Miocene Evaporites of the Red Sea Coast, Egypt: Sedimentological studies.

A Thesis submitted to Geology Department, Faculty of Science, Zagazig University
As partial fulfillment for the degree of Master of Science in geology

BY
Gamal Abd Allah Abd El Fattah

Supervisors
Prof. Dr. Oussama M. El Badry
Geology department
Faculty of science
Zagazig University

Prof. Dr. F. M. Abu El- Enein  Prof. Dr. M. A. M. Aref
Geology department  Geology department
Faculty of science  Faculty of science
Zagazig University  Cairo University

2004
ACKNOWLEDGMENTS

I would like to thank Prof. Dr. Oussama El Badry Geol. Dept., Fac. of Sciences, Zagazig Univ. his continuous encouragement, support and for his valuable discussion are lightly appreciated.

Many thanks to Prof. Dr. Ezzat Abd-El Shafy the head of Geol. Dept., Fac. of Sciences, Zagazig Univ. for his continuous encouragement and facilities offered during the preparation of the thesis.

I would like to thank Prof. Dr. F. M. Abu El- Enein Geol. Dept., Fac. of Sciences, Zagazig Univ. for his continuous encouragement and support and for his valuable discussion during the preparing for this work.

I wish to express my deepest gratitude to Prof. Dr. M. A. M. Aref Geol. Dept., Fac. of Sciences, Cairo Univ. for his assistance during the fieldwork and collection of samples, analysis of samples at the laboratories of the institute of Geologische Wissenschaften und Geiseltalmuseum, Martin-Luther-Universität, Halle-Wittenberg, Germany. Preparing the thin sections and photo sampling under microscope, his constant supervision, kind helps, encouragement and support during the preparation of this work.

Thanks to the Geol. Dept. Fac. of Science, Zakazik Univ. and Geol. Dept. Fac. of Science, Cairo Univ. for facilities offered during the preparation of the thesis.

Thanks to all who helped me directly or indirectly during the progress of this work.

At last but not the least, I would like to express my gratitude and thanks to my family and my wife, who have encouraged me greatly and were behind the progress of this work.
## CONTENTS

### CHAPTER I: INTRODUCTION
- A – LOCATION .................................................. 1
- B – ACCESSIBILITY ........................................... 2
- C – TOPOGRAPHY ............................................. 2
- D – METHOD OF STUDY ..................................... 2
- E – PURPOSE .................................................. 3
- F – ECONOMIC IMPORTANCE .............................. 4
- G – AGE OF EVAPORITE .................................... 4

### CHAPTER II: GEOLOGIC SETTING .................................................. 6
- A. REGIONAL STRATIGRAPHY ............................... 6
- B. LOCAL STRATIGRAPHY ................................... 12
  1. BASEMENT ROCKS ........................................ 12
  2. CRETACEOUS ROCKS ..................................... 13
  3. THE MIOCENE SEDIMENTS ............................... 15
     1 - Ranga Formation (lower Miocene) ................ 15
     2 – Um Mahara Formation (Middle Miocene) ........ 15
     1 - Gebel El Rusas Formation ........................... 16
     2 – Abu Dabbab Formation ............................... 17
  4. THE MIOCENE – PLIOCENE (SAMH FORMATION) .......... 21
  5 - THE PRESENT WORK .................................... 34
     1-WADI GASUS AREA ....................................... 34
        A - surface sections .................................. 34
        B - subsurface sections ............................... 34
     2- WADI TEABAN AREA .................................... 39
        A - surface sections .................................. 39
        B - subsurface sections ............................... 39
     3- WADI WIZR AREA ....................................... 39
A- surface sections 39
B-subsurface sections 39

6. THE PLIOCENE 48
   A - GABIR FORMATION) 48
   B - SHAGARA FORMATION 48

7. RECENT DEPOSITS 48

CHAPTER III: PETROGRAPHY 50
1 – MASSIVE GYPSUM 52
2 – REGULAR LAMINATED GYPSUM 63
3 - MICROBIAL LAMINATED GYPSUM 63
4 – STROMATOLITIC GYPSUM 64
5 - NODULAR MOSAIC ANHYDRITE 65
6 - ENTEROLITHIC ANHYDRITE NODULES 65

CHAPTER IV: DIAGENESIS 79
1 - Porphyrotopic gypsum 86
2 - Poikilotopic gypsum 86
3 - Alabastrine gypsum 86
4 - Granular gypsum 87
5 – Selenitic gypsum 87
6 – Gypsum veins 88
   Mutual relationships between fabric types of secondary gypsum 88
   Origin of secondary gypsum 89

CHAPTER V: MINERALOGY AND GEOCHEMISTRY 96
1. MINERALOGY OF THE EVAPORITES 97
2. GEOCHEMISTRY OF THE EVAPORITES 97

CHAPTER VI: ENVIRONMENT OF DEPOSITION 113
1. The subaerial-supratidal environment (coastal sabkha and salina) 117
2. The subaqueous intertidal and subtidal environment (shallow subaqueous environment) 119

CHAPTER VII: SUMMARY AND CONCLUSIONS 123
## List of Figures

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure I-1</td>
<td>Location map of the studied Miocene evaporites in the Red Sea coastal plain of Egypt.</td>
<td>5</td>
</tr>
<tr>
<td>Figure II-1</td>
<td>Exposure of the Abu Dabbab evaporites in the Red Sea region.</td>
<td>22</td>
</tr>
<tr>
<td>Figure II-2</td>
<td>Slight folding of the Pliocene Samh Formation at Wadi Wizr.</td>
<td>22</td>
</tr>
<tr>
<td>Figure II-3</td>
<td>Lithic log of the evaporite sequence at the eastern gypsum quarry of Wadi Gasus.</td>
<td>24</td>
</tr>
<tr>
<td>Figure II-4</td>
<td>Lithic log of the evaporite sequence at the western gypsum quarry of Wadi Gasus.</td>
<td>25</td>
</tr>
<tr>
<td>Figure II-5</td>
<td>General views of the Miocene evaporite at Wadi Gasus.</td>
<td>26</td>
</tr>
<tr>
<td>Figure II-6</td>
<td>Selenite pocket with massive texture that enclosed in the white gypsum layers of Wadi Gasus.</td>
<td>26</td>
</tr>
<tr>
<td>Figure II-7</td>
<td>Black iron sulphide and yellow limonite from patches between the black crystals of gypsum.</td>
<td>27</td>
</tr>
<tr>
<td>Figure II-8</td>
<td>Nodular to enterolithic white anhydrite that form the top part of the gypsum quarry at Wadi Gasus.</td>
<td>28</td>
</tr>
<tr>
<td>Figure II-9</td>
<td>Exposure of the western gypsum quarry of Wadi Gasus area.</td>
<td>29</td>
</tr>
<tr>
<td>Figure II-10</td>
<td>Gradational contact between the gray gypsum layer and the yellow thin laminated gypsum.</td>
<td>30</td>
</tr>
<tr>
<td>Figure II-11</td>
<td>Irregular bodies of green mudstone that enclosed in the gypsum layers of Wadi Gasus gypsum quarry.</td>
<td>31</td>
</tr>
<tr>
<td>Figure II-12</td>
<td>A sharp contact between irregular pebbly sandstone bodies and the host gypsum layers.</td>
<td>32</td>
</tr>
<tr>
<td>Figure II-13</td>
<td>Different composition of the gravels that are floating in the pebbly sandstone bodies.</td>
<td>33</td>
</tr>
<tr>
<td>Figure II-14</td>
<td>Location map for the boreholes at Wadi Gasus area.</td>
<td>36</td>
</tr>
<tr>
<td>Figure II-15</td>
<td>Lithic logs of the boreholes at Wadi Gasus area.</td>
<td>37</td>
</tr>
<tr>
<td>Figure II-16</td>
<td>Lithic log of the evaporite sequence at the gypsum quarry of Wadi Teaban.</td>
<td>41</td>
</tr>
<tr>
<td>Figure II-17</td>
<td>Black gypsum layers enclose selenite pockets and white patches of gypsum.</td>
<td>38</td>
</tr>
<tr>
<td>Figure II-18</td>
<td>Location map for the boreholes at Wadi Teaban area.</td>
<td>42</td>
</tr>
<tr>
<td>Figure II-19</td>
<td>Lithic logs of the boreholes at Wadi Teaban area.</td>
<td>43</td>
</tr>
<tr>
<td>Figure II-20</td>
<td>Lithic log of the evaporite sequence at the eastern gypsum quarry of Wadi Wizr.</td>
<td>44</td>
</tr>
<tr>
<td>Figure II-21</td>
<td>Lithic log of the evaporite sequence at the western gypsum quarry of Wadi Wizr.</td>
<td>45</td>
</tr>
<tr>
<td>Figure II-22</td>
<td>Location map for the boreholes at Wadi Wizr area.</td>
<td>46</td>
</tr>
<tr>
<td>Figure II-23</td>
<td>Lithic logs of the boreholes at Wadi Wizr area.</td>
<td>47</td>
</tr>
</tbody>
</table>
Figure III-1 Random arrangement of bundles of cleavage flakes of gypsum of black and light brown color.

Figure III-2 Replacement of laminated gypsum by massive gypsum with sharp gradational contact.

Figure III-3 Inclined gypsum layers showing gradational contact between the lower black gypsum and the overlying yellowish gypsum.

Figure III-4 Petrographic log of the evaporite rocks at the eastern gypsum quarry of Wadi Gasus.

Figure III-5 Petrographic log of the evaporite rocks at the western gypsum quarry of Wadi Gasus.

Figure III-6 Petrographic log of the evaporite rocks at the eastern gypsum quarry of Wadi Wizr.

Figure III-7 Petrographic log of the evaporite rocks at the western gypsum quarry of Wadi Wizr.

Figure III-8 Petrographic log of the evaporite rocks at the gypsum quarry of Wadi Teaban.

Figure III-9 Stylolitic boundaries of coarse porphyrotopic gypsum, Polars Crossed.

Figure III-10 Long arms of porphyrotopic gypsum, Polars Crossed.

Figure III-11 Dense microbial micrite laminae intersect the growth of the porphyrotopic gypsum, Polars Crossed.

Figure III-12 Pseudomorphic replacement of prismatic anhydrite by poikilotopic gypsum, Polars Crossed.

Figure III-13 Clear poikilotopic gypsum cements the framework of pebbles fragments, Polars Crossed.

Figure III-14 Random arrangement of subhedral to euhedral gypsum crystals that form the massive structure of black gypsum, Polars Crossed.

Figure III-15 Corrosion of the coarse size porphyrotopic gypsum by patch of fine alabastrine gypsum, Polars Crossed.

Figure III-16 Long satin spar gypsum crystals filling fracture that enclose detached wall rock materials, Polars Crossed.

Figure III-17 Fracture in gypsum enriched in microbial micrite is filled with euhedral to subhedral granular gypsum, Polars Crossed.

Figure III-18 Thin microbial micrite mixed with fine silt in porphyrotopic and poikilotopic gypsum crystals, Polars Crossed.

Figure III-19 Polars crossed extinction of celestite in the micrite rich lamina, Polars Crossed.

Figure III-20 Irregular brownish thin microbial laminae interleminated with thicker white gypsum laminae.

Figure III-21 Irregular laminae of dense aggregates of microbial micrite, with scattered zoned dolomite crystals in poikilotopic gypsum, Polars Crossed.

Figure III-22 Random arrangement of coarse gypsum crystals that are dispersed in clayey material, Polars Crossed.

Figure III-23 Wavy, contorted thicker, white gypsum laminae and thinner, dark microbial laminae that formed laterally linked stromatolite type.

Figure III-24 Aggregates of variable size of nodular mosaic anhydrite, that form crust on the anhydrite exposure.

Figure III-25 Gradational contact between dark coloured gypsum at bottom and white
nodular anhydrite at top.

Figure III-26 Replacement of secondary gypsum by epigenetic prismatic anhydrite crystals, Polars Crossed.

Figure III-27 Secondary gypsum pseudomorphically replaces a square shaped precursor halite, and are replaced by felted epigenetic anhydrite, Polars Crossed.

Figure III-28 White enterolithic anhydrite nodules at bottom that change upward to mosaic anhydrite nodules.

Figure IV-1 Intertongueing relationship between black and yellow secondary gypsum.

Figure IV-2 Relics of anhedral anhydrite corroded and replaced by phorphyroblastic gypsum, through the intermediate stage bassanite, Polars Crossed.

Figure IV-3 Clear selenite masses that formed near the upper part of the gypsum sequence.

Figure IV-4 Flow chart for the formation of different crystal fabrics of gypsum under different diagenetic conditions.

Figure V-1 Graphical representation of the geochemical data of the studied gypsum.

Figure V-2 Graphical representation of the correlation coefficient in the studied gypsum.

Figure V-3 Euhedral celestite crystals randomly distributed in microbial laminites, Polars Crossed.

Figure V-4 Comparison of the relation between Sr (ppm) versus CaO (wt %), and SO$_3$ (wt %).
List of Tables

<table>
<thead>
<tr>
<th>Table No.</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Classification of Miocene rocks of the Red Sea coastal area according to different authors after Said (1990)</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Geochemical and mineralogical analyses of the studied Neogene evaporite deposits in Egypt</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Correlation coefficient for the studied elements (Wt %)</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

The Miocene evaporites extend for hundreds of kilometers along the coastal plain of the Red Sea. They have variable thicknesses, which increase generally toward the north. They have circular to elliptical patchy distribution and their thickness vary from 90 to 100 m on the coast while in the offshore area they have thickness up to 5000 m near the rift axis and are mainly composed of halite (Mokhtar, 1996). The sedimentology of the Miocene evaporites is the interest of many workers; among them are Youssef, (1988), Abdel Wahab and Ahmed (1987), Aref (1997), and Soliman (1994). They studied nearly weathered evaporite samples from outcrop or wadi courses.

A - Location:

In the present work three quarries in three different localities along the Red Sea coastal plain are chosen for the study. They are Wadi Gasus, Wadi Teaban, and Wadi Wizr from north to south (Fig. I-1). They provide fresh evaporite samples in contrast to the weathered surface exposure of the evaporite in the Red Sea region. This study also depends on the data obtained from fresh samples from 50 boreholes in the three studied quarries, 20 boreholes from Wadi Gasus, 20 boreholes from Wadi Teaban, and 10 boreholes from Wadi Wizr.

The three quarries are situated along the coast of the Red Sea from Safaga to the south of Quseir by about 40 km (Fig. I-1). These are from north to south; Wadi Gasus Quarry, Wadi Teaban Quarry, and Wadi Wizr Quarry.

1-Wadi Gasus Quarry

Wadi Gasus is located along the Red Sea coast south of Safaga City by about 29 km between latitudes 26º 34´ 05´´ and 26º 36´ 10´´ N and longitudes 33º 55´ 25´´ and 33º 58´ 25´´ E. Wadi Gasus Quarry consists of several small quarries that located west of Safaga - Quseir asphaltic road by about 10 km, and covers an area of about 7 km².
2 – Wadi Teaban quarry

Wadi Teaban quarry is located along the Red Sea coast north of Hamrawein City by 1 km, between latitudes 26° 17’ 30” and 26° 19’ 30” N, and between longitudes 34° 07’ 20” and 34° 09’ 30” E. It extends to the west of Safaga - Quseir road for about 5 km, and covers an area of about 3.4 km².

3 – Wadi Wizr quarry

Wadi Wizr quarry is located along the Red Sea coast south of Quseir city by 40 km, along Quseir - Mersa Alam asphaltic road, between latitudes 25° 43’ 50” and 25° 45’ 50” N, and longitudes 34° 25’ 00” and 34° 27’ 30” E. It extends to the west of Quseir - Mersa Alam asphaltic road for about 10 km, and covers an area of about 3.5 km².

B - Accessibility

The main Red Sea road provides good access to the studied quarries. The three quarries have also good access for four wheels drive cars through the asphaltic roads and tracks belonging to the former Red Sea Phosphate Company.

C – Topography

The studied areas are bounded to the east by the recent sediments of the shoreline of the Red Sea. Most of the sedimentary rocks in the three studied areas are of relatively moderate to low relief and their elevation decrease generally towards the shoreline, the evaporite hills and their mantle of anhydrite are the most conspicuous physical features of the areas. The studied areas are characterized by drainage patterns of denderitic type, where the three main wadies of Gasus, Teaban, and Wizr slope gently from west to east.

The studied areas are bounded from the west by the Middle and Upper Cretaceous formations (Nakheil, Thebes, Esna, Tarawan, Dakhla, Duwi and Quseir), and other formations of the Nubia Sandstone group.

D – Method of study

This work is based on field examination of the Miocene evaporites in three wadies (Wadi Gasus, Wadi Teaban and Wadi Wizr). In the studied locations, detailed field sampling of fresh evaporite rocks are available through five quarries. Field check up of the different
lithologic units is made through wadi courses or outcrops. The subsurface data are obtained from a number of boreholes made by the Egyptian Geological Survey to the former Red Sea Phosphate Company. The boreholes have an average depth of 20 m. The sampling spaces ranges from 5 to 10 cm. 10 boreholes are covering the three wadies (4 boreholes in Wadi Gasus, 4 boreholes in Wadi Teaban, and 2 boreholes in Wadi Wizr).

Petrographic examination of the evaporite rocks is based on the study of 60 thin sections and 30 polished slabs. The thin sections are made at the lab of Cairo University under dry cool condition with epoxy cement. These conditions prevent the alteration and dehydration of the gypsum, hydration of anhydrite, or solution of halite.

Twenty-one gypsum samples were selected and analyzed by XRD and XRF at the laboratories of the institute of Geologische Wissenschaften und Geiseltalmuseum, Martin-Luther-Universität, Halle-Wittenberg, Germany. All samples were pulverized in a disc mill to 63 µm plus/minus 2 µm for later analyses, followed by drying at 22 °C and 35 % relative humidity for a good reproduction. Each sample was pressed to a tablet (10 mm high and 40 mm diameter) for XRD analysis using the new generation of PAN-analytical Philips Powder-Diffractometer. Each sample was very well crystalline for X-Ray investigations by XRD. The XRD adjustment for each X-Ray investigation ranged from 3° to 55° 2θ; count time: 1.0 second, step size: 0.02 degrees, at room temperature of 22°C, also the samples were prepared by the same person for minimizing the human errors. The quality of the X-Ray diffractograms was excellent and showed crystalline phases over 1% in the sample.

The conditions for XRF were adjusted to semi quantitative analysis using an equipment of Siemens SRS3000, X-Ray tube: Rh-Anode.

**E- PURPOSE**

This study is concerned with the Miocene evaporites (gypsum and anhydrite) in the Red Sea gypsum quarries. The studied areas are believed as the sites of concentration of high-grade gypsum (CaSO₄ over 90 %) that exploited by Red Sea Phosphate Company for the extraction of gypsum and anhydrite rocks of different grades, which are used for many industries in Egypt and also for export to other countries.

Also the purpose of the present work is to study the different textures and fabrics of the gypsum and their mutual interrelationship, which help in the interpretation of the depositional and diagenetic environments of the gypsum. The inflow of hydration water and
exhumation history of the evaporites are dealt with, aiming to give useful information about the origin of gypsum in the northern Red Sea coastal plain of Egypt.

F- ECONOMIC IMPORTANCE

The Red Sea Phosphate Company (RSPC) started the exploration of high grade gypsum in the Miocene evaporites of the Red Sea region since 1989. They discovered three localities which are Wadi Gasus, Wadi Teaban and Wadi Wizr. The RSPC exploit about 100,000 ton of high grad gypsum for export to different countries, especially for Saudi Arabia and United Arab Emirates.

In Egypt, gypsum is used in the manufacture of gypsum for building purposes, in cement industry, and for agriculture. On the other hand the anhydrite is used in the manufacture of high weighted wall, which is used in some building purposes.

G. AGE OF EVAPORITE

The age of the Red Sea evaporites are controversial among different authors because of the absence of fossils. They are believed to be of Middle Miocene age in the Quseir area (Beadnell, 1924; Souaya, 1963; Akkad and Dardir, 1966), while in Safaga area, the evaporites are of Langhanian age (Thiriet et al 1986). Montenat et al, (1986); Purser et al (1990), considered the evaporites in the NW Red Sea to belong to Middle to Upper Miocene age (Serravallian – Tortonian), that can also be extended to Quseir – Safaga area according to Soliman (1994).
Figure I – 1 Location map of the studied Miocene evaporites in the Red Sea coastal plain. (Wadi Gasus, Wadi Teaban and Wadi Wizr)
GEOLOGIC SETTING

A. REGIONAL STRATIGRAPHY


Beadnell (1924) in his work between Quseir and Wadi Ranga classified the Miocene section into the following units:

- Upper Miocene - Ostrea – Pecten Series
- Middle Miocene - Gypseous Series
  - Brackish water marls and sandstones
  - Massive gypsum with oil tainted limestone
  - Basal group

Waring and Jones (1940) in their unpublished work on the Red sea coastal plain between latitudes 23° 30´ and 25° 20´ N classified the Miocene - Pliocene section into the following units arranged from younger to older:

- Pliocene - Wadi Gasus beds
- Middle Miocene - Gypseous series
  - Limestone series
  - Abu Hamra beds

Thiebaud (1943) in his work on the Red sea coastal plain between Safaga and Ras Benas divided the Miocene rocks into the following units arranged from younger to older:

- M4 - Sands and Gravels
- M3 - Marls, marly limestone with sandstone and shales
- M2 - Gypsum
- M1 - Calcareous sands and gravels
Said (1962) revised earlier literatures and proposed the following units for the Miocene - Pliocene sections:

- **Pliocene**
  - *Clypeaster – laganum series*
  - *Oyster and cast beds*

- **Miocene**
  - Evaporite series
  - Basal limegrits

El-Akkad and Dardir (1966) in their work on the Red sea coastal plain between Ras Shagra and Mersa Alam proposed the following rock units:

- **Pliocene**
  - *Shagra Formation*
  - *Gabir Formation*

- **Miocene**
  - *Samh Formation*
  - *Gypsum Formation*
  - *Gebel El – Rusas Formation*

Ghorab and Marzouk (1967) in their work on the Miocene non-marine and coastal facies of the Gulf of Suez, tried to extend their units to the Red Sea coastal plain. Although their units were satisfactory correlated with the lower clastic and middle evaporite units of the Red Sea. Yet the upper clastic units of the Red Sea coastal plain are still incorrelatable.

Dardir (1968) proposed the following rock units to represent the Miocene rocks between Hurghada and Ras Benas:

- **Top**
  - *Samh Formation*
  - *Taref Formation*

- **Bottom**
  - *Gebel Rusas Formation*

Issawi et al. (1971) applied the following rock units in Safaga - Quseir coastal plain:

- **Top**
  - *Gasus Formation*
  - *Gypsum Formation*

- **Bottom**
  - *Gebel El Rusas Formation*

El Bassyony (1971) proposed the following rock units to represent the Miocene rocks of the Red Sea coastal plain:

- **Top**
  - *Samh Formation*
  - *Abu Dabbab Formation*

- **Bottom**
  - *Gebel El Rusas Formation*
The Miocene rocks of the Red Sea coastal plain were reviewed by NSC (1974), where they differentiated the Miocene rocks into one group and two formations. Zug El Bahar Group represents all the Miocene rocks of the Red Sea coastal plain. It is classified into the following two formations and two informal members arranged from younger to older:

- Abu Dabbab Formation
- Gebel El Rusas Formation
  - Upper Calcareous Member
  - Lower Clastic Member

Where possible the Miocene-Pliocene rocks were represented by the so-called Samh Formation, which is undifferentiated from the overlying Pliocene Formation. The formal name Gasus Formation is applied to represent the undifferentiated Samh, Gabir and Shagra formations.

According to the National Committee of Geological Sciences of Egypt, 1974, no lower or upper Miocene rocks were reported from the Red Sea coastal plain, where all the Miocene formations are of middle Miocene age (NSC op. cit.). Gebel El Rusas and Abu Dabbab formations in the Red Sea region correlate well with Abu Gerfan and Ras Malaab formations of the Miocene in the Gulf of Suez region.

Samuel and Saleeb-Roufaiel (1977) on their study on Abu Ghusun – Um Mahara area subdivided the Miocene sequence into:

- Top: Samh Formation
  - Um Gheig Formation
  - Abu Dabbab Formation
    - Gypsum – Anhydrite Member
    - Conglomerate Member
  - Um Mahara Formation
    - Fossiliferous limestone Member
    - Sandy limestone Member
- Base: Ranga Formation

El – Khadragy (1980) studied the sedimentology and geochemistry of some Miocene deposits in 5 localities (Wadi Sifien, Gebel El Rusas, Wadi Abu Dabbab, Um Ghaig and Sherm El Bahari) between Quseir and Mersa Alam, Red Sea Coast. He recognized five rocks units arranged from base to top as follows:
Hammad (1981) dealt with the sedimentology and geochemistry of some Miocene rocks cropping out between Esh El Mellaha and Quseir, he recorded four formations from older to younger as follows:

**Younger**
- Sherm El Bohari Formation
- Abu Dabbab Formation
- Carbonate Formation

**Older**
- Clastic Formation

Philobbos et al. (1983) classified the Miocene and younger sediments in Quseir – Safaga area into the following rock units:

**Top**
- Wadi Alluvium
- Terraces and raised beaches

**Pleistocene**
- Shagra Formation
- Gasus Formation

**Pliocene**
- Abu Dabbab evaporites
- Gebel El Rusas formation

El Haddad (1984) gave the following rock units for the Miocene and later sediments in the Red Sea coast:

**Top**
- Mobarak Group
  - B- Shagara Formation
    - 2-Sharm El Arab Member
    - 1-Dashet El Dabaa Member
  - A-Mersa Alam Formation
    - 2-Abu Shigeili Member
    - 1-Wizr Member

**Zug El Bohar Group**

| Miocene | 1-Middle – Upper Miocene |
E-Um Gheig Formation
D-Abu Dabbab Formation
C-Siyatin Formation
B-Um Mahara Formation
A-Ranga Formation

\{ Middle Miocene \}

A-Lower Miocene

El Badry et al, 1986. On their study along the Red Sea Coast (south of Wadi Bali) denoted lithostratigraphic unites of Middle Miocene age from the oldest to youngest are: Gebel El Rusas formation; Ambaut Formation; Abu Dabbab Formation; Eassal Formation; and Sherm El Bahari Formation.

Abdel Wahab and Ahmed (1987) differentiated the Miocene rocks into:

Top

2-Abu Dabbab Formation
1-Gebel El Rusas Formation

B-Upper carbonate Member
A-Lower clastic Member

Soliman (1994) mentioned that the Miocene evaporites in the Quseir – Safaga district comprise two distinct units, which are;

1- The earlier unit consists of thick evaporite beds (individual bed is up to 6 m thick) this unit has a very limited extension, localized only within subsiding peripheral grabens at wadi Gasus. The Oligocene-Early Miocene age is assigned to this unit.

2- The second evaporite unit is well exposed along the Red Sea coastal plain. The age of this major unit is Middle Miocene in the Quseir area (Beadnell, 1924; Souaya, 1963; Akkad and Dardir, 1966).

In the Safaga area Thiriet et al., (1986) assigned a Langhanian age to the second evaporite unit. On the other hand, Montenat et al. (1988) and Purser et al. (1990) considered the evaporite unit in the NW Red Sea to belong to the Middle to Upper Miocene age. Soliman (1994) denotes also Middle to Upper Miocene age for the evaporite in the Quseir-Safaga district. Also, Mahran et al. (1999), in their study on south of wadi Abu Ghusun denotes Middle to Upper Miocene age for the evaporite.

In summary, the sedimentary sequence in the Red Sea coastal plain ranges in age from upper Cretaceous to Holocene and includes an important stratigraphic hiatus of upper Eocene – Oligocene age Sellwood and Netherwood, (1984). The Neogene sediments form three well-pronounced belts parallel to the present shore of the Red Sea Philobbos et al., (1985). The
Red Sea coastal plain is covered mainly by sedimentary rocks unconformably overlying the Precambrian – Cambrian crystalline rocks, they are represented mainly by Miocene, Pliocene and Pleistocene sediments (El Aref et al., 1985).

Formations below this break suggest sedimentation unrelated to the present Red Sea rifting Purser et al., (1987), Neogene sediment above this hiatus have been deposited in a basin whose origin is intimately related to the rifting and drifting of African and Arabian plates whose modern expression is the Red Sea Purser et al., (1987), The western older Miocene belt unconformably overlies either Cretaceous-Eocene sequence or the Red Sea basement range.
### B. LOCAL STRATIGRAPHY

The general stratigraphy of the exposed rocks in the investigated areas is described under the following rock units from base to top:

<table>
<thead>
<tr>
<th>Rock Formation</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Holocene deposits</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>- Shagara Formation</td>
<td></td>
</tr>
<tr>
<td>- Gabir Formation</td>
<td>Pliocene</td>
</tr>
<tr>
<td>- Samh Formation</td>
<td></td>
</tr>
<tr>
<td>- Um Gheig Formation</td>
<td></td>
</tr>
<tr>
<td>- Abu Dabbab Formation</td>
<td></td>
</tr>
<tr>
<td>- Um Mahara Formation</td>
<td></td>
</tr>
<tr>
<td>- Ranga Formation</td>
<td></td>
</tr>
<tr>
<td>- Basalt Flow</td>
<td>Oligocene</td>
</tr>
<tr>
<td>- Thebes Formation</td>
<td>Eocene</td>
</tr>
<tr>
<td>- Esna Formation</td>
<td>Paleocene</td>
</tr>
<tr>
<td>- Tarawan Formation</td>
<td></td>
</tr>
<tr>
<td>- Dakhala Formation</td>
<td></td>
</tr>
<tr>
<td>- Duwi Formation</td>
<td></td>
</tr>
<tr>
<td>- Nubia Formation</td>
<td>Cretaceous</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>B-Quseir Clastic Member</td>
<td></td>
</tr>
<tr>
<td>A-Taref Sandstone Member</td>
<td></td>
</tr>
<tr>
<td>- Basement rocks</td>
<td>Precambrian</td>
</tr>
</tbody>
</table>

### 1. BASEMENT ROCKS

The basement rocks include various igneous and metamorphic rocks. The pink granite is the common rock type in the studied areas and occupies an area of high relief. The basement rocks were studied by many authors (e.g. Said, 1962; and Sabet 1972.)
2. CRETACEOUS ROCKS

In the Quseir-Safaga area the Nubia group rest unconformably over the basement complex. The beds occupy many of the topographic lows and are divided into two units. The lower unit is 200 m thick and is made up of seemingly non-fossiliferous sandstone beds with intercalations of mudstones. The upper unit is 70 m thick and is made up of variegated shales of the Quseir Formation (Said 1990).

In Wadi Teaban and Wadi Gasus areas, the Cretaceous sediments (Nakheil, Thebes, Esna, Tarawan, Dakhla, Duwi (phosphate) and Nubian formations) overlie unconformably the basement rocks and underlie unconformably the middle Miocene rocks.

Nubian Formation:

The Nubian Formation is represented by the two Members, Taref Sandstone Member, and Quseir Clastic Member. The Taref Sandstone Member passes gradually into the overlying Quseir Clastic Member. In Quseir region, Youssof (1957) used the term Quseir variegated shales for the varicolored shales below the phosphate bearing beds and above the Taref Sandstone. In the studied areas this rock unit makes the slope of the main outcrops underlying the Duwi Formation. It consists of relatively thick sequence of varicolored shales with minor sandstone beds. The upper part of this unit includes a number of phosphate beds. The thickness of this unit ranges from 30 to 40 m.

Duwi (phosphate) Formation:

In Quseir-Safaga region, the Duwi Formation is represented by three phosphate horizons separated by beds of marl, shale and oyster limestone with flint. The middle horizon (the Duwi or B- beds) is exploited in the Safaga mines. It is mad up of several phosphate beds separated by thin shales, marl and silicified limestone beds. The upper phosphate horizon (the Atshan or A-beds) is exploited in the Quseir area. This horizon is made up of phosphate beds (between 3 and 7), which are separated by shales and marls (Said 1990).

In Wadi Teaban and Wadi Gasus areas, the Duwi (phosphate) Formation is made up of marly shale, marly limestone, oyster limestone beds and sandstone intercalations. The phosphate beds in Duwi Formation are mined in both Wadi Teaban and Wadi Gasus areas by
the former Red Sea Phosphate Company as open cast in some localities and as underground mines on other localities for the production of Phosphate ore.

**Dakhla Formation:**

The Dakhla Formation is formed of alternating shales, marls in its lower part and a thick succession of shales resembling the Esna Shale in its upper part. The thickness of this Formation in the Safaga area ranges from 40-50 m.

**Tarawan Formation:**

The Tarawan Formation is made up of marl to marly limestone and ranges in thickness from 8 to 12 m.

### 3 – PALEOCENE-EOCENE ROCKS

**Esna Formation:**

It is made up of gray laminated shales; its thickness in the Quseir-Safaga area varies from 16-54m (Said, 1990).

**Thebes Formation**

The Thebes Formation makes up the top part of all the high land in the study areas. It caps Esna Formation and makes the main cliff and plateau surface. Lithologically, the Thebes Formation consists of thick limestone beds with flint bands, which increase at the top, whereas the lower part is chalky and the contact with the underlying Esna Formation is gradational.

**Nakheil Formation**

The Nakheil Formation (Akkad and Dardir, 1966) overlies the Thebes Formation and consists of thick section of breccia beds interbedded with fine-grained lacustrine sediments made up of varicolored limestones, clays and sandstones. This formation is widely spread in the Quseir-Safaga district and may reach a thickness of 60 m or more (Said 1990).

In the Quseir-Safaga district, as on the western side of the Red Sea hills, marine upper Eocene and Oligocene deposits are absent (Said 1990). Most of the synclinal folds were due to the drag of the western parts of the sediments over the underlying basement complex (Akkad and Dardir 1966).
In Wadi Wizr, the basement rock is unconformably overlain by the younger sedimentary rocks including the Nubian Formation, which consists of two Members; (1) Taref Sandstone Member, and (2) Quseir Clastic Member. The Taref Sandstone Member (Coniacian) outcrop at the base of the sedimentary sections in Wadi Wizr area and is made up of sandstone beds of different colors varying from white to dark brown. The sandstone is fine to coarse grained, generally cross-bedded with ripple marks in some places. The Quseir Clastic Member consists of relatively thick sequence of varicolored shales with minor sandstone beds. The Middle Eocene and Upper Cretaceous Formations in Upper Egypt (Nakheil, Thebes, Esna, Tarawan, Dakhla and Duwi formations are not recorded and completely absent in Wadi Wizr Area. The Nubian formation underlies unconformably the Middle Miocene rocks.

4 - THE MIOCENE SEDIMENTS

The Miocene and later sediments form a strip along the coast. They are essentially littoral in character exhibiting marked lithological changes laterally and vertically (Said 1990). The Miocene sediments fall into the following formations; Table 1 show the classification of Miocene rocks of the Red Sea coastal area according to different authors after said (1990).

1 - Ranga Formation (Lower Miocene)

The Ranga overlies unconformably the older sediments. In Ranga locality, the formation is 186 m thick. In Abu Ghusun area, it is 103 m thick. This formation consists of unfossiliferous gypsiferous conglomerates and sandstones. Iron and manganese oxides are abundant; this formation is best developed at Wadi Abu Ghusun (Samuel and Saleeb-Roufaiel, 1977). South of Abu Ghusun, the Ranga Formation is 40 m thick, the lower part is composed of mixed conglomerates, sandstones, siltstones and calystones. The upper part is represented by superimposed conglomerates and sandstone channels separated by erosional surfaces. Lenses of reefal carbonates are encountered near the top (Mahran et al., 1999). To the north in Wadi Essel, it is 166 m thick (Issawi et al., 1971). In Gasus area, it is 123 m thick.

2 – Um Mahara Formation (Middle Miocene)

The Ranga and Um Mahara formations were first described as one unit, the Gebel El Rusas Formation, by El-Akkad and Dardir (1966). The Gebel El Rusas formation subdivided
into two units, a lower clastic unit and upper carbonate unit. The Um Mahara Formation is well developed at Wadi Um Mahara and rests unconformably over the Ranga Formation. It is separated from the Ranga Formation by a thin conglomerate bed. The Um Mahara Formation is 181m thick in the Abu Ghusun area and is made up of a lower sandy limestone member and an upper gypsiferous and fossiliferous limestone member (Samuel and Saleeb-Roufael 1977). The beds are massive, partly dolomitic; the unit thins toward the north and have a thickness of 60 m in Um Gheig. In Wadi Essel, the unit is 27 m thick (Issawi et al. 1971). Mahran, (1994), in his study on Wadi Queih-Wadi Um Aish area, south of Safaga, subdivided the Um Mahara into two parts; a lower reefal carbonates and mixed siliciclastics-carbonates (total thickness 10-50 m), and an upper mixed siliciclastics and algal laminated carbonates (40-80 m). The Um Mahara Formation (50 m in thickness) overlies the Ranga Formation; in the area between Wadi Abu Ghusun and Wadi Ranga. It is composed dominantly at the base of coral-algal reefal carbonates, while the upper part is represented by algal laminated and stromatolitic limestones (Mahran et al. 1999).

The Middle Miocene rocks in the area between Quseir and Mersa Alam along the Red Sea coastal plain consists of a clastic carbonate sequence (Gebel El Rusas Formation) that is overlain by an evaporite sequence (Abu Dabbab Formation), Abdel Wahab and Ahmed, (1987). In the study areas, the exposed Miocene sediments are represented by two formations, which are;

1 – Gebel El Rusas Formation

Samuel and Saleeb-Roufaiel (1977) subdivided the Gebel El Rusas Formation in the Abu Ghusun-Um Mahara area, Red Sea coast, Egypt, into the Ranga and Um Mahara formations. The Gebel El Rusas Formation represents the oldest Miocene rocks recorded on the Red Sea coastal plain, El Akkad and Dardir (1966). Gebel El Rusas Formation consists of two main units; the lower unit is represented by white cross-bedded sandstone with thin clay intercalations. The upper unit consists of successions of sandstones and siltstones in the lower part and marly limestone with clay intercalations in the upper part. The marly limestone displays the common and main rock type of this formation (El. Aref et al., 1985).

Youssef and Abu-Khadrah (1984) subdivided the Gebel El Rusas Formation into three units: 1- the lower fan-conglomerate, with sandstone and occasional shale beds, representing a coastal alluvial fan environment. 2-Gypsiferous green shale and argillaceous biomicrite rich
in miliolids and mollusks, with occasional thin beds of microcrystalline dolomite representing a back-reef environment. 3-Coarl-algal biolithite with abundant mollusks, echinoderms and corals at the base and with dominance of algae, evaporite minerals and sometimes-planktonic foraminifera towards the top.

The Gebel El Rusas Formation consists mainly of bedded marly limestone at the top, and a thin succession of sandstones and conglomerates at the base (El Aref and Ahmed, 1986). The Gebel El Rusas Formation is formed of a Lower Clastic Member and an Upper Carbonate Member. The Clastic Member consists of a foreshore/shoreface quartz arenite that is overlain by conglomerate of alluvial fan origin. The Upper Carbonate Member consists of dolostones, lime mudstones, reefal, oncolitic and skeletal rocks, which are interpreted as deposited on a supratidal intertidal and reefal environments (Abdel Wahab and Ahmed, 1987). The Gebel El Rusas Formation overlies unconformably basement rocks and underlies Abu Dabbab Formation.

2 – Abu Dabbab Formation

The Red Sea Miocene evaporites have been described by different lithostratigraphic terms such as Gypsum Series (Beadnell, 1924); Evaporite Series (Said, 1962); Gypsum Formation (El Akkad and Dardir, 1966); Abu Dabbab Formation; (El Bassyouni, 1971), (El Badry et al, 1986); Abu Dabbab Gypsum (NSC, 1974); Abu Dabbab Evaporites; (El Khadragy, 1980), (Hammad, 1981), Abu Khadrah and Youssef (1984), Philobbos and El Haddad (1983); Group C (Montenat et al., 1986); the Major Evaporite Unit (Orszag-Sperber et al., 1993. Most of the authors believed that the evaporites are of Middle Miocene age, with the exception of Philobbos and El Haddad (1983); Montenat et al., (1986b); Orszag-Sperber et al., (1993); Purser and Philobbos (1993), they assigned them a late Miocene age on the basis of their stratigraphic position or as compared with the evaporite deposits of Saudi Arabia that overlie the Serravallian marls (Le Nindre et al., 1986). The Red Sea Miocene evaporites were first named Gypsum Formation by El Akkad and Dardir (1966). The stratigraphic Sub-Committee of the National Committee of Geological Sciences (NSC) (1974) accepted the name (Abu Dabbab Gypsum) for this formation, rather than Abu Dabbab Formation that introduced by El-Bassyouni (1971). Because of the presence of evaporite minerals such as anhydrite, gypsum and dolomite, in addition to minor amounts of halite and celestite, Table (1), Abu Khadrah and Youssef (1983) suggested the name Abu Dabbab
evaporites for this sequence. Hume (1916), Akkad and Dadir (1966), Issawi et al. (1971), Abu Khadrah and Abdel Wahab (1978), El Khadragy, (1980), and El Badry et al, (1986). Pointed out that gypsum is the main mineral composing the Red Sea evaporites. On the other hand, Heybroek (1965), and Friedman (1972) believed that the Gulf of Suez and Red Sea evaporites are composed of both gypsum and anhydrite. The Abu Dabbab evaporites of the Quseir-Safaga region are composed of anhydrite with subordinate gypsum, halite, calcite and dolomites (Philobbos et al., 1985). It consists mainly of a thick succession of gypsum and/or anhydrite intercalated with thin layers of limestone, clay and green shale and usually capped by marly limestone (El Aref et al., 1985). The Miocene evaporites in the Quseir-Safaga district comprise two distinct units; 1-the first unit consists of thick evaporite beds, the individual bed up to 6 m thick (Plaziat et al., 1990). This unit has a very limited extension, localized only in thin subsudent peripheral grabens at Wadi Gasus and in Ras Honkorab near Abu Ghusun (Orzag-Sperber, 1993). The Oligocene-Early Miocene age is assigned to this unit (Montenat et al., 1986; Thiriet et al., 1986). 2- the second unit is well exposed along the Red Sea coastal plain. The age of this major unit is Middle Miocene in the Quseir area (Beadnell 1924; Souaya, 1963; Akkad and Dadir, 1966). In the Safaga area, this unit is of Langhanian age (Thiriet et al., 1986). On the other hand (Montenat et al., 1988; Purser et al., 1990; Soliman, 1994) consider the evaporite unit in the Red Sea to belong to the Middle to upper Miocene age. Mahran, (1994), in his study on Wadi Queih-Wadi Um Aish area, south of Safaga, denoted that the Abu Dabbab Formation (Upper Miocene) is represented by sulphates (20 m thick). Eastwards it is composed of primary sulphates and carbonates intercalated with fine siliciclastics (total thickness 80 m). El Aref, (1997) on his study in Um Reigha area south of Quseir pointed that the sedimentary succession consists of polymictic and reefal conglomerates at the base intercalated with sandstone and mudstone (lower member of Gelel El Rusas formation), the evaporite sequence is represented by about 40 m gypsum that have very thin mudstone intercalations near the top. It encloses scattered irregular masses of dolostone that have a hydrocarbon small when freshly broken.

The evaporite distribution along the coastal plain of the Red Sea is patchy and their thickness varies from one place to another, being in the range of 90 to 400 m in the onshore area. In few localities, the Abu Dabbab Formation rests upon the flanks of the basement complex, but more often it overlies conformably the Um Mahara Formation. The Abu Dabbab Formation consists of solid white gypsum, weathered to a hard coralloid-like hackly surface.
of characteristic yellowish brown color. Intercalated shales are rare and generally confined to the base of the formation while sands and gravels are practically absent. The formation is non-fossiliferous but its age is assumed to be middle to late Miocene (Said 1990).

Abdel Wahab and Ahmed (1987) believed that the Abu Dabbab Formation mostly does not cover the Gebel El Rusas Formation but lies at the same level indicating that faulting and uplift occurred after deposition of the Gebel El Rusas and before deposition of the Abu Dabbab evaporites. Hathout and Orabi (1995), on their study in Mersa Alam area pointed out that the Abu Dabbab and Samh formations (Miocene age) are non-fossiliferous.
4. THE MIocene – PLIOCENE (SAMH FORMATION)

The type section of the Samh Formation is measured by El Akkad and Dardir (1966) in Wadi Samh, north of Mersa Alam; it overlies unconformably the Abu Dabbab Formation. The Um Gheig bed forms the basal bed of the Samh Formation as described by Abu Khadrah and Abdel Wahab, (1978). El Bassony (1971) designated that Wadi Wizr is the type locality for Samh Formation. He described a 53 m-thick section of sandstones, marls, and shales. Philobbos and El-Haddad (1983) described a non-marine unit of fine-grained clastics and limestones, which they named as Wizr Formation that are correlatable with the Samh Formation. Mahran (1994), in his study areas in wadi Queih-wadi Um Aish area, south of Safaga, pointed out that the lower Samh Member of Mersa Alam Formation (Upper Miocene) composed of 30 m thick fine siliciclastics (siltstones, claystones and sandstones). Hathout and Orabi (1995), in their study at Mersa Alam reveled that the Samh Formation (Late Miocene) is easily recognized by its light gray to light green color. Mahran et al., 1999, on their study along the Red Sea coast between Wadi Abu Ghusun and Wadi Ghazal pointed out that Samh Member (Upper Miocene) comprising a lower part of thinly bedded sandstones, siltstones and claystones of continental (fluvial) facies, and an upper part of coarse sandstones with restricted marine carbonate interbeds. The Samh Member reaches 40 meters in thickness and its lower part is composed of reddish to yellowish brown thinly bedded siltstones and claystones. The upper part is dominated by massive fine to medium grained sandstones and siltstones. Ribbles cross bedding and bioturbations are the dominant primary structures. It is believed that the lower part of the Samh Member was deposited in a fluvial environment whereas the upper part accumulated under restricted marine conditions.
Figure II-1: Exposure of the Abu Dabbab evaporites in the Red Sea region shows cone-shaped hills, looking south, at Wadi Wizr.

Figure II-2: Panorama showing slight folding of the Pliocene Samh Formation, looking south, at Wadi Wizr
In the present work, the Abu Dabbab evaporite is directly and conformably overlies the Gebel El Rusas Formation and is overlain by Samh Formation. All three formations are of Miocene age (Said, 1962; El Akkad and Dardir, 1966; Issawi et al., 1971) and represent one complete evaporite cycle.

The Abu Dabbab Formation represents the main sedimentary outcrops of the studied areas at Wadi Gasus, Wadi Teaban and Wadi Wizr (Fig. II-1). It occupies a moderate relief in the west and decreases generally to low relief towards the east. It consists mainly of a thick succession of gypsum and/or anhydrite intercalated with thin layers of limestone, clay and green shale and usually capped by marly limestone of Um Gheig Formation (El. Aref et al., 1985). Due to dissolution of the gypsum, the exposure of the Abu Dabbab evaporite is characterized by cone shaped hills (Fig. II-2), cavities and erosional surfaces (Abdel Wahab and Ahmed, 1987).

Field examination of the Miocene evaporite rocks in 5 active quarries distributed in the three wadies have revealed that approximately the lower 2/3 of the evaporite sequence is composed of gypsum, and approximately the upper 1/3 is composed of anhydrite. The gypsum has many textures, fabrics and colors that vary vertically and laterally, whereas anhydrite is represented only by white powdery to hard materials. On the other hand, the subsurface section in the boreholes is represented mainly by white, brownish or gray gypsum. The following is a field description of the evaporites in the three wadies.
<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>BED NO.</th>
<th>SAMPLE NO.</th>
<th>Lithic LOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDDLE MIocene</td>
<td>ABU DABBAB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>19</td>
<td></td>
<td></td>
<td>Anhydrite, regular laminated, nodular.</td>
</tr>
<tr>
<td>14</td>
<td>18</td>
<td>17</td>
<td></td>
<td>Anhydrite, nodular, nodules &lt; 1mm nodular single, coalesced, interlithic brown micrite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gypsum, yellow, crystalline.</td>
</tr>
<tr>
<td>13</td>
<td>16</td>
<td>15</td>
<td></td>
<td>Sulfides, black, dispersed around gray gypsum.</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>Sulfides, (golden pyrite) inside massive gray gypsum.</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>Gypsum, black, laminated, crystalline, with white gypsum crystals and yellow earthy materials with black sulfides.</td>
</tr>
<tr>
<td>10</td>
<td>14</td>
<td></td>
<td>9</td>
<td>Selenite, white, haney yellow, to gray.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>8</td>
<td>Selenite, glassy, over clay lens.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>7</td>
<td>Gypsum, thin laminated, crystalline, dissimenated gypsum micrite.</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td></td>
<td>6</td>
<td>Clay, sand, bedded laminated.</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td></td>
<td>5</td>
<td>Clay lens.</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td></td>
<td>4</td>
<td>Mud, regular, thicker, and thin gypsum, (scattered 1mm nodules and 1-5cm long-bedded nodules of white turbid anhydrite nodules in brown orange, buff micrite, pyramidal.</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td></td>
<td>3</td>
<td>Anhydrite and clay, regular laminated, with gypsum veins, the bottom is stromatolistic gypsum,(thin micrite thicker white gypsum 1mm-5cm thick).</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
<td>2</td>
<td>Clay, or silt, or mud, brown, regular laminated, and thicker brown gypsum.</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
<td>1</td>
<td>Gypsum, brown and black, bedded, with gypsum veins,</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>Gypsum, black, crystalline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Gypsum, black, with clear selenite pockets over the clay body.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>Gypsum, laminated, with gypsum veins.(strike 130, dip 22).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Clay body.</td>
</tr>
</tbody>
</table>

Fig. II-3 Lithic logs of the exposed evaporite rocks in eastern Gasus quarry

2 cm.
<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>BED NO.</th>
<th>SAMPLE NO.</th>
<th>LITHIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDDLE MIocene</td>
<td>ABU DABBAB</td>
<td>12</td>
<td>38</td>
<td>Gypsum, white, crystalline, with shop contact with basement sandy fragments.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>37</td>
<td>Gypsum, white, hard crystalline, massive, nodular, with mash texture of yellow brown clay,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36</td>
<td>Gypsum contact with conglomerate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>35</td>
<td>Gypsum, regular laminated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>33</td>
<td>Gypsum, massive, crystalline, glassy, and yellow micrite laminas.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>32</td>
<td>Gypsum, brown, regular laminated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>31</td>
<td>Gypsum with sand, regular laminated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>Gypsum, yellow, hard crystalline, with sharp contact of conglomerate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>29</td>
<td>Anhydrite, white to yellow, hard crystalline, nodular, with scattered micrite streak.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28</td>
<td>Gypsum, white, crystalline, with sharp contact with basement sandy fragments.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>Gypsum, fine, with high contact of green mud.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>23</td>
<td>Gypsum, white, crystalline, with shop contact with basement sandy fragments.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>22</td>
<td>Anhydrite, white to yellow, hard crystalline, nodular, with scattered micrite streak.</td>
</tr>
</tbody>
</table>

Fig. II-4 Lithic logs of the exposed evaporite rocks in western Gasus quarry
Figure II – 5: General views of the Miocene evaporites, Looking North west, at Wadi Gasus

Figure II – 6: Selenite pockets with massive texture that enclosed in the white gypsum layers, beds No. 6,7,8 and 9 at Wadi Gasus S – selenite, An – anhydrite,
Figure II – 7: black iron sulphide and yellow limonite from patches between the black crystals of gypsum, beds No. 6, 7, 8 and 9 in the eastern quarry of Wadi Gasus.
Figure II – 8: nodular to enterolithic white anhydrite that forms the top part of the gypsum quarry, beds No. 10 and 11, at Wadi Gasus.
Figure II – 9: exposure of the western gypsum quarry, looking north west at Wadi Gasus area.
Figure II – 10: gradational contacts between the gray gypsum layer and the yellow thin laminated gypsum, bed No. 4,5,6,7,8,9 and 10 in the eastern Gasus quarry.
Figure II – 11: irregular bodies of green Claystone that enclosed in the gypsum layers of Wadi Gasus gypsum quarry.
Figure II – 12: a sharp contact between irregular pebbly sandstone bodies and the host gypsum layers in the eastern quarry of Wadi Gasus.
Figure II – 13: different compositions of the gravels that are floating in the pebbly sandstone bodies in the western quarry, beds No. 9 and 10, at Wadi Gasus.
1-WADI GASUS AREA

A- surface sections

The following is a description of the surface sections in two active gypsum quarries in Wadi Gasus area (Figs. II-2 and II-4). In the eastern gypsum quarry (Figs. II-3 and II-5), the evaporite sequence consists of eleven gypsum and/or anhydrite beds separated by some beds of clay, marl, and sands (Fig. II-5), which form the Abu Dabbab Formation of Middle Miocene age, (Akkad and Dardir, 1966). The evaporites are represented at the base by gypsum beds, about 10 m thick (Fig. II-3) that are brown to black in color, massive, laminated or show nodular structures, with clay bodies, and clear selenite pockets, beds No. 1, 2 and 3. Followed up words sequence by a zone of bedded, regular laminated gypsum beds that enclose brown clay, mud and sand, and is topped by regular laminated anhydrite, with thin gypsum veins, beds No. 4, 5 and 6. The top part of the eastern quarry consists of white, yellow, gray to black, thin laminated, crystalline gypsum that enclose gray, white, or honey yellow selenite pockets (Fig. II-6). Also, black sulphide or yellow limonite is dispersed between the gray gypsum, beds No. 6, 7, 8 and 9. (Fig. II-7). This section is capped by about 4 m thick of regular laminated, nodular to enterolithic anhydrite, beds No.10, and 11. (Fig. II-8).

In the western gypsum quarry of Wadi Gasus area (Figs. II-4 and II-9), the section of the Abu Dabbab evaporites consists at the base of gray to black massive gypsum, beds No. 1, 2 and 3. That change vertically or laterally into white to yellow laminated gypsum, beds no. 4, 5, 6, 7, 8, 9 and 10. (Fig. II-10). These layers enclose with sharp contact more than 2 m in size irregular bodies of clastic materials such as green mudstone (Fig. II-11), or pebbly sandstone (Fig. II-12). The latter is composed of laminated sandstone that encloses dispersed pebbles and granules of basement and sedimentary composition (Fig. II-13). This sequence change upward into white to yellow, hard crystalline, nodular anhydrite with scattered micrite streak, bed No. 11.

B-subsurface sections

Samples in boreholes No. 5, 7, 10, and 12 were available for study, where borehole No. 5 is located at the west of Wadi Gasus, borehole No. 7 is located to the south of Wadi Gasus, boreholes Nos. 10, and 12 are located at the east of Wadi Gasus (Fig. II-14). These four boreholes have different surface elevations (Fig. II-14). The sedimentary sequence (Fig. II-15) is represented at the bottom by pale gray to dirty white, with violet bands, crystalline,
compact gypsum, interbedded with yellow, soft, cracked, wet and gypsiferous clay. This gypsum is overlain by dirty whit to pale gray compact gypsum. The top part of this section consists of pale yellow, moderately hard, cavernous gypsum (Fig. II-15).
WADI GASUS AREA


Surface level 61.49  surface level 57.87  surface level 50.35  surface level 61.49
Depth 20 m.  Depth 20 m.  Depth 20 m.  Depth 20 m.

Figure II-15: Lithic logs of the boreholes at Wadi Gasus area.

Gypsum  Clay
Anhydrite  Overburden
Figure II – 17: black gypsum layers enclose selenite pockets and white patches of gypsum, beds No. 1, 2, 3, 4 and 5, AT Wadi Gasus.
2- WADI TEABAN AREA  
A- surface section  
In the active gypsum quarry of Wadi Teaban, the evaporite sequence is composed at the base of brown to black gypsum beds No. 1, 2, 3, 4, and 5. (Fig. II-16) with several sedimentary structures such as regular laminated, nodular, massive, irregular laminated, and enterolithic nodules. These gypsum layering are interbedded with green marl, clay, or enclose selenite bodies at the middle parts of the sequence (Fig. II-17). While at the top part, it consists of 4 - 6 m thick nodular anhydrite layers beds No. 7, 8, and 9.

B- subsurface section  
Samples in boreholes Nos. 1, 4, 8, and 12 are available for examination in the present study (Fig. II-18). Borehole No. 1 is located at the east of Wadi Teaban. Boreholes Nos. 4 and 8 are located at the middle part of Wadi Teaban area, while Borehole No. 12 is located at the west of Wadi Teaban area (Fig. II-18). These Boreholes are of different surface elevations (Fig. II-19). The sedimentary sequence (Fig. II-19) is represented by whitish, gray, moderately hard, and crystalline gypsum interbedded with greenish gray, compact, soapy clay.

3- WADI WIZR AREA  
A- Surface section  
In Wadi Wizr, there are two active gypsum quarries. The sedimentary sequence in the eastern and western quarries (Figs. II-20 and II-21) is composed at the lower part of alternation of gypsum and anhydrite layers beds No. 1, 2, 3, and 4., that are occasionally encloses green marl streak. Near the top, nodular and enterolithic anhydrite are the common evaporite facies also similar to the evaporite sequences at Wadi Gasus and Teaban; irregular bodies of glassy selenite are common near the top part of the evaporite sequence beds No. 4 and 5.

B - Subsurface section  
Samples in boreholes Nos. 1, 3, and 4 are available for examination in the present work. Borehole No. 1 is located at the middle of Wadi Wizr area, whereas boreholes Nos. 3 and 4 are located at the western part of Wadi Wizr area (Fig. II-22). The three wells are of
different surface elevations (Fig. II-23). The data obtained from the three boreholes revealed that the sequence is composed of yellowish gray, compact, crystalline, gypsum, interbedded with yellow, soft, friable, clay (Fig. II-23).
<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>BED NO.</th>
<th>SAMPLE NO.</th>
<th>LITHIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDDLE</td>
<td>MIocene</td>
<td></td>
<td></td>
<td>Anhydrite, thick nodular, large in size, that grade upward to fine</td>
</tr>
<tr>
<td>ABU DABBAB</td>
<td></td>
<td>10</td>
<td>14</td>
<td>nodular gypsum in brown silty sand. The gypsum changes to anhydrites that protected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>13</td>
<td>to clay.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>12</td>
<td>Gypsum, white, high aggregates of nodules, with few brown to gray clay in-between,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>11</td>
<td>the nodules form massive to banded structure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>10</td>
<td>Sands, friable, thick.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>8</td>
<td>Anhydrite, thick banded, nodular, changes into massive black gypsum at the bottom.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>6</td>
<td>Gypsum, red to green, regular laminated, that changes into massive gypsum, brown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5</td>
<td>scattered lamina dip to the east.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3</td>
<td>Gypsum, milky white, in green marl.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>Marl, brown to green,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Selenite, glassy, in black clayey gypsum.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gypsum, regular laminated, and brown red marl with gypsum veins.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Marl, yellow, rich in gypsum veins.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gypsum, black, with nodular structure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gypsum, nodular, with white carbonate coat.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The gradual contact between brown and black gypsum.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gypsum, haney yellow, regular laminated, with green marl fissile, massive gypsum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>replaces the lamina structure.</td>
</tr>
</tbody>
</table>

2M

Figure II-16 lithic log of the evaporite sequence et the gypsum quarry of wadi Teaban.
WADI TEABAN AREA

B. H. NO. 1
Surface level 49.21
Depth 20 m.

B. H. NO. 4
Surface level 69.28
Depth 20 m.

B. H. NO. 8
Surface level 73.08
Depth 25 m.

B. H. NO. 12
Surface level 84.39
Depth 20 m.

Figure II-19: Lithic logs of the boreholes at Wadi Teaban area.

Gypsum

Anhydrite

Clay

2 M
<table>
<thead>
<tr>
<th>LITHIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDDLE MIocene</td>
</tr>
<tr>
<td>ABU DABBAB</td>
</tr>
<tr>
<td>FORMATION</td>
</tr>
<tr>
<td>SAMPLE NO.</td>
</tr>
<tr>
<td>LITHIC LOG</td>
</tr>
<tr>
<td>AGE</td>
</tr>
<tr>
<td>BED NO.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>19</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>Anhydrite, nodular.</td>
</tr>
<tr>
<td>Anhydrite, nodular, enterolithic</td>
</tr>
<tr>
<td>Anhydrite, nodular, enterolithic</td>
</tr>
<tr>
<td>Gypsum, twin morphology of the black layer.</td>
</tr>
<tr>
<td>Selenite, within the white bed.</td>
</tr>
<tr>
<td>Anhydrite, bedded nodular.</td>
</tr>
<tr>
<td>Anhydrite, bedded nodular.</td>
</tr>
</tbody>
</table>

Fig. II-20 Lithic logs of the exposed evaporite rocks in Eastern Quarry of Wadi Wizr
**LITHIC DESCRIPTION**

<table>
<thead>
<tr>
<th>AGE</th>
<th>FORMATION</th>
<th>SAMPLE NO.</th>
<th>LITHIC LOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIDDLE MIocene</td>
<td>ABU DABBAB</td>
<td>1</td>
<td>Gypsum, light gray, stain spar,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td><strong>2M</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Marl, green streak, gypsum, light gray, crystalline, with thin coat of micrite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>The contact between the white, dark, and the gray layers with yellow steak.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Anhydrite, white, irregular laminated, nodular, crystalline, with irregular yellow carbonate streak.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>Yellow batches in the dark layer of selenite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>Anhydrite, nodular boundary, with planer surface of the nodules (cavity filling).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Anhydrite, nodular boundary, with planer surface of the nodules (cavity filling).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>Anhydrite, earthy clay boundary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>Yellow batches in the white layer of selenite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>Anhydrite, earthy clay boundary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>Anhydrite, earthy clay boundary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13</td>
<td>Yellow batches in the white layer of selenite.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
<td>Anhydrite, nodular boundary, with planer surface of the nodules (cavity filling).</td>
</tr>
</tbody>
</table>

Figure II- 21 lithic log of the evaporite sequence at the western gypsum quarry of Wadi Wizr.
WADI WIZRAREA

B. H. NO. 1  
Surface level 44.66
Depth 20 m.

B. H. NO. 3  
Surface level 48.44
Depth 20 m.

B. H. NO. 4  
Surface level 50.02
Depth 20 m.

Figure II-23: Lithic logs of the boreholes at Wadi Wizr area.

- Gypsum
- Anhydrite
- Clay
- Overburden

2 M
5. THE PLIOCENE

A - GABIR FORMATION

The Gabir Formation is equivalent to the oyster and cast beds of Beadnell (1924), that lay down during the first marine transgression after the evaporite, which may be a reflection of the global rise of sea level (Vail et al., 1979). The Gabir Formation is made up mainly of brown sandstone with marl and limestone intercalation (Akad and Dardir, 1966), marly-sandy limestones, dolostones, silistones and sandstones (El Badry et al., 1986) or the sequence is composed of fossiliferous, calcareous sandstones (Hathout and Orabi, 1995). It is given a Pliocene age according to Beadnell (1924); Akkad and Dardir (1966); (El Badry et al., 1986), Hathout and Orabi, (1995), in their studied areas. The Gabir Formation overlies conformably the Samh Formation and underlies conformably the lower Member of the overlying Shagara Formation, (Hathout and Orabi, 1995). Mahran et al. (1999), in their studied area south of wadi Abu Ghusun, mentioned that the Gabir Member is directly overlies the Samh Member and is marked near the contact by a deformed sandstone layer. The Gabir Formation is composed of sandstones with gravel interclations. Cross bedding, cross lamination and convolute bedding as will as birds eye structure are common.

B - SHAGARA FORMATION

The Shagara Formation is equivalent to the Clpeaster-Laganum series of Beadnell (1924). It extends as a very narrow ridge close to the present Red Sea shore. Mahran (1994), in his study areas in wadi Queih-wadi Um Aish area, south of Safaga, pointed out that the sediments of the Shagara Formation are composed of two parts; 1-lower siliciclastics-carbonates sequence (20 m thick), and 2-upper dominantly carbonate sequence (40 m thick). The sediments are composed dominantly of open marine carbonates occasionally intercalated with lenticels of cross-bedded sandstones, and lying unconformably over the Gabir Formation. The open marine Shagara Formation is considered as the lateral transition of the top part of the Gabir Member lying to the west.

6. RECENT DEPOSITS

The Recent deposits are represented by gravel terraces and Quaternary reefal terraces.
A) The gravel terraces

The gravel terraces are widely distributed in the studied areas. They are dipping towards the east, which range in thickness from one meter to five meters. They are composed mainly of reworked boulders and gravels of igneous and metamorphic origin.

B) Quaternary reef terraces

Quaternary reef terraces along the Red Sea coast, Egypt, are two to six terraces; three of them can be distinguished in several areas El-Sorogy (1990), Mansour (2000). Each reef unit exhibits a short distance lateral facies development beginning at the shore with mainly siliciclastics beach, and ending at the reef zone of carbonate sediments (El-Sorogy 1990, Mansour 2000). Reefs with their siliciclastic associations occur in the form of repeated cycles reflecting their tectonic effect and/or sea level changes. El-Sorogy (1990), Mansour (2000). believed that tectonism controls the aerial distribution of the depositional systems and influences the number, thickness, extension, and elevations of the reef sequences.

The Pleistocene sequences comprise continental sediments and shallow-water carbonates and siliciclastics of different facies. He also interpreted that all reef sequences revealed transgressive phases developed during the sea level rise, while the alluvial deposits are regressive sequences accumulated during the lowering of sea level. Sea level fall caused deposition of large alluvial deposits that buried the pre-existing reefs, also deposition of evaporites in the depressions of the raised beach adjacent to the sea, Ziko and El-Sorogy (1995), Mansour (2000).
PETROGRAPHY

This chapter is concerned with the petrographic description of the Abu Dabbab evaporites in the three localities of Wadi Gasus, Wadi Teaban and Wadi Wizr. The purpose for studying the petrography of the three areas collectively is to avoid repetition in description of similar facies, also to compare minor differences in texture, structure and mineralogy or newly observed features in references to each of the studied location.

The term “sedimentary facies” as employed here, follows the general usage of Schreiber et al. (1976), which designates “any particular kind of distinguishable sediment or sedimentary rock formed under a specific environmental condition, without regard to age or geologic setting and without reference to designated stratigraphic units”.

The recent realization that evaporites are significant hydrocarbon source rocks (Warren, 1986 and 1989; Evans and Kirkland, 1988 and Schreiber, 1988) and are commonly associated with carbonate rocks containing major hydrocarbon reserves (North, 1979; Kirkland and Evans, 1981 and Zhang and Yi-Gang, 1981) has encouraged the publication of a large number of papers on the subject. In addition, studies of modern evaporite deposits have shown many similarities between recent and ancient evaporites and have pointed out the importance of these rocks in interpreting the environmental framework of major sedimentary basins. Because of the great variety of descriptive terms used in these studies, a standardized terminology, which can be applied for the evaporite rocks of the Red Sea coastal plain is suggested. The evaporite classification followed in the present work was developed during the study of five stratigraphic sections representing the best evaporite exposures in five active quarries in three areas along the Red Sea coast from south of Safaga to south of Quseir, which are Gasus area, Teaban area, and Wizr area, in addition to samples and data obtained from eleven wells penetrated in these three localities. Most of the terms of the classification have been previously used in the literature. The arrangement and restricted definitions of these terms were given by Maiklem et al. (1969) and Ciarapica et al. (1985).

Two basic properties considered by the present author in classifying evaporite rocks are structure and texture. The structural terms are based on variations in external features of the evaporites masses, while the textural terms are based on the mineralogy and details of crystal fabric within the evaporite mass.
The following is a short review of the different facies that are described from the evaporites rocks of the Red Sea region.

Philobbos et al. (1985 described three facies types of the Abu Dabbab evaporites in Quseir – Safaga area that are forming a cycle of deposition, which is repeated upwards in the succession at least two times, these are from bottom to top; the nodular-mosaic anhydrite, the nodular – laminated anhydrite and the thinly bedded anhydrite – halite facies

Abdel Wahab and Ahmed (1987 based on the petrographic analyses as well as the megascopic features of evaporites in seven localities (north of Wadi Essel, Wadi Essel, north of Wadi Sharm el Bahari, Wadi Abu Ghorban, Wadi Um Rheiga, Wadi El Anz and Gebel El Rusas mine) recognized the following ten lithofacies units; 1–nodular calcium sulphate with clastic sediments, 2–nodular stellate evaporite, 3–thinly bedded anhydrite, 4–laminated anhydrite, 5–anhydrite micrite with secondary selenitic gypsum, sulphur and pyrite, 6-nodular laminated calcium sulphate, 7-massive alabasterine gypsum, 8-marly limestone, 9-dolostone, and 10-dolomitized grainstone.

Barakat, M. A. et al, 1992, denoted that the major depositional facies of the Miocene sedimentary sequences in the Gulf of Suez and the Red Sea Coastal zones are: 1 – alluvial facies. 2 – marginal facies. 3 – lagoonal facies (subtidal lagoon, beach, shore face zone). 4 – reefal facies. Lagoonal facies includes the Miocene evaporites which are formed in subtidal lagoons, besides sandy sediments formed on beach and the shore face zone, Coastal lagoons, in the late Miocene represents the shallow water environment isolated from the open sea. In the Miocene lagoons, laminated sediments were deposited by evaporation.

Soliman (1994) classified the Miocene evaporites and their associated sediments in his studied area in Quseir – Safaga district into seven distinctive facies based on their composition, textures and primary sedimentary structures, 1–gypsum rudites and arenites, 2–thin-bedded gypsum sulfates, 3-coarse-grained cavoli and grass-like selenites, 4-massive and laminated gypsum, 5–nodular anhydrite, and 6-sulphatized carbonates.

Aref, 1997.in his study at Um Reiga area interpret two depositional environments; 1- a shallow subaqueous environment, the formation of evaporites in this environment results from direct precipitation from saturated brines. Shallow subaqueous environments include three facies; a- coarsely crystalline selenite, b- wavy laminated gypsum. C- massive gypsum. 2- a supratidal sabkha environment in which the evaporite deposition takes place within the
sediment column from concentrated pore fluids in the capillary and upper phreatic zones beneath the sabkha surface.

In the present work the study of component minerals (confirmed by XRD analysis), their interrelationships and textures as well as their primary and diagenetic features resulted in the following evaporite facies:
1 - Massive gypsum
2 - Regular laminated gypsum
3 - Microbial laminated gypsum.
4 – Stromatolitic gypsum
5 - Nodular mosaic anhydrite
6 - Enterolithic anhydrite nodules

1 - MASSIVE GYPSUM

This facies is the most dominant structural type in the study area. Massive gypsum facies is recorded in the three areas as black, brown, white or even pale yellow colors of masses of gypsum, without any observed structures. Massive gypsum may form from the mixing of several patches of varied colors. Sometimes, traces of microbial laminae and/or gypsum veins are intersecting the homogenous massive structure. Massive gypsum also forms from random, intersecting cleavage flakes or sheath of gypsum (Fig. III-1). In other cases, the irregular laminated structure is replaced by the massive structure with gradational boundary (Fig. III-2). Therefore the massive structure replaces and obscure any trace of former bedding or primary structures. Near the bottom of the quarries, the general black color of the massive gypsum obscure the brownish or pale yellows colors of the overlying facies (Fig. III-3).

In the eastern gypsum quarry of Wadi Gasus, massive gypsum occurs in beds No. 3 and 4 with 4 - 6 m in thickness (Fig. III-4), whereas in the western gypsum quarry, it occurs in beds No. 1 and 3 with 4 m thick (Fig. III-5).

In Wadi Teaban, the massive gypsum occurs in beds No. 1, 6 and 7 with 4-6 m in thickness (Fig. III-8).

In the eastern quarry of Wadi Wizr (Fig. III-6), it occurs in bed No. 1 with 2-3 m thick, whereas in the western quarry of Wadi Wizr (Fig. III-7), it occurs in beds No. 10 and 11 with 2-4 m thick.
Under the microscope, the massive structure is composed of 80 – 90 % gypsum, and 10 – 20 % of microbial micrite, celestite, iron oxides, or anhydrite. Gypsum is represented mainly by porphyrotopic, poikilotopic, alabastrine or granular texture (Figs. III-4 to 8). Porphyrotopic and poikilotopic gypsum are dominant near the bottom, whereas granular and alabastrine gypsum are dominant near the top. At the middle, all textural types are mixed with each other.

Porphyrotopic gypsum is composed of large (700 – 2000 µm) anhedral crystals that may be equant or parallel to the microscopic laminations. The gypsum crystal boundaries are generally irregular, with interpretation stylolitic boundaries in-between (Fig. III-9). Sometimes, the porphyrotops of gypsum is composed of elongated arms of gypsum that interpenetrate the surrounding crystals (Fig. III-10).

Dense patches of microbial micrite are usually enclosed and intersecting the crystal fabrics of the porphyrotopic gypsum (Fig. III-11). The microbial micrite is composed of dense, < 10 µm in size micrite grains, with brownish organic patches in-between.

Poikilotopic gypsum facies is composed of clear gypsum crystals of large size, 600 – 1500 µm, similar to the porphyrotopic gypsum. The crystals have also irregular crystal boundaries and may interpenetrate and enclosing some of the surrounding crystals. Microbial micrite is also found as patches or laminae distributed within the poikilotopic crystals. Poikilotopic gypsum may preserve the original morphology of the former crystals by the existence of microbial micrite laminae (Fig. III-12).

In the conglomerate masses, poikilotopic gypsum forms the cementing material to the clastic grains (Fig. III-13). The gypsum is recorded as clear anhedral crystals that coat or replace the quartz grains.

Some patches in the massive gypsum facies is dominated with granular gypsum that is composed of anhedral to euhedral crystals, < 200 µm in size, that randomly distributed without any preferred orientation (Fig. III-14).

Alabastrine gypsum is composed of microcrystalline gypsum crystals, < 50 µm in size, that distribute between the large size porphyrotopic, poikilotopic and granular gypsum (Fig. III-15). The porphyrotopic gypsum is usually form patches randomly distributed in the massive gypsum structure, and may be responsible for the pale coloration of the massive gypsum.
Veins of gypsum may intersect the massive structure, but in low amount with respect to the middle and upper parts of the section. The veins are composed of either satin spar crystals, or granular gypsum crystals. The satin spar is composed of prismatic, elongated gypsum that oriented normal to the fracture wall of the gypsum masses. Sometimes, the satin spar gypsum encloses detached wall rock materials in the central part of the fracture or near the fracture wall (Fig. III-16). Also, the fractures in the massive gypsum may be filled with clear, euhedral crystals of granular gypsum that have a sharp boundary to the fracture wall (Fig. III-17).
**Figure III-1:** Random arrangement of bundles of cleavage flakes of gypsum of black and light brown color, beds No. 2,3,4 and 5 in Wadi Gasus.

**Figure III-2:** Replacement of laminated gypsum by massive gypsum with sharp gradational contact, bed No. 2, Wadi Teaban.
**Figure III-3:** Inclined gypsum layers showing gradational contact between the lower black gypsum and the overlying yellowish gypsum, beds No. 3 and 4, Wadi Teaban.
Figure III-4: Petrographic log of the evaporite rocks at the eastern gypsum quarry of Wadi Gasus.

Legend

- **Gypsum**
- **Anhydrite**
- **Selenite nodule**
- **Marl or Shale**
- **Conglomeratic body**
- **Clay body**

<table>
<thead>
<tr>
<th>Lithic log</th>
<th>Sedimentary structures</th>
<th>Gypsum</th>
<th>Selenite</th>
<th>Granular</th>
<th>Porphyrotopic</th>
<th>Microcrystalline</th>
<th>Veins</th>
<th>Lenticular</th>
<th>Anhydrite</th>
<th>Selenohedral calcite</th>
<th>Microbial micrite</th>
<th>Brown organic</th>
<th>Mud</th>
<th>Gravel</th>
<th>Celestite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sedimentary Structure**

- Massive
- Ragular laminae or bed
- Irregular laminae
- Enterolithic nodules
- Nodules

- Dominant (>50%)
- Abundant (20-50%)
- Present (<20%)
### Figure III-5: Petrographic log of the evaporite rocks at the western gypsum quarry of Wadi Gasus.

**Legend**
- **Gypsum**
- **Anhydrite**
- **Selenite pocket**
- **Marl or Shale**
- **Conelomeric body**
- **Clay body**

**Sedimentary Structure**
- **Massive**
- **Regular laminae or bed**
- **Irregular laminae**
- **Enterolithic nodules**
- **Nodules**

<table>
<thead>
<tr>
<th>Lithic log</th>
<th>Sedimentary structures</th>
<th>Gypsum</th>
<th>Selenite</th>
<th>Granular</th>
<th>Porphyrotopic</th>
<th>Microcrystalline</th>
<th>Veins</th>
<th>Lenticular</th>
<th>Anhydrite</th>
<th>Scalenohedral calcite</th>
<th>Microbial micrite</th>
<th>Brown organic</th>
<th>Mud</th>
<th>Gravel</th>
<th>Celestite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Dominant (>50%)**
- **Abundant (20-50%)**
- **Present (<20%)**
Figure III-6: Petrographic log of the evaporite rocks at the eastern gypsum quarry of Wadi Wizr.

<table>
<thead>
<tr>
<th>Lithic log</th>
<th>Sedimentary structures</th>
<th>GYPSUM</th>
<th>Sedimentary Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selenite</td>
<td>Granular</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Porphyrotopic</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Microcrystalline</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Veins</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lenticular</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Anhydrite</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selenite pocket</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Marl or Shale</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>conglomeratic body</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Clay body</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Gypsum</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Anhydrite</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Selenite pocket</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Marl or Shale</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>conglomeratic body</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td></td>
<td>Clay body</td>
<td>▲</td>
<td>▲</td>
</tr>
</tbody>
</table>

**Legend**

- Gypsum
- Anhydrite
- Selenite pocket
- Marl or Shale
- conglomeratic body
- Clay body
- Massive
- Ragular laminae or bed
- Irregular laminae
- Enterolithic nodules
- Nodules
- Dominant (>50%)
- Abundant (20-)
- Present < (20%)
**Figure III-7: Petrographic log of the evaporite rocks at the western gypsum quarry of Wadi Wizr.**

<table>
<thead>
<tr>
<th>Lithic log</th>
<th>Sedimentary structures</th>
<th>Selenite</th>
<th>Granular</th>
<th>Porphyrotopic</th>
<th>Microcrystalline</th>
<th>Veins</th>
<th>Lenticular</th>
<th>Anhydrite</th>
<th>Selenohedral calcite</th>
<th>Microbial micrite</th>
<th>Brown organic</th>
<th>Mud</th>
<th>Gravel</th>
<th>Celestite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anhydrite</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selenite pocket</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marl or Shale</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conglomeratic body</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay body</td>
<td></td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**
- Gypsum
- Anhydrite
- Selenite pocket
- Marl or Shale
- conglomeratic body
- Clay body
- Massive
- Ragular laminaeor bed
- Irregular laminae
- Enterolithic nodules
- Dominant (>50%)
- Abundant (20-50%)
- Present <20%
Figure III-8: Petrographic log of the evaporite rocks at the gypsum quarry of Wadi Teaban.

**Legend**

<table>
<thead>
<tr>
<th>Lithic log</th>
<th>Sedimentary structures</th>
<th>Gypsum</th>
<th>Sedimentary Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selenite</td>
<td>Granular</td>
<td>Massive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Porphyrotopic</td>
<td>Dominant (&gt;50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microcrystalline</td>
<td>Regular laminae or Bed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Veins</td>
<td>Irregular laminae</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lenticular</td>
<td>Enterolithic nodules</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anhydrite</td>
<td>Dominant &lt;20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selenite pocket</td>
<td>Present&lt;20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marl or Shale</td>
<td>nodule</td>
</tr>
<tr>
<td></td>
<td></td>
<td>conglomeratic body</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay body</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sedimentary Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
</tr>
<tr>
<td>Anhydrite</td>
</tr>
<tr>
<td>Selenite pocket</td>
</tr>
<tr>
<td>Marl or Shale</td>
</tr>
<tr>
<td>conglomeratic body</td>
</tr>
<tr>
<td>Clay body</td>
</tr>
</tbody>
</table>
Figure III-9: Stylolitic boundaries of coarse porphyrotopic gypsum, in beds No. 2 and 4 in the eastern quarry and in beds No. 1 and 3 in the western quarry of Wadi Gasus. Polars Crossed.

Figure III-10: Long arms of porphyrotopic gypsum, in beds No. 2 and 4 in the eastern quarry and in beds No. 1 and 3 in the western quarry of Wadi Gasus. Polars Crossed. PrG=porphyrotopic gypsum
2-REGULAR LAMINATED GYPSUM

This facies is recorded only in the quarries of Wadi Gasus and Wadi Teaban. In Wadi Gasus, the regular laminated facies is recorded in bed No. 4 from 2-3 m thick in the eastern quarry, and in beds No. 2,5,6 and 8 from 6-8 m thick in the western quarry (Figs. III-4 and 5), whereas in Wadi Teaban, this facies is recorded in bed No. 2 from 2-3 m thick, (Fig. III-8). This facies is composed of regular, even laminae composed of alternation of few millimeters thick white or glassy gypsum laminae, that interlaminated with very thin (< 1 mm) brown, gray or greenish microbial or clayey laminae. Sometimes, thin gypsum veins are enclosed between the regular lamination of the clastic laminae and the white gypsum laminae, or intersect the regular lamination and fill fractures of any orientation. At some rock exposure, the regular laminated structure is replaced by massive texture of gypsum of brown or black colors (Fig. III-2).

Under the microscope, the white gypsum laminae in the regular laminated facies are composed of poikilotopic, porphyrotopic, granular or alabastrine crystals. The poikilotopic and porphyrotopic gypsum are large in size (300-2000 µm) that intersect and enclose the clay or microbial laminae, without any disturbance (Fig. III-18). The granular gypsum crystals have a size range of 200 – 400 µm, anhedral to subhedral crystals that show random orientation. The alabastrine gypsum crystal does not form all the rock samples but may form patches within the large size porphyrotopic and poikilotopic gypsum.

On the other hand, the thin laminae are composed of dense micrite grains mixed with orange or brown specks of organic remains, or may be composed of fine silt or clayey materials that scattered between the thicker gypsum laminae.

The white gypsum laminae in this facies may be corroded and replaced by rosette crystals of celestite that shows cross extinction (Fig. III-19). Usually the contact between the celestite and gypsum is gradational corrosive boundary that indicates the replacement of gypsum by celestite.

3 – MICROBIAL LAMINATED GYPSUM

This facies is dominant in the three quarries. It is recorded in the eastern quarry of Wadi Gasus in beds No. 6 with thickness from 2-4 m, while in the western quarry it is recorded in beds No. 4 and 7 with thickness from 4-6 m. In Wadi Teaban, it occurs in bed No. 5 with thickness 2-4 m. In Wadi Wizr, it occurs in the eastern quarry in beds No. 4 with
thickness from 2-4 m thick, and at the western quarry, it occurs in beds No. 1,2 and 5 with thickness from 4-6 m (Figs.III-4 to 8). The rock of this facies consists of irregular interlamination of thicker (few millimeters) white, gray or pale yellow gypsum laminae and thinner (< 1 mm), green, yellow or brown microbial laminae (Fig. III-20).

Under the microscope, the white thicker laminae consist of porphyrotopic, poikilotopic and lenticular gypsum crystals, whereas the thinner dark laminae consist of dense microbial micrite with brown specks of organic remains (Fig. III-21). The porphyrotopic and poikilotopic gypsum crystals are large in size that may intersect the microbial laminae, or have sharp growth boundary to the microbial laminae. Sometimes, euhedral rhombic dolomite crystals are randomly distributed in the large gypsum crystals (Fig. III-21), and probably of microbial origin. The dolomite consists of dark core, which may represent a speck of organic materials, and clear outer rims (Fig. III-21). On the other hand, the microbial laminae may be thin (50 µm), or thicker (300 µm) that consist of dark microbial dense micrite that show generally irregular network pattern (Fig. III-21).

The white laminae may also form from euhedral lenticular gypsum crystals that have a length of 100-500 µm, and width of 30-200 µm (Fig. III-22). These lenticular crystals are randomly distributed and enclosed between dense microbial micrite rich in finer lenticular gypsum and silt fragments (Fig. III-22).

4. STROMATOLITIC GYPSUM

This facies is closely linked with the microbial laminated gypsum facies, where they pass vertically from laminated to stromatolitic gypsum or vice versa (Fig. III-23). The stromatolitic gypsum facies consists of wavy, regular contortion of white gypsum laminae and darker greenish or brownish microbial laminae. The contortion of this lamination is similar to the laterally linked hemispheroid stromatolite type of Logan et al. (1964). Sometimes, satin spar gypsum veins are widespread in this facies, where the fractures are usually parallel or inclined to the contorted structure.

Under the microscope, the composition of both the white thicker gypsum laminae and the thinner dark microbial laminae are closely the same as the above mentioned microbial laminated gypsum facies. The difference between them is related to the general morphology, which is controlled by conditions in the depositional environment.
5 - NODULAR MOSAIC ANHYDRITE

This facies is the most common at or near the upper part of all quarries. In the eastern quarry of the Wadi Gasus, it is recorded in beds No. 5, 10 and 11 ranging in thickness from 4-6 m, while in the western quarry it is recorded in beds No. 11 of 2-4 m thick. In Wadi Teaban it is recorded in beds No. 8 and 9 with 4-6 m thick. In the eastern quarry of Wadi Wizr it is recorded in bed No. 6 with thickness from 2-4 m, while in the western quarry it is recorded in beds No. 6 and 7 with 4-6 m thick, (Figs. III-4 to 8). This facies consists of less than 3 cm in size white or turbid anhydrite nodules that are separated with brownish, greenish clayey or silty materials (Fig. III-24). The boundaries of the nodules may be straight, or rounded that resemble the chicken-wire structure. In some locations, the mosaic anhydrite nodules form > 30 cm surficial weathered crust that mantle the interior anhydrite composition. Downward in all quarries, the anhydrite nodules show gradational change to secondary gypsum rock. At the gradational contact, the anhydrite nodules form mosaic or enterolithic morphology that is floating in the brownish or blackish massive gypsum (Fig. III-25).

Under the microscope, the nodules are composed of variable mixture of anhydrite and gypsum crystals. The anhydrite form short prismatic crystals that are randomly distributed, floating and replacing the porphyrotopic gypsum (Fig. III-26). Sometimes, the nodules are composed of fine laths of felted epigenetic anhydrite crystals that are also replacing the precursor secondary gypsum (porphyrotopic or poikilotopic gypsum). With increase in the degree of replacement of gypsum by anhydrite, felted and/or prismatic anhydrite crystals form random, decussate or massive texture.

It is worth to mention that the growth of the anhydrite nodules is a diagenetic feature, which obliterate any primary depositional features. Therefore, the mosaic anhydrite nodules are a diagenetic facies that formed during in the late history of the rock, either during burial or exhumation. In other cases, the nodular anhydrite is an early diagenetic facies as evidenced by the preservation of square shaped morphology of the precursor halite crystals (Fig. III-27).

6 - ENTEROLITHIC ANHYDRITE NODULES

Near the upper part of the sedimentary sequence in the studied quarries, dense aggregates of anhydrite and/or gypsum nodules are coalesced along certain horizontal direction form the characteristic enterolithic nodules. The nodules range in size from few
millimeters to less than 2 centimeter. The matrix between the nodules is composed of greenish, brownish, or turbid white clay, silt or muddy sediments (Fig. III-27).

Under the microscope, the nodules are composed of either short prismatic anhydrite crystals or felted epigenetic anhydrite that is replacing former gypsum crystals. The matrix is composed of aggregates of fine quartz silt, brownish clay, sometimes with dissemination of dense micrite.
**Figure III-11:** Dense microbial micrite laminae intersect the growth of the porphyrotopic gypsum, bed No. 1 in the eastern quarry and beds No. 10 and 11 in the western quarry of Wadi Wizr. Polars Crossed. PrG- porphyrotopic gypsum, Mc-micrite.

**Figure III-12:** Pseudomorphic replacement of prismatic anhydrite by poikilotopic gypsum, Bed No. 1 in the eastern quarry and beds No. 10 and 11 in the western quarry, Wadi Wizr. Polars Crossed.
Figure III-13: Clear poikilotropic gypsum cements the framework of pebbles fragments, beds No. 2 and 4 in the eastern quarry and beds No. 1 and 3 in the western quarry, Wadi Gasus. Polars crossed.

Figure III-14: Random arrangement of subhedral to euhedral gypsum crystals that form the massive structure of black gypsum, , beds No. 2 and 4 in the eastern quarry and beds No. 1 and 3 in the western quarry, Wadi Gasus. Polars Crossed. GrG = gray gypsum, AlG = alabastrine gypsum.
Figure III-15: Corrosion of the coarse size porphyrotopic gypsum by patch of fine alabastrine gypsum, beds No. 2 and 4 in the eastern quarry and beds No. 1 and 3 in the western quarry, Wadi Gasus. Polars Crossed. PrG= porphyrotopic gypsum, AlG= Alabastrine gypsum
**Figure III-16:** Long satin spar gypsum crystals filling fracture that enclose detached wall rock materials, bed No. 1 in the eastern quarry and beds No. 10 and 11 in the western quarry, Wadi Wizr. Polars Crossed. SG = satin spar gypsum
Figure III-17: Fracture in gypsum enriched in microbial micrite is filled with euhedral to subhedral granular gypsum, beds No. 1, 6 and 7, Wadi Teaban, Polars Crossed. GrG=gray gypsum
Figure III-18: Thin microbial micrite in porphyrotopic and poikilotopic gypsum crystals, bed No. 2 in the eastern quarry and beds No. 2, 5, 6 and 8 in the western quarry, Wadi Gasus. Polars Crossed.
**Figure III-19:** Polars crossed extinction of celestite in the micrite rich lamina, bed No. 2 in the eastern quarry and beds No. 2, 5, 6 and 8 in the western quarry, Wadi Gasus, Polars Crossed.

**Figure III-20:** Irregular brownish thin microbial laminae interlaminated with thicker white gypsum laminae, bed No. 6 in the eastern quarry and beds No. 4 and 7 in the western quarry, Wadi Gasus
Figure III-21: Irregular laminae of dense aggregates of microbial micrite, with scattered zoned dolomite crystals in poikilotopic gypsum bed No. 4 in the eastern quarry and beds No. 1, 2, and 5 in the western quarry, Wadi Wizr, Polars Crossed.

Figure III-22: Random arrangement of coarse gypsum crystals that are dispersed in clayey Material, bed No. 6 in the eastern quarry and beds No. 4 and 7 in the western quarry, Wadi Gasus. Polars Crossed.
**Figure III-23:** Wavy, contorted thicker, white gypsum laminae and thinner, dark microbial laminae that formed laterally linked stromatolite type, beds No. 5 and 6 in the eastern quarry, Wadi Gasus.

**Figure III-24:** Aggregates of variable size of nodular mosaic anhydrite, that form crust on the anhydrite exposure, beds No. 6 and 7, Wadi Wizr.
**Figure III-25**: Gradational contact between dark colored gypsum at bottom and white nodular anhydrite at top, beds No.10 and 11, Wadi Gasus.
**Figure III-26:** Replacement of secondary gypsum by epigenetic prismatic anhydrite crystals, bed No. 6 in the eastern quarry and beds No. 6 and 7 in the western quarry, Wadi Wizr. Polars Crossed. Cross Nicole.

**Figure III-27:** Secondary gypsum pseudomorphically replaces a square shaped precursor halite, and are replaced by felted epigenetic anhydrite bed No. 6, the eastern quarry of Wadi Wizr and bed No. 11, the western quarry of Wadi Gasus. Polars Crossed.
Figure III-28: White enterolithic anhydrite nodules at bottom that change upward to mosaic anhydrite nodules, beds No.7, 8 and 9, Wadi Teban.
DIAGENESIS

Evaporites suffer from the effect of diagenesis more readily than any other sediment. Alteration begins accompanying deposition; the earliest change is cementation, and most if not all evaporites are cemented as they are formed (Schreiber, 1988). Even the simplest changes in climate may cause substantial variation in both mineralogy and morphology of the deposits. The ease of transformation, both during formation and more particularly after burial, has led some authors to consider much of the evaporite diagenesis as a sort of (progressive metamorphism) (Borchert and Muir, 1964).

Although gypsum is common in recent evaporitic sediments and primary gypsum is preserved in some Neogene evaporite formations that have been buried to only relatively shallow depths. It is characteristically not found in borehole cores taken from evaporites at depths greater than approximately 1000 meters where anhydrite is normally the only calcium sulfate mineral present. It is therefore generally believed that gypsum becomes unstable in consequence of the increase in rock temperature which accompanies burial and that at some critical depth, determined by the local geothermal gradient and the salinity of the connate waters, it is made over into anhydrite Shearman (1983).

The late change from gypsum to anhydrite, which should take place during burial, would be mainly a response to the rise in rock temperature that accompanies increasing depth of burial. That increase in temperature would be expected to affect any group of beds uniformly. So the diagenetic effects should be pervasive. Accompanying the increase in the depth of burial is the volume changes that should result from the mineral alteration. If the system is closed so that calcium and sulfate ions are neither lost nor added, the change should result in a decrease in volume of the solid phase of approximately 38 % (Shearman, 1983; warren, 1999). Where the change from gypsum to anhydrite takes place syndepositionally, the reduction in volume is largely compensated for by the very loose packing of the anhydrite crystals in the resultant nodules. However, at the depth of burial where the late diagenetic changes believed to occur the system should be virtually closed with respect to calcium and sulfate ions. Under the overburden load which would prevail. Shearman (1983) mentioned that the effects of the 38 % reduction in bed thickness should be expressed in the detail of the structure of the anhydrite bed.
Nodules of gypsum and anhydrite have been found, or have been interpreted to form, in a variety of diagenetic environments, including:

1- Supratidal evaporites (e.g. Kinsman 1966; Shearman 1966; Butler 1969, 1970a, 1970b; Butler et al. 1982).
2- The vadose zone (Schreiber et al. 1976).
3- In shallow subaqueous gypsum beds as syndepositional or postdepositional alteration products (Shearman, 1983; Schreiber 1988).
4- As replacements of laminated carbonate and/or sulfate deposits (Bebout and Maiklen, 1973; Dean et al., 1975).
5- As replacement of gypsum along the hinge of tectonic folds and faults (Schreiber et al. 1982)
6- Displacively within the uppermost layers of sediments deposited in more than 2000 m of water (Bischoff 1969; Ross and Degens 1969).
7- Displacively and replacively during burial at depths of tens to several hundred meters (Machel and Burton 1991).
8- Subaqueous growth with wave action (Imlay 1940).
9- Subaqueous growth influenced by water depth and degree of agitation (Richter-Bernburg, 1955).
10- concretionary growth (Jung 1958)
11- syndepositional flowage of semi fluid sediment (Riley and Byrne 1961).
12- replacement of displacive gypsum nodules with concomitant partial replacement of the surrounding carbonates sediment (e.g. Murray 1964).
13- subaqueous growth as cement (Langbein, 1983).
14- growth as floating nodules (Richter-Bernburg, 1985)
15-nodules development during compaction of bedded gypsum/anhydrite (Langbein 1983).
16-the nodular anhydrite can form at depths exceeding 2500-3000 m., the more presence of anhydrite nodules has no particular significance genetically or paleoenvironmentally, yet that the origin of anhydrite nodules at any location can often be determined using petrographic and/or geochemical criteria (Machel, 1992).

Warren (1999) mentioned that most ancient evaporites show strong evidence of secondary or diagenetic textural overprints. Providing brine is saturated with respect to a
particular evaporite mineral it has the potential to precipitate that mineral, this potential exists both at the surface and in the subsurface.

There is no real consensus on the meanings of the terms primary and secondary as applied to evaporites. The 1962 International Conference on Saline Deposits defined primary minerals as those which precipitate directly from solution, while secondary minerals are those formed later than the primary ones (Ingerson, 1968). Stewart (1963) held similar views and dealt with (penecontemporaneous changes) and (postconsolidation changes) under secondary changes. Braitsch (1971), on the other hand, included early diagenetic alteration in his definition of (primary precipitation). These differences are in one sense semantic (Hardie et al., 1983), since all acknowledge that initial precipitates must be altered soon after deposition, and it becomes a matter of preference to authors whether to include early alteration under primary Braitsch (1971) or under secondary Stewart (1963).

On the other hand, the distinction between early diagenetic changes and later burial changes is truly a pivotal decision. Hardie et al., (1983) put some terms that explicitly acknowledge the timing of such changes. In terms of timing a mineral, mineral assemblage, texture, fabric, fluid inclusion or structure could be:

1. Depositional, i.e. formed at the time of deposition of a sedimentation unit or deposition in its existing form.
2. Post-depositional but pre-burial, i.e. formed diagenetically soon after deposition by processes controlled by the existing environment.
3. Post-burial, i.e. formed by late diagenetic or metamorphic-metasomatic processes controlled by subsurface burial environment.

Of the first two classes, one is primary (depositional) and the other is secondary (diagenetic) but both depend on processes operating in the depositional environment and house valuable information about primary environmental parameters. For this reason, Hardie et al. (op. cit.) grouped them together under syndepositional features, and put a third class (ambiguous features) with no decisive criteria that point to the time of origin.

The diagenesis of evaporites is complicated because of the continuous changes that are associated with the changing environmental conditions.

In general, the evaporites are suffered from the effect of diagenetic sequence in three stages; syndepositional (pre-burial) stage, burial stage and uplift stage. The first two stages
were suggested by Hardie et al. (op. cit.) and Shearman (1983), and the last stage by Monty et al. (1987).

1-Syndepositional (pre-burial) stage

Gypsum rather than anhydrite is the most common form of sedimentary CaSO₄ at earth surface temperature. Intense solar heating in very arid regions can dehydrate gypsum to form anhydrite at the surface. Gypsum also converts to anhydrite in the capillary zones of sabkhas and evaporitic mudflats where the gypsum is bathed in highly saline NaCl brines (Warren, 1999). This is the very early stage in which diagenesis is penecontemporaneous with sedimentation, or is effective soon after sedimentation. The main controlling factors are the composition of the host sediments and brine waters and climatic conditions.

2 – burial diagenetic stage.

Gypsum, the common expression of calcium sulfate in surface conditions, becomes unstable at depth as a consequence of temperature increase and is changed into anhydrite. The transformation produces a textural homogenization with obliteration of the gypsum crystallization structure and the development of nodular and mosaic anhydrite (Rouchy, 1976 and Loucks and Longman, 1982). The transformation of gypsum into anhydrite may occur at depths as shallow as 1-2 m, when the pore fluid are saline (Holser, 1979; Shearman, 1983 and Hovorka, 1988) and up to 2.3 km (Sonnenfeld, 1984). The range of depth at which gypsum converts into anhydrite depends on various parameters, principally the geothermal gradient, tectonism, seismicity and salinity of the connate waters (Deer et al., 1962; Heard and Rubey, 1966 and Rouchy et al., 1987). Douglas and Goodman (1957) showed that pressure alone (i.e. depth) could not control dehydration, and that gypsum remains stable under pressure equivalent to a load of about 18000 ft of rock. Also Sonnenfeld (op. cit.) mentioned that (pressure alone will not cause conversion of gypsum to anhydrite, and that gypsum rather than anhydrite forms at pressure up to 51 MB (2.3 km or 7500 ft depth). Deer et.al. (Op. cit.) Stated that the dehydration of gypsum is an endothermic reaction and as gypsum is buried, the increasing temperature favors dehydration. So, the dehydration reaction is more dependants on temperature than on depth.

The thick beds of widespread nodular anhydrite were formed in early burial as thick beds of primary gypsum were compacted and converted to anhydrite (Warren, 1990). When
gypsum is buried and ambient temperature rises above 50-60ºC, it converts to nodular anhydrite. The depth of transformation is between a few meters to more than a kilometer. The exact depth in any region will depend on lithostatic pressure, local geothermal gradient and pore brine salinity (Warren, 1990).

If the near surface pore-fluid salinity approaches halite saturation, the conversation from gypsum to anhydrite can occur at shallower depths and much lower temperatures 35-45º C. Such temperatures occur as shallow as 1-2 meters below the depositional surface of a halite-saturated brine pool and lie in the zone of active phreatic flow or brine reflux. At such depths the buried gypsum bed retains well-developed intercrystalline porosity and inherently high permeability (Warren, 1999).

With less saline brines in the pores of a buried CaSO₄ bed the conversation of gypsum to anhydrite may not occur until burial depths of hundreds of meters. By such depths, the natural compaction has greatly depleted intercrystalline porosity in the gypsum bed. Release of water from already compressed and cemented gypsum will create 40 % water-filled porosity in an otherwise impervious anhydrite unit. Over the long time this water is not retained but escapes into the subjacent sediments. The converting CaSO₄ bed has a decrease in its inherent strength and in compressive situation, and an increased ability to act as a lubricating horizon (Warren, 1999).

3 – Uplift diagenetic stage.

Some diagenetic processes are believed to occur during or after uplift under the influence of exhumation, which permits rehydration, solution and calcitization. Rehydration, particularly of anhydrite is accompanied by a considerable volume expansion, and when occurs at the surface, results in spalling and cracking in the new gypsum (Schreiber, 1988). Near surface rehydration does not present a great problem, because the volume changes simply results in slight uplift. At a distance below the surface, hydration is far slower and commonly takes place along fractures and faults (Schreiber et al., 1982 and Schreiber, 1988). In areas where strain buildups occur, as in earthquake-prone regions, water may be forced along fractures in anhydrite. Coarse gypsum forms along porous and permeable zones in intercalated clastics and carbonates, and water slowly moves farther in along crystal boundaries and small fractures, forming the typical interlocking mosaic of alabastrine gypsum (Schreiber, 1988). Open fractures forced by overpressured water, may become the sites of
satin spar formation (Mossop and Shearman, 1973). Also calcitization of sulfate minerals and of associated dolomite beds commonly takes place in the zone of penetration by meteoric water.

Most common is the conversation of exhumed and uplifted anhydrite beds into diagenetically regenerated gypsum (Warren 1999). Two commonplace gypsum fabrics are the result of exhumation: coarse porphyrotopic gypsum and fine-grained alabastrine gypsum (Holliday, 1970; Warren et al., 1990). The change from porphyrotopic to alabastrine may be depth-related (Warren et al., 1990). Porphyrotopic gypsum defines the re-emergence of nodular anhydrite from the stagnant phreatic into the deep portion of the zone of active phreatic flow. Alabastrine gypsum forms in the zone of more active phreatic flow (Warren, 1999).

The following is a description of the works carried out in the Red Sea evaporites to describe the different diagenesis of the evaporites in the Red Sea region.

Hume (1916) believed that the evaporites of the Red Sea region are of a replacement origin of an original limestone.

Akkad and Dardir (1966) advocated a lagoonal origin for the Miocene evaporites. Friedman (1972) believed a sabkha origin to the Miocene evaporites of the Red Sea region.

Philobbos et al (1985) mentioned that during the formation of the nodular mosaic anhydrite, the nodular laminated anhydrite and the thinly bedded anhydrite – halite facies, the anhydrite passed through three stages of diagenesis.

1- First it was deposited as gypsum penecontemporaneous with sedimentation.
2- Then was replaced by epigenetic felty anhydrite.
3- Occasionally this anhydrite was further affected by a third diagenetic stage where secondary gypsum began to form as a result of hydration.
4- Replacement by calcite, dolomite and silica occasionally affect the evaporites at a later stage of diagenesis.

Abdel Wahab and Ahmed (1987), in their study in seven localities (north of Wadi Essel, Wadi Essel, north of Wadi Sharm el Bahari, Wadi Abu Ghorban, Wadi Um Rheiga, Wadi El Anz and Gebel El Rusas mine) mentioned that the diagenesis of evaporites is
complicated because of the continues changes that are associated with changing environmental conditions. They interpret three stage of diagenesis;
1-pre-burial early stage, this is the early stage of diagenesis that is penecontemporaneous with sedimentation.
2-burial stage, this stage includes all the diagenetic processes that took place at shallow and deep burial levels.
3-Uplift stage, includes some diagenetic process occurred after the uplift under the influence of intensive sub-aerial weathering.

Diagenesis of the studied evaporite rocks at Um Reigha area developed in two different settings, they include 1- normal shallow subsurface and uplift digenetic environment linked mainly with dehydration of gypsum. 2- diagenetic setting connecting with secondary diagenetic (bioepigenetic) transformation of sulphate into carbonate and sulphur, Aref, 1997

In the present work, the calcium sulfate rocks cropping out in the studied quarries are composed of secondary gypsum in the lower 2/3 of the quarries, whereas the upper 1/3 is composed dominantly of anhydrite, which is believed to have been formed from solar dehydration of secondary gypsum. Secondary gypsum is defined as those rocks produced by hydration of preexisting anhydrite rocks, or by dissolution and re-precipitation of gypsum by the action of ground water and/or surface weathering. Several basic types of gypsum fabrics may develop, such as porphyrotopic, poikilotopic, alabastrine, granular, selenite masses and satin spar veins. The non-evaporite minerals are represented by scalenohedral calcite, rhombic dolomite, microbial micrite, organic matter, claystone and celestite (Figs.III-4 to 8). It is important to point to the absence of any dominant gypsum crystal fabrics in certain horizons, but they vary in abundance throughout the studied gypsum sequence. However, near the base of the gypsum sequence, porphyrotopic and poikilotopic gypsum are dominate, which impart a black coloration to the gypsum (Fig. III-3) that decrease in abundance upward. On the other hand, alabastrine, selenitic and granular gypsum, and gypsum veins are abundant near the top of the gypsum sequence, which impart a pale yellow color to the gypsum, that decrease in abundance downwards. The boundary between the black and pale yellow gypsum is usually gradational intertonguing relationship (Fig. IV-1), with the pale yellow arms pointing downwards representing a possible pathway of descending meteoric water along fractures, or discontinuities between the porphyrotopic and poikilotopic gypsum crystals. The following is
a description of the petrographic characteristics of the identified types of the secondary gypsum and their mutual interrelationship.

1 - Porphyrotopic gypsum

Porphyrotopes of gypsum commonly occur as mutually interfering aggregates at the lower part of the gypsum sequence, or as floating crystals within the alabastrine gypsum near the upper part of the gypsum sequence. The porphyrotopes are characterized by the presence of microscopic relics of anhydrite and bassanite (Fig. IV-2) that are distinctive to anhydrite-to-gypsum hydration process. The porphyrotopes are generally composed of coarse crystals up to 3 mm in size, with interpenetrating crystals boundary with the surrounding crystals. Occasionally, the porphyrotopes have thin, elongate, prismatic arms that penetrate the adjacent crystals (Fig. III-10). The porphyrotopic gypsum usually encloses undisturbed microbial micrite laminae (Fig. III-11) that is associated with the dissemination of scalenohedral calcite or celestite crystals. The undisturbed nature of the microbial micrite indicates that the replacement of anhydrite by gypsum took place on a volume-to-volume basis, without any change in volume.

2 - Poikilotopic gypsum

This variety of secondary gypsum also encloses relics of anhydrite precursor and is abundant near the bottom of the gypsum sequence, similar to the porphyrotopic gypsum variety (Figs.III-4 to 8). Poikilotopic gypsum usually encloses dense microbial micrite (Fig. III-18), or pyrite. The poikilotopic gypsum also locally preserves the precursor morphology of the prismatic anhydrite or gypsum crystals (Fig. III-12), a phenomenon that indicates either no volume changes have occurred during the transformation of anhydrite into gypsum or vice versa, or due to dissolution of former gypsum or anhydrite crystals and precipitation of poikilotopic gypsum.

3 - Alabastrine gypsum

Alabastrine gypsum consists of either subcrystals with shadowy grain boundaries and extinction (super-individual polarization of Ogniben (1957), or aggregates of microcrystalline gypsum with a size less than 50 µm (Fig. III-15). The latter type is equivalent to type-2 hydration texture of Holliday (1967 and 1970). It is dominant near the top of the gypsum
sequence, but it cannot form the whole rock. It is usually found associated with porphyrotopic, poikilotopic or granular gypsum. The alabastrine gypsum is usually recorded as circular, elongate or irregular patches adjacent to, or within, the porphyrotopic and poikilotopic gypsum (Fig. III-15). The boundaries between the microcrystalline gypsum and the coarse gypsum crystals are usually gradational interpenetrating contact, indicating the replacement of the coarse crystals with the finer ones. This process of replacement of the coarse gypsum by fine gypsum has been described before by Watson (1988), and Aref (2003b) from pedogenic gypsum crusts.

4 - Granular gypsum

The granular gypsum is recoded in variable amounts in the gypsum sequence (Figs. III-4 to 8). It is composed of coarse (~ 250 µm) clear, subhedral to euhedral gypsum crystals (Fig. III-14). It is recoded either as patches in the alabastrine or porphyrotopic gypsum, or as filling types in extensional cracks between the microbial laminae and gypsum laminae (Fig. III-17). The morphology of granular gypsum, the absence of anhydrite inclusions and their cross cut relationship with porphyrotopes and alabastrine gypsum indicates that they postdate the latter crystal fabrics. The CaSO₄ necessary for formation of the granular gypsum have possibly been derived from the excess sulfate in the process of hydration of anhydrite to gypsum, or from dissolution and recrystallization of former gypsum crystals.

5 - Selenitic gypsum

The term selenitic gypsum is used to describe clear and colorless variety of gypsum occurring in distinct transparent crystalline masses (Bates and Jakson, 1980). The selenite is recorded in the study area as patches. Up to 2 meters in size, having irregular gradational boundaries with the enclosing gypsum rock (Fig. IV-3). It is also recoded as fracture filling in the black or white secondary gypsum (Fig. III-B). Microscopically, it is composed of very clear euhedral and subhedral gypsum crystals that may enclose patches of alabastrine or porphyrotopic gypsum. The cross cut relationship of the selenite with the alabastrine and porphyrotopic gypsum indicates the relatively late stage origin of the selenite.
6 - Gypsum veins

The gypsum veins are recorded in discontinuities between microbial laminae and gypsum laminae, i.e. oriented parallel to the depositional surface, or may cross cut them. The veins are composed of fibrous gypsum crystals, with lengths more than 2 mm. The fibers may grow from one wall to the other, with micrite ships aligned between fibers. Also, the fibers may grow centripetally from the walls to the central parting and may enclose detached wall rock materials parallel to the fracture wall (Fig. III-16). The gypsum veins may be composed of straight fibers, or slightly twisted fibers showing optical continuity. The later may represent original growth under the influence of syngrowth shear during fracture dilation (Ramsay and Huber, 1983). The existence of several wall rock materials parallel to the fracture wall indicates an episodic opening of the fracture, contemporaneous with filling of the fracture with gypsum crystals. Similar to that described by El Tabakh et al. (1998), and Aref and Morsy (2000).

MUTUAL RELATIONSHIPS BETWEEN FABRIC TYPES OF SECONDARY GYPSUM

Where different crystal types of secondary gypsum occur together in the same sample, a mutual relationship exists. The porphyrotopic and poikilotopic secondary gypsum usually have relics of anhydrite, indicating that they are of replacive origin during early exhumation of the rock (Fig.IV-2), similar to that described by Ogniben (1957); Holliday (1967 and 1970). Mossop and Shearman (1973); Warren et al. (1999); Aref et al. (2003). The relatively coarser size of porphyrotopic and poikilotopic secondary gypsum suggests that nucleation and growth were, in general, relatively slow at or near equilibrium conditions. This is most likely to be achieved where the water is introduced at depth, early in the exhumation history (Mossop and Shearman, 1973).

Where porphyrotopic and alabastrine gypsum occur together, the alabastrine gypsum has thin, elongate arms protruding into and corroding the porphyrotopic gypsum (Fig. III-15). The process of replacement of the relatively coarser gypsum by the finer gypsum is similar to micritization of sparry calcite in carbonate rocks, that are described before in the process of gypcrete formation by Watson (1988), and Aref (2003b). The relatively fine sizes and the disordered crystal structures indicate that the original nucleation centers were closely spaced and that hydration was characterized by rapid growth under conditions far removed from
equilibrium (Mossop and Shearman, 1973). The granular and satin spar gypsum veins usually have sharp boundaries with the enclosing porphyrotopic, poikilotopic and alabastrine gypsum, indicating that they are late in the diagenetic history of the secondary gypsum rock. The selenite pockets that intersect all secondary gypsum post-date their formation and represent the last forming secondary gypsum during the late exhumation of rocks (Fig. IV-4).

**Origin of secondary gypsum**

Three main possible mechanisms for hydration of secondary anhydrite have been described by Holliday (1970), and Mossop and Shearman (1973):

1- direct addition of structural water to anhydrite crystal lattice. Because of the difference in crystal lattice of anhydrite (orthorhombic) and gypsum (monoclinic), Mossop and Shearman (1973) point to the difficulty of re-organization of the lattice structure in solid state.

2- Hydration of anhydrite through intermediate bassanite and hemihydrate ultimating to gypsum.

3-The dissolution of anhydrite and subsequent precipitation of gypsum.

In the present work, the existence of bassanite in some samples (Fig. IV-2) indicates that the intermediate phase had possibly occurred locally. However, the third mechanism of anhydrite dissolution and subsequent precipitation of gypsum is the main mechanism, as accepted by most workers. This dissolution-reprecipitation mechanism is evidenced by the general absence of features indicating any volume increase associated with gypsification in the studied samples, a phenomenon that suggests that the excess sulfate is carried away in solution to form gypsum veins and selenite pockets (Figs. III-16, III-17, and IV-3).

The widespread occurrence of porphyrotopic and poikilotopic gypsum near the base of the gypsum sequence has been formed when the hydration reaction took place slowly at near equilibrium condition in the early exhumation history of the rock. When the reactions were more rapid because of extreme disequilibrium, the resulting gypsum crystals, after porphyrotopic and poikilotopic gypsum, were equant and is fine-grained alabastrine gypsum. This had possibly occurred at the late exhumation history of the rock (Fig. IV-4).

Three ways of supplying water necessary for hydration of anhydrite were described by Mossop and Shearman (1973):
1. Water is already present within the rocks (formation water contained in porous strata).
2. Water can be introduced from underlying water-bearing strata.
3. Percolation of surface water during exhumation.

The field relationships of the secondary gypsum rocks point to the absence of porous strata, such as sandstone or fractured limestone, within the evaporite sequence, a phenomenon that rules out the first possibility of processes. To favor the second possibility, the secondary gypsum must be localized at the lower part of the evaporite sequence, close to the underlying water-bearing strata. In this process, hydration takes place from bottom to top, and the un-replaced anhydrite should be at the top of the evaporite sequence. This process is also ruled out because of the existence of anhydrite mantle that post-date the secondary gypsum due to solar heating, and the widespread of secondary gypsum in all the studied sections. Therefore remains the possibility of infiltration of meteoric water, which is believed to be the most favorable process for the formation of the examined secondary gypsum. This process probably took place during later (Pliocene and/or Pleistocene) pluvial periods, when intense rainfall over the uplifted anhydrite rock lead to their hydration to gypsum. Accompanying the uplift of the evaporite sequence, is its tilting to the east and its exposure to exhumation. This resulted in the expansion of the CaSO4 deposits, which accompanied the unloading of the Pliocene and some parts of the Pleistocene sediments. Percolation of meteoric water through fractures that resulted during unloading or during rifting, to the evaporite sequence led to the hydration of anhydrite to gypsum in two diagenetic environments (Fig. IV-4). The first took place below the water table, in a stagnant phreatic zone, leading to the widespread hydration of anhydrite into porphyrotopic and poikilotopic gypsum under equilibrium conditions (Fig. IV-4). The second took place in active phreatic conditions, leading to the dissolution of the early-formed porphyrotopic and poikilotopic gypsum by under-saturated meteoric water with respect to gypsum and its rapid recrystallization, in disequilibrium conditions, into alabastrine gypsum (Fig. IV-4). It is also possible that the selenite pockets have been formed in the active phreatic zone; as evidenced by the absence of erosional features characteristics of dissolution caves or pipes, and the precipitation of very large selenite masses under equilibrium conditions. The existence of subsurface dissolution channels filled with conglomerate or clay point to the relatively later intensive rainfall periods that played the role in the formation of secondary gypsum. The possibility that the
Red Sea waters had no effect in the hydration process is here ruled out due to the observed arrangement of the various types of gypsum vertically rather than laterally, an observation in favor for a meteoric water source from above.
**Figure IV-1:** Intertongueing relationship between black and yellow secondary gypsum, beds No. 3 and 4, Wadi Teaban.

**Figure IV-2:** Relics of anhedral anhydrite corroded and replaced by phorphyroblastic gypsum through the intermediate stage bassanite bed No. 7, Wadi Teaban. Polars Crossed. PrG- phorphyroblastic gypsum An- anhydrite Bs-bassanite.
Figure IV-3: Clear selenite masses that formed near the upper part of the gypsum sequence, beds No. 5, Wadi Wizr.
Figure V-3: Euhedral celestite crystals randomly distributed in microbial laminates, bed No. 3 in the eastern quarry and beds No. 3,4 and 5 in the western quarry, Wadi Wizr. Polars Crossed.
(Fig. IV-4)- Flow chart for the formation of different crystal fabrics of gypsum under different diagenetic conditions, (after Aref et al., 2003).

<table>
<thead>
<tr>
<th>Diagenetic environment</th>
<th>Diagenetic agent</th>
<th>Crystal fabrics</th>
<th>Diagenetic processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcrop</td>
<td>Solar heating</td>
<td>Felted &amp; prismatic anhydrite</td>
<td>▪ Climatic dehydration of gypsum into anhydrite</td>
</tr>
<tr>
<td>Late exhumation</td>
<td>Invasion of meteoric water</td>
<td>Active phreatic Selenite pockets</td>
<td>▪ Slow crystal growth. ▪ Equilibrium condition.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Granular gypsum &amp; Alabastrine gypsum</td>
<td>▪ Dissolution &amp; rapid recrystallization of gypsum. ▪ Disequilibrium condition.</td>
</tr>
<tr>
<td>Burial</td>
<td>Geothermal gradient</td>
<td>Epigenetic anhydrite</td>
<td>▪ Shallow or deep burial dehydration of primary gypsum into anhydrite.</td>
</tr>
</tbody>
</table>
MINERALOGY AND GEOCHEMISTRY

Evaporite minerals can be considered as some of the purest chemical compounds, in terms of lack of trace contaminants, produced by many geologic processes (Dean, 1978). However, an indirect method to determine the major elements in the composition of evaporites is the microscopic determination of the evaporite minerals (Dronkert, 1985). Fortunately, most evaporite rocks contain one dominant mineral so that comparison of analyses of a particular evaporite lithology is usually more meaningful than a comparison of analyses of other sedimentary rock types that have more complex and variable mineral composition. To differentiate between evaporites of the same species, chemical analyses (e.g. Rosell et al., 1998; Risacher et al., 2002, with references), fluid inclusions (Attia et al., 1995; Aref, 1997; Kovalevych et al., 2002, with references), and isotopic compositions (McArthur, 1995; Kirkland et al., 2000, with references) of these minerals can yield significant results.

Because of the high susceptibility of evaporite rocks to the post-depositional environmental changes, both depositional and diagenetic environments leave their imprints on the element composition of the evaporite minerals. The presence of both major and minor (or trace) quantities of elements may allow conclusions as to paleosalinity, the composition of the original brines, the water depth of the depositional basin, the paleotemperature, the composition of the earth’s atmosphere, etc. (Holser, 1979a, 1979b; Dronkert, 1985). Also, element analyses may yield some data on the diagenetic history of the evaporites. However, important element analyses have merely a theoretical value without field observations, macroscopic and microscopic mineral determinations of the evaporite rocks. For this reason, Dronkert (1985) stated that the chemistry of evaporite rocks could never be an aim in itself; it can only be a useful tool to the study of evaporite rocks.

Most studies on the Neogene evaporites of Egypt are related to sedimentological, mineralogical and environmental characteristics of the deposits, whereas a few works discussed the geochemical characteristics of the evaporites (e. g. Awadallah and Wali, 1985; Wali et al., 1989; Aref, 2001). The scarce geochemical works on evaporites may probably be due to the difficulties in obtaining fresh rock samples, the susceptibility of evaporites to post depositional diagenesis, and the difficulties to interpret the geochemical data with regard to the state of evaporite diagenesis. On the other hand, numerous works dealt with the geochemistry of recent sabkha sediments and brines (e. g. Philip et al., 1992; Aref et al., 1999 and 2002, among others).
In the present chapter, the mineralogy and geochemical characteristics of the studied gypsum deposits are dealt with in a separate section.

1. MINERALOGY OF THE EVAPORITES

Mineralogical investigation of the studied Miocene evaporites by XRD techniques indicates that gypsum is the most abundant mineral in all samples, with the exception of samples No. 12 TB in Wadi Teaban, where calcite is the abundant mineral (Table-2). Minor constituents of other minerals, which vary from one area to another, are detected in most samples. These minerals in a decreasing abundance are quartz, calcite, anhydrite, magnesite, celestite, and dolomite. Other minerals recorded are Fairchildite in Wadi Gasus (Table 2). The variation in mineralogical composition reveal variable conditions in the evolution of the gypsum deposits since their formation in the depositional basin, the type and nature of the parent brine, reactions of the parent brine with surrounding rocks, reactions of the gypsum with formational water and meteoric water during diagenesis, variation in climatic conditions … etc.

2. GEOCHEMISTRY OF THE EVAPORITES

The data on chemical analysis of the studied Neogene evaporites by XRF techniques are listed in Table 2, and are graphically presented in figure V-1. The correlation coefficients of the studied elements are listed in table 3, and are presented in figures V-2. The obtained geochemical data on the studied evaporites lead to the following inferences.

Sulfate (SO₃)

Obviously, sulfate dominates the studied evaporites, except samples 12 TB (Wadi Teaban), which is more calcareous (Fig. V-1). The sulfate content varies from 40 to 52 wt% (av. 46.83 wt%) in Wadi Gasus, 45 to 49 wt% (av. 47.0 wt%) in Wadi Wizr, 6.1 to 49 wt% (av. 37.62 wt%) in Wadi Teaban, (Tables 2 and 3). In some samples, the low sulfate contents are usually accompanied by higher contents of CaO (e.g. samples 12TB in Wadi Teaban) that are necessary to satisfy SO₃ to form gypsum, or are accompanied by higher contents of SiO₂ in Wadi Gasus (Table 2 and Fig. V-1). This observation is confirmed by the existence of calcite and quartz in the above-mentioned samples through XRD study (Table 2).
**Calcium oxide (CaO)**

Also similar to sulfate, the CaO is abundant in all samples. It ranges from 36 to 54 (av. 45.67 wt%) in Wadi Gasus, 46 to 49 wt% (av. 47.25 wt%) in Wadi Wizr and 47 to 69 wt% (av. 54.2 wt%) in Wadi Teaban. The highest CaO contents (samples 12TB) are usually accompanied by a decrease in SO$_3$ contents (Fig. V-1), and also accompanied by the presence of calcite and dolomite (Table 2). The CaO has a positive correlation with SO$_3$ (Table 3 and Fig. V-2) due to the formation of gypsum.

**Alumina (Al$_2$O$_3$)**

Al$_2$O$_3$ is recorded as a trace constituent in the studied samples. The Al$_2$O$_3$ content ranges from 0.038 to 4.1wt% (av. 0.725 wt%) in Wadi Gasus, less than 0.14wt% (av. 0.1055 wt%) in Wadi Wizr and between 0.30 to 2.7wt% (av. 0.858wt%) in Wadi Teaban. The Al$_2$O$_3$ has positive correlations with K$_2$O, Fe$_2$O$_3$, TiO$_2$ and SiO$_2$ (Table 3 and Fig. V-2), which most probably be related to the presence of clay minerals (e.g. illite).

**Fe$_2$O$_3$ and MnO**

Relatively, higher contents of Fe$_2$O$_3$ are recorded in Wadi Gasus, (2.9 wt%) and Wadi Teaban, (2.0 wt%) whereas values less than 0.5 wt % are recorded in Wadi Wizr (Table 2). On the other hand, MnO is recorded in values less than 0.8 wt % in Wadi Gasus, Wadi Wizr, and Wadi Teaban. The presence of trace amounts of Fe$_2$O$_3$ (Fig. V-1C) and MnO (Fig. V-1F) in the studied evaporite minerals is probably more closely related to inclusions of detrital and organic impurities rather than true solid solution in crystal structure as described by Dean (1978), or due to the existence of microbial laminites, which offered reducing conduction favorable for precipitation of Fe and Mn similar to that described by Saunders et al. (1997) and Galmed, or due to surficial encrustation. MnO has positive correlations with Sr and Zr, and Fe$_2$O$_3$ has positive correlation with TiO$_2$ (Table 3 and Fig. V-2). Because MnO and Fe$_2$O$_3$ are among the most scavengers of trace elements (Loring, 1984), therefore the trace elements Sr, Zr and TiO$_2$ are scavenged on Fe and Mn compounds from solution during diagenesis of the gypsum.

**Potash (K$_2$O)**
The K$_2$O has positive correlation with Al$_2$O$_3$ and SiO$_2$ (Table 3 and Fig. V-2) as mentioned above, despite its lower concentration (Table 2). This indicates the existence of the clay mineral illite in the studied gypsum. Generally the K$_2$O content is less than 0.5 wt % in most samples (Fig. V-1D). Probably, trace concentration of potassium is adsorbed or occluded in the sulfate minerals (Dean, 1978). No substitution of potassium to calcium in the gypsum crystal structure because of its low replacement power.

**Magnesia (MgO)**

The MgO content is much higher than K$_2$O in the studied evaporites. It ranges between 0.13 to 7.60 wt% (av. 1.46 wt% in Wadi Gasus, 0.27 to 4.60 wt% (av. 2.89 wt%) in Wadi Wizr and 0.13 to 2.60 wt% (av.0.68 wt%) in Wadi Teaban. The high MgO content is recorded in the studied samles that contain dolomite or magnesite. MgO has not significant relations to the other elements (Table 3).

Mg and K are very soluble and do not form primary mineral phases, until long after saturation with respect to halite is reached (Dean, 1978). Due to the absence of halite in the studied evaporite deposits, the minor or trace amounts of magnesium may be due to substitution for calcium in CaSO$_4$, or due to adsorption or occlusion of Mg and K in the CaSO$_4$ structure, according to Dean (1978).

**Na$_2$O and Cl**

The Na$_2$O and Cl are recorded in the areas (Table 2 and Fig. V-1G and V-1K). The Na$_2$O and Cl have a very good positive correlation (Table 3 and Fig. V-2), most probably due to the formation of halite despite that it is not detected microscopically or by XRD analysis. The Cl content averages of 211, 223, 248 and 218 in Wadi Gasus, Wadi Wizr and Wadi Teaban. The trace concentration of Na$_2$O in the studied evaporites are probably adsorbed or occluded according to Dean (1978); Kushnir (1980). The amount of Na incorporated in Ca-sulfates would be a good paleosalinity indicator (Land and Hoops, 1973), where the higher values indicate a relatively higher saline condition. The higher concentration of Na$_2$O and K$_2$O in the studied evaporites may be also due to adsorption in clays by post depositional processes.

The smaller concentration of co-precipitated Na, K and Mg in the studied evaporite deposits indicates a relatively low salinity of the brine waters that precipitate CaSO$_4$ under
equilibrium condition. These low concentration values are expected in the studied gypsum because of their common association with microbial laminites.

Under equilibrium condition, the distribution coefficient for $K^+$, $Na^+$, $Mg^{2+}$ in calcium sulfate facies are governed by solid solution distribution, and these trace elements have potential for paleosalinity studies (Dean and Anderson, 1974). However, some other results of Dean and Anderson (1974) suggest caution in the interpretation of salinity. They found that quickly deposited anhydrite had much higher trace elements content than slowly deposited anhydrite. This indicates control by kinetic or adsorption effects rather than solid solution equilibrium, which would distort any salinity estimates (Holser, 1979).

**Silica (SiO$_2$)**

Silica (SiO$_2$) forms a major oxide in Wadi Gasus and Wadi Teaban. Where they range from 0.64 to 14.0 wt% (av. 3.13 wt%) in Wadi Gasus, and 0.41 to 5.1 wt% (av. 2.7 wt%) in Wadi Teaban. SiO$_2$ has positive correlations with Al$_2$O$_3$, K$_2$O and TiO$_2$ (table 3 and Fig. V-2), which indicate that not all the SiO$_2$ present in the studied gypsum is in a free state as quartz grains, but also it occurs in clay minerals. This is confirmed by the detection of quartz and clay minerals through microscopic and XRD studies.

**TiO$_2$**

The TiO$_2$ is recorded in most samples with averages of 0.074, 0.085, in Wadi Gasus and Wadi Teaban and not detected in Wadi Wizr. The TiO$_2$ has positive correlation with Al$_2$O$_3$, Fe$_2$O$_3$, K$_2$O, and SiO$_2$ and negative correlation with SO$_3$ (Table 3and Fig. V-1). The high TiO$_2$ is scavenged on Fe compound associated with the clay minerals, as mentioned above.

**Zr**

High contents of Zr are observed ranges from 152 to 2345 mg/kg (av. 846 mg/kg) in Wadi Gasus, 87 to 3577 mg/kg (av. 1512 mg/kg in Wadi Wizr and 115 to 3823 mg/kg (av. 2763 mg/kg) inWadi Teaban (table 2; Fig. V-1M). The Zr has positive correlations with Sr and MnO, and negative correlation with SO$_3$.The existence of Zr may be related to surface water running over the weathered nearby granitic rocks of the Red Sea Range.
The Sr content varies considerably among the studied areas. The Sr shows a wide range in the studied evaporites (table 2; Fig. V-1L). It ranges from 527 to 24632 mg/kg (av. 8861 mg/kg in Wadi Gasus, 950 to 36749 mg/kg (av. 15690 mg/kg) in Wadi Wizr, and 1055 to 110289 mg/kg (av. 31984 mg/kg) in Wadi Teaban. The highest Sr content is due to the existence of celestite associated with microbial laminites (Fig. V-3), that is also confirmed by XRD data (table 2). The behavior of Sr, Ca, SO3 is closely similar (Figs. V-1N and V-1O), with the exception of samples 12TB, due to the very low content of SO3 compared with CaO (table 2).

The Sr has positive correlations with Zr and MnO, and negative correlation with SO3 (table 3; Fig. V-2) this may indicate the derivation of Sr from granite or from carbonate rocks. A comparison of the relation between Sr (ppm) versus CaO (wt %), and SO3 (wt %) is shown schematically in Figure V-4. For Wadi Gasus, the highest Sr is conformable with the highest CaO, and the lowest SO3. For Wadi Teaban, a wide scatter of Sr/CaO and Sr/SO3 is noticed. The highest and lowest Sr contents are associated with the lowest CaO (Fig. V-4). For Wadi Wizr, a positive relation between Sr/CaO, and a negative relation between Sr/SO3 are noticed.

Dean (1978) believed that mostly trace Sr2+ in evaporite rocks is in true solid solution. He considered that concentration of strontium in carbonate and sulfate minerals does not vary greatly, and is usually in the range of 1000 to around 2000 ppm, and suggested that most strontium is probably substituting for calcium in sulfate and carbonate minerals. Dronkert (1985) found that gypsum could incorporate up to 7000 ppm Sr. Usdowski (1973) mentioned that the high (~ 6500 ppm) Sr incorporated in gypsum indicates deposition of gypsum in the halite phase. However, between 7000 and 60 000 ppm Sr incorporated in gypsum, is not only elemental Sr but also as celestite crystals are detected. This celestite will only be formed by diagenetic processes, or in environments of total desiccation, as can be expected in the sabkha environment (Butler 1973).

However, a major complication factor is the appearance of celestite, with Sr as a major rather than trace element (Holser, 1979). Holser (op. cit.) pointed out that the concentration of Sr in the brine is controlled by the balance between celestite solubilities and sulfate concentration. The sulfate concentration is controlled by: (1) evaporation which increase SO4 concentration, (2) normal precipitation of gypsum and anhydrite will take up some SO4 but
still allow it to increase in the brine (Morris and Dickey, 1957), consequently Sr\(^{2+}\) decrease in the brine, (3) dolomitization of previously precipitated aragonite or calcite release Ca\(^{2+}\) which precipitates additional gypsum, depresses SO\(_4\) nearly to zero, and allow Sr\(^{2+}\) to rise in the brine (Bulter, 1973), (4) organisms may segregate variable amounts of Sr\(^{2+}\) in shell or skeletal growth, and (5) Sr may be taken up by clays (Bausch, 1965). The situation is further complicated by post-depositional redistribution of Sr (e.g. transformation of gypsum to anhydrite). Because Sr is less soluble in gypsum than in anhydrite, so that secondary celestite forms during surface alteration of anhydrite to gypsum (Ham, 1962). A significant decrease (up to 40\%) in Sr content during the hydration of anhydrite into gypsum has been reported by Ham (1962) and Ichikuni and Musha (1978).

Dean (1978) mentioned that the calcium sulfate precipitating in equilibrium with waters of relatively low salinity (where a bed of CaSO\(_4\) is interbedded with carbonates) would contain smaller concentrations of co-precipitated Na, k and Mg than the calcium sulfate precipitated at a higher salinity (where a bed of CaSO\(_4\) is interbedded with halite). On the contrary to the preceding theory, where the Red Sea gypsum contains numerous calcitized microbial laminites, high enrichment of the Sr ions as well as other trace elements in the evaporite sediments (Fig. V-1) is due to their release (mainly) by meteoric water from weathered granitic rocks of the Red Sea Range. Therefore, the parent brine of the Red Sea gypsum is partially derived from continental (meteoric) water source. It is important to point out that there is no dissolution of former halite in the secondary gypsum due to the undisturbed nature of the microbial laminites (Aref et al., 2003).

Because Sr is less soluble in gypsum than in anhydrite, secondary celestite forms during surface alteration of anhydrite to gypsum (Ham, 1962). On this basis, probably some of the celestite recorded in the Red Sea gypsum will be formed during hydration of burial anhydrite into gypsum. Also, the Sr and other minor elements may be concentrated by the activity of microbial mats (Fig. V-3), similar to the enrichment of heavy metals in microbial mat environment (Taher et al., 1994).

Parmar et al. (2000) in an experimental study, pointed out that the greater percentage of solid phase capture of Sr\(^{2+}\) occurred in presence of the Fe\(^{3+}\)-reducing bacteria Shewnella alga as due to both sorption and precipitation processes.

The very high concentration of Sr in the Red Sea gypsum deposits are perhaps also related to the leaching of Sr from the basement rocks in the Re Sea region or due to carbonate
dissolution. Thus Sr is either deposited inorganically by combination with SO$_4$ to form celestite, or it was deposited by the action of microbial mats. Therefore, the higher values of Sr in the Red Sea are related to the presence of celestite crystals, in addition to a solid solution in the gypsum crystals.

In the Red Sea gypsum deposits, the high Sr anomalies result in the formation of celestite (Fig. V-3 and Table 2). The celestite is precipitated either because of the negative temperature coefficient of SrSO$_4$, according to Braitsch (1971), or as a result of the mixing of continental freshwater and evaporite basinal brines, according to Chabou-Mostefai et al. (1978).

The present study proves that the Red Sea evaporites, which were previously considered as marine deposits, are actually hybrids formed by a combination of marine and nonmarine (continental) waters as evidenced by the high enrichment of trace and minor elements.
ENVIRONMENT OF DEPOSITION

This chapter throws light on the depositional environment of the studied evaporite rocks in Wadi Gasus, Wadi Teaban, and Wadi Wizr areas.

Evaporite deposits are known to have formed somewhere during virtually every geologic period. Though they make up a small part of the stratigraphic column, probably less than 1 percent in most areas (Schmalz, 1969), they are of particular interest to geologists as paleogeographic and paleoclimatic indicators. The hypersaline conditions that characterize basins of evaporite deposition impose severe restrictions on the flora and fauna, which inhabit these basins. The very restricted and specialized fossil assemblages of such basins pose problems of correlation and dating, but afford the opportunity to study the environmental adaptation of extinct species (Schmalz, op. cit.).

The deposition of geologically significant evaporite sequences can be accomplished only in environments where four basic conditions are satisfied (Schmalz, op. cit.);

1- Dry and usually hot climate with a high net evaporation rate.
2- Closed or semi restricted basin in which brines can be concentrated.
3- Intermittent or continuous supply of seawater.
4- Mechanisms to allow the physical accommodation of the accumulating salt.

These basic requirements may be met with in any of several situations, but each site of evaporite deposition probably represents a unique environment, and its value as paleoclimatic and paleoenvironmental indicators depends upon the validity of the model considered in its interpretation.

Environments under which evaporites can form and accumulate are as diverse as are those for carbonates; also for every type of carbonate and siliciclastic sediments, there is an equivalent evaporite deposit (Schreiber, 1988). Schreiber et.al. (1976) Identified five major categories (or regimes) for evaporite precipitation with subdivisions in each category as to whether the evaporites are calcium sulfate or halites. Regimes grade into each other such that the identification may depend more upon associated facies than upon internal characteristics (Schreiber et. al., op. cit.).

1 – The subaerial, continental regime (continental sabkha and associated facies)
Much of the sediment in this regime is terrigenous in origin. The detritus is laid down as talus accumulations, mass flows, and alluvium and stream and lake bed accumulations. The evaporites form by precipitation from interstitial waters or within playas and hypersaline lakes and are commonly emplaced by displacement within the detrital sediments. The ionic input for these sediments is mainly from ground water and/or from dissolution and remobilization of wind-blown salts.

2 – The supratidal regime (coastal sabkha and associated facies)

They may be detrital (continental) or reworked shallow water marine in origin, together with indigenous algal mats and other biogenic debris. The sediments are usually emplaced by flash floods from the continental side, or by sea storms, then shaped and reworked by wind to create a surface of deflation. The periodic flooding by storms and wetting by sea spray permit the growth of extensive and characteristic algal mats. Between the layered mats and in the interstitial spaces of the sediments, sulfate deposits develop displacively. The ionic input of this environment is derived primarily from marine flooding but a substantial input may be from continental ground and surface water (Patterson and Kinsman, 1976).

The Abu Dahabi sabkha in the Arabian Gulf are the most widely recognized examples of syndepositional secondary evaporites; the nodules form displacively and replacively from concentrated pore fluids in the capillary and upper phreatic zones beneath the sabkha surface. These intrasediment crystal growths precipitate in a matrix of upper intertidal and supratidal sediments. With continued CaSO$_4$ saturation in the pores, the gypsum and anhydrite nodules grow and coalesce to form the enterolithic fold and chicken wire textures (Warren 1999). Anhydrite nodules in a sabkha grow (from the inside out) as new laths of anhydrite form between older laths (Shearman & Fuller, 1969). As successive laths crystalline in a nodule, they displace, rotate or break the older laths and the growing nodule pushes aside the adjacent hot matrix. The end result of this (inside-out) growth is a near pure anhydrite nodule, with laths about the edge of the nodule rotated into a subparallel alignment with the nodule margin. (Warren 1999).

3 – The subaqueous intertidal and subtidal regime

This zone is subjected to strong wave action, scour currents as well as periodic drying, and is well within the range of biogenic activity (i.e. photic zone, 10-120 m or less, Schreiber, 1988). Varied amounts of both continental and marine sediments are added periodically to
this environment. Precipitation may occur at the water-air interface, at the sediment-water interface or even beneath the sediment surface. The ionic input into this environment is directly from concentrated marine brines with a minor amount of ionic influx from run-off waters from surrounding continental areas.

4 – The subaqueous photic zone

This zone is below the range of current activity but still falls within the range of light penetration as indicated by the presence of algal structures. The depth limit of the photic zone is below 120 m. hypersaline water is turbid because of high bacterial and algal productivity and slow setting of fine suspended materials. The ionic input for these sediments is mostly from concentrated marine waters.

5 – The deep subaqueous zone

Crystal growth probably occurs at the water-air interface, but continued growth of crystals for a very short time while sinking through the water column is inhibited by the presence of organic matter. The build up of suspended organic matter in hypersaline water and the activity of anaerobic bacteria become high, thus inhibiting sulfate accumulation (Friedman, 1972) and result in the production of micritic carbonate. Salt deposition is influenced by brine stratification and subsequent mixing (Raup, 1970). Evaporite turbidities, developed from shallow water accumulation of carbonate, sulfate and salts, may be emplaced within this environment (Schreiber et al., 1976). The ionic input for these sediments is from marine water. The above evaporitic environments may be present in a wide spectrum of tectonic settings (Kendall, 1984 and Schreiber 1988). They may occur within:

1- Continental margins and shelves.
2- Interior cratonic basins of varying depths
3- Rifted continental margins
4- Pullapart, back arc, foreland and simple fault controlled basins may also become the locus of evaporite deposition, wherever the climate and water sources are appropriate.

To a large extent, the problem of mineralogy, stratigraphy and structure of ancient marine environments have been solved (Braitsch, 1962 and many others), but the depositional environment of many evaporite sequences is a matter of some debate (Schmalz, 1969). The most reliable approach to this problem is to use modern evaporitic environments as models

The following is a review of the works carried out to define the depositional environment of the evaporites in the Red Sea region.

Philobbos et al. (1985) found that the nodular – mosaic anhydrite and the nodular – laminated anhydrite represent an advanced and an early stage (respectively) of displacive growth of anhydrite in a Sabkha environment, whereas the thinly bedded anhydrite–halite facies is a lagoonal facies. On the other hand, (Montenat et al., 1988) mentioned that the evaporite series is deposited in restricted graben environments; where several highs persisting during the evaporite deposition were sites of fetid dolomicritic sedimentation.

(Youssef, 1986,) interpreted two depositional environments are the sedimentation of the Miocene evaporites on the Red Sea Coast; these are 1-coastal sabkha environments, 2-shallow subaqueous evaporite environment.

(Orszag-Sperper et al., 1993) found that the regular laminated evaporite and interbedded green marls, which are typical of the evaporites at Gasus, Siatin, Ambagi, Sharm el Bahari, Sharm el Qibli and Ras Hinkorab areas, together with the absence of sabkha type structure indicate that they have formed in subaquatic possibly relatively deep environment.

Hassaan et al. (1996) found that the central part of the Red Sea coastal zone at Marsa Um Tonduba, Marsa Sefiein, Marsa Igla, Wadi Abu Dabbab, and Wadi Homra represents an area of arid climate (low rainfall and high evaporation). This represents marine sabkha environment of evaporite deposition. They also pointed out that the source rocks supplying the sediments of these sabkhas are the Precambrian rocks forming the high Red Sea hills and the relatively narrow belt of broken-up phanerozoic limestone evaporite-clastic plateau.

The study of synsedimentary and diagenetic features diagnostic of the depositional process, and comparing recent and well known ancient evaporite deposits, resulted in the reconstruction of two main environments of deposition (Fig. IV-4) that are developed on the margin of a shelf basin: 1) subaerial-supratidal environment, and 2) subaqueous subtidal to intertidal environment.

1) The subaerial-supratidal environment includes the following facies:
   A) Nodular mosaic and enterolithic gypsum (part of it)
   B) Nodular anhydrite (cheken wire anhydrite)
2) The subaqueous subtidal to intertidal environment includes the following facies:
   A) Regular laminated gypsum
   B) Microbial laminated gypsum
   C) Stromatolitic gypsum
   D) Nodular mosaic gypsum (part of it)

The following is a description of each of the above depositional environments:

1) The subaerial-supratidal environment (coastal sabkha and salina):
   Kinsman (1969) defined a coastal sabkha as an area landward of a marine shore-line composed of 'broad, salt encrusted, supratidal surfaces or coastal flats …which are inundated occasionally...’ The term sabkha (correct plural is sabkhat not sabkhas, Hussain and Warren, 1989) is the English form of the Arabic root word ‘sebaka’

   Studies on the modern coastal evaporative systems began in the early sixties along the sabkha area of the Arabian Gulf by Shearman (1963 and 1966); Kinsman (1966 and 1969); Butler (1970a and 1970b) and others. Since then, the Abu Dhabi became the standard model for carbonate sabkhat. Mixed carbonate and siliciclastic sabkhat were recognized along the coastal area of the Mediterranean Sea, in Spain (Dronkert, 1978), in Tunisia (Busson and Perthuisot, 1977), in Egypt (West et al. 1979 and 1983 and Ali and West, 1983; Aref et al., 1999). Other siliciclastic sabkhat were described in different parts of the world, around the Mediterranean Sea, in Baja California, in the Gulf of Suez (Abdel Wahab, 1991) in the Gulf of Aqaba (Friedman et al., 1985), around the Red Sea (Orszag-Sperber et al., 1993) and in Southern Australia (Warren and Kendall, 1985 and Kendall and Warren, 1989).

   The major characteristics identified in the study area relating the evaporites to the sabkha facies are:
   2. Evaporite layers occur along strike continuity in contrast to the bull's eye pattern of salina deposits (Warren and Kendall, op. cit.),
   3. The presence of nodular enterolithic gypsum (Fig. II-8) which is morphologically and texturally similar to the enterolithic anhydrite nodules of modern sabkhat of Persian Gulf
4. The evaporite layers are dominated by a siliciclastic matrix of silt size in the nodular mosaic gypsum, or clay and marl in the nodular enterolithic gypsum.

5- the lenticular form of the gypsum crystals (Fig.III-10 ) Was described by Kinsman (1966) and Shearman (1966) from intertidal and supratidal sediments of the Trucial Coast of the Persian Gulf. It is also recorded from the Holocene sabkha of Ras Shukeir (Abdel Wahab, 1991). Lenticular gypsum crystals grow either in mud rich in organic matter (Cody and Cody, 1988 and Magee, 1988) or from aqueous solutions high in Ca\(^{2+}/SO_4^{2-}\) ratio (Kushnir, 1980).

In the sabkha environment, most of the evaporite deposition takes place within the sediment column, in a zone that occurs above or below the water table. The evaporite minerals, form by displacive and replacive growth within the sediment, i.e., it is emplaced diagenetically after the host rock was laid down. Either gypsum or anhydrite may be the primary mineral formed, depending on the temperature and/or the presence of certain organic impurities (West et al., 1979; Cody and Hull, 1980; Cody 1988 and Magee, 1988). In the Arabian Gulf sabkhat, gypsum is the sulfate mineral growing below the water table as isolated lenticular crystals and prisms, whereas anhydrite is common above the water table and in the landward part of the sabkha as chicken-wire and enterolithic folds (Butler et al., 1982). In areas prone to flooding by wadi outwash or an influx of continental ground water in the Arabian Gulf sabkhat, anhydrite nodules hydrate to gypsum (Kinsman, 1966 and Butler, 1970a and 1970b).

The hydrology of the present sabkha environment is probably similar to that of Abu Dhabi sabkha (Kinsman, 1969; Mckenzie et al., 1980 and Patterson and Kinsman, 1981). After marine flooding, seawater sinks into the sabkha sediment, raising the water table. Capillary evaporation subsequently lowers the water table, increases salinity and promotes upward water movement within the phreatic zone by evaporative pumping. Salinity also decreases downwards (caused by surface evaporation and upward movement of less saline brine induced by evaporative pumping (Kendall, 1984). Such upward movements produce evaporative reflux of the dense brine.
In the study area, the main ground water source is the sea, either by flooding or by subsurface seepage, while continental waters may play a secondary role. Concentration of ground water causes precipitation of diagenetic minerals. Gypsum grows displacively into prismatic and felted crystals below the sediment surface. Soon after burial, gypsum is converted into, or is pseudomorphosed by aggregates of anhydrite crystals (Shearman, 1966). The pseudomorphs gradually enlarge, lose their shape and ultimately grow into anhydrite nodules. Schreiber et al. (1976) mentioned that once anhydrite nodules have been formed, new ones continue to develop by the collision breeding mechanism. Continued growth of gypsum results in closely packed nodules (Fig.III-14) and ultimately into contorted layers or enterolithic folds (Fig III-15). The gypsum nodules tend to form in layers subparallel to the bedding and with continuous growth the layers become contorted into ptygmatic structures.

The occurrence of rafts of halite crystals (now molds filled with gypsum replaced by anhydrite (FigIII-27) indicates the presence of a saline pan (Lowenstein and Hardie, 1985) within the subaerial sabkha environment. In the saline pan, gypsum crystals precipitate first, but as the brine becomes supersaturated, halite crystals nucleate at the water surface and grow as flat platy crystals (Dellwig, 1955; Gornitz, 1965 and Arthurton, 1973). The suspended plates, that show stepped habit (Fig.IV-2) coalesce into mats which eventually sink to the bottom.

2. The subaqueous intertidal and subtidal environment (shallow subaqueous environment)

Deposition of shallow water evaporites occurs from brines that were at or near saturation with respect to gypsum, in environments that my have been subjected to strong wave and current action, causing sediment scour, transport and redeposition. Microbial activity is significant in more protected (or deeper?) environments and many sediments were subjected to periodic drying up (Schreiber et at., 1976). Although water depth may range from a few centimeters to 20 m or more, most facies probably formed in water less than 5 m deep (Kendall, op. cit.). All depositional events are subaqueous even though the site may have been subaerially exposed for some time. Evaporite precipitation may occur at the air-water interface, at the sediment-water interface or beneath the sediment surface, with varying
amounts of continental and marine derived sediments periodically transported into the evaporitic environment.

Most of the knowledge on shallow water evaporites has come from the interpretation of ancient examples, particularly the Miocene of the Mediterranean (Schreiber et al., 1976 and 1978; Hardie and Eugster, 1971; Rouchy et al., 1987; Youssef, 1988; Friedman, 1991 and Schmalz, 1991). However, studies on Holocene and Recent salinas have provided valuable information confirming the older interpretations of ancient evaporites and suggesting others (Warren, 1982a; Friedman et al., 1985; Lowenstein and Hardie, 1985; Rosen and Warren, 1990 and others).

The major characteristics of the studied evaporites that relate them to a shallow subaqueous environment are:

1. Evaporite layers are relatively thick (2-12 m. Figs II-10, III-3,) compared to the thin cycles documented in the modern sabkha (generally 0.25-1 m, Sarg, 1981 and Warren and Kendall, 1985).
2. The continuity of up to 30 m thick evaporite succession with few marl intercalations is not a definite criterion of a prograding sabkha environment.
3. The evaporite layers are sulfate dominated (>90 % gypsum and anhydrite) with minor matrix in contrast to the supratidal sabkha deposits which are matrix dominated.
4. The presence of current induced structures, such as uneven irregular and crenulated stromatolitic laminae (Fig.III-23) in the gypsum facies indicate an upper subtidal to intertidal environment.
5. The lateral restriction of gypsum laminae excludes the deep-water origin of the evaporites, in which individual laminae can be traced for a long distance (~116 km, Anderson et al., 1972).
6. The presence prismatic gypsum crystals (Fig.III-14) with random (Fig.III-22) orientation, indicate free growth of the crystals at the water-air interface and their settling in subtidal and intertidal environments respectively.
7. The carbonates intercalating the regular laminated gypsum, microbial laminated gypsum, stromatolitic gypsum do not show evidences of the supratidal-subaerial environment (such as fenestral fabrics, mud cracks, or evaporite solution breccia (Sarg, 1981).
8. The continuity of 2-10 m nodular mosaic gypsum that lacks features of stacked sabkha sequence is related to displacive growth within the bottom sediment in shallow subaqueous environment.

9. The domal to contorted thin laminated gypsum (Fig.III-23) represents growth of stromatolite into petee structure (Gavish et al., 1985) in a shallow subaqueous environment.

In the subaqueous environment, gypsum is the primary form of CaSO₄. Despite that the precursor gypsum crystals have suffered from diagenetic changes to anhydrite to secondary gypsum, the precursor morphology such as prismatic crystals, or the association with regular and microbial or stromatolitic laminations are existed. The diversity in morphology of the gypsum crystals may be due to several factors: salinity of the brine, its circulation and current activity, the presence of organic materials, influxes of less saline ground and/or seawater, the depth of the brine body, etc. These factors affect the recorded sedimentary structures (thin regular lamination, irregular microbial lamination and stromatolitic lamination).

The following is a description of the depositional environments of the facies deposited in shallow subaqueous environments:

Laminated or varve-like evaporites are widespread in the geologic record. The most famous evaporites of this type are the laminated Permian anhydrite-carbonate, and anhydrite-halite deposits in the United States of America and Europe (King, 1947 and Richter-Bernburg, 1957). Laminated evaporites also appear in the Jurassic (Anderson and Kirkland, 1966) and Devonian (Davies and Ludlam, 1973) of North America and in the Messinian of the Mediterranean basin (Ogniben, 1957 and Garrison et al., 1978). The environment of deposition of these laminated deposits is often disputed. Anhydrite-carbonate laminations of the Permian Castile Formation were interpreted to have been seasonally deposited from a large hypersaline body as a result of fluctuations in the salinity of the brine (Anderson et al., 1972 or due to climatic changes (Anderson, 1982). The Messinian algal laminated gypsum deposits were interpreted as having been formed in a shallow environment (Schreiber et al., 1976 and Garrison et al., op. cit.). Ogniben (1957) and Warren (1983) interpreted the carbonate-gypsum laminations as having been seasonally deposited due to change in brine
chemistry and salinity, whereas Hardie and Eugster (1971) suggested that laminations were deposited under current or wave action.

In the present work the authors believed that the thin regular laminated gypsum was formed in a similar shallow subaqueous depositional environment. When salinity reaches the range of gypsum precipitation, fine-grained gypsum crystals nucleate at the air-water interface. Then settle down to the bottom as fine crystal ‘rain’ (Dean and Anderson, 1978). The gypsum crystals are reworked at the depositional interface by density currents (Hardie and Eugster, 1971 and Schreiber, 1988). The regular laminated gypsum (Fig.III-3) represents deposition of the reworked gypsum in a quiet water environment, below the wave base (Schreiber et al., 1976 and Schreiber, 1988). Inflow of seawater or ground water to this shallow environment will lead to precipitation of micritic carbonate and clayey material. In the irregular laminated gypsum, the thin gypsum laminae may represent growth and binding of gypsum crystals under the influence of microbial mats (Cody and Cody, 1988).

The contorted thin laminated gypsum is believed to be formed in a shallow subaqueous environment, either in a shallow saline pan (gypsum pan), or an intertidal to subtidal environment (Gerdes, 1985 and Dahanayake and Krumbein, 1985). The contorted thin laminated gypsum composed of laterally linked domes with rounded crests (Fig.III-20) was termed petee structure by Gavish et al. (1985) since it forms as a result of biogenic activity. The formation and growth of this petee structure was described by Reineck et al. (1990) as a result of the activity of microbial mats. Shinn (1983) mentioned that microbial mats act in the same way as the slickly flypaper which capture and bind the allochtonous sediment particles with the growing gypsum crystals.

The nodular mosaic gypsum, which are recorded in continuous layers, 2-10 m thick, are believed to form displacively under the sediment surface in shallow subaqueous environment, and do not represent stacked sabkha facies. The nodular mosaic gypsum is formed in a manner similar to the growth of gypsum nodules in the subaerial environment, but the source of CaSO\(_4\) might be from upward, downward or lateral migration of dense, more saline water, relative to interstitial water and sea water (Dean et al. 1975).
SUMMARY AND CONCLUSIONS

The studied Middle to Upper Miocene Abu Dabbab evaporites at the coastal plains of the Red Sea represent the middle belt that is bounded to the west by the Lower Miocene clastics of the Ranga Formation, and the carbonates of Um Mahara Formation, and to the east with a belt composed of Upper Miocene, Pliocene and Pleistocene sediments (Philippos et al., 1985). These Miocene formations are unconformably overlying the Eocene, Cretaceous and Precambrian basement rocks to the west. The Abu Dabbab evaporites are characterized by a relatively simple and homogenous mineralogy primarily made up of secondary gypsum at quarries (Wadi Gasus, Wadi Teaban and Wadi Wizr), and anhydrite at rock exposure and at the top part of quarry facies (Aref et al., 2003). The primary deposited texture is represented by microbial laminites that are partially obscured by the massive texture of the secondary gypsum. The microbial laminites have a composition of calcite, dolomite, magnesite, celestite, or sulfides. The secondary gypsum is mainly represented by porphyrotopic, poikilotropic gypsum near the bottom of the quarries, and alabastrine, granular, selenite masses and satin spar gypsum veins near the top of the quarries (Aref et al., 2003). Due to the common absence of primary depositional features other than microbial laminites, the purity of the secondary gypsum beds and their thickness (~ 20 m), indicate that the gypsum was deposited dominantly in subaqueous rather than in a sabkha environment (Aref et al., 2003).

The present work deals with the geological features, sedimentological characteristics and origin of evaporite deposits in Wadi Gasus, Wadi Teaban, and Wadi Wizr areas, located along the Re Sea coastal plain between Safaga and Mersa Alam from north to south. The geomorphology, lithostratigraphy, tectonic setting and petrology were used to give a clear picture in the aim of throwing more light on the depositional environments of the different evaporite facies.

Geomorphologically, The studied areas are bounded on the east by the recent sediments of the shoreline of the Red Sea. Most of the sedimentary rocks in the three studied areas are of relatively moderate to low relief and its elevation decrease generally towards the shoreline. The evaporite hills and their caped mantle of anhydrite are the most conspicuous physical features of the areas. The studied areas are characterized by drainage patterns of dendritic type. The three main wadies Gasus, Teaban, and Wizr slope gently from west to east.
The three areas under study, wadi Gasus, wadi Teaban, and wadi Wizr contains economic gypsum deposits, with respect to the grade agent. The quantities of gypsum and anhydrite which used for industrial proposes (manufacture of gypsum for building proposes, in cement industry, for agricultures, …etc) composed of more than thousand millions ton of pure gypsum.

The exposed rock units at wadi Wizr are represented by the basement rocks (various igneous and metamorphic rocks; the pink granite is the common rock type), of Precambrian age. The Nubian Formation consists of two Members; (A) Taref Sandstone Member, Coniacian in age, outcrop at the base of the sedimentary sections, and (B) Quseir Clastic Member, The middle and the upper Cretaceous Formation in upper Egypt (Nakheil, Thebes, Esna, Tarawan, Dakhla, Duwi (phosphate) formations are not recorded and completely absent in wadi Wizr Area. The Nubian formation underlies unconformably the Middle Miocene rocks.

In wadi Teaban and wadi Gasus areas the Nubian formation, consists of the two Members Taref Sandstone Member and Quseir Clastic Member. The Cretaceous sediments (Nakheil, Thebes (the top part of all the high hills in the study areas), Esna, Tarawan, Duwi and Nubian formations) overlie unconformably the basement rocks and underlie unconformably the middle Miocene rocks. The phosphate beds in Duwi Formation are mined in both wadi Teaban and wadi Gasus areas by Red Sea Phosphate Company as open cast in some localities and as under ground mines on other localities for the production of Phosphate ore.

In the study areas two Middle Miocene formations, were recorded, 1-Gebel El Rusas Formation (consists of the lower clastics and upper carbonate units0, and 2 – Abu Dabbab Formation that represents the main sedimentary outcrops of the studied areas. It consists of gypsum and anhydrite with some carbonate intercalations in the upper part. The Miocene – Pliocene (Samh formation), in the studied areas lie along the Red Sea coastal plain parallel to the Red Sea. The Pliocene (Gabir Formation) overlies conformably the coral reefs of Samh Formation Pliocene.

The evaporite rocks are differentiated into the following facies; 1 - Massive gypsum, 2 - Regular laminated gypsum, 3 - Microbial laminated gypsum, 4 – Stromatolitic gypsum, 5 - Nodular mosaic anhydrite, and 6 - Enterolithic anhydrite nodules
Diagenetically, the evaporite rocks have been affected during the three main stages; syndepositional stage, burial stage and uplift stage.

Petrographic investigation show that the Middle to Upper Miocene Abu Dabbab evaporites of the northern Red Sea coastal plain of Egypt are composed mainly of secondary gypsum rocks that are mantled with 2-3 m thick anhydrite deposit. Several fabric types of secondary gypsum are recorded; these are porphyrotopic, poikilotopic, alabastrine, and granular, selenitic and satin spar gypsum veins. All these types occur in the gypsum sequence, with predominance of porphyrotopic and poikilotopic gypsum near the base, and alabastrine, selenitic granular and satin spar gypsum veins near the top. Fractures inherited in the evaporite rocks due to unloading accompanying uplifting and eastward tilting, and that accompanied rifting, favored pathways for percolation of meteoric water during pluvial periods. The coarse porphyrotopic and poikilotopic gypsum were formed during early exhumation of the rock at near equilibrium condition by slow crystal growth.

The fine alabastrine gypsum is formed in an active phreatic water condition and postdates the coarse porphyrotopic and poikilotopic gypsum by their dissolution and rapid crystal growth under disequilibrium condition. The gypsum veins represent excess volume of sulfate that resulted from conversion of anhydrite into gypsum. The selenite pockets represent the latest secondary gypsum rock, formed by the dissolution of all the above-mentioned types and their later recrystallization under phreatic conditions, with very slow crystal growth under equilibrium conditions.

With regard to the geochemical characteristics of the studied gypsum, relatively higher concentration of FeO, MnO, k2O, MgO, TiO2, Sr, and Zr are observed. This indicates that the parent brine, from which the Red Sea gypsum was deposited, had relatively higher concentration of these elements. The only possibility to maintain such high concentration of these elements is their derivation from the nearby basement rocks and the pre-Middle Miocene rocks of the Red Sea region via meteoric water. Therefore, meteoric water over the Red Sea basement rocks and the pre-Middle Miocene rocks led to the leaching of the minor and trace elements, which was flushed to the evaporite basins. Deposition of these evaporites from mixing of meteoric water enriched in minor and trace elements, with marine water lead to precipitation of gypsum highly enriched in minor and trace elements. Further on, during burial diagenesis of the Red Sea gypsum to anhydrite, followed by exhumation to secondary gypsum (Aref et al., 2003), the necessary waters that hydrate the anhydrite are also enriched.
in trace and minor elements coming from the Red Sea basement rocks and the pre-Middle Miocene rocks during the Pliocene and Pleistocene rainy periods.

Environmentally, the studied evaporite facies in the Red Sea region is either deposited in supratidal sabkha environment (nodular mosaic anhydrite and nodular enterolithic anhydrite) or shallow subaqueous (subtidal to intertidal) environment (regular laminated gypsum, microbial laminated gypsum, stromatolitic gypsum). In the supratidal sabkha environment, deposition of primary gypsum nodules is by displacive or replacive growth in siliciclastic host sediment and primary dolomite. Continued growth of the gypsum nodules led to the formation of enterolithic gypsum nodules. In the subaqueous environment, deposition of gypsum took place from the brine-air interface or from the sediment-water interface as fibrous or prismatic crystals. These crystals are either draped over microbial laminites or deposited over mud or silt laminae that led to the formation of couplets of gypsum-microbial laminites.
REFERENCES


Aref, M.A.M., 2001, Petrography, geochemistry and genesis of Quaternary gypcrete from Middle Egypt (Girsia and Qattamia areas), Egypt. 5th Conference on Geochemistry, Alexandria University, Egypt, (Abstract).


Dardir, A.A., (1968), A proposed classification for the Miocene and post Miocene sediments along the Egyptian Red Sea coastal plain Geol, Surv., U. AR.,


evaporites-a core workshop, SEMP core workshop no 3, Calgary, p. 130- 173.


Magee, J.W., 1988, Chemical and clastic sediments and late Quaternary history, Prunngle Lake, New South Wales (M. Sc. Thesis): Australia National University, Canberra.


Schreiber, B.C., 1978, Environments of subaqueous gypsum deposition, in Marine evaporites : SEPM short course, Notes 4, p. 43 – 73.


Schreiber, B.C., Roth, M.S., and Helman, M.L., 1982, Recognition of primary facies characteristics of evaporites and the differentiation of these forms from diagenetic overprints, in Handford, C. R., Loucks, R., and Davies, G. R., eds., Depositional and diagenetic spectra of evaporites, a core workshop, Calgary, p. 1-33.
Sellwood, B.W., and Netherwood, R.E., 1984, Facies evolution in the Gulf of Suez area- sedimentation history as an indicator of rift initiation and development. Modern Geol., v. 9, p. 43-69.


Vail, P.R., and Hardenbol, J., 1979, Sea level changes during the Teriary :Oceanography, v. 22, p. 71-79.


Waring, G. A., and Jones, T. H., 1940, (Geology of the Red Sea Coast of Egypt between Lat 25 30° and 23 50°N.
ملخص الرسالة

تختص الرسالة بدراسات ترسيبية لبعض صخور المتبخرات لعصر الميوسين على ساحل البحر الأحمر.
وقد اخترعت هذه الدراسة ثلاث مناطق على ساحل البحر الأحمر هي وادي جاسوس - وادي الشعان - وادي وزر من الشمال إلى الجنوب على التوالي. وتختتم هذه الرسالة على ستة فصول.

يتناول الفصل الأول مقدمة لدراسة كل منطقة من المناطق الثلاث على حدة وتحديد أماكنها وبيان كيفية الوصول إليها وكذلك دراسة جيومورفولوجية لها. تعقب منطقة وادي جاسوس بين خطي عرض ٢٦°٥٧ شمالي وخطي طول ٠٢°٣٤ شرقا وتعقب منطقة وادي الشعان بين خطي عرض ٢٦°٥٧ شمالي وخطي طول ٠٢°٣٤ شرقا وتعقب منطقة وادي وزر بين خطي عرض ٢٦°٥٧ شمالي وخطي طول ٠٠°٣٤ شرقا وتعقب مساحة قدرها ١.٥ كم².

إذا، وجدنا أن المناطق الثلاث تحتوي على كميات كبيرة واحتياطي هائل من خام الجبس متوسط وعالي الجودة.

من الناحية الاقتصادية، تحتوي المناطق الثلاث على كميات كبيرة، واحتياطي هائل من خام الجبس متوسط وعالي الجودة.

وقد خخص الفصل الثاني بالناحية الاستراتيغرافية التي بينت أن مناطق الدراسة الثلاث تتكون من تتابع صخور الجيب والأنهيدريت التابع لعصر الميوسين.

ويشمل الفصل الثالث على دراسات بتروغرافية للمناطق الثلاث مجتمعة وقد توصلت الدراسة إلى وجود سحنة صخرية واحدة هي المتبخرات التي تقع إلى عقد ستة سحبات مختلفة من الجيب والأنهيدريت.

ويتناول الفصل الرابع دراسة العمليات المبسطة لصخور المتبخرات وقد قسمت هذه العمليات التي أثرت على صخور المتبخرات إلى ثلاثة مراحل أولى: عمليات تحدث أثناء الترسيب، ثانيا: عمليات دفن هذه الصخور في العمق، ثالثا: عمليات رفع صخور المتبخرات إلى السطح.

ويستمتع الفصل الخامس على دراسة النظائر الجيوكيميائية لأكاسيد الكبريت الكليسيوم والألمنيوم والحديد والمنجنيز والبوتاسيوم والمغنيسيوم والكودرو، والسيليكراوات، والزئبق والزئبق والإستراتيغي. وقد أثبتت هذه الدراسة أن المتبخرات عصر الميوسين لساحل البحر الأحمر تكونت بواسطة مزيج من المياه البحرية والمعنوية القارية الضحلة.

ويستمتع الفصل السادس على دراسة بيئة الترسيب وعمل نماذج لسحبات المتبخرات الموجودة وقد بينت الدراسة أن صخور المتبخرات للمناطق الثلاث على ساحل البحر الأحمر تكونت أحياناً في بيئة السبخة وأحياناً في بيئة مائية ضحلة.
جامعة الزقازيق
كلية العلوم
قسم علم الجيولوجيا

متبخرات عصر الميوسين- ساحل البحر الأحمر- مصر،
دراسات سدمنتولوجية.

رسالة مقدمة إلى
قسم الجيولوجيا- كلية العلوم- جامعة الزقازيق
للحصول على درجة الماجستير في العلوم
(جيولوجيا)
من
جمال عبد الله عبد الفتاح عمرو

تحت إشراف

الأستاذ الدكتور
أسامة محمد عبد المنعم البدرى
أساتذة الجيولوجيا- قسم الجيولوجيا
كلية العلوم- جامعة الزقازيق

الأستاذ الدكتور
محمود أحمد محمد عارف
أساتذة الجيولوجيا- قسم الجيولوجيا
كلية العلوم- جامعة القاهرة

الدكتور
فكري محمد أبو العينين
أساتذة الجيولوجيا- قسم الجيولوجيا
كلية العلوم- جامعة القاهرة

2004