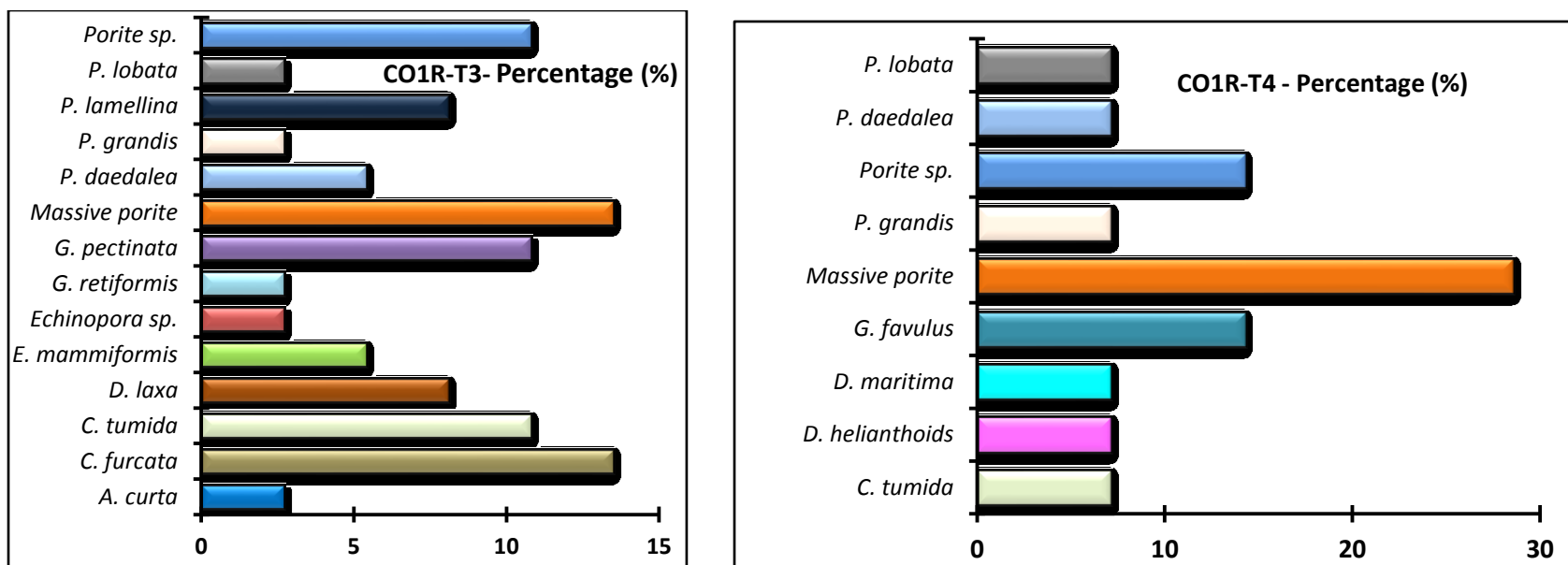
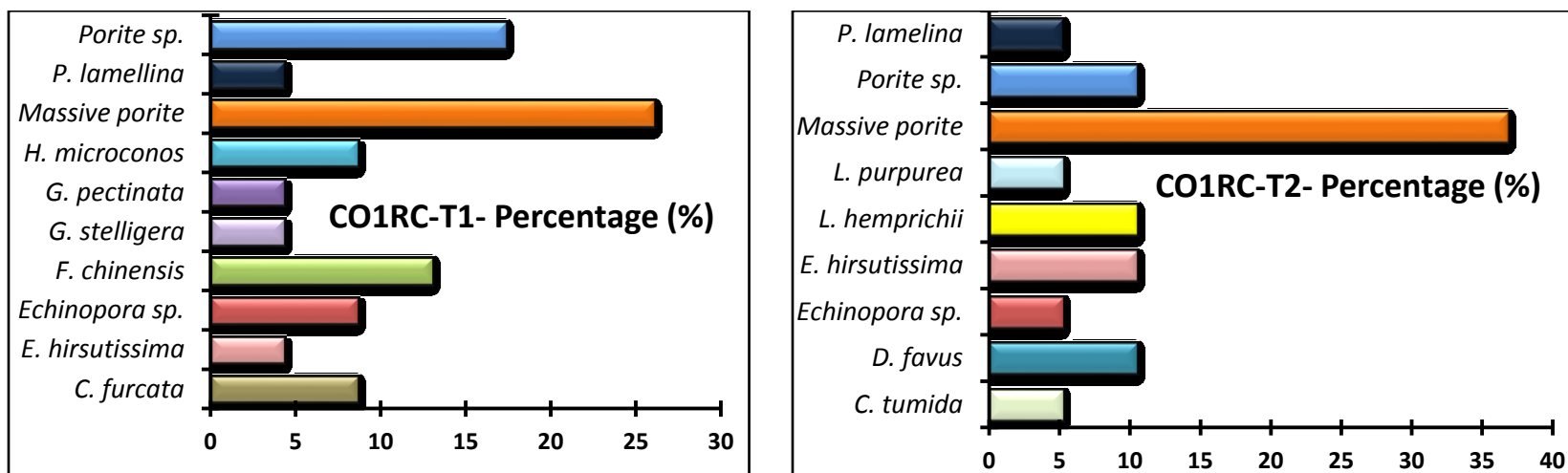


Fig.2.1. CO1R four transects percent abundance plot



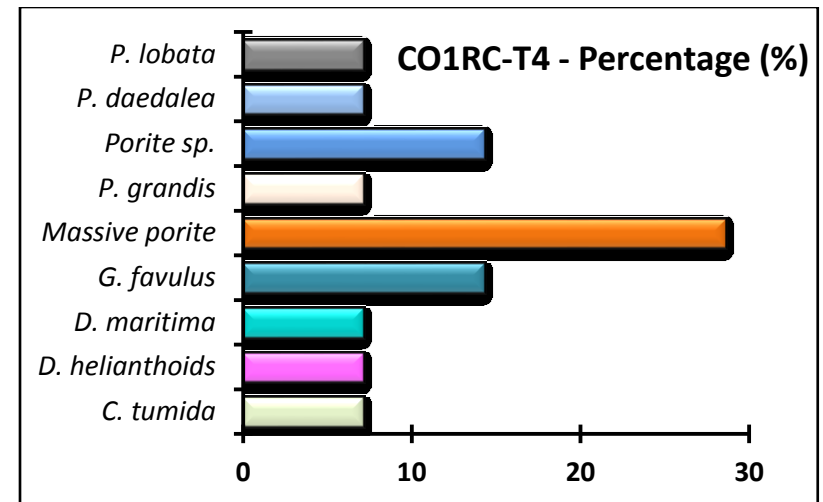
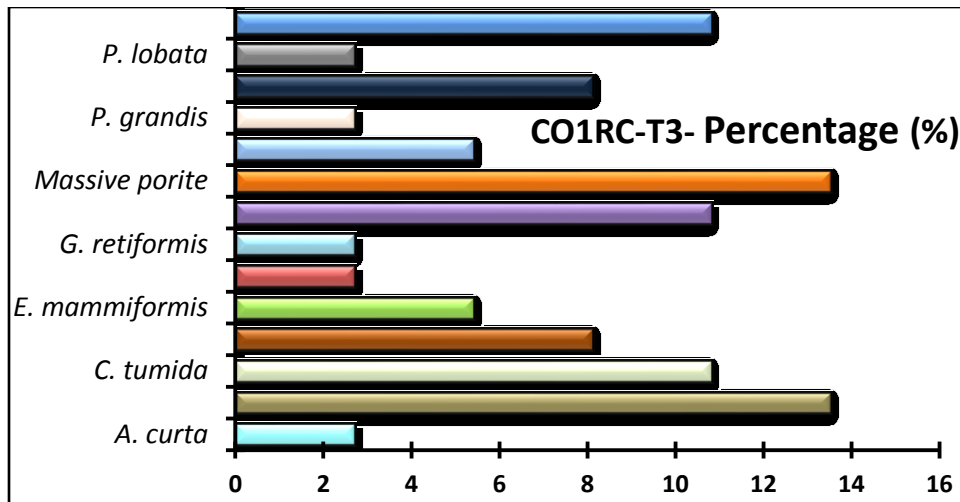
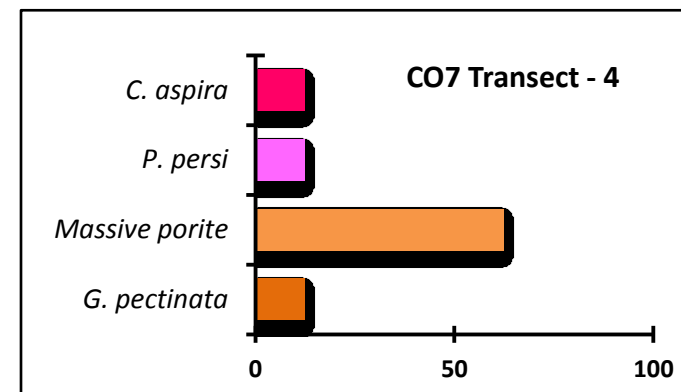
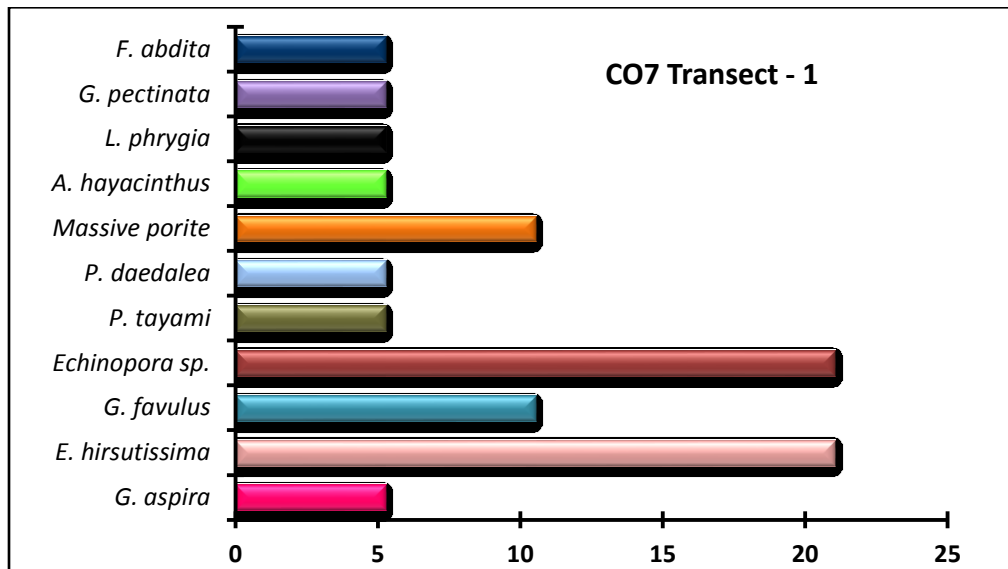


Fig.2.2. CO1RC four transects percent abundance plot



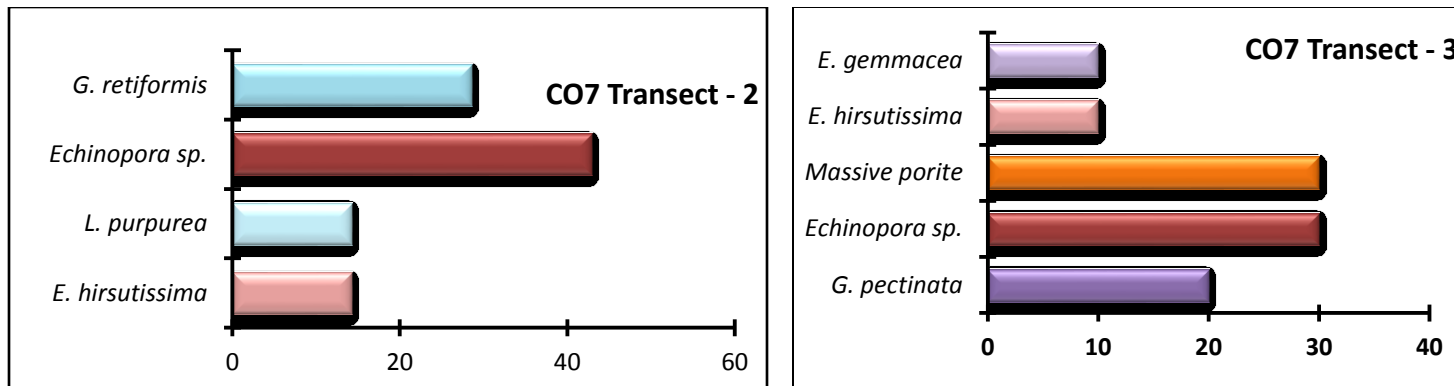


Fig.2.3. CO7 four transects percent abundance plot

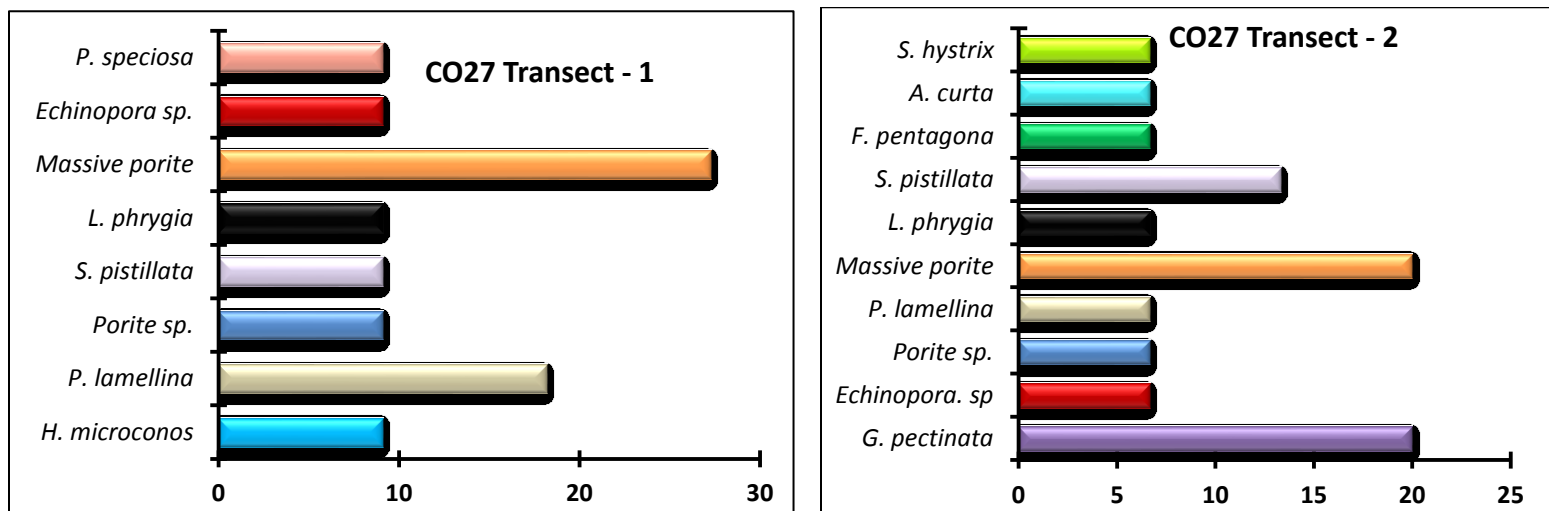


Fig.2.4. CO27 two transects percent abundance plot

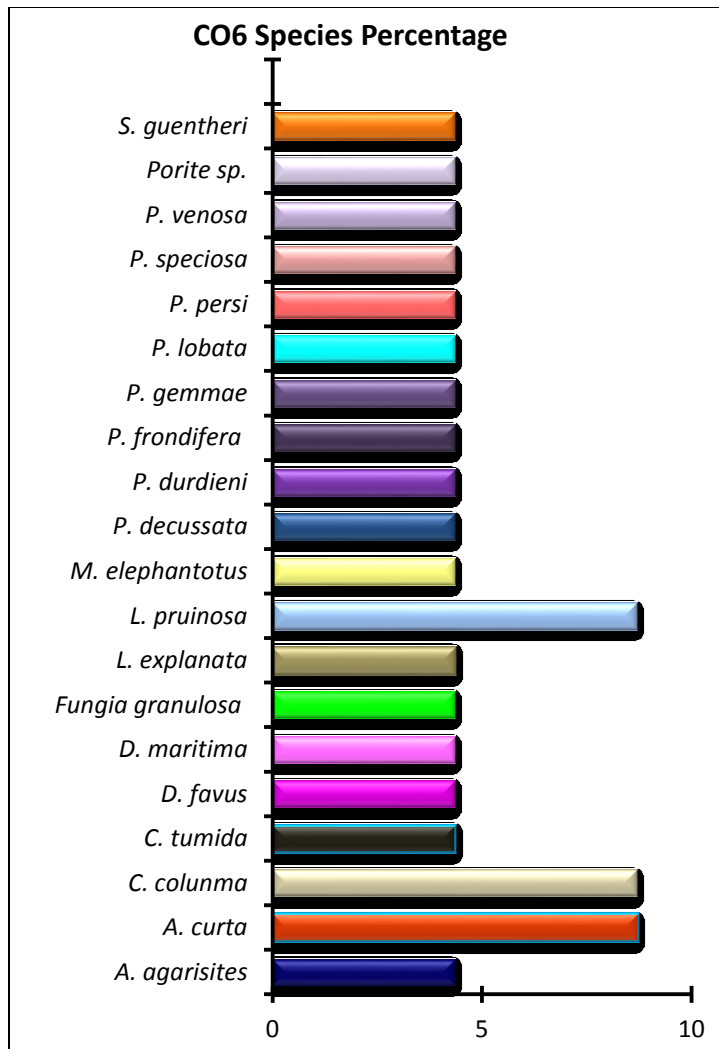


Fig.2.5. CO6 percent abundance plot

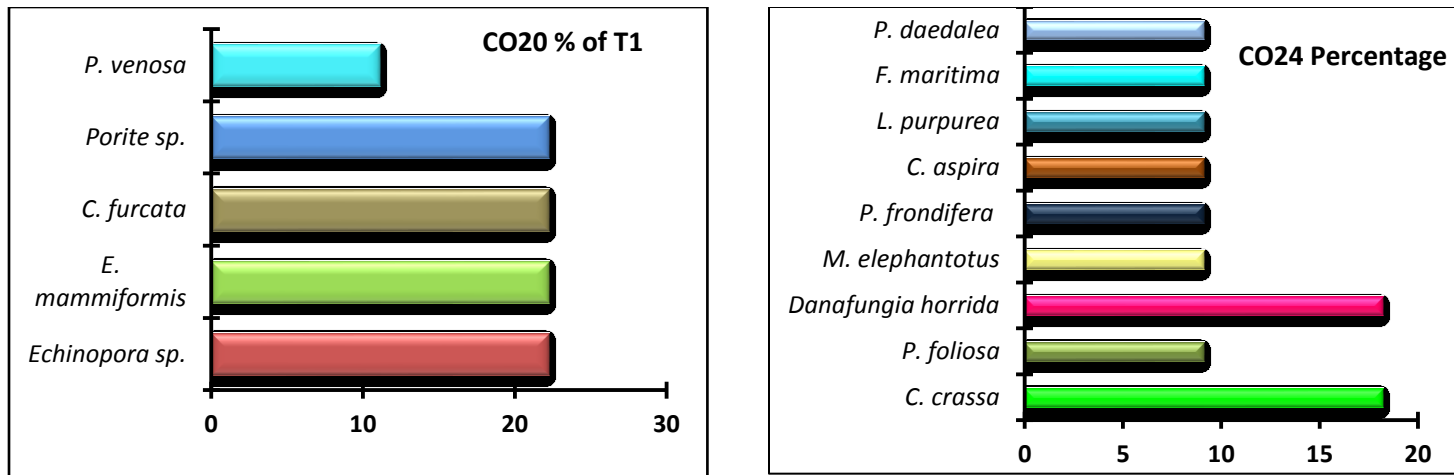


Fig.2.6. CO20 and CO24 percent abundance plot

**Annex – IV: Diversity Indices (PAST 3 Results)**

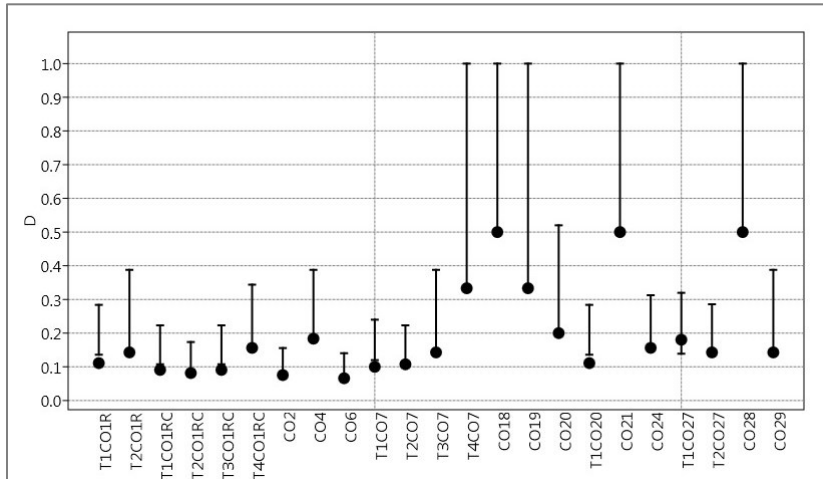


Fig.A. Dominance variation for the coral outcrops

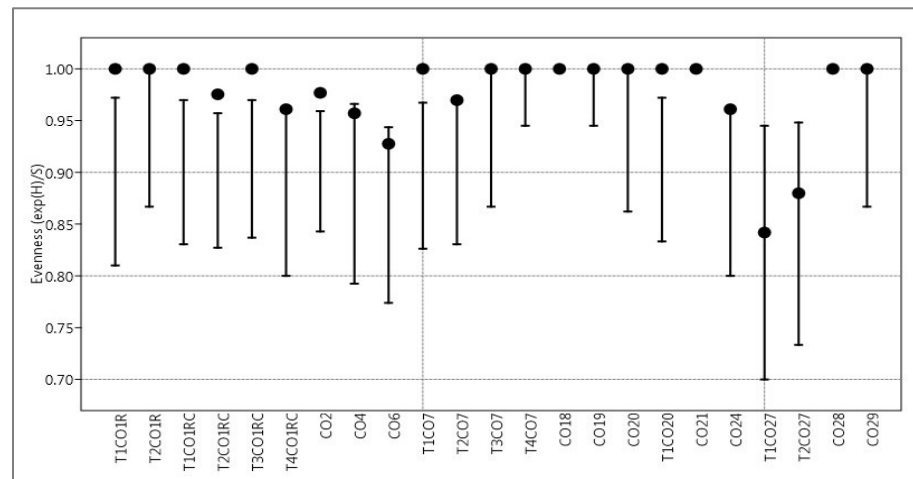


Fig.B. Evenness variation for the coral outcrops of the area

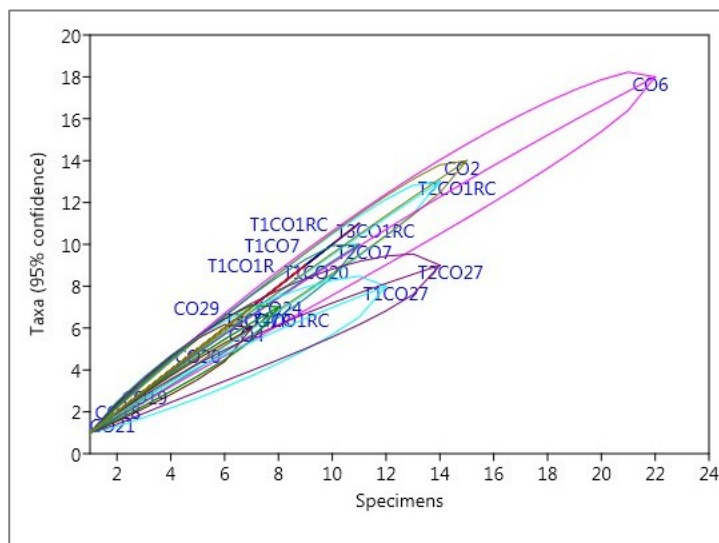


Fig.C. Individual rarefaction curve for each coral outcrops

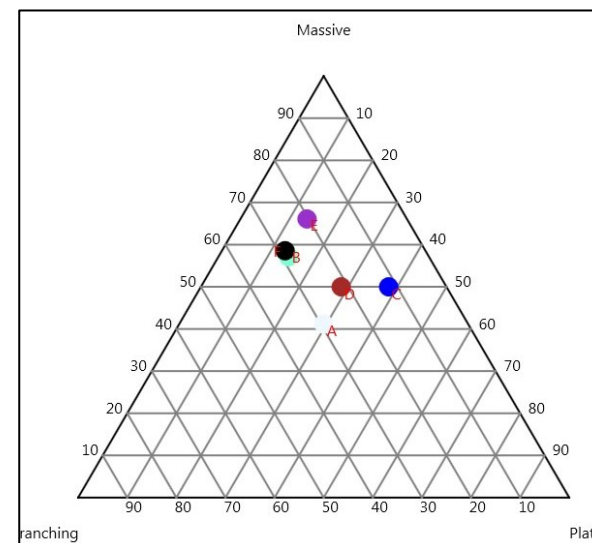


Fig.D. Ternary plot for coral colony morphology

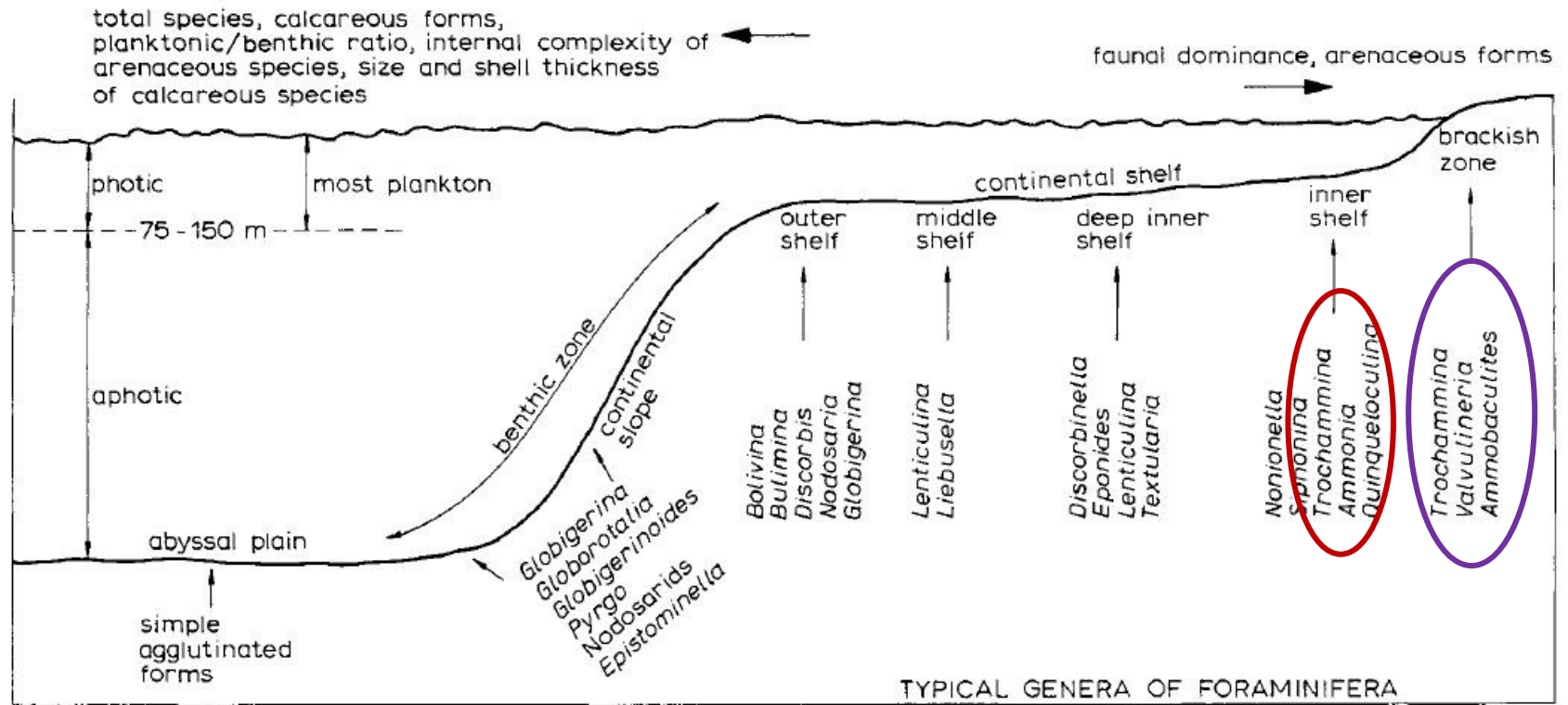
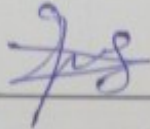


Fig. E. Distribution of Foraminifera genera (Source: Boersma, 1998)

## DECLARATION OF ORIGINALITY

I, the undersigned, declare that the thesis is original Master's Degree work under the supervision of Dr. Balemwal Atnafu, School of Earth Sciences; Addis Ababa University during the year 2017. I further declare that this work has not been presented or submitted by any other Universities or Institutions for the award of any other degree or diploma. All sources and materials used for the thesis have been accordingly acknowledged.

Addis Hailu Endeshaw



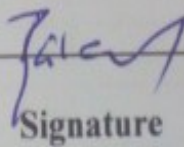
Signature

Nov. 10/2017

Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Dr. Balemwal Atnafu (Advisor)



Signature

Nov. 10/2017

Date