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# طباقية التتابع لتكوين المشرف في حقول غرب القرنة و الرميلة الشمالي و الزبير، جنوب العراق

رسالة مقدمة إلى كلية العلوم

بجامعة بغداد كجزء من متطلبات نيل

درجة الماجستير في علم الأرض

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بسم الله الرحمن الرحيم

{الله لا إله إلا هو الحي القيوم لا تأخذه سنة و لا
نوم له ما في السموات وما في الأرض من ذا الذي
يشفع عنده إلا بإذنه يعلم ما بين أيديهم و ما
خلفهم ولا يحيطون بشيء من علمه إلا بما شاء وسع
كرسيه السموات و الأرض ولا يؤوده حفظهما و
هو العلي العظيم }

صدق الله العظيم

# (( الإهداء ))

إلى أجمل نعمة انعم الله علي بها والدي أمي و

أبي

إلى إخوتي الأحباء

إلى أساتذتي الأفاضل

إلى أصدقائي الأوفياء و كل من دعا لي

بالموفقية و النجاح

اهدي لهم رسالتي هذه

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ABSTRACT

The Mishrif Formation in the study area was deposited on a shallow carbonate platform with a gentle ramp setting. Four major subenvironments were recognized: Deep marine, Shallow open marine, Rudist biostrome, and Shoal environments. This succession was affected by many diagenetic processes, The most affective were dissolution, dolomitization, and cementation.

The Mishrif succession is represented by three third order sedimentary cycles which can be divided into a number of fourth order cycles. These cycles are asymmetrical and reflected the variability of the rates of sea level rises and stillstands. The eustatic component is the major controlling factor on development of these cycles.

Variability of the factors controlling the development of these cycles controlled the effect of diagenesis processes, mainly dissolution, dolomitization and cementation, The variation of intensity of these different processes controlled the development of porosity through dissolution and mixing dolomitization whereas intense cementation at other intervals destroyed the porosity hence affecting the reservoir quality of the different reservoir units of the formation. This was clearly evident from the log response of the sonic and density logs which enabled the recognition of intervals of good reservoir characteristics.

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Hany Hassan

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University of Baghdad
College of Science

# SEQUENCE STRATIGRAPHY OF THE MISHRIF FORMATION AT WEST QURNAH, NORTH RUMAILA, AND ZUBAIR FIELDS SOUTHREN IRAQ

**A Thesis Submitted to the college of Science University of Baghdad In partial Fulfillment Of the Requirements for the Degree of Master of Science in Geology**

**By**

**Hany Hassan Flyieh Al-Rubiay**

**B.Sc. 2004**

**Supervised by**

**Prof. Ali D. Gayara, Ph.D.**

**2009**

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**In view of available recommendation, I forward this thesis for depate by the examining committee.**

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Title: Professor.

Address: Head of Department of Geology–College of Science-University of Baghdad.

Date :

## المستخلص

يتمثل تكوين المشرف في منطقة الدراسة بترسبات مصطبة كاربونايتية ضحلة ذات ميل قليل جدا خلال أربع بيئات رئيسية هي البحر العميق، البحر المفتوح، ترسبات الرودست و البيئة الضحلة و قد تأثر التتابع بعدد من العمليات تحويرية أهمها الإذابة، الدلمتة و السمنتة .

يتمثل تتابع المشرف بثلاث دورات رسوبية رئيسية من الدرجة الثالثة والتي يمكن تقسيمها إلى عدد من الدورات من الدرج الرابعة و هذه الدورات تتميز بعدم التناظر و التي تعكس تغيرات في ارتفاع و ثبات مستوى سطح البحر والتي تعتبر المسيطر الرئيسي على تطور هذه الدورات .

أن التغيرات في العوامل التي تؤثر على تطور هذه الدورات تؤثر من ناحية أخرى على العمليات التحويرية و شدتها خاصة الإذابة و الدلمتة و السمنتة. أثرت التغيرات في شدة العمليات التحويرية على تطور المسامية من خلال الإذابة و الدلمتة. أما السمنتة في أعماق أخرى فقد دمرت المسامية و هذا اثر على الصفات المكمنية للوحدات المكمنية المختلفة للتكوين و هذا يظهر واضحا من خلال استجابة مجسات الصوت و الكثافة والتي تميز أعماق ذات مواصفات مكمنية جيدة.

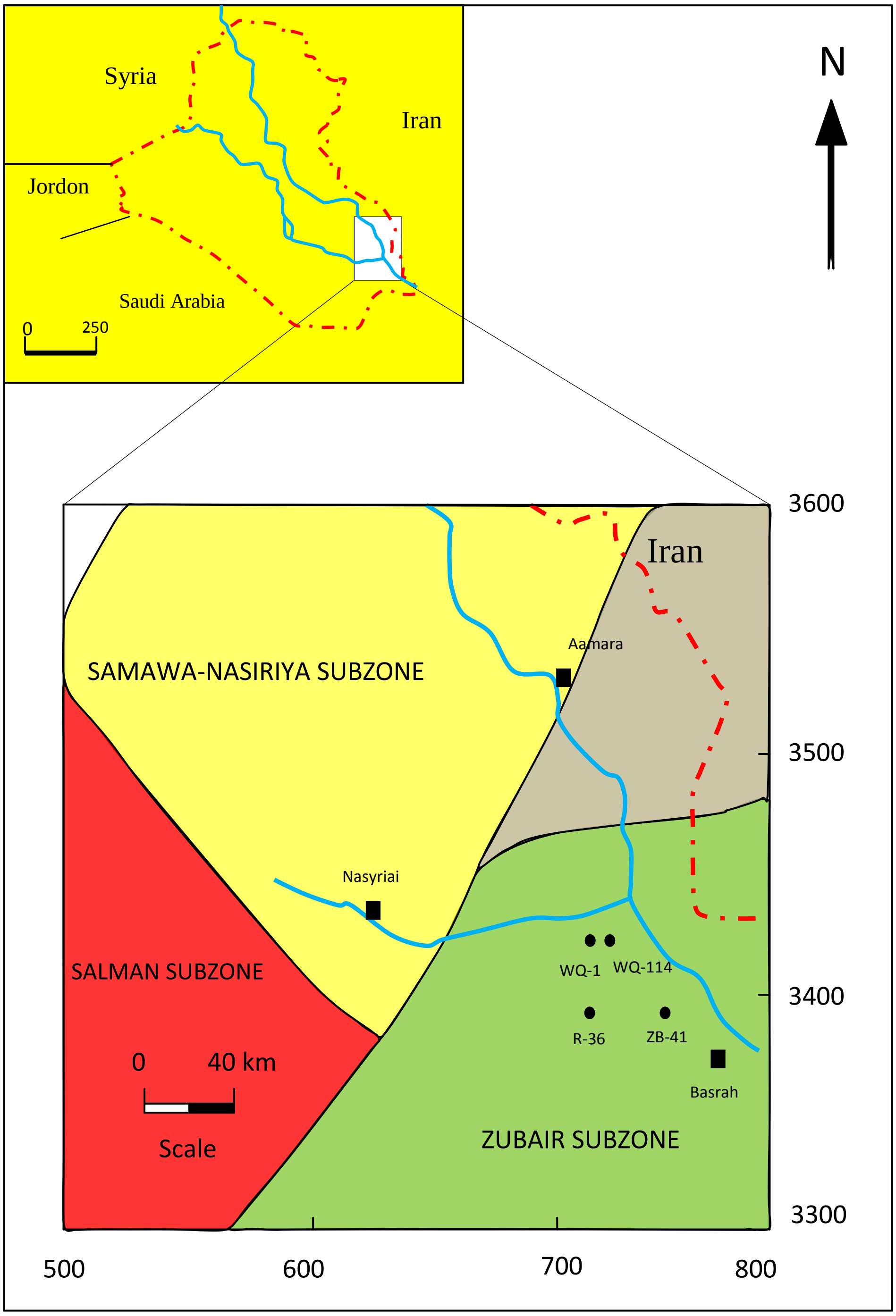



Figure (1- 1) Location map with Tectonic subdivisions of Southern Iraq (after Al-Khadhmi et al., 1996).

# CHAPTER ONE

## INTRODUCTION

### 1.1. Preface

The Mishrif Formation represents an important reservoir in southern Iraq and has extensive distribution in the Middle East. The formation is a carbonate sequence represented predominantly by shallow open marine carbonates deposited during the Middle Cenomanian-Lower Turonian cycle as a part of the Wasia Group (Albian-Turonian). It is affected by different diagenetic processes that affects porosity and permeability.

### 1.2. Aims of the study

1- Microfacies analysis and paleoenvironment interpretation.
2- Development of the depositional basin environmentally and tectonically.
3- To study of the vertical and horizontal changes and distribution of stratigraphic reservoir units.
4- To compare the depositional framework with other fields.

### 1.3. Methods of study

1- Detailed study of Cores and sampling of the available wells (WQ-1, WQ114, R-36 and ZB-41).
2- Petrographic study aimed towards microfacies analysis.
3- Well Log Analysis.

### 1.4. Study area

The study area is located in South of Iraq are include three fields; North Rumaila, Zubair, and west Qurna (Fig. 1-1). North Rumaila field is located about 50 Km west of Basrah and about 32 Km from Zubair field. This field represented an anticline trending Northwest for a distance of more than 100 km, and 18 Km wide. The Zubair field is located about 20 Km south of Basrah and represented by an anticline whose axis is parallel to the axis of North Rumaila field. West Qurna field is located about 70Km Northwest of Basrah. This field represented an anticline with Northwest to Southeast trending axis (Jassim and Goff, 2006).

### 1.5. Stratigraphy and Setting

During the Middle Cretaceous extensive carbonate platforms covered the eastern part of the Arabian plate, many of the major hydrocarbon accumulations were found in the Middle Cretaceous reservoir rocks developed as a carbonate platform (Alsharhan and Kendall, 1995; Farzadi, 2006a). The Mishrif Formation (Middle Cenomanian-Early Turonian) is a carbonate sequence rich in Rudists and benthonic foraminifera. The lower boundary of the Mishrif Formation is represented by the change from the basinal Rumaila Formation to the shallow open marine facies of the Mishrif Formation. The upper boundary with the Khasib Formation is truncated by an unconformity surface separating the Middle from Late Cretaceous (Ziegler, 2001). The equivalent formations of the Mishrif are Gir-bir Formation in the North and the Balambo Formation, upper part of the Sarvak Formation in Iran, and Magwa Formation in Kuwait (Alsharhan and Nairn, 1988) (Fig. 1-2).

The early studies on age were from Smout (1956), Owen and Naser (1958) suggested the age Turonian due to the presence of *Nazzazata sp*. Chatton  and Hart (1961), and Al-Sayyab (1984) suggested that the upper unconformable boundary of the formation represents the end of the Cenomanian-Turonian cycle.

The Middle to Late Cretaceous was a period of major change in the area of Eastern Arabian plate represented by steadily rising Global sea level (Sharland, 2001; Farzadi, 2006a). The Late Cenomanian to Early Turonian was a period of generally favorable conditions worldwide for high organic productivity, and the eustasy was the major element controlling the growth, development and location of builtup (Van Buchem et al., 2002), Salt diapirism and local subsidence had minor influences on their development (Farzadi, 2006a). The Cenomanian-Turonian period spanned the deposition of the Mishrif, Ahmadi, and Rumaila that corresponds to the platewide Mid Turonian unconformity resulting from the start of Ophiolit abduction along the eastern margin of the Arabian plate. The sediments were deposited on platforms within an intrashelf basin on the passive margin of the plate (Ziegler, 2001). The study area is located within the Zubair subzone which is part of the Mesopotamia Zone (Al-Khadhmi, 1996) (Fig 1-1).

Rudist facies were recorded from most of the fields west of Basrah in Iraq, and also from Majnoon and Buzurgan fields. Similar facies are present all around the northern end of the Gulf (Ziegler, 2001). West of Baghdad is an extensive evaporate pan Kifl Formation, Which represent the beginning of sea withdrawal in response to the epiorogenic movements acted through this period (Cenomanian-Touranian) creating a subaerial unconformity (Melhi and Diah, 1984). Sea withdrawal could be related to the Austrian orogeny causing normal regression through the Late Cenomanian-Early Turonian stage. The Austrian orogeny inhibited most of the sedimentation factory in different settings from the studied area. This caused a decreasing rate of subsidence then creating maximum sea level fall. Thus, accommodation potential is suspected to be seaward stepping event trending East-South East. (Minas H. and Gayara A., 2006).

This time period of low subsidence may be to related with three Positive elements (Al-Ubaidy, 2004) :-

I-Regional extended uplift (Hail-Rutba-KhIeisia) curve.

2 -Horsts and fault blocks

4- Salt domes

## 1.6. Previous studies

Many studies were aimed to interpret the environment and stratigraphy and reservoir quality of the Mishrif Formation. The first study was by Rabanit(1952) in Zubair well no.3 and was named Khatiyah Formation. He divided the succession into three formations (Ahmadi, Mishrif, and Rumaila).

James and Wynd(1965) studied the Sarvak Formation and suggested the upper part of this formation as the Mishrif formation.

Al-Naqib (1967), Owen and Naser (1958) defined the upper part of the Wasia Group as time equivalent to the Mishrif Formation.

Chatton and Hart (1961) included the Maotsi, Fahad, and Meheliban Formations in the Rumaila Formations, and included M’sad, Gir Bir, and Mergi Formations in the Mishrif Formation.

Gaddo (1971) studied the petrography and paleoenvironments of the Mishrif Formation and divided the Mishrif into five environments represented by Rudist bearing reefs, Lagoon facies, Algal facies, Shallow open facies, and sub-basinal facies.

Al-Sherwani (1983) divided the environments of the Mishrif formation to supratidal, tidal, subitdal Rudist facies, Rudist coral banks and shelf facies.

Al-Sherwani (1988) studied the succession and the sedimentlogical system of the Cenomanian–Early Turonian in South Iraq.

Al-Obaidi (1996) studied the permeability and porosity distributions in West Qurna oil field by using kriging technique to simulate reservoir quality and described the distribution of vertical and horizontal permeability nonsymmetrical. The porosity is more symmetrical than permeability.

AL-Jumaily (2001) studied the sedimentlogical facies and environment of the Mishrif formation in West Qurna, Zubiar, and Nassriya oil fields.

Al-Ubaidy (2004) studied the stratigraphic sequence of the Mishrif Formation in Zubair Field and suggested four major subenvironments within the carbonate platform; these are shallow restricted, shallow open marine, shoal, and deep marine environment.

Farzadi (2006a) studied the Middle Cretaceous carbonate platforms of the Gulf and Mishrif Formation using seismic stratigraphy. He suggested that the Mishrif Formation is an equivalent to the upper part of the Sarvak Formation and represented by high concentration of organic matter in an intrashelf basin associated with shallowing upward succession.

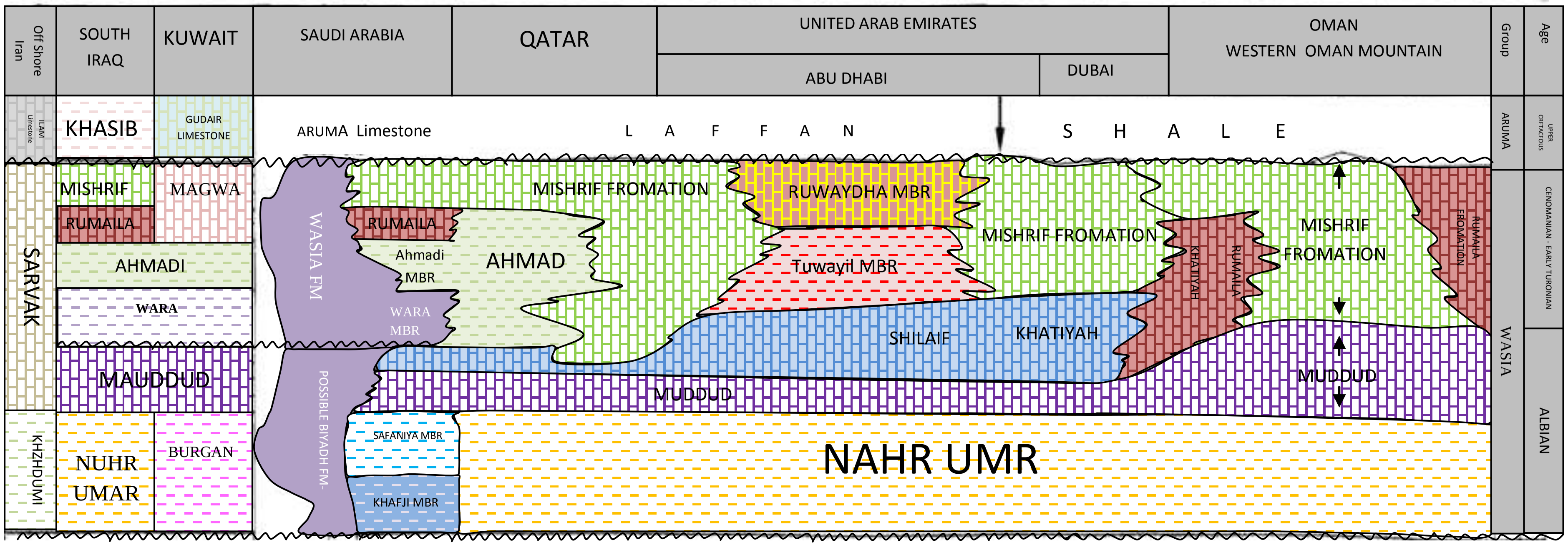
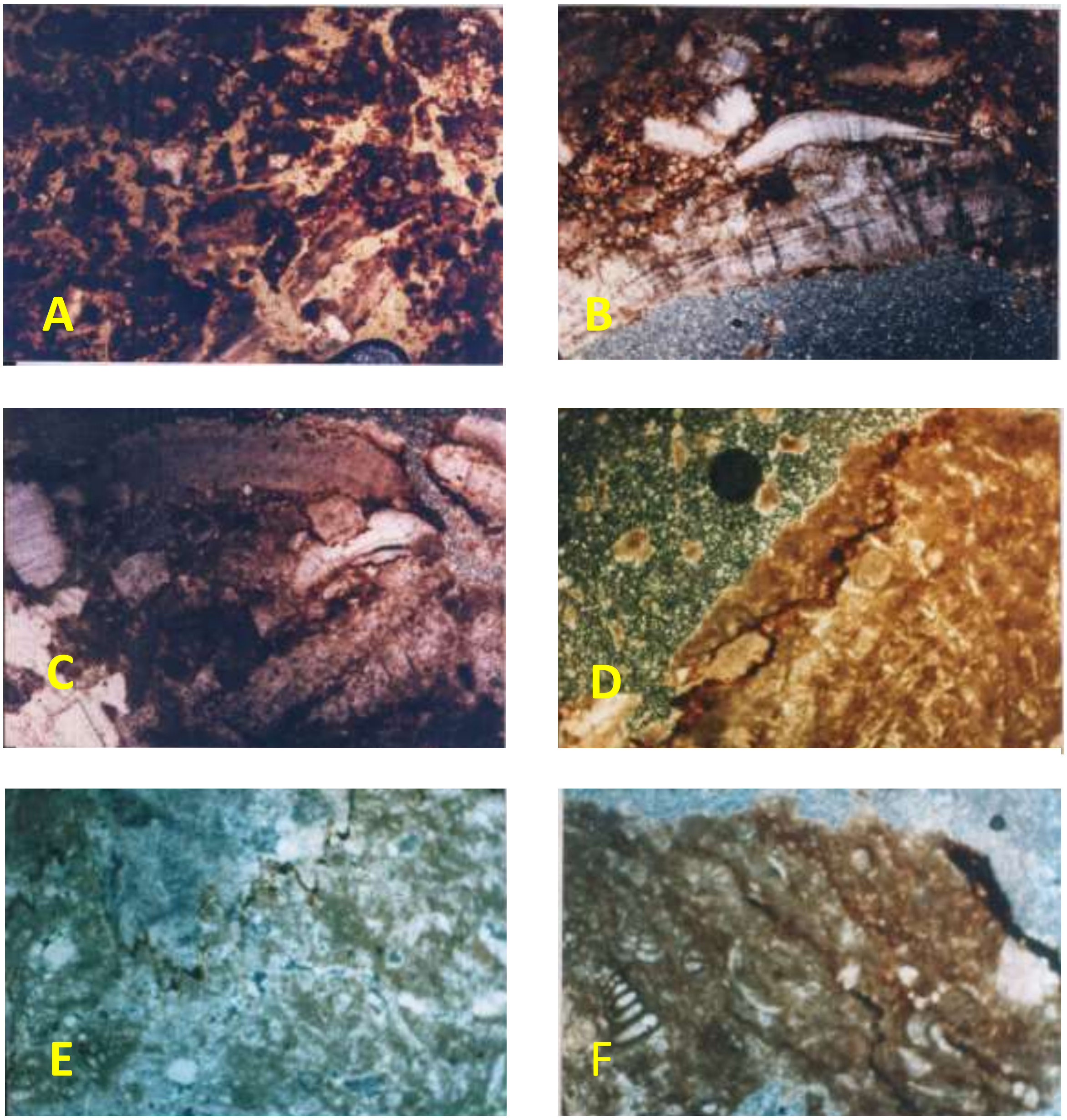



Figure (1-2) Lithostratigraphic correlation of the Middle Cretaceous in the Arabian peninsula ( after Alsharhan and Nairn, 1988)

# *PLATE 8*




A-Rudist debris with dolomite crystals in Rustone facies (WQ-114 depth 2372.3 m.), 40X.

B-Stylolite with echinoderm plates and small dolomite crystals in packstone facies (WQ-114 depth 2363.6 m.), 40X.

C-Echinoderms plates affected by Stylolitization type **Microstylolite** in packtone facies (WQ-114 depth 2363.6 m.), 50X.

D-Stylolite as **Solution seam** in wacktone facies (WQ-114 depth 3778 m.), 50X.

E-Stylolite peak high amplitude in wackstone facies (WQ-1 depth ), 50X.

F- Stylolite as **Wispy seam** in wackstone facies (WQ-114 depth 2378 m.), 50X.

## 2.2. Skeletal grains

The skeletal parts of organisms are commonly composed of calcite, magnesium calcite, aragonite or opaline silica. This mineralogy determines the susceptibility of the skeletal fragment to diagenetic changes and so its current composition and fabric in a limestone or dolomite (Kendall, 2003). The Mishrif Formation in the study area consists of various skeletal grains commonly composed of calcite as whole fossils or bioclasts of different sizes. Benthonic Foraminifera and Rudist are the main components skeletal grains, Gastropods, Ostracodes, Corals, Calcareous algae, Coralline algae, Echinoderms, Calcispheres, Sponge spicules, and Planktonic Foraminifera constitute the less abundant components.

### 2.2.1. Rudists

In the studied Mishrif succession the Radiolitdae Family (Fig. 2-2) is the most dominant one and appears in thin section as noncompact normal cellular structure with radial ridges or folded ridges with a network shape (Pons and Vicens, 2006). Most of Rudists were found as debris (Pl. 1- A, B, &C). especially in the middle part of the Mishrif Formation and associated with other components especially Benthonic Foraminifera, Corals, and some Echinoderms plates. The Rudist bodies in the Mishrif succession were 3-5 meters thick.

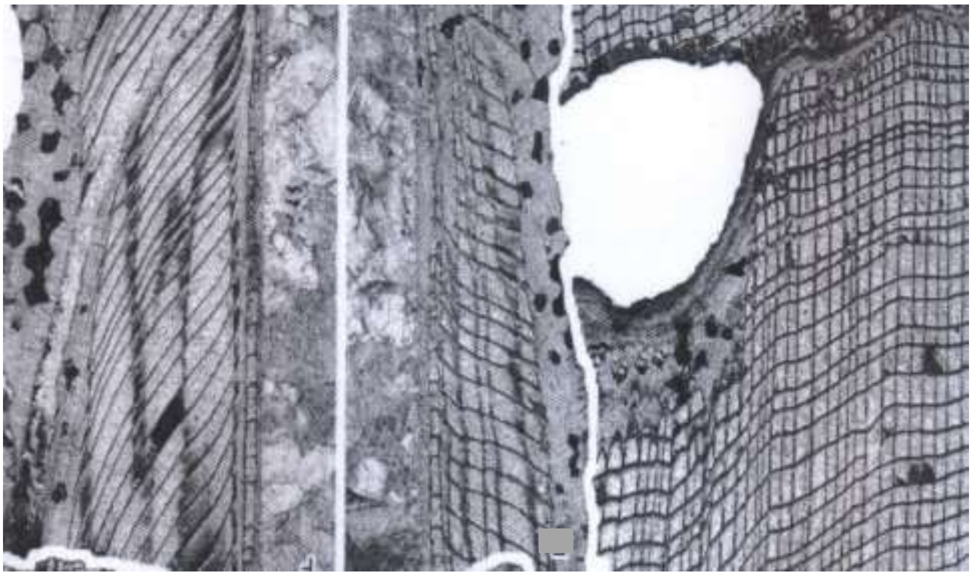


Figure (2-2) Radiolitdae Family in thin section with noncompact normal cellular structure with continues radial ridges (after Pons and Vicens, 2006).

### 2.2.1.1 Rudist habitat

The habitat of Rudists is mainly at the bottom of shallow waters, they extend from the Late Jurassic to the Late Cretaceous, These organisms are epifaunal, which means they are usually attached to the sea floor sediments. The clustering and building up of Rudist habitats caused the creation of "Rudist Reefs" which were the dominant reef frameworks in the Cretaceous oceans (Destari, and Sartorio, 1995), ( Fig. 2-3).

Figure (2-3) Different shapes of Rudists (after Destari, and Sartorio, 1995)

Rudists were classified as mollusks, but differ by its hetrodont bivalve and their bizarre shell-shape; they had two asymmetric valves with one valve attached to the sea floor. Today, their fossils are found throughout the tropics in the Mediterranean, the Middle East, the Caribbean, and Southeast Asia**.** (Fig. 2-4) Rudists dominated the world of reefs throughout the Cretaceous**.** (Arthur et al., 1996).

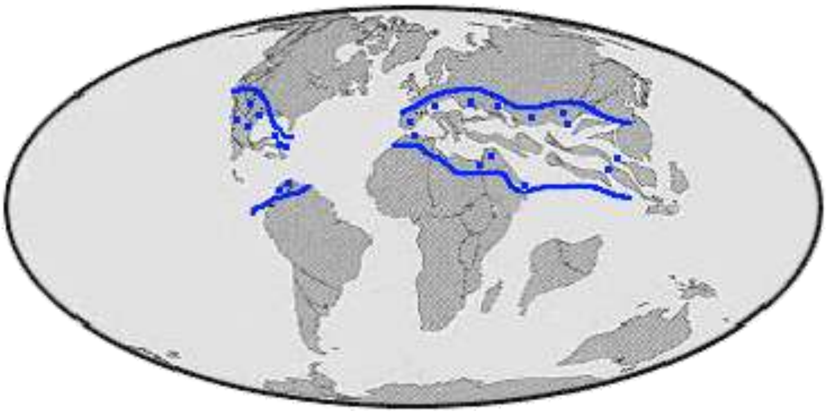


Figure (2-4) Extent of Rudist reefs during the Cretaceous.
(after Arthur et al., 1996)

From the late Jurassic throughout the Cretaceous, a succession of events took place that related to global changes and they affected the Tethys ocean and most of this linked to the geological evolution of area. There are 17 events that took place during this time, several mass extinction events (Fig. 2-5) affected the abundance and diversity of Rudists. These extinction events occurred during the Late Aptian, Late Cenomanian, Late Turonian, Middle Coniacian, and Late Maastrichtian (Destari, and Sartorio, 1995). The final mass extinction of all Rudist species occurred at the Late Maastrichtian Cretaceous-Tertiary boundary, mass extinction event that caused their demise; however, a decline of species in this superfamily is also seen just before the K/T event (Johnson and Kauffman, 1990).

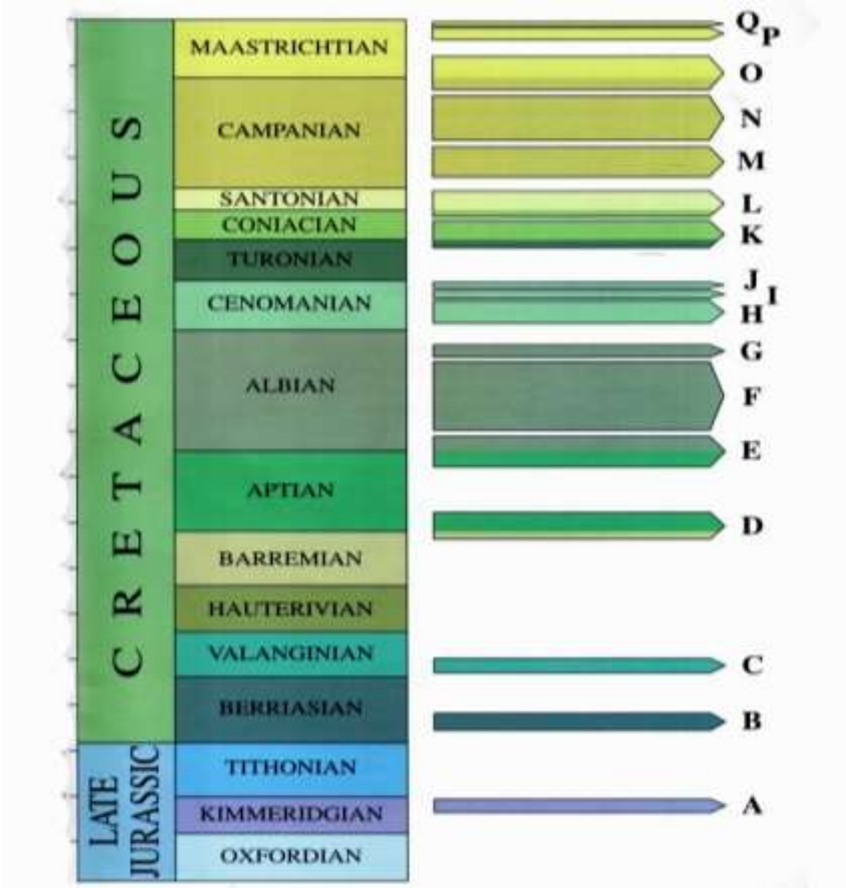



Figure (2-5) Events of Rudist ( after Destari, and Sartorio, 1995)

These sessile benthic organisms flourished in carbonate environments and characterize several Cretaceous successions as significant organic builders and sediment producers. (Destari, and Sartorio, 1995)

Rudists were classified into six main Families, These are:-

Diccratidae(middle-late Oxfodian-?Valanginian )

Requieniidae(early Tithonain-Maastrichtian)

Caprotinidae (early Tithonain-Maastrichtian)

Caprinidae (late Barremian- Maastrichtian)

Radiolitidae (? early Aptian- Maastrichtian)

Hippuritidae (Turonian- Maastrichtian)

### 2.2.2. Gastropods

Gastropods have an external univalved unchambered shell that is usually coiled. Coiling may be either in a single plane or a helical spiral about an imaginary axis ( Flugle, 2004). It is recognized in the upper part of studied succession especially in the upper part of well R-36, and affected by cementation. Geopetal cement (Pl. 1-D) fills part of the shell and consequently useful to determine the orientation of the beds.

### 2.2.3. Benthonic Foraminifera

Benthonic foraminifera are the most dominant skeletal grains in the Mishrif carbonate indicating a shallow open marine environment, It was found as the main component or associated with other components with varied percentages like Rudist debris, Corals, and Echinoderms. There are many types of benthonic foraminifera recognized in the Mishrif succession. They are represented by *Praealveolina tenuis* REICHEL (Pl. 1-E), *Cisalveolina fallax* REICHEL (Pl. 1-F), *Chrysalidina gradata* D'ORBIGNY (Pl. 2-A), *Biconcava bentori* HAWAOUI and *Pseudolitunella reichli* (Pl. 2-B), *Textularid* (Pl. 2-C), *Miliolide* (Pl. 2-D), *Praealveolina gr. Cretacea* (d'ARCHIAC) (Pl. 3-F), *Dicyclina schlumbergri* (Pl. 3-B), *Taberina bingistani* HENSON (Pl. 3-C).

Benthonic foraminifera dominate the middle parts of the succession (about 10-20 meters interval) where complete specimens are usually abundant, some Benthos were partially Micritized and may be affected by dissolution to producing moldic porosity.

### 2.2.4. Ostracodes

Ostracodes are bivalve shell smaller than millimeter in size and characterized by its ovate or kidney shaped outline (Flugel, 2004).

In the Mishrif succession; They were recognized in some thin horizons and usually affected by Neomorphism (Pl. 3-D).

### 2.2.5. Corals

They are important as the Reef-builders in shallow warm waters and normal salinity, and can be important factor in carbonate platform margin developments because of their rapid growth rates, and their ability to produce large amounts of sediments. The skeleton which is exoskeletal in origin is characterized commonly by an outer wall and internally by a series of vertical plates ( septa ) arranged radically perpendicular to the outer wall, and which may or may not meet in the center of skeleton corals are interpreted as marine animals and were most abundant in clear shallow carbonate seas, where they were major contributors to reef and bank from Ordovician to the recent (Alan and Paul, 1971). The corals in the Mishrif

Formation found in the middle of the succession in small horizons, and may be affected by Micritization and some Cementation (Pl. 3-E, F).

### 2.2.6. Calcareous algae

They are marine and nonmarine aquatic plants attached bottom dwellers (sessile benthos). Individual plants are commonly a few centimeters in maximum dimension and internally cell dimension is measured in microns. Two basic cell types were noticed, basal cells, and small cells. It was distributed worldwide from late Jurassic to Recent and is an important constituent of Cenozoic and Recent environments. (Alan and Paul, 1971). In the Mishrif succession, Calcareous algae (Pl. 4-A) is less abundant, and can be found within the middle part of the succession in small horizons. Coralline algae (Pl. 4-B) is another type of Calcareous algae classified as red algae and vary in size from thin crusts to massive and appears in thin section as fine network structure with cell size < 5-15 um. Differentiation of different types is based according to cell size and arrangement (Flugel, 2004).

### 2.2.7. Echinoderms

Echinoderms plates were found associated with other component like benthonic foraminifera, Rudist debris, Corals and some planktons in various percentages. Echinoderms plates exhibit an open meshwork (porous) structure in thin sections, the meshwork displays a characteristic gray color as light refracted along the numerous boundaries between the plate meshwork and the infilling calcite cement (Alan and Paul, 1971).

In the Mishrif succession, Echinoderms are dominant especially in the bottom of the succession and indicate a relatively deeper environment of the shallow platform. The echinoid spines (Pl. 4-D) indicate the deep marine environment and were found with planktons. Most of echinoderm plates were observed in some horizons as big plates and in contact with each others (Pl. 4-C).

### 2.2.8. Calcispheres

Calcispheres are small hollow grains with single or double walls with or without perforations, Calcispheres are typically tens to hundreds of micrometers in diameter (Scholle, 2003). Calcispheres were chiefly observed in Devonian and Mississippian rocks, and assumed to be marine plankton (Alan and Paul, 1971). In the Mishrif succession, it was found in the lower part and sometimes associated with planktons and sponge spicules as well as small bioclasts indicating deep marine environment.

### 2.2.9. Sponge spicules

Most sponges live in water less than l00 meter deep on hard bottoms where there is some water circulation. Sponge spicules are commonly all that is preserved. These are composed of silica (Kendall, 2003), Sponge spicules can be recognized in the lower part of the Mishrif succession in thin horizons associated with planktons and other small bioclasts indicating deep marine environment. The composition and general architecture of spicules are used to classify sponges into classes. The form of spicules and the manner in which they are combined to construct the skeletal structure are the basis for further systematic subdivisions. They commonly occur freely within the soft parts of the sponge. Major architectural spicules types are differentiated according to the number of axis (Flugel, 2004).

#### 2.2.10. Planktons

These skeletal components are recognized in the lower parts of the studied wells in some small horizons; they indicate the deep marine environment in study succession and the lower energy of water (Pl. 4-E).

### 2.3. Nonskeletal grains

It is less dominant than skeletal grains and recognized in very small horizons and mainly include; peloides and lithoclasts

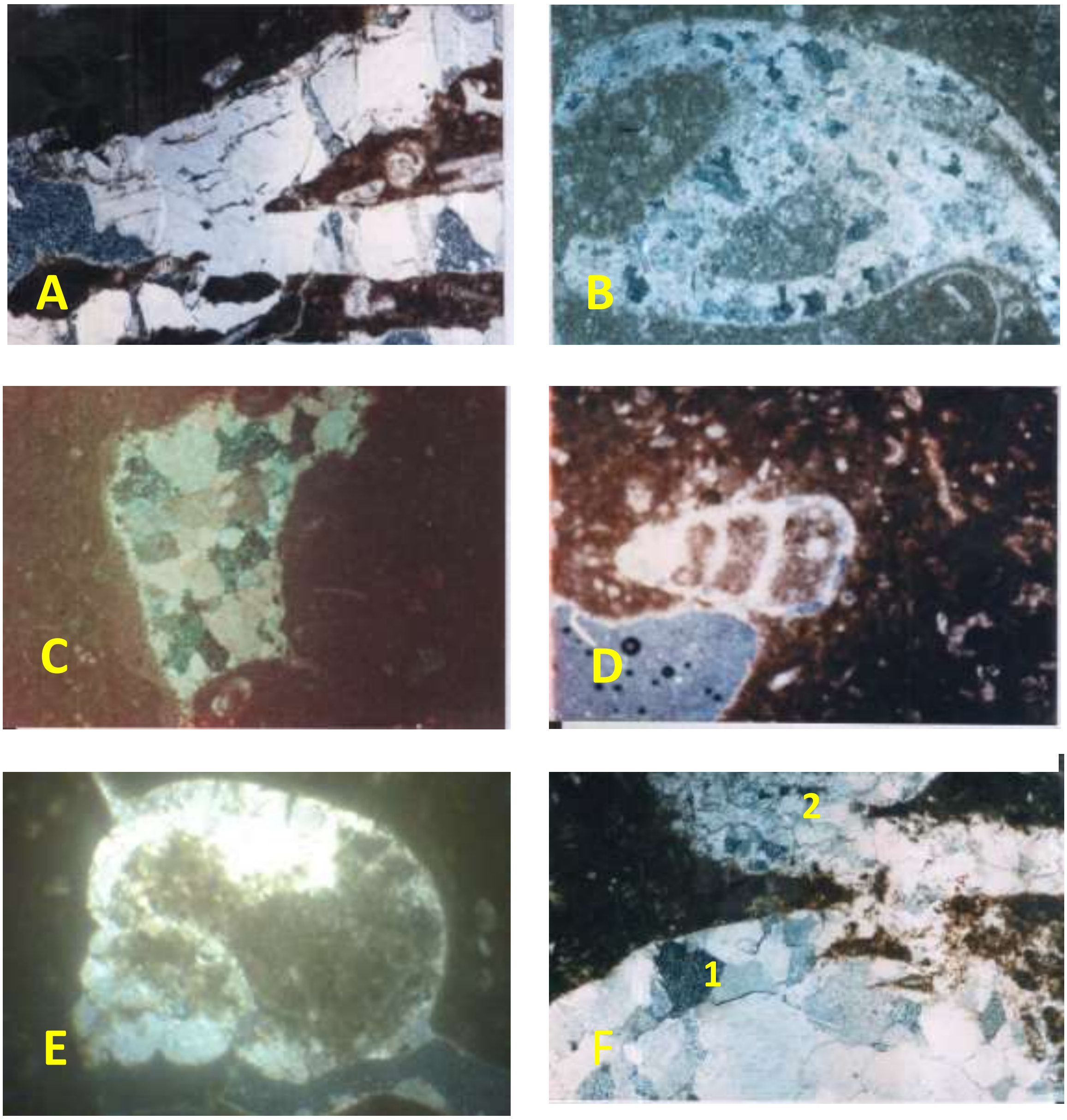
#### 2.3.1. Peloides

Peloides are composed of aggregated carbonate mud formed by Micritization of other carbonate grains mainly bioclasts and may retain slight vestiges of their original internal structure (Scholle, 2003). Peloides are observed at the top of the Mishrif succession in a very small horizon indicting high energy shoal environment (Pl. 4-F).

### 2.3.2. Lithoclastes

They are very restricted in occurrence in the Mishrif succession and observed in well R-36 in the middle parts in very small horizons and represented by big particles with no inner structure, without any specific shape and very clear boundary.

## *PLATE 6*




**A-** Blocky Cement fill the fractures (WQ-114 depth 2366 m.), 40X.

**B-** Blocky cement with some Neomorphism in Gastropod shell in packstone facies (R-36 depth 2264.5 m.), 40X.

**C-** Two generation of cement (WQ-1 depth 2310 m.), 40X.

**D-** Geopetal cement in Gastropod shell in wackstone facies (WQ-114 depth 2370 m.), 40X.

**E-** Geopetal cement in Gastropod shell in wackstone facies (WQ-1 depth 2351.5 m.), 40X.

**F-** Blocky Cement (1) and Drusy Cement (2) in Gastropod shell in packstone facies (WQ-114 depth m.), 40X.

# CHAPTER TWO

# PETROGRAPHY

## 2.1. Preface

The Mishrif carbonates were classified according to Embry and Klovan (1971) scheme (Fig. 2-1). The different types of skeletal and nonskeletal carbonate grains were studied as well as the diagenetic processes which have affected the succession. The processes include Micritization, Neomorphism, Cementation, Dissolution, Dolomitization, Compaction, and Stylolitization.

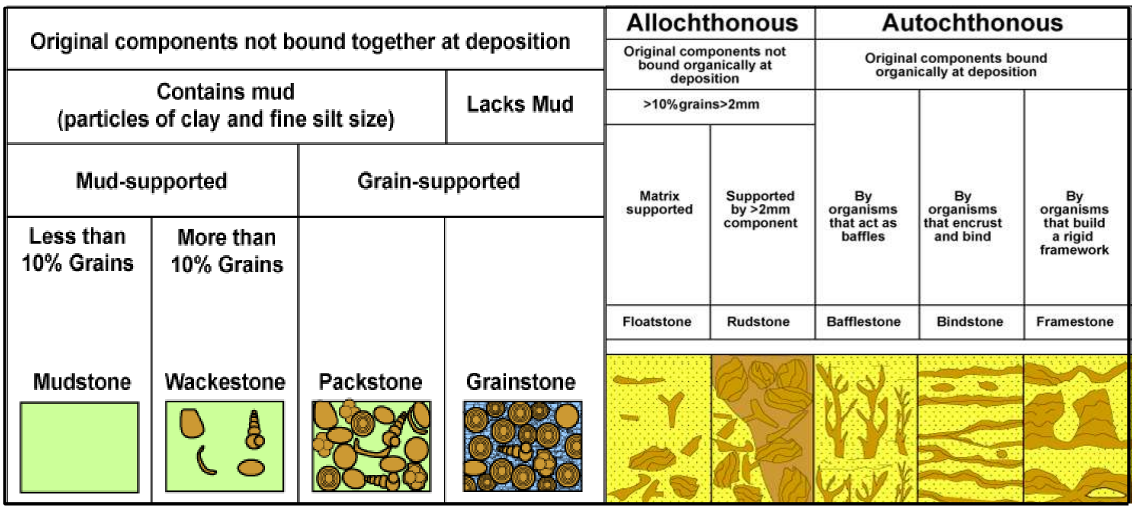



Figure (2-1) The classification of carbonate rocks ( after Embry and Klovan, 1971).

## 2.4. Diagenesis

Diagenesis is very important in carbonate rocks especially carbonate reservoirs because of its effect on porosity and permeability. The Mishrif formation was affected by many diagenetic processes depending on the changes in diagenetic environments during developments sequence. The succession was affected by four major diagenetic environments typical of shallow subsurface. These environments were usually defined on the basis of fluid chemistry and the distribution of fluid in the pores (Longman, 1980). These include vadose zone, Freshwater phreatic zone, Marine phreatic zone, and Mixing zone (Fig. 2-6).

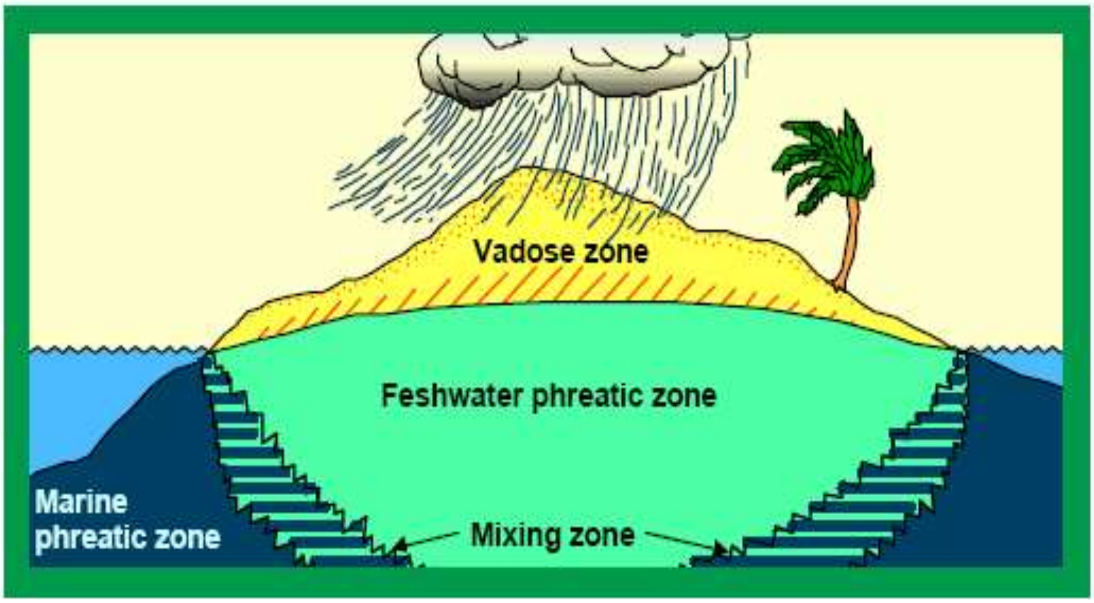



Figure (2-6)

Diagenetic environments of carbonate rocks (according to Longman, 1980)

**Vadose zone** lies above the water table, where the pores are filled with air and meteoric water and undersaturated with $CaCo_3$. In this zone, if the water became saturated with $CaCo_3$ or decrease in $Co_2$ pressure calcite may be precipitated. Solutions occur at the top of the vadose zone where water is undersaturated with $CaCo_3$ and increasing $Co_2$ pressure. Precipitation of calcite occurs within the capillary fringe zone due to increase in temperature and/or decreases in $Co_2$ partial pressure, Drusy calcite cement may form in this environment (Longman, 1980).

**Fresh water phreatic zone** lies under the water table , all pore space is filled with meteoric water containing variable amounts of dissolved carbonates and the amount of water that pass from the vadose zone to this zone depending on climate and nature of rainfall. (Harris, 1971). The geometry of this zone is controlled by topography , rainfall and distribution of porosity and permeability in the rocks. This environment can be divided into three subzones:-

a- **zone of solution** : solution by undersaturated meteoric water and may produce moldic or vuggy porosity.

b- **Stagnant zone**: water with slow movement and saturated with $CaCo_3$ where neomorphism and some cement may form.

c- **Active zone**: Good water circulation and water saturated with less $CaCo_3$ and $Co_2$ pressure decrease. It occurs in the upper part.

**Marine phreatic zone** where the pore space is filled with normal marine water; it is affected by temperature and saturation with respect CaCo3. It is divided into two subzones.

a- **Active**: Water moves readily into sediments.

b- **Stagnant**: water moves too slowly through sediments.

**Mixing zone** lies between the marine phreatic and freshwater phreatic environments and marked by brackish water. The dolomitization is the main process in this environment due to good water circulation caused by Tides (Ladd and Schlanger, 1960), and the changing seasons (dry or wet) that makes vertical movement.

The fresh water body passes downward into seawater pore fluids via a zone of diffusion or mixing potentially; these mixing zones may result in dissolution of carbonates or in some cases, dolomitization. On small islands, mixing zone can be as little as one or two meters to up to 15 m or can be tens of meters thick (Longman, 1980). In regional aquifers with high permeability and high flow, the mixing zone may be very broad (Harris, 1971). The different diagenetic processes affected the Mishrif succession with different intensities at different intervals (Fig. 2-7, 2-8, 2-9, 2-10).

### 2.4.1. Micritization

Miricte is represented by an envelope surrounding the skeletal whole organisms or the skeletal bioclasts; it can be considered as a primary diagnostic process in origin shortly after deposition (Flugle, 2004). Micritization occurs by boring algae and fungi near the sediment/water interface (Kobluk and Risk, 1979) in stagnant marine phreatic zone (Longman, 1980).

This process affected the benthonic foraminifera (Pl. 5-A), Coral (Pl. 5-B) and Rudist (Pl. 5-C) observed in packstone and wackstone facies in the Mishrif succession, and may be affecting whole skeletal components and produce Peloids. This process is most effective in the middle part of the Mishrif succession.

### 2.4.2. Neomorphism

It is the process that change the type of mineral due to change in crystal system like from aragonite to calcite (Inversion) or Recrystallization where crystals growth causes increasing size of crystals without changes in crystal system (Longman, 1980). In the studied succession, this process is represented by recrystallized micrite and the skeletal grains (Pl. 5-D, E). This process affected many horizons affecting both the matrix and grains in many intervals (Pl. 5-F).

### 2.4.3. Cementation

This process is most dominant in many horizons in the Mishrif succession where voids are filled partially or completely with cement.

Cementation apparently occurs where water is originally forced into the sediments and saturated with $CacCo_3$ and where $CO_2$ degassed (Hanor, 1978). Different types of cements can be recognized; these are blocky cement, geopetal cement, and drusy cement.

#### 2.4.3.1. Blocky cements

They are big calcite crystals, which reflect slow crystallization undersaturated solution and formed at late stages of the diagenetic history. This process represents fresh water phreatic zone (Longman, 1980). It is anhedral to subhedral crystal generally >10 to 60 um, usually with no preferred orientation of crystals, formed after lithification of sediment and compaction (Bathurst, 1958). In the studied succession, this cement was recognized in many horizons as big crystals filling fractures (Pl. 6-A) or inside skeletal grains like Gastropods (Pl. 6-B) may be the pore filled by small calcite crystals in internal boundary, and after that filled by big crystals of calcite fill all the remaining pore space this called two generation of cement (Pl. 6-C).

### 2.4.3.2. Geopetal cement

It is represented by cavities filled partially by micrite and the remainder of the cavity filled usually with cement and indicates freshwater vadose environment (Flugel, 2004). This cement was observed in the Mishrif succession within few horizons (Pl. 6-D, E). It is useful to determine the orientation of the beds.

### 2.4.3.3. Drusy cement

Computation for space between growing crystals often combines with decreasing nucleation rated due to low permeability to cause crystals to coarsen significantly toward pore centers, it represents early diagenetic process and occur in freshwater phreatic zone (Longman, 1980). Continued precipitation of calcite may fill the pores completely with crystals that coarsen toward pore centers (Schroeder, 1972). This process is less dominant in the Mishrif succession and recognized in the lower and middle parts within small horizons (Pl. 6-F).

### 2.4.4. Dissolution

This process is very important affecting the porosity and reservoir quality, it is related to meteoric water (fresh water undersaturated in calcite and high pressure of $CO_2$) (Longman, 1980). In the Mishrif succession, this process is very dominant in many horizons causing big vugs, moldic pores, channel, and other types of porosity (Pl. 7-A, B, C, D). In some horizons calcite cement filled these voids after dissolution.

### 2.4.5 Dolomitization

Dolomite in the Mishrif succession dominate many horizons and most of the dolomite is ***cloudy centered –clear rimmed dolomite*** **(CCCR)** (Pl. 7-E) where crystals of dolomite are medium to large in size in the micrit matrix; most of the crystals are dark in the center. This type of dolomite may reflected local source (Sibely, 1982). In many horizons, dolomite is associated with stylolite (Pl. 7-F) where dolomite crystals are small to very small and almost without complete rhomb boundary. It also represent local source late dolomite related to clay (McHargne and Price, 1982).

### 2.4.6 Compaction

It refers to any process that decreases the bulk volume of rocks; this includes mechanical processes that decrease the bulk volume of single grains (grain deformation) or that cause closer packing of grains (re-orientation) (Flugle, 2004). In the Mishrif succession, this process is represented by pressure solution (stylolite) and deformation of particles especially rudist debris and represented in many small horizons. Stylolites are generally regarded as the result of pressure solution and in limestone stylolitization may start just after the deposition of the grains and necessary burial depth to produce a strong stylolitization. It represent late diagenetic process when the pressure and temperature increase with active water circulation (Flugle, 2004).

Stylolitization is present in many horizons in the studied succession in different amplitudes from high and very clear to low amplitudes. Many of the stylolites were found especially in the lower and may be in the upper or the middle parts and found affecting echinoderms plate in packstones of shallow open marine (Pl. 8- B). Moore (1989) divided the pressure solution into four types:-

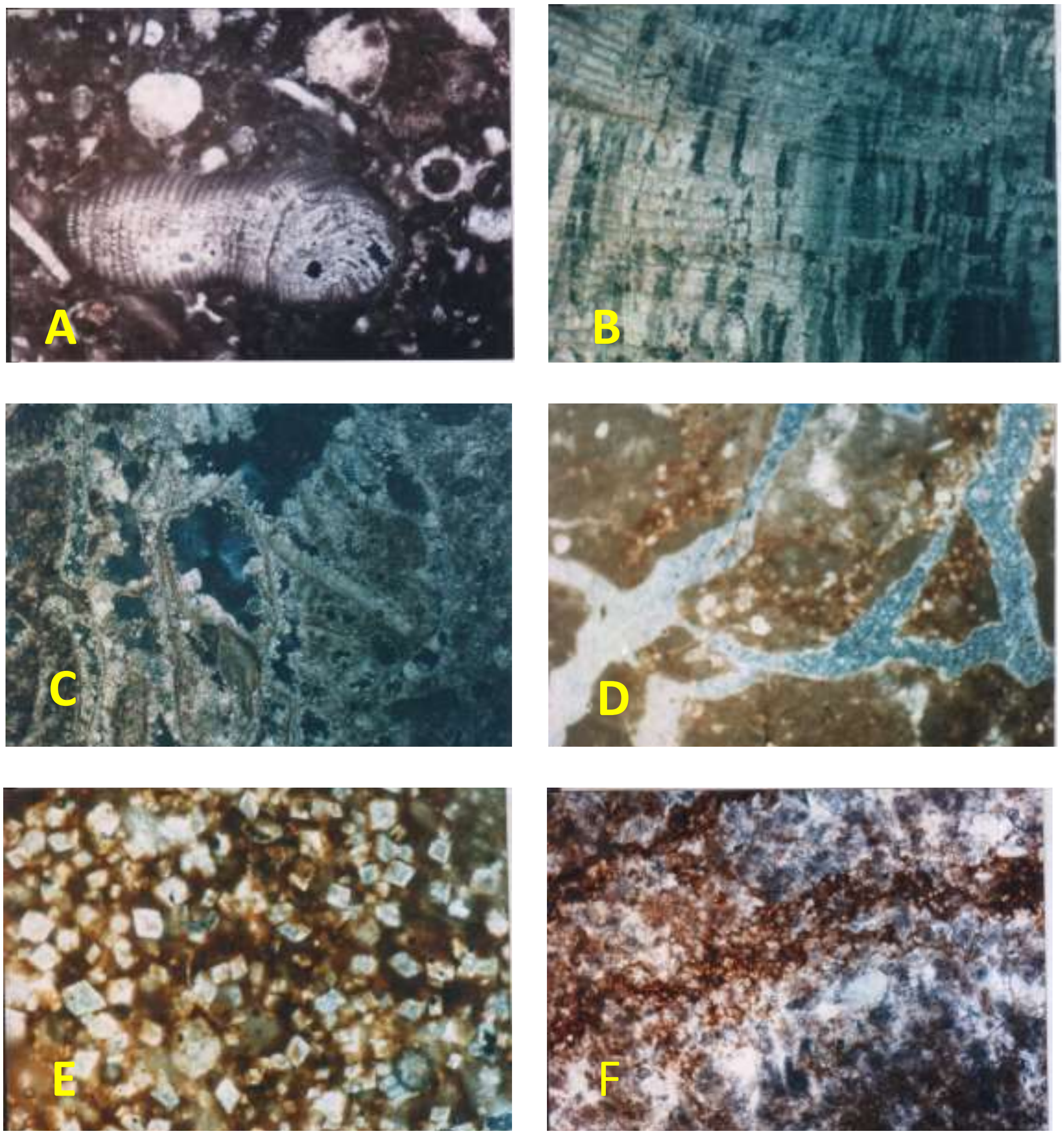
1. **Microstylolite**: sutured contacts between interpenetrating grain and amplitude < 0.25 mm. (Pl. 8-C).
2. **Solution seam**: insoluble residue accumulation >= 1 mm ( Pl. 8-D)
3. **Stylolite**: amplitude > = 1cm classify as peak high amplitude (Pl. 8-E).
4. **Wispy seam** : converging and diverging sutured and amplitude < 1 cm. ( Pl. 8-F )

## 2.5. Paragenesis

Textural relationships of the studied samples shows clear sequence of diagenetic features of the Mishrif carbonate (Fig. 2-11), The earliest processes are micritization and neomorphism followed by dissolution.

Drusy calcite cement and CCCR dolomite were formed at an intermediate stages of diagenesis, whereas geopetal and blocky calcite cement formed at late stages. Late dolomite related to stylolite was the latest to form well after compaction.

# *PLATE 7*




A- *Taberina bingistani HENSON* affected by dissolution and Micritization in packstone facies (WQ-114 depth 2370.3 m.), 60X.

B- Rudist affected by Dissolution in Rudstone facies (WQ-1 depth 2344 m.), 50X.

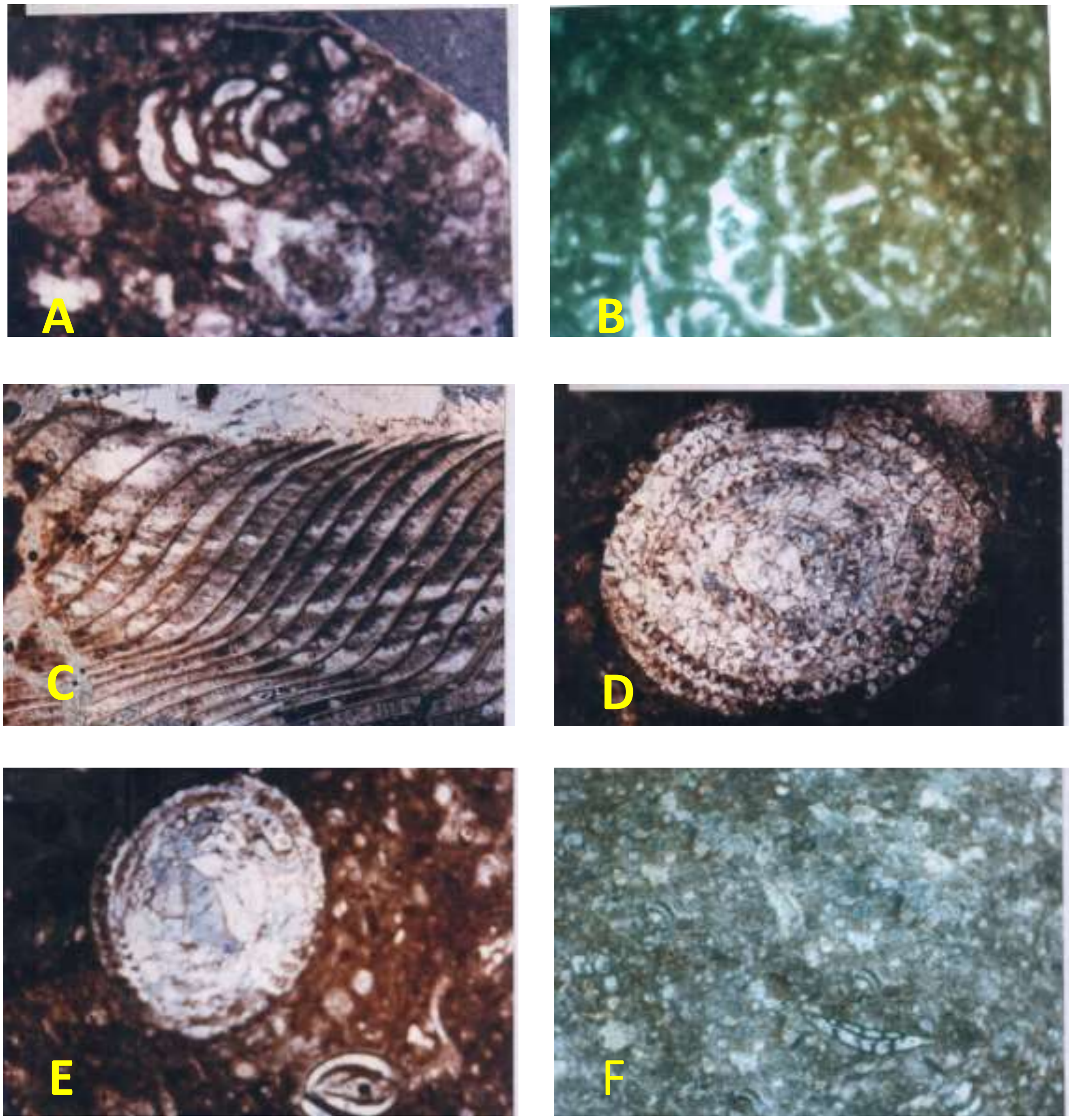
C- Rudist affected by Dissolution in Rudstone facies (WQ-1 depth 2344 m.), 50X.

D- Dissolution of matrix in wackstone facies ( channel porosity) (WQ-114 depth 2374 m.), 50X.

E- Dolomitization with cloudy center and complete and noncomplete dolomite crystals (WQ-1 depth 2288 m.), 40X.

F- Dolomite crystals associated with Stylolitization (WQ-1 depth 2373 m. ), 60X.

# *PLATE 5*




**A-** *Chrysalidina gradata D'ORBIGNY* affected by Micritization in wackstone facies (WQ-114 depth 2367.5 m.), 50X.

**B-** Cup of coral affected by Micritization in wackstone facies (R-36 depth 2200 m.), 50X.

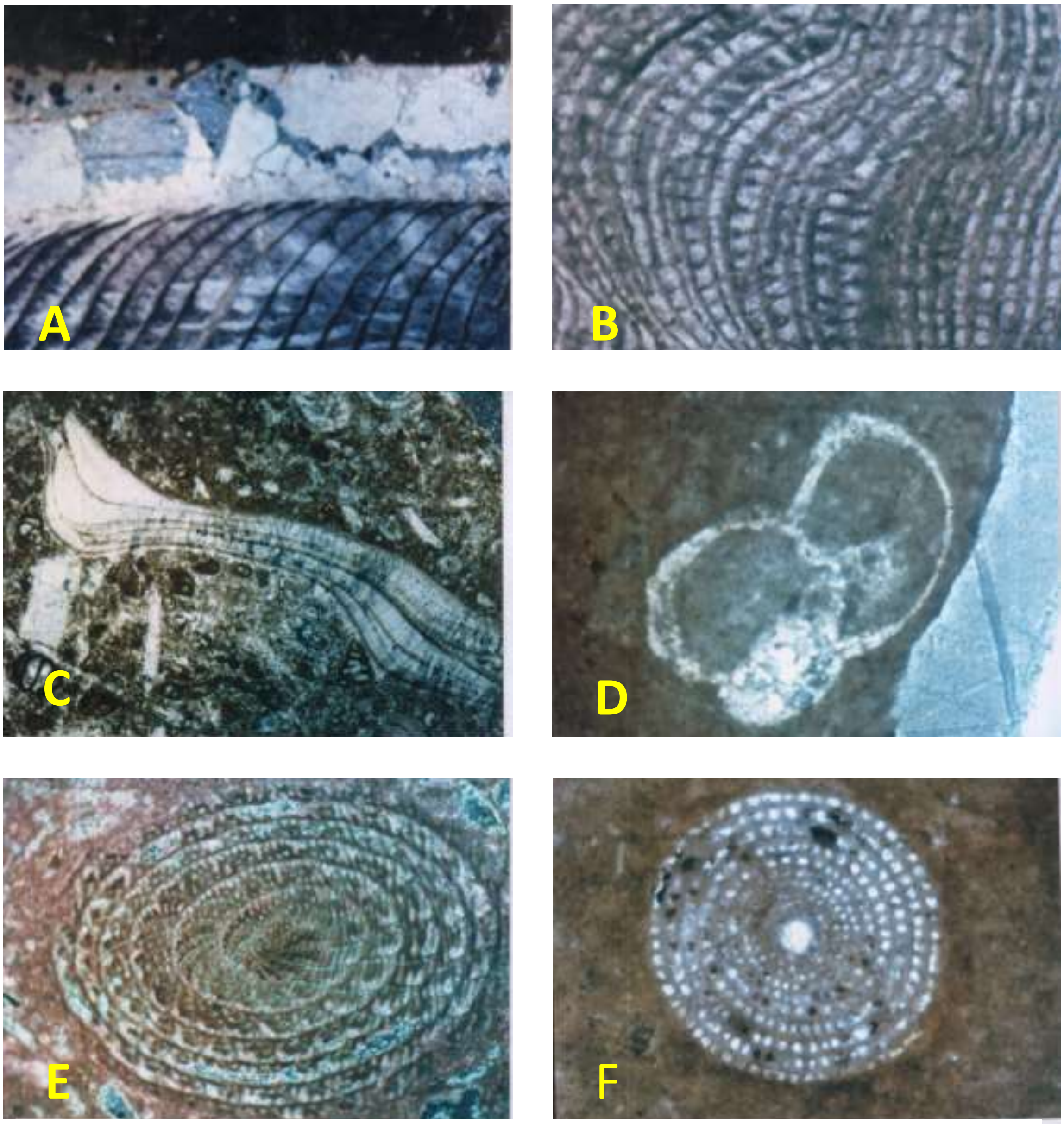
**C-** Rudist with inner structure affected by Micritization in Rudstone facies (WQ-114 depth 2367 m.), 60X.

**D-** *Cisalveolina fallax? REICHEL* affected by Neomorphism in wackstone to packstone facies (WQ-1depth 2336 m.), 60X.

**E-** *Cisalveolina fallax? REICHEL* affected by Neomorphism in wackstone to packstone facies (WQ-114 depth 2370 m.), 50X.

**F-** *Nezzazata sp*. affected by Neomorphism in wackstone to packstone facies(R-36 depth 2266.5 m.), 50X.

## *PLATE -1*




A- Inner structure of Rudist in Rudstone facies showing calcite cement (WQ-114 depth 2367 m.), 40X

B- Inner structure of Rudist in Rudstone facies (R-36 depth 2233 m.), 50X

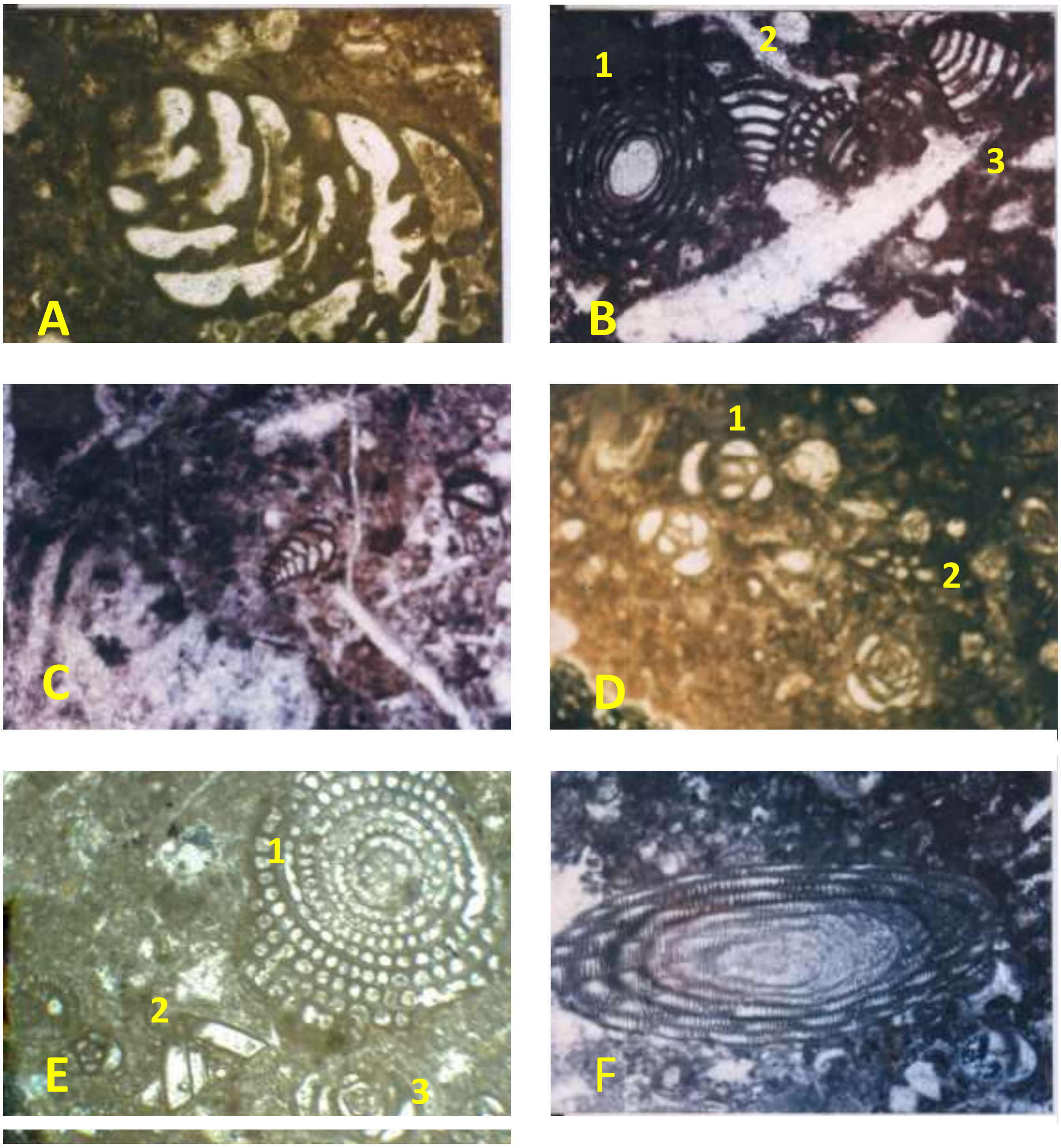
C- Rudist affected by deformation in Rudisted packstone to grainstone facies(WQ-114 depth 2378 m.), 40X

D- Gastropod shell in micrite matrix ( R-36 depth 2229.4 m.), 50X

E- Transversal oblique section of *Praealveolina tenuis* REICHEL in packstone facies (WQ-1 depth 2370 m.), 50X

F- *Cisalveolina fallax* REICHEL in wackstone faceis (R-36 depth 2229 m.), 50X

# *PLATE 2*




A- Longitudinal section of *Chrysalidina gradata* D'ORBIGNY affected by Micritization in packstone facies(WQ-1 depth 2332 m.), 60X.

B- *Cisalveolina fallax* REICHEL (1) ,*Biconcava bentori* HAWAOUI (2) and *Pseudolitunella reichli* (3) in packstone facies(WQ-114 depth 2370.3 m.), 50X.

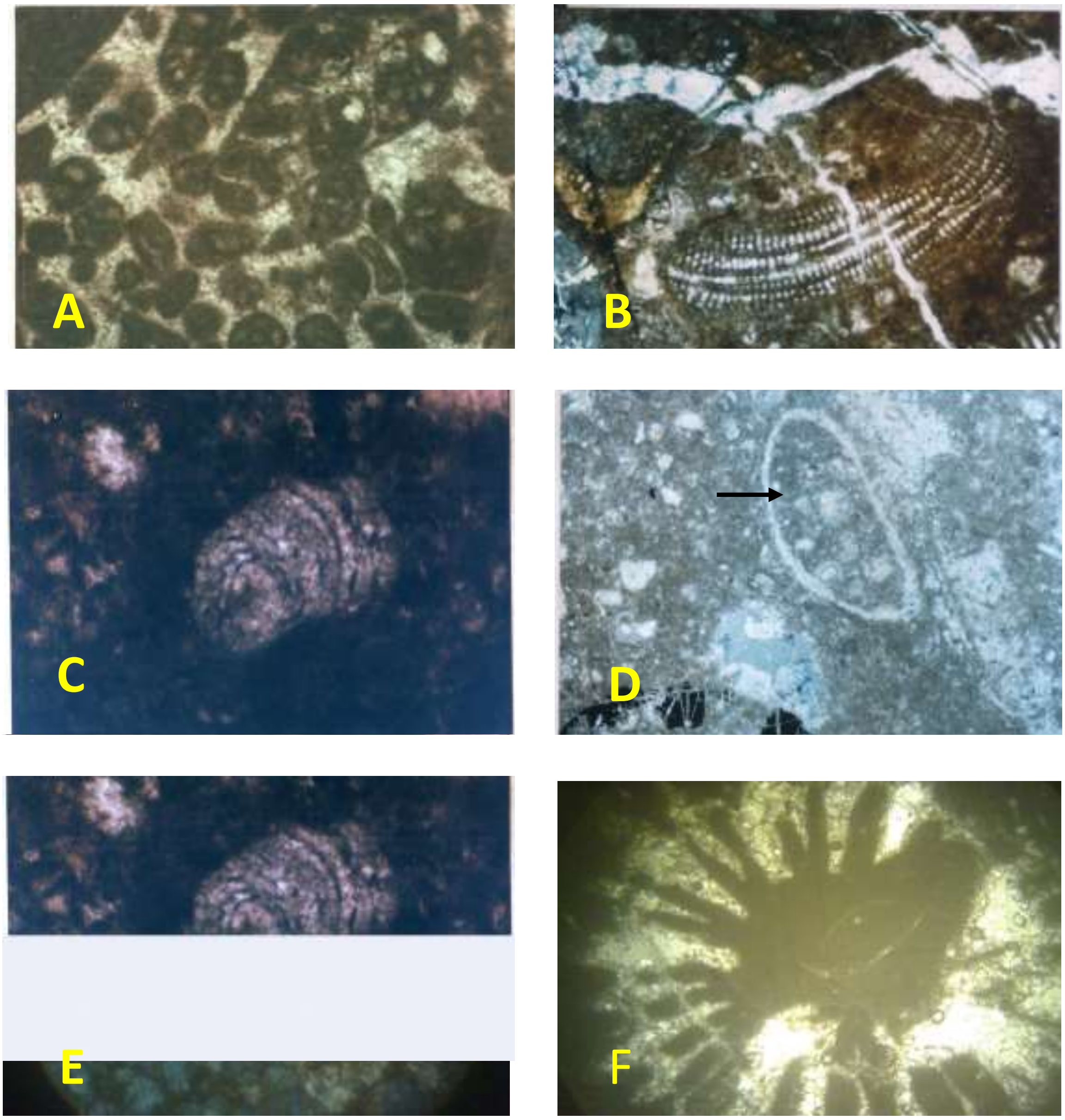
C- *Textularid* in wackstone facies (WQ-114 depth 2371 m.), 50X.

D- *Miliolid* (1) and *Nazzazata sp. (2),* as packstone facies (WQ-1 2330 depth m.), 50X.

E- *Cisalveolina fallax* REICHEL (1) , *Nazzazata gr.conica* (SMOUT) (2) and *miliolide* (3) in micorsprite matrix (WQ-1 2336 m.), 50X.

F- *Praealveolina gr. Cretacea* in packstone facies (d'ARCHIAC) (WQ-114 depth 2370.3 m.), 40X.

## *PLATE 3*




**A-** Foraminifral packstone to grianstone (WQ-1 depth 2244 m.), 50X

**B-** *Dicyclina schlumbergri* in packstone facies (WQ-114 depth 2389 m.), 40X

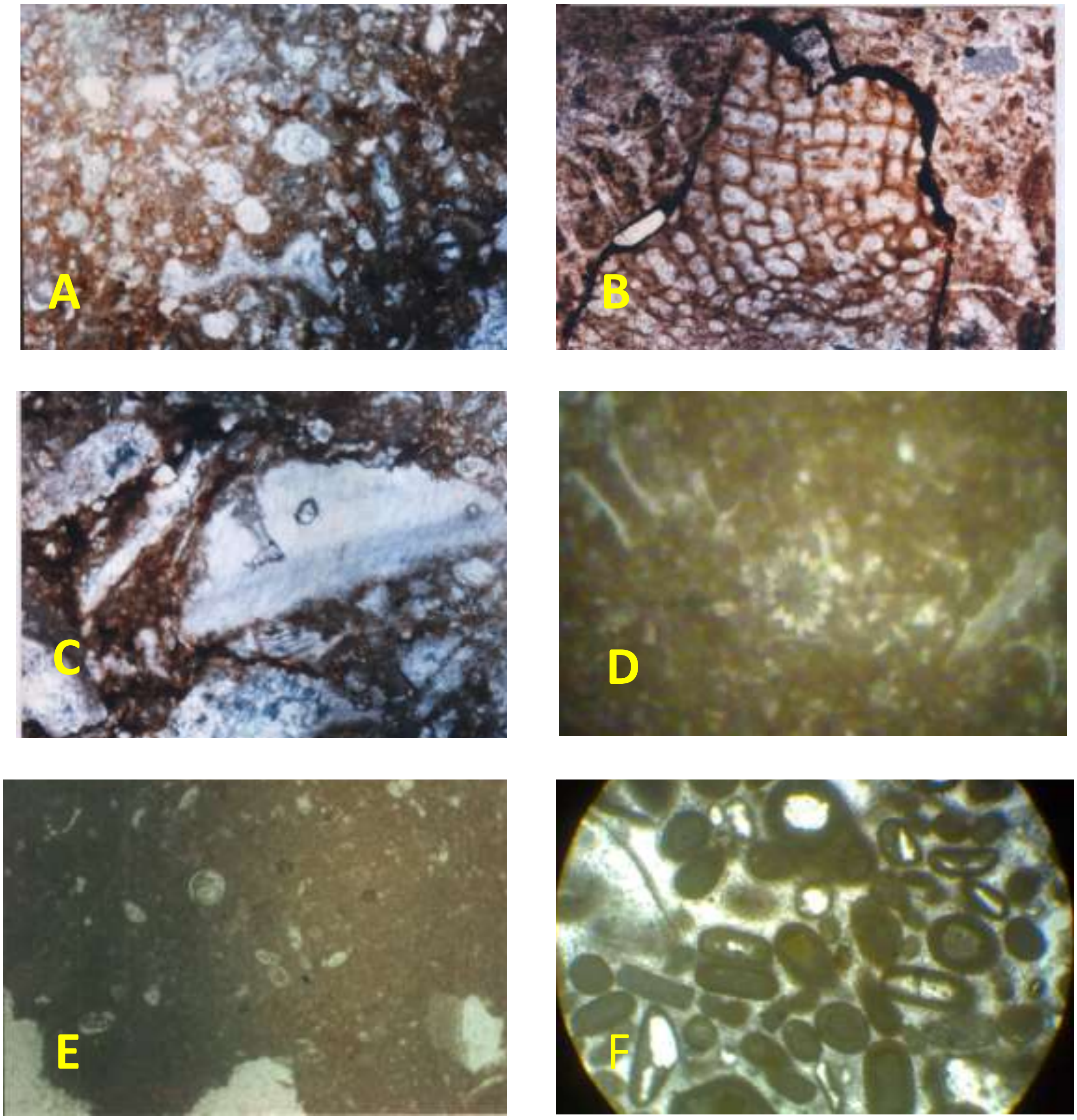
**C-** *Taeberina bingistani HENSON* Transversal oblique section in wackstone to packstone facies (WQ-114 depth 2388 m.), 60X.

**D-** Neomorphized Ostracoda in wackstone facies ( R-36 depth 2264.5 m.), 40X

**E-** Transverse section of Coral showing internal dissepiments and thick fibrous outer wall in packstone facies,(WQ-1depth 2356 m.), 40X.

**F-** Transverse section of cup coral showing solid radial septa and recrystallized wall structure in packstone facies, (R-36 depth 2200 m.), 40X.

## *PLATE 4*




**A-** Calcareous algae with bioclasts in packstone facies (WQ-114 depth 2358 m.), 40X.

**B-** Coralline algae affected by high amplitude stylolite in packstone facies (WQ-114 depth 2366.55 m.), 40X.

**C-** Echinoderms plates in packstone facies (WQ-114 depth 2358 m.), 40X.

**D-** Echinoderm spine in mudstone to wackstone facies (WQ-1 depth 2406 m.), 50X.

**E-** Plankton mudstone to wackstone facies (R-36 depth 2307 m.), 50X.

**F-** Peloidal bioclastic grianstone (R-36 depth 2180 m.), 50X.

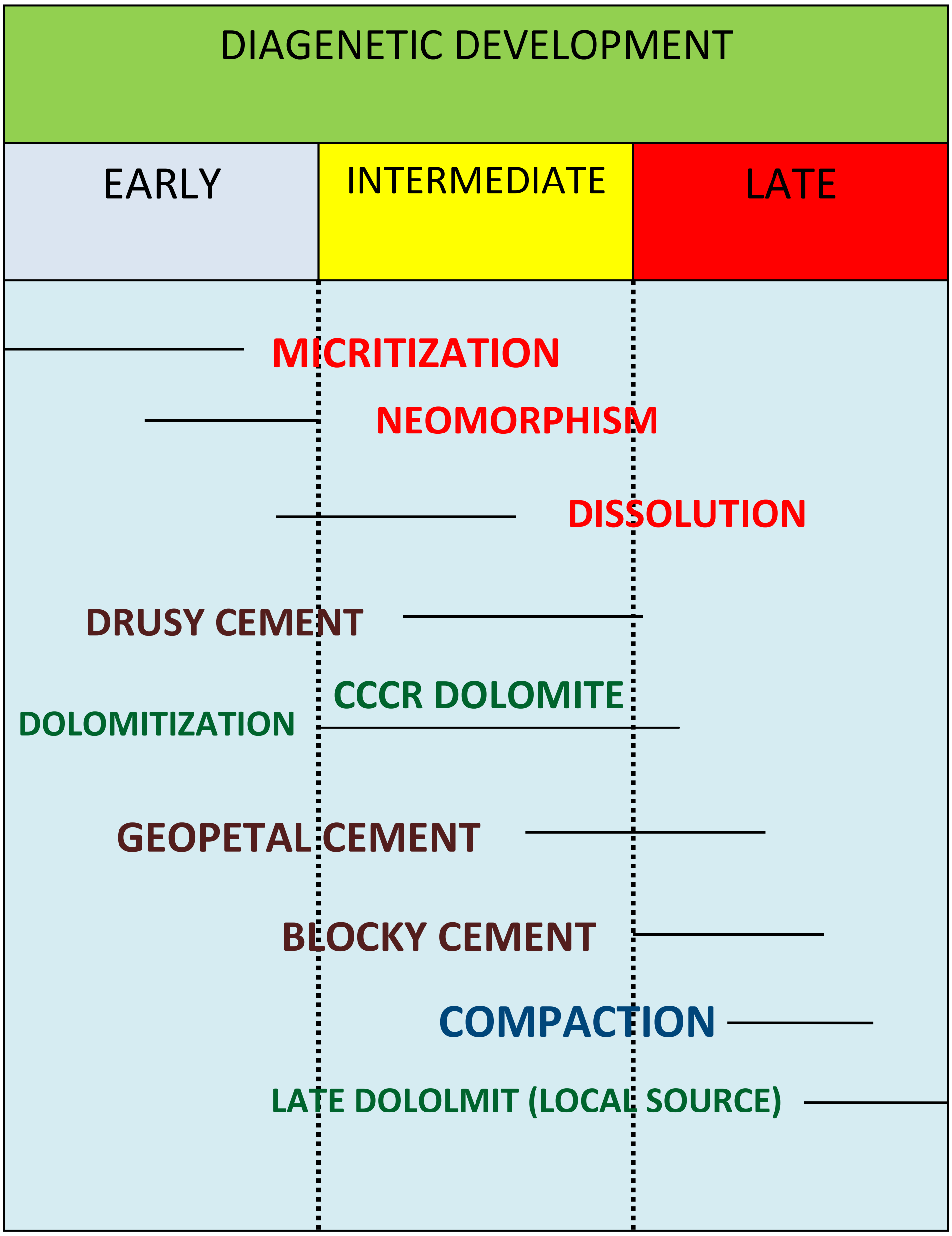



Figure (2-8) Development of diagenetic processes of the Mishrif succession.

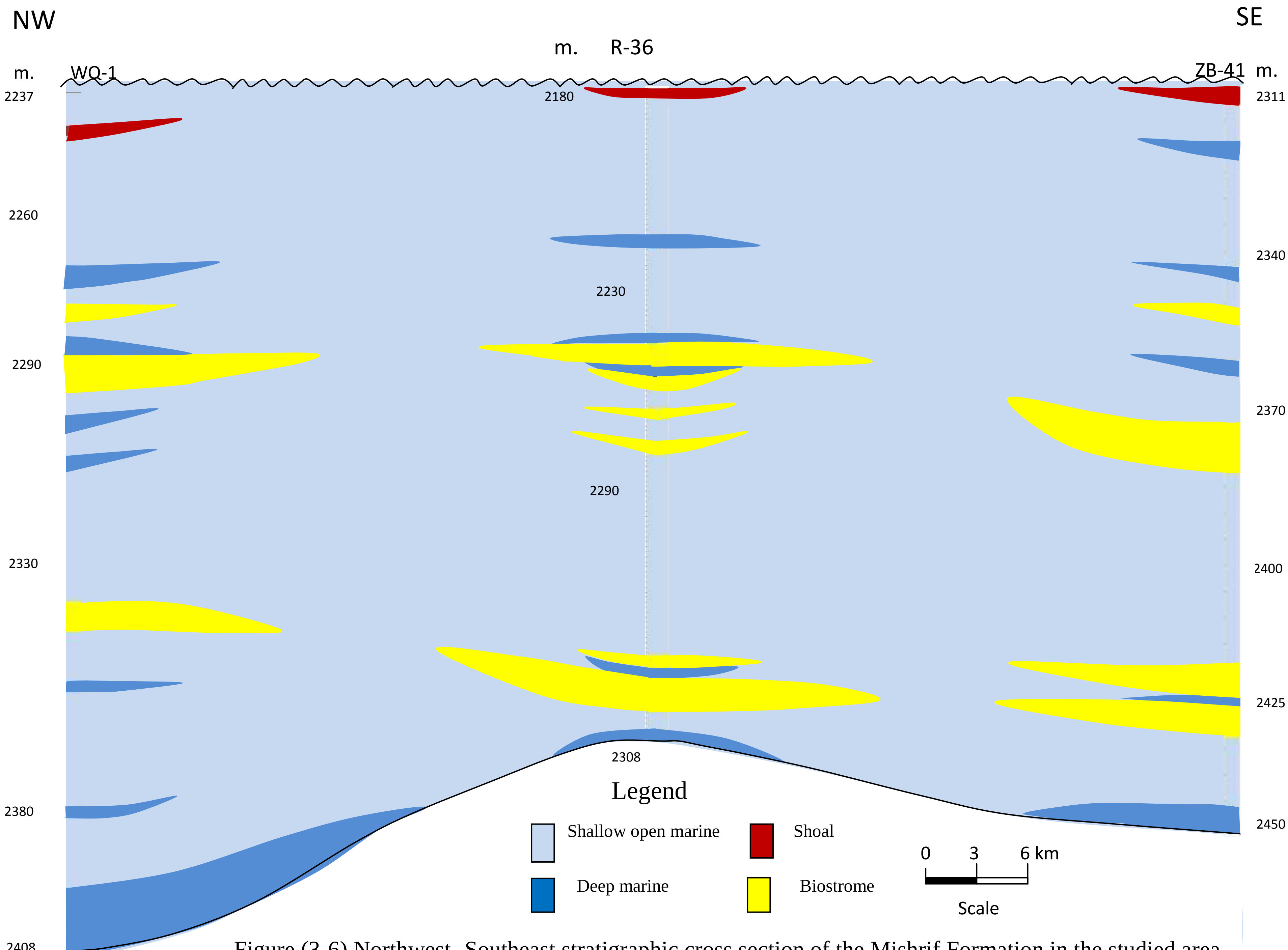



Figure (3-6) Northwest- Southeast stratigraphic cross section of the Mishrif Formation in the studied area

# CHAPTER THREE

# PALEOENVIRONMENTS

## 3.1. Preface

The Mishrif formation was deposited in a variety of subenvironments within the carbonate platform. These subenvironments where identified according to different microfacies, and were determinated according to the type of grains and depositional texture as well as the comparison with the standard facies zones by Wilson (1975) (Fig. 3-1). As a result four major subenvironments were recognized; they include deep marine, shallow open marine, Biostrome, and shoal.

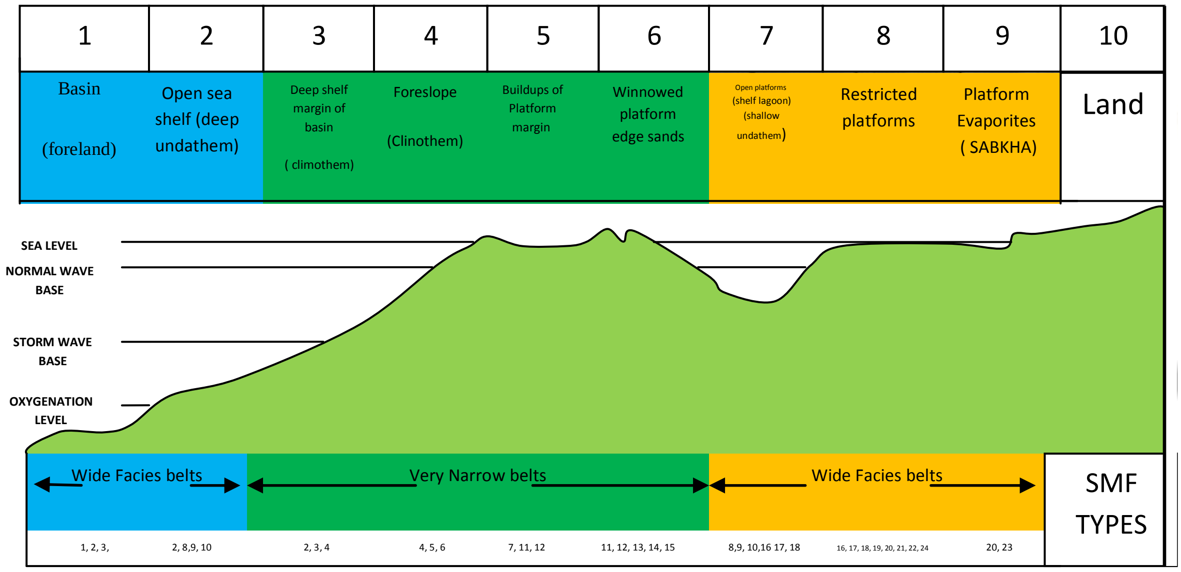



Figure (3-1) Facies scheme after Wilson (1975) as modified by Flugle (1982).

### 3.2. Deep marine

This environment is represented by planktonic bioclastic mudstones to wackstones, this microfacies is characterized by planktones being the main skeletal component. Few calcispheres, sponge spicules, small echinoderm plates, echinoderms spine, and some bioclasts of benthonic foraminifera were also observed. This facies may represent the deep margin in Wilson design where low to medium energy condition. This facies is represented mainly in the lower parts of the Mishrif succession. (Fig. 3-2, 3-3, 3-4, 3-5).

### 3.3. Shallow open marine

Shallow open marine conditions dominants the Mishrif platform most of the time and represented by a variety of microfacies. This wide area of shallow open marine condition is characterized by diversity of funa which characterize the Mishrif carbonates. (Fig. 3-2, 3-3, 3-4, 3-5,).

Benthonic foraminifera is the most abundant in this environment and represented by well preserved whole fossils with some bioclasts. The area near biostrome is represented by association of benthonic foraminifera and Rudist debris, corals, and rarely algaes.

The deeper part of the platform is represented by benthonic foraminifera associated with echinoderms. Four major microfacies characterized the shallow open marine conditions of the Mishrif platform; they include foraminiferal wackstones and packstones, foraminifral bioclastic wackstones and packstones, echinoderms bioclastic wackstones and packstones and coralline bioclastic wackstones and packstones.

### 3.3.1. Foraminiferal wackstone and packstone

The dominance and diversity of different benthonic foraminifera generally characterizes this major microfacies, few Rudist debris and bioclasts can be also observed. Such microfacies is an excellent indicator for shallow open marine conditions with open circulation.

### 3.3.2. Foraminiferal bioclastic wackstone and packstone

This microfacies is the most dominant in the mishrif succession and constitute thick horizons at different levels. It is represented mainly by large benthonic foraminifera like *Prealviolina* and *Cisalviolina*, smaller faune like *Miliolide*, *Nazzazata sp.* are also common. Rudist debris are also common and abundant at certain intervals; this may indicate nearness to the biostrome body. Other components like Gastropods and Echinoderms are also common.

### 3.3.3. Echiondermal bioclastic wackstone and packstone

This micorfacies characterizes the lower part of the Mishrif where Echinoderms represent the main skeletal component and large echinoderms plates are abundant at different horizons. Few bioclasts and Planktons where rarely associated. This micorfacies represent the deeper part of the platform.

### 3.3.4. Coralline bioclastic wackstone and packstone

Few intervals of the Mishrif succession are characterized by the abundance of coralline algae as the main component with bioclasts and Rudist debris being the minor constituents; this micorfacies is also an indicator of shallow open marine conditions.

### 3.4. Biostrome

It is represented by the builtup environment in Wilson's design (1975) where Rudist debris constitutes the main component of the body. This facies is present along the studied succession as 3-5 m. thick horizons. It consists mainly of Rudstone and Rudisted bioclastic wackstones, packstones and grainstones.

The Rudstone consists almost entirely of Rudists and represents high wave energy at the platform margin. The affect of dissolution in this facies produced large vuggy porosity.

The Rudist bioclatic packstones and grianstone microfacies are also common, where Rudists are abundant as well as other bioclats. This facies represent the bank margin of the biostrome as a transition from the shallow open marine to the main biostrome body. (Fig. 3-2, 3-3, 3-4, 3-5,).

### 3.5. Shoal

The shoal facies in the studied Mishrif succession is present as a relatively thin horizon near the top of the succession. It is represented mainly by Peloideal bioclastic grainstone where Peloides are the main components as well as some benthonic foraminifera. This facies is present at the top of the Mishrif succession (Fig. 3-2, 3-3, 3-4, 3-5,).

### 3.6. Depositional setting

Generally, the facies association and distribution of the Mishrif Formation in the study area may represent deposition on a shallow carbonate ramp setting.

The concept of ramp carbonate was given by Ahr ( 1973). In contrast to the steep slope rimmed shelves the ramp is characterized by low angle slope less than $1^0$ or no slop at all (Read, 1985), Write (1980) and Burchutte (1990) defined four sedimentation environments of ramp (Fig. 3-6). The studied Mishrif succession has some certain facies characters which may indicate the ramp setting, These are:-

1- Coarsening upward of skeletal grains, this was observed especially in the changes of foraminifera bioclasts.
2- The planktonic bioclastic mudstone to wackstone of the deep facies represent the outer ramp area.
3- The shallowing upward nature of the packstone or grainstone article of the ramp area.
4- The upward increase in sorting of carbonate grains; it also characterized the inner ramp.
5- The clustering shell fragments, algal material, and benthonic foraminifera may also accumulate at the gently sloping ramp.

Such characteristics where identified by (Van Wagonar et al, 1988) for carbonate ramp setting.

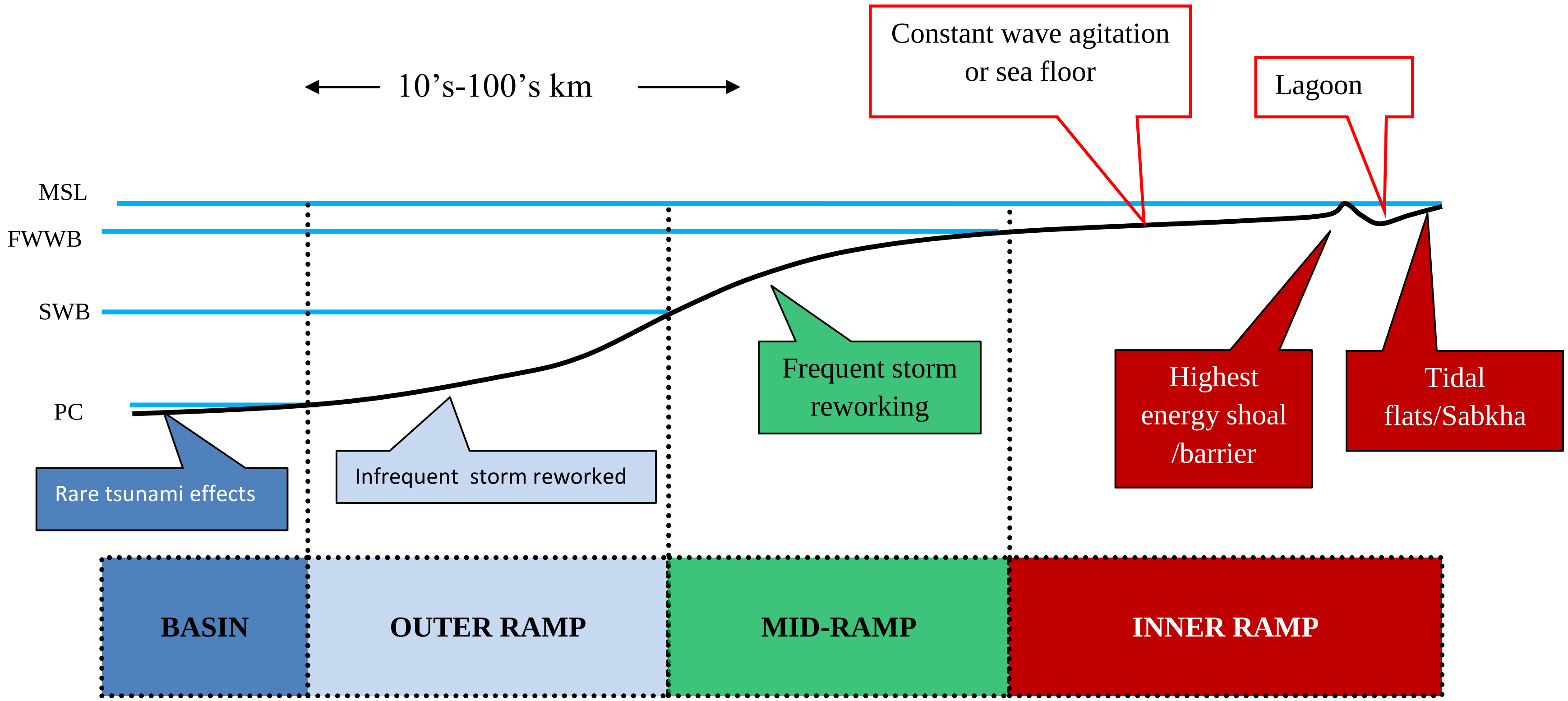



Figure (3-6) Main environment subdivisions of a "homoclinal ramp" (after Burchutte and Wright, 1992).

### 4.6. Cycles of the Mishrif Formation

The Mishrif succession in the study area is represented by three major third order eustatic cycles (A, B, C) (Fig. 4-5). Two of these cycles (A and C) are characterized by their shallowing upward nature, whereas cycle B wells represents an episode of relatively rapid sea level rise and represented a long episode of relatively sea level rise in Zb-41 well due to the changes in local subsidence. The variability of the rate of eustatic change and subsidence have affected the nature of these cycles as well as the intensity of diagenentic processes at each part of the section.

Cycle A represents the lower part of the Mishrif succession and consists of a general shallowing upward during a period of sea level stillstand following the transgressive upper part (basinal) of the underlying Rumaila Formation. Hence the lower boundary of the Mishrif succession can be considered as a maximum flooding surface (MFS) separating the underlying basinal Rumaila from deep and shallow open facies of the lower part of the Mishrif (HST of cycle A); this part of cycle A can be divided in to a number of asymmetrical fourth order cycles (up to four as in well WQ-114), (Fig. 4-6, 4-7, 4-8, 4-9). They are represent short episodes of transgression represented by the deep and/or shallow open facies of the TST, followed by relatively long episodes of sea level stillstands represented by shallow open and/or Rudist biostrome.

Cycle B reflects a different behavior of the relative sea level rise rate where the faceis stacking pattern shows clearly relatively thick (TST) represented in general of shallow open facies and/or deep facies followed by a thin Rudist biostrome and/or shallow open facies of the (HST). This cycle can be divided to up four asymmetrical forth order cycles at R-36 (Fig. 4-6, 4-7, 4-8, 4-9), this may be due to minor relative sea level fluctuation due to the tectonic component rather than the eustatic, this state may be related to the local development of antiforms during the Mesozoic within the Zubair Subzone (Buday and Jassim, 1987).

Cycle C shows a general shallowing upward up to the upper unconformable boundary (SB1) of the formation reflecting the major sea level fall during the Early Turonian. It can be divided also in to up to three fourth order asymmetrical cycles (Fig. 4-6, 4-7, 4-8, 4-9); they are characterized by short episodes of transgression followed by relatively long episodes of stillstands. The MSF of cycle C1 coincide with K140 of Sharland, 2001, Which can be correlated with other sections in the Arabian plate.

In general, the sedimentary cycles of the Mishrif succession shows a grain-rich mud-poor lithology. This may indicate that the carbonate production kept pace with the relative sea level rise (keep up parasequences). In such an area of low rate of subsidence, the eustatic component is the main controlling factor on the Mishrif sequence development.

### 4.7. Eustatic control on diagenesis

The rate of fluctuation of successive sea level rise and stillstand greatly affected the intensity of diagenesis at different parts of the Mishrif Formation. The general shallowing upward of cycles A, A2, A3, and A4, where long episodes of sea level stillstands have caused the meteoric lens to migrate basinward. This was manifested by the intensity of dissolution (Fig. 4-6, 4-7, 4-8, 4-9) of most of cycle A; whereas mixing dolomitization affected the lower part at the base of the formation. This was reflected by the increase of porosity of this interval as evident from sonic and density logs.

Cycle B on the other hand shows a different effects of diagenesis (Fig. 4-6, 4-7, 4-8, 4-9) where dissolution is less effective and dolomitization is relatively more intense. This may be related to the relatively longer episodes of sea level rise causing a landward migration of the meteoric lens leaving the lower part of this cycle under the effect of mixing zone. More intense cementation was noticed and this may be due to the effect of marine phreaitc environment (zone of precipitation) affecting this interval after the landward migration of meteoric lens. The diagenetic effect on cycle C is greatly similar to that of cycle A; where in addition to the effect of general shallowing upward, meteoric dissolution related to the upper unconformable boundary which is an additional factor contributing to the porosity development of this interval.

### 4.8. Reservoir units

The Mishrif Formation in the study area was divided by previous studies (unpublished reports) into three reservoir units (MA, MB1and MB2) (Fig. 4-6, 4-7, 4-8, 4-9). The lowermost unit MB2 coinside with cycle A and shows a good reservoir quality, where high porosity and permeability are related to the higher intensity of dissolution and mixing dolomitization; the best quality is within its upper parts (MB2.1). This may be related to the high intensity of dissolution. This high porosity can be recognized by the high value of sonic log and low value of density log. The thickness of this unit is different within the study wells area represent a thick unit in WQ-1, WQ-114 wells, and less in R-36 and ZB-41 well.

Reservoir unit MB1 shows very poor reservoir quality due to high intensity of cementation (Mainly Blocky calcite cement); it is cap rock was designated as the nonporous nonpermeable mudstone of the deep facies within the top of cycle B. The sonic and density logs confirmed the low porosity of this unit by low value of sonic log and high value of density log. This unit have almost the same thickness in all wells.

Reservoir unit MA shows good reservoir quality also due to the effect of dissolution and mixing dolomitization; this unit is capped by the overlying unconformable boundary (SB1). The top of MA is poor reservoir quality and shows a low value of sonic log and high value of density log. MA unit shows a good reservoir quality in the lower part due to dissolution, which is the main diagenetic processes; dolomitization is less effective in this interval; this can also be recognized by high values of sonic log and low values of density especially in WQ-1 well.

The uppermost nonpores unite (CR1) is widespread and can be correlated with other fields with varied thicknesses. Reservoir unite MA is of good reservoir quality especially (Ma.2), Its equivalent at other fields such as the Gharraf of less quality (unpublished reports).

Unit CR2 which is consist of nonpores deep marine mudstones is also consistent in other fields separating MA from Mb1. Mb1 is of poor reservoir quality, Its equivalent in other fields vary in thickness and quality depending on facies changes and diagenesis.

Reservoir unit Mb2 is of very good reservoir quality where intensive dissolution characters the interval, It equivalent at Gharraf field (MB3) is also of good quality where bioclastic wackstone facies dominants the interval (unpublished reports).

The lowermost part of Mb2 at base of the Mishrif succession is of poor reservoir quality and it is equivalent unit MC of the Gharraf field and shows poor to nonporse properties in the field (unpublished reports).

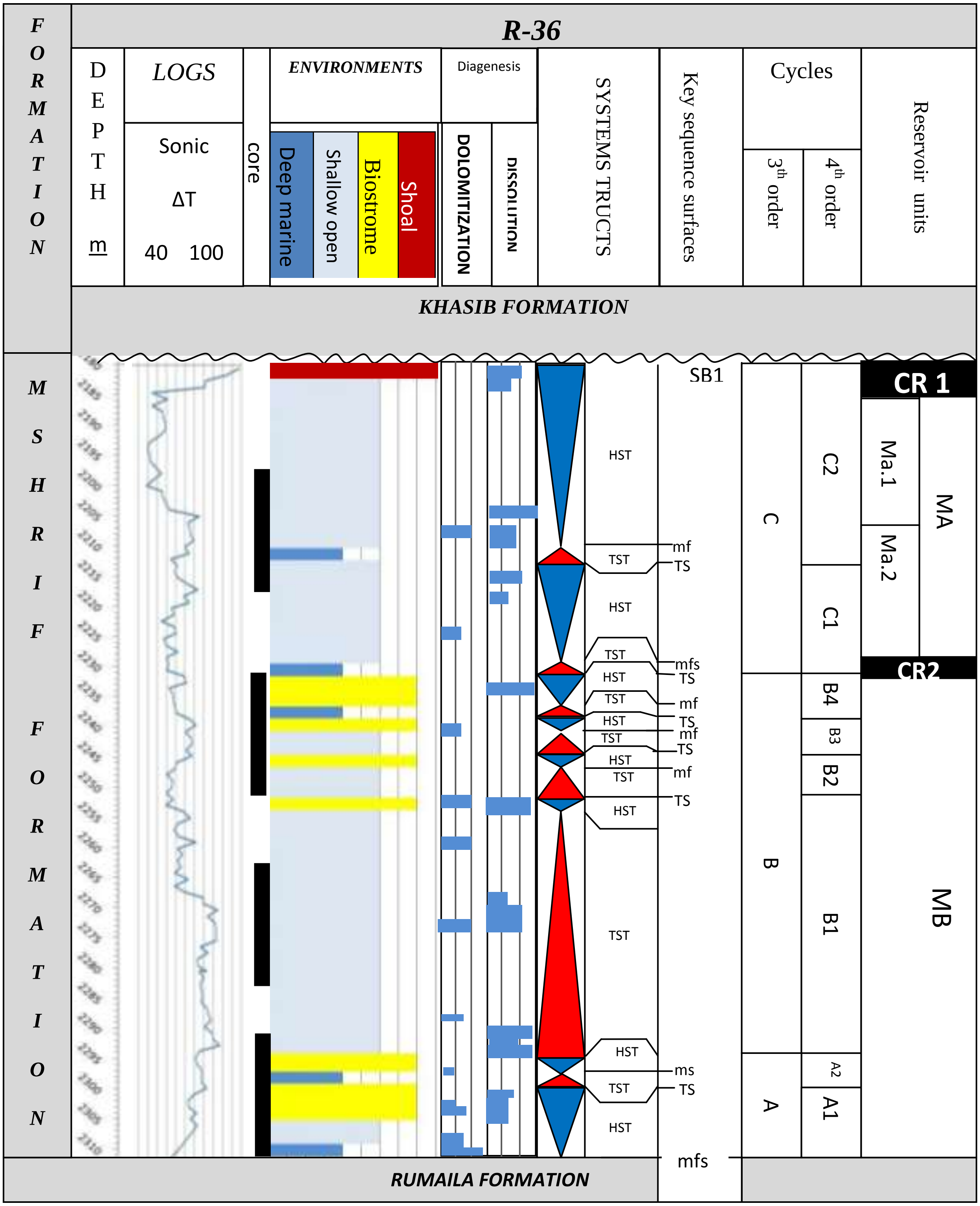



**Figure (4-8 ) Systems tracts, cycles, reservoir units and key surfaces along the Mishrif succession at R-36 well.**

# CHAPTER FOUR

# SEQUENCE STRATIGRAPHY

## 4.1. Introduction

Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive genetically related strata bounded by the surface of erosion or nondeposition, or their correlative conformities (Vail et al, 1977; Van Wagonar et al., 1988). The stratigraphic signatures and strata patterns in the sedimentary rock record are the result of the interaction of tectonics, eustasy, and climate. (Emery and Myers, 2003). The interpretation of sedimentary sections and prediction of their facies involves the analysis and integration the data. The reassembly tracks, the evolution of the sedimentary system, its hydrodynamic setting, and accommodation. The genetic characters of sedimentary sequences, cycles, and parasequences are determined by assuming that they are the products of changes in accommodation as the sediment is reassembled. The limits to this analytical strategy are tied to knowledge of the inferred depositional setting, while the advantage is that it formulates new questions that lead to more realistic interpretations and enhanced predictions of lithofacies heterogeneity's (Kendall, 2003).

## 4.2. Relative sea level

It is the sea surface relative to a fixed datum near the sea floor and affected by two components: eustasy and vertical movement of the sea floor (tectonism or sediment compaction ) (Posamentier and Allen, 1999). The rise or fall of the relative sea level depends on the relation between the eustatic sea level that refer to global sea level surface position with reference to a fixed datum including the center of the earth of a satellite in fixed orbit around the earth, and the rate of subsidence, (Fig. 4-1) (Catuneanu, 2002).

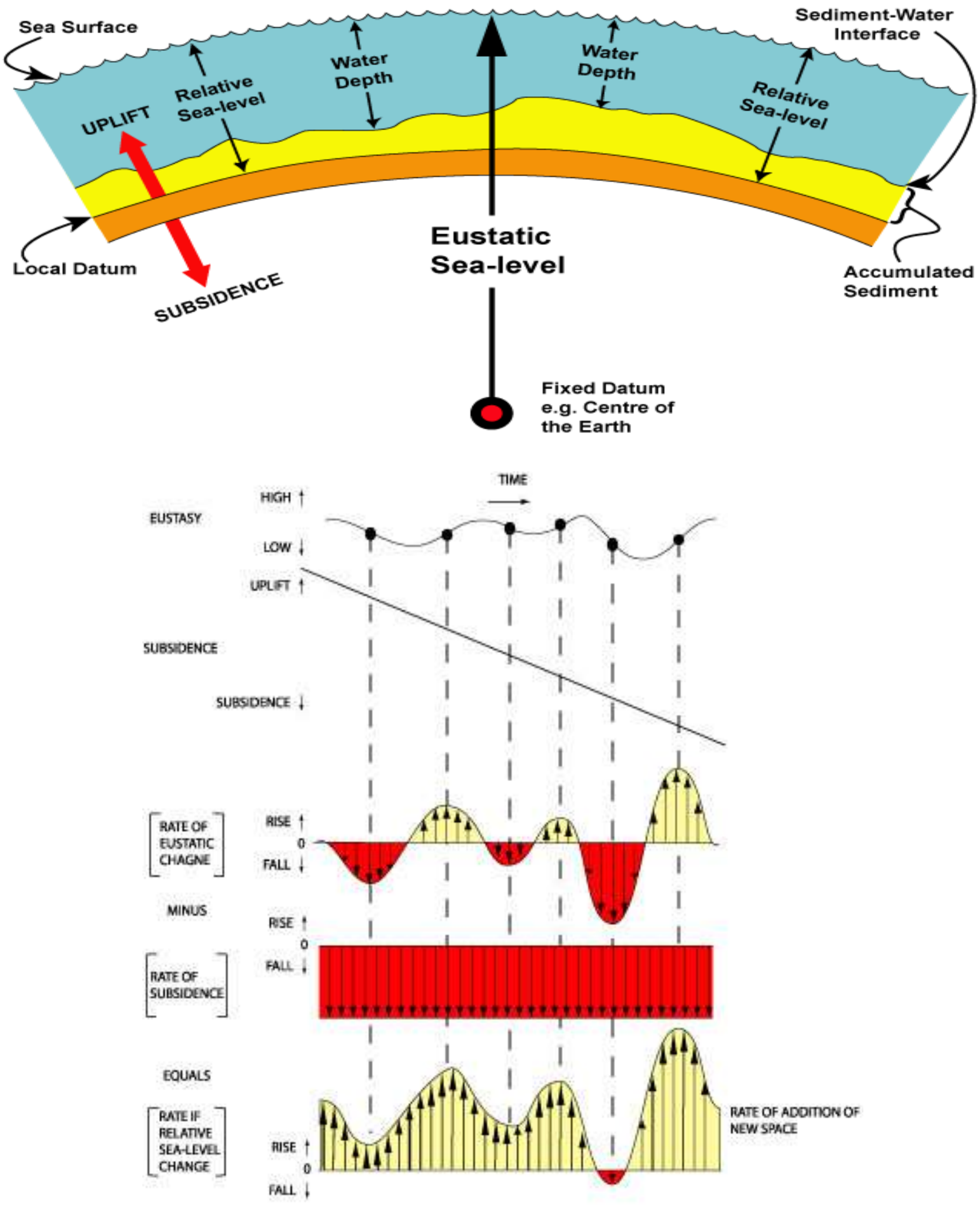



Figure (4-1) Relation between Relative sea level changes and Eustatic and subsidence changes (after Van Wagoner, 1988; Catuneanu, 2002).

By combining eustatic sea level and subsidence rates; the space available for carbonates deposits will change according to this combination; this space was called Accommodation defined by Jervey

(1988) as "the space available for potential sediment accumulation”. It is the combination of three factors (Fig. 4-2), There are :-

- The sea surface (eustasy: global sea level measured from a datum such as the center of earth).
- The sea floor (tectonics).
- Changes in rates of sediment accumulation.

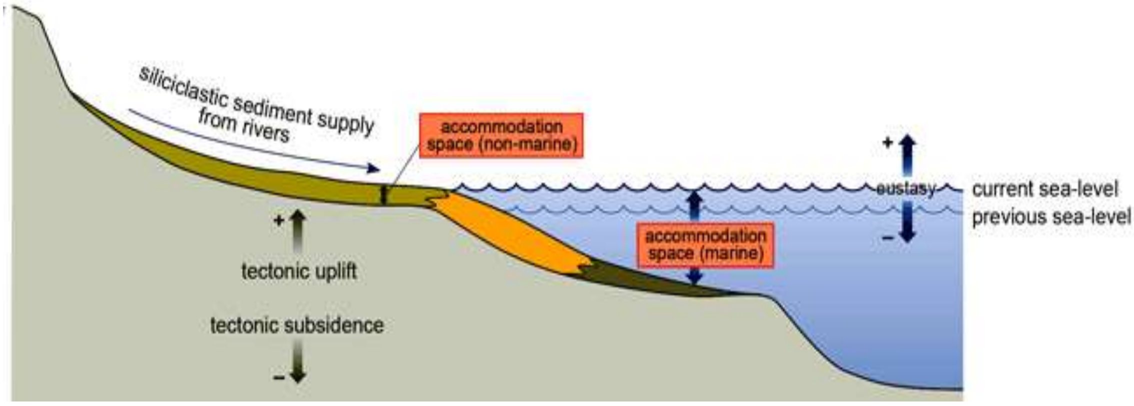



Figure (4-2) Accommodation space with sea level changes and tectonic subsidence (after Van Wagoner, 1988; Emery, 1996).

Jervey (1988) suggested that the major controls on accommodation are changes in relative sea level (i.e. the combined product of eustasy and tectonic movement). Curray, (1964), Posamentier and Allen (1999), Coe et al (2002), and Catuneanu (2002) suggested that the rates of sedimentation have the least control on accommodation. The changes of relative sea level balanced against rates of sediment accumulation lead to accommodation space that is responses to transgressions and regressions. (Fig. 4-3).

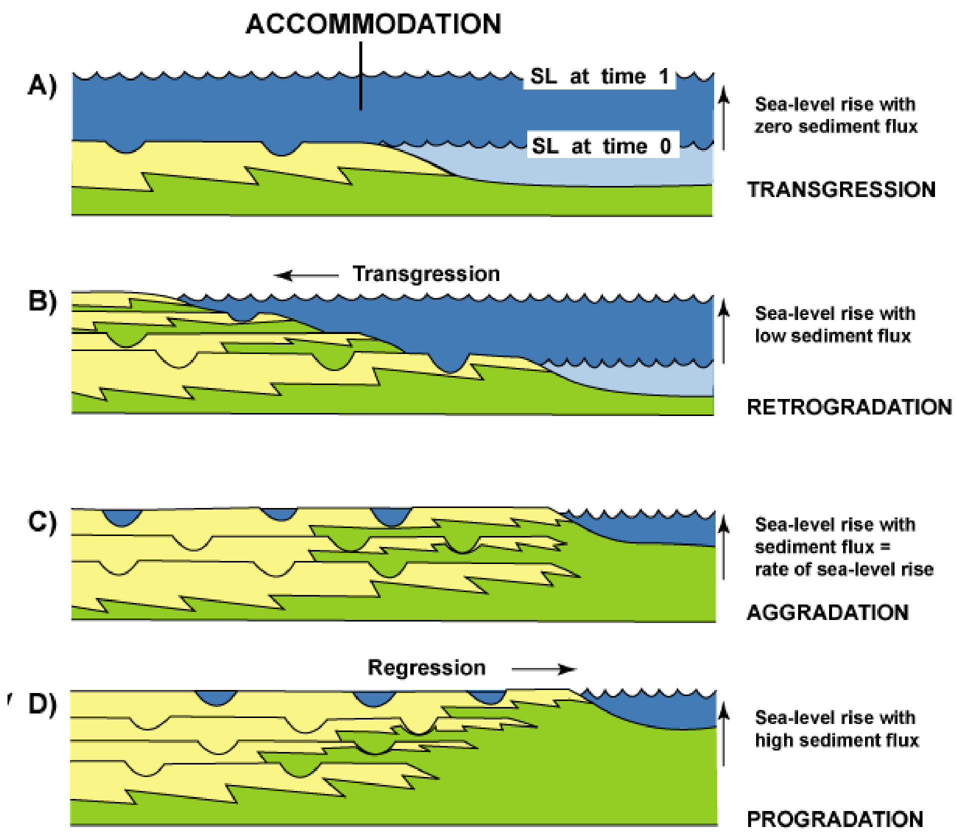



Figure (4-3) The relation between the accommodation space and relative sea level (after Posamentier and Allen, 1999).

## 4.3. Systems tracts

The sequence can be subdivided into distinctive units that are called systems tracts. They are a linkage of contemporaneous depositional environments, (Posamentier et al, 1992). They are characterized by the nature of their boundaries and by their internal geometry (Emery and Myers, 2003). There are three main systems track that characterized different parts of the relative sea level cycle (Fig. 4-4). Lowstand systems tracts (LST), Transgressive systems tracts (TST), and Highstand systems tracts (HST).

### 4.3.1. Lowstand systems tracts ( LST)

It is the basal subdivision of a sequence, and it is represented by deposition during the relative sea level fall and during the early part of the subsequent relative sea level rise that precedes the start of transgression (Van Wagoner, 1988). The LST is represented by basin floor fan and slope fan deposition grading to the lowstand wedge.

### 4.3.2. Transgressive systems tracts (TST)

It was defined by the retrogradational set of parasequences and underlain by transgressive surface (TS). Which is a marine flooding surface that forms the first significant flooding surface in the sequence. It marks the onset of the period when the rate of creation of accommodation space is greater than the rate of sediment supply. It forms the base of the retrogradational parasequence stacking patterns of the Transgressive Systems Tracts (Kendall, 2003). The TST is overlains by the maximum flooding surface. It is an overall deepening upward succession (Fig. 4-4). The relative sea level continues to rise at different rates and consequently the accommodation space varies (Van Wagonar et al., 1988).

### 4.3.3. Highstand systems tracts (HST)

The HST is bounded below by the maximum flooding surface and above by a sequence boundary, and represent an overall shallowing (Fig. 4-4). It is represented by deposits during the waning stage of relative sea level rise (Posamentier et al, 1992). This parasequence consists of an aggradational to progradational sets where the rate of relative sea level rise begins too slowly and the relative sea level eventually begins to fall prior to the next boundary, and the accommodation space destroyed at a relatively slow rate (Van Wagonar et al., 1988).

### 4.4. Sequence boundaries (SB)

They can be divided into type 1 (SB1) and type 2 (SB2) (Fig. 4.4). Type 1 sequence boundary (SB1) forms where the sea level falls at a rate more than the rate of subsidence exposing the carbonate platform to erosional processes for a relatively long time (Emery and Mayes, 1996). Type 2 sequence boundary (SB2) on the other hand is distinguished by subearial erosion at the platform margin and forms when the sea level falls at a rate less than or equal to the rate of subsidence exposing the high parts of the carbonate platform ( Emery and Mayes, 2003).

### 4.5. Maximum Flooding Surface (MFS)

A surface of deposition at the time the shoreline is at its maximum landward position (the time of maximum transgression) (Posamentier and Allen, 1999). The surface marks the time of maximum flooding or transgression of the shelf and it separates the Transgressive systems tracts from Highstand Systems Tracts (Fig. 4-4). Marine shelf and basinal sediments associated with this surface are the result of slow rates of deposition by pelagic sediments and they are usually thin and fine grained. These fine sediments, make up the condensed section (Mitchum, 1977). The Maximum Flooding Surface often mark the bounding surface between coarsening and fining upward cycles and are used to relate these cycles for deepening and shallowing in the geological section (Helland and Gjelberg, 1994).

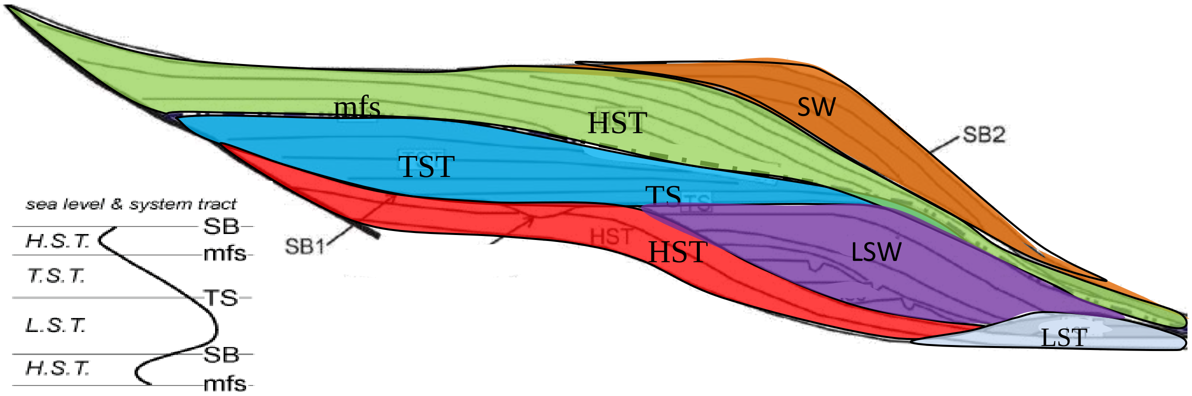



Figure (4-4) Systems tracts and sequence boundaries (after Handford and Loucks, 1993).

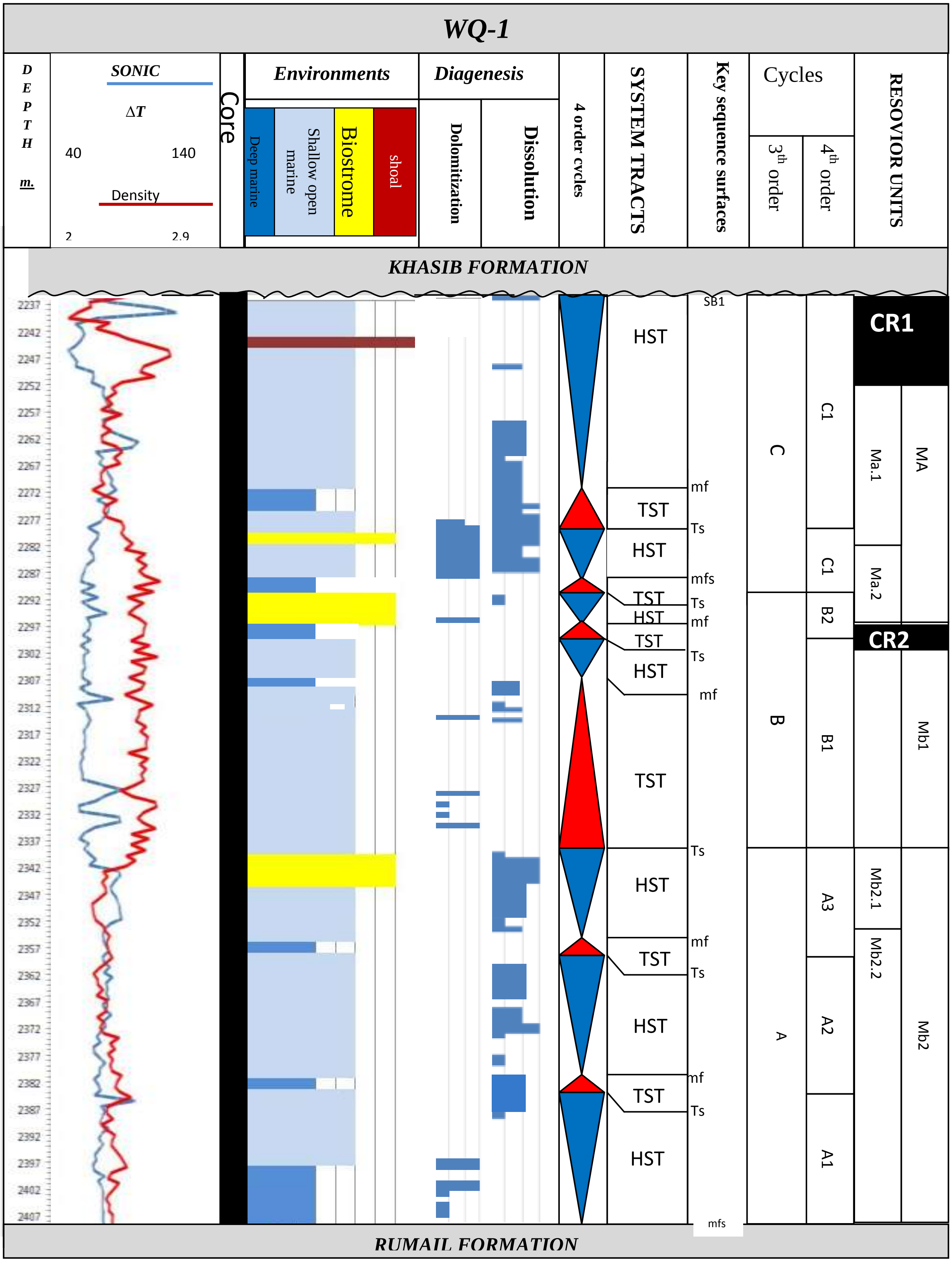



**Figure (4-6) Systems tracts, cycles, reservoir units and key surfaces along the Mishrif succession at WQ-1 well.**

WQ-114

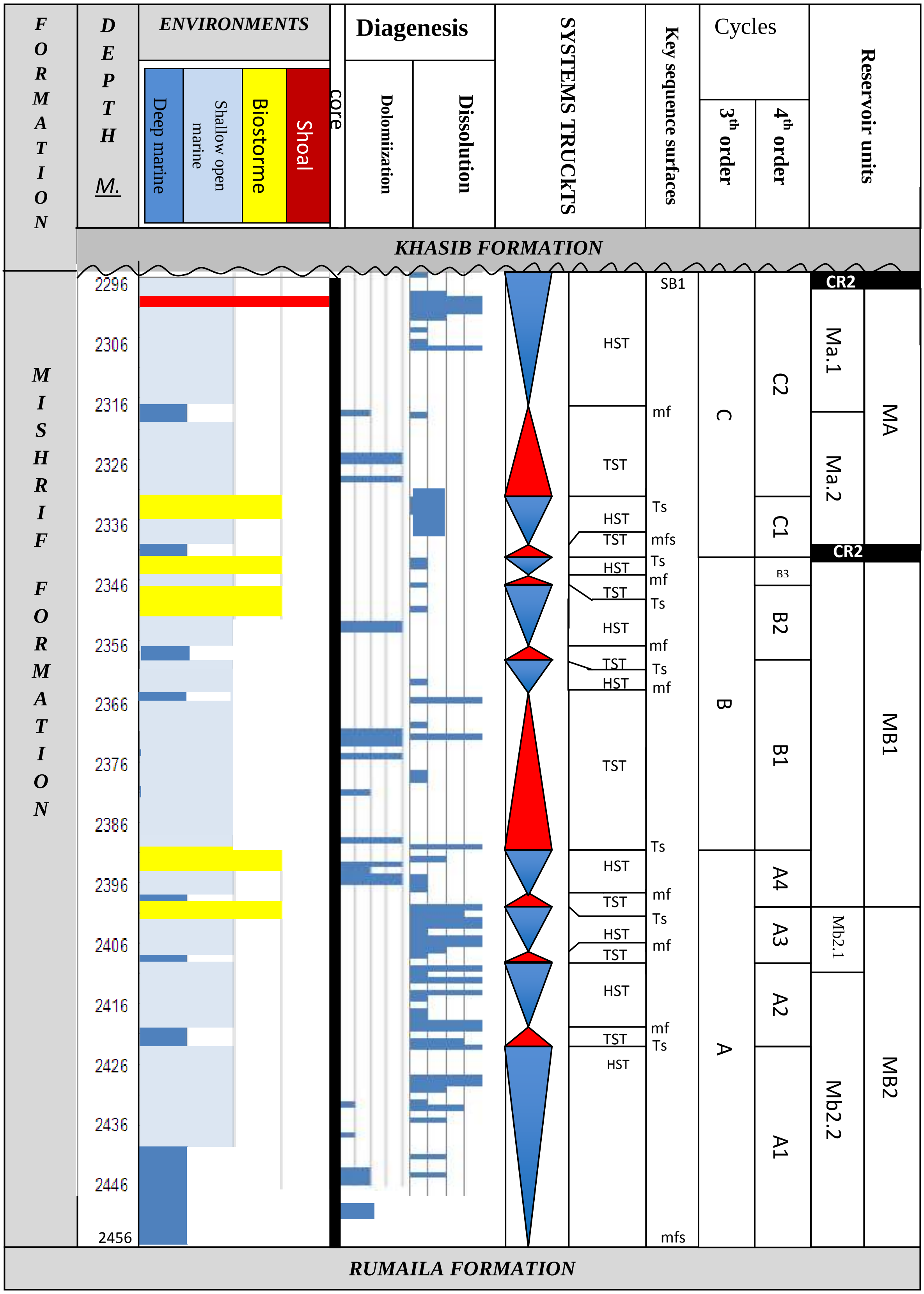



**Figure (4-7) Systems tracts , cycles, reservoir units and key surfaces along the Mishrif succession at WO-114 well.**

## ZB-41

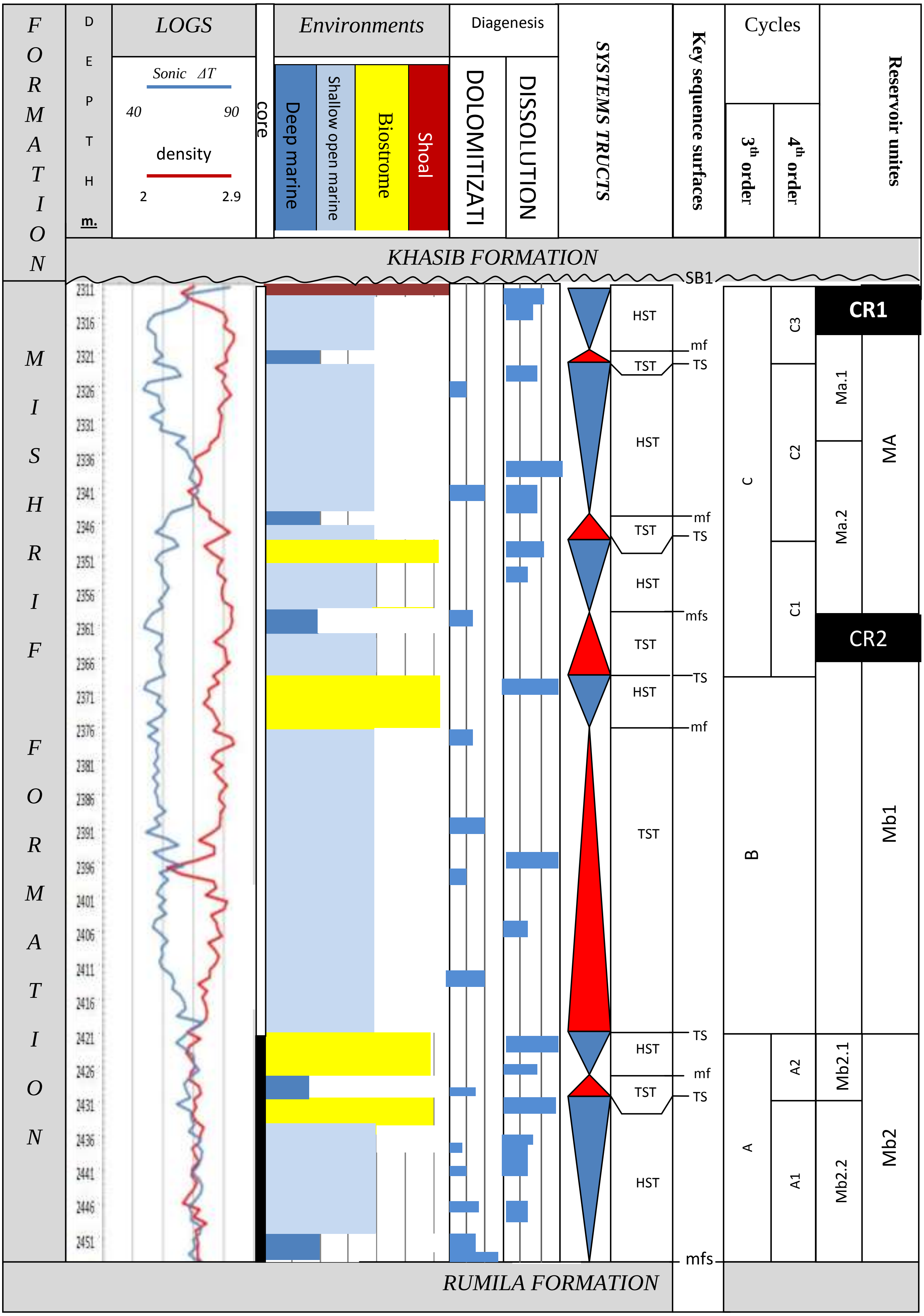



Figure (4-9) Systems tracts, cycles, reservoir units and key surfaces along the Mishrif succession at ZB-41 well.

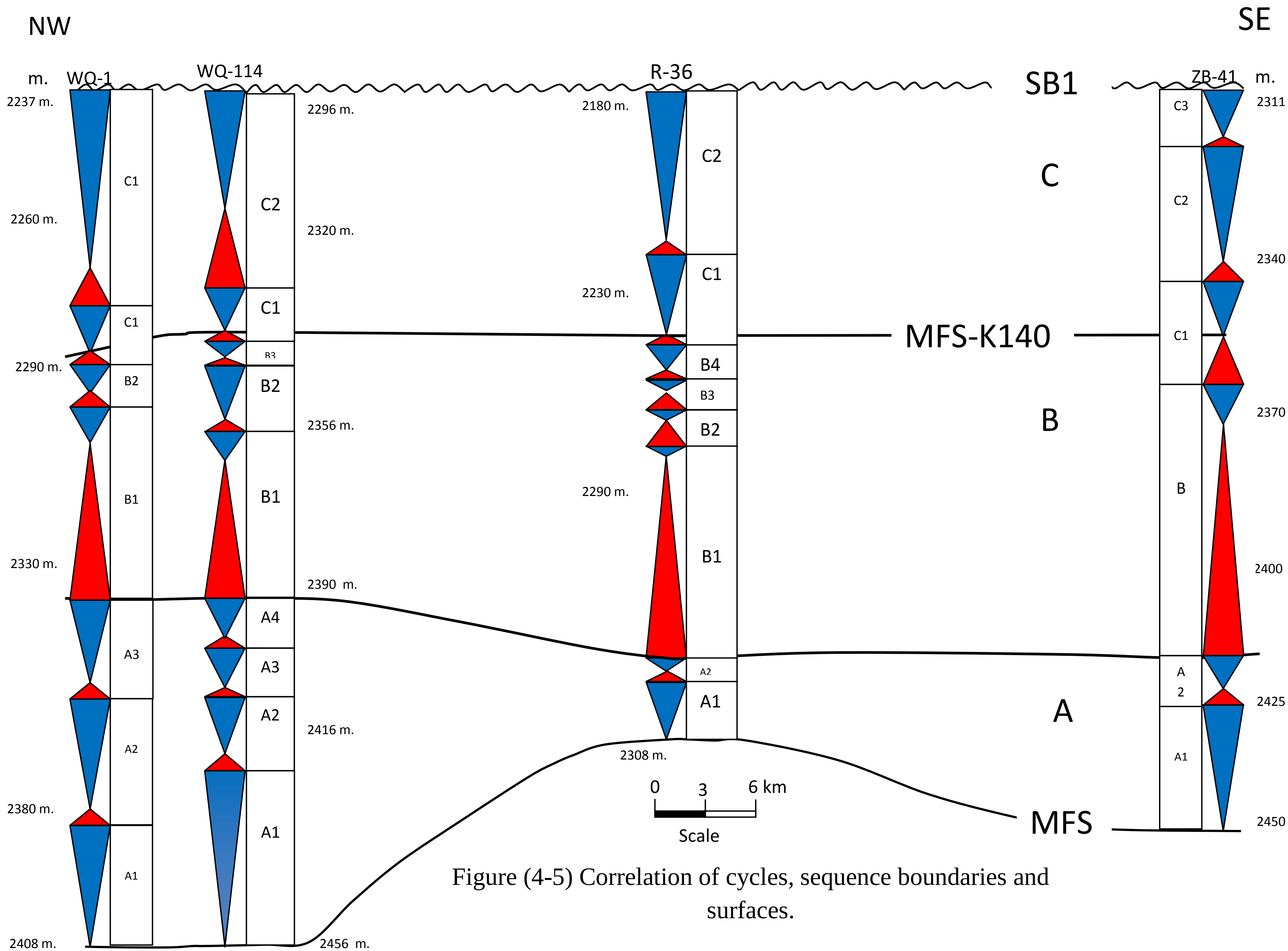



Figure (4-5) Correlation of cycles, sequence boundaries and surfaces.

# CHAPTER FIVE

# SUMMARY AND CONCLUSIONS

The Mishrif Formation in the study area is a shallow water carbonate succession with Rudist Biostrome. Four major subenvironments, where recognized within the Mishrif. They include, deep marine, shallow open marine, biostrome, and shoal environments. This Formation generally represent deposits on  a shallow carbonate platform with gentle ramp setting recognized by Coarsening upward of skeletal grains, the shallowing upward nature of the packstone or grainstone, shell fragments benthonic foraminifera, Rudist, and algal material as well as an upward increase in sorting of carbonate grains. All above mentioned may represent good evidences to ramp setting.

The Mishrif Formation was affected by different diagenetic processes; they include Micritization, Neomorphism, Cementation, Dissolution, Dolomitization, and Compaction. Dissolution is the main diagenetic process that affected in the succession especially in the lower part of succession producing the bulk porosity, which include Vugs, Moldic, and Channel porosity. Mixing dolomitization also produces porosity but less effective then dissolution. The Cementation is another important diagenetic processes destroying porosity especially in the middle parts of the formation.

The Mishrif Formation in the study area is represented by three third order cycles (A, B, C), (A) and (C) show a general shallowing upward and cycle B shows generally deepening upward. These cycles are asymmetrical and have different thicknesses in studied area and each of cycle represented by Transgressive systems tracts which represents deepening upward, and Highstand systems tracts which represents shallowing upward is the main trend of facies in Mishrif succession. Cycle A represents the lower part of

Mishrif succession; it is incomplete and started by the maximum flooding surface (MFS) separating the underlying Rumaila Formation (TST), and end by the Rudist facies. This cycle can be divided into four fourth order cycles (A1, A2, A3, A4), They are asymmetrical and different in thicknesses; almost of all them represent low short episodes of sea level rises (Transgrasive systems tracts), and long episodes of sea level stillstand (Highstand systems tracts). Cycle B is characterized by a long episode of sea level rise showing general deepening upward and can be divided into four fourth order cycles (B1, B2, B3, B4). This cycle started by a long period of sea level rise and represented by thick deposits of transgrasive systems tracts bounded by a transgrasive surface. Cycle C shows a general shallowing upward and ending by episode of fall of sea level represented by type one sequence boundary (SB1) at the upper boundary of the Mishrif with the Khasib Formation.

The fluctuation of the rate of sea level rises and stillstands was reflected on the type and intensity of diagenetic processes affecting the different parts of the Formation. This was related to the nature of development of each cycle. Cycle A is characterized by intense dissolution and this may be attributed to longer episode of stillstand, where the meteoric lens migrated basinward. The lower part was affected by mixing dolomitization. Cycle B on the other hand shows a different trend, where dissolution was less effective due to the landward migration of the meteoric lens; this was the result of long episodes of transgression. The main diagenetic process affecting this interval was cementation. Cycle C shows similar effects by diagenetic processes as cycle A.

The main diagenetic processes which affected the formation; include Dissolution, Dolomitization, and Cementation and they greatly affected the porosity and permeability of different intervals. This was reflected by the sonic and density logs responses, where high porosity intervals were affected by intense dissolution and dolomitization, and reflected by high sonic values and low density values; Whereas nonpores intervals which were affected mainly by cementation are represented by low sonic values and high density values.

The eustatic control on diagenesis was reflected on the reservoir quality of the different parts of the formation. Three reservoir units were previously determined, These are from bottom to top (Mb2, Mb1, MA). Mb2 is the best in terms of reservoir characteristics, where dissolution is the main controlling factor of porosity development. This unit includes cycles A1, A2, A3, its upper part Mb2.1, which include cycle A3. Mb1 was considered to be the best in reservoir quality. MB1 includes cycles A4, B1, B2, B3, B4; its capped by a thin unit (CR2) characterized by deep marine mudstones and showed a poor reservoir quality. This interval is characterized by the intensity of cementation destroying the porosity. The uppermost reservoir unit MA includes cycles C1, C2, and C3; its lower part shows the best reservoir quality due to dissolution, whereas its top shows lower quality due to the effect of cementation. This unit is capped by a nonpores unit directly below the unconformable upper boundary of the formation.

In comparison with other oil fields the different reservoir units and their equivalent intervals shows a variation in thicknesses and reservoir qualities. This can be attributed to variation in facies and diagenetic effects which is the main controlling factor in determining the reservoir quality of each interval.

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