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Petrology, Mineralogy and Diagenesis of the Rus and Jil Formations (l-Eocene) in Najif and Samawa areas, Southern Iraq

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Abstract

This research deals with study of the Petrology and mineralogy of the Rus and Jil Formations at Najif and Al-Muthanna Governorates, Southern Iraq. The Rus Formation consists mainly of evaporites and subordinate carbonates. The evaporites are characterized by nodular structure (compound wispy, wispy, structureless and mosaic structures) with some laminated structure at the studied sections. Compound wispy to wispy structure are the dominant structures. The Jil Formation consists almost entirely of carbonate. The carbonate rocks are dolomitic limestone and dolomite beds, massive, fossiliferous, cavernous sometime friable and bioturbated in its lower part. The Jil Formation contains evaporites as thin beds, sometimes nodular and contains selenite gypsum and very thin veins of satin-spar.

X-ray diffractometry reveals that the non-clay minerals are dominantly dolomite, gypsum and calcite. The clay minerals present in the Rus Formation are: illite, smectite, chlorite and kaolinite. In the Jil Formation the main clay minerals are illite and smectite. The clay minerals are referring to climate arid to semi arid.

Keywords: carbonate petrology, Rus Formation, Jil Formation, Evaporites.

الصخارية والمعدنية والعمليات التحويرية لتكويني الرص والجل في مناطق مختارة جنوب العراق

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الخلاصة:

يتناول هذا البحث دراسة الصخارية والمعدنية والعمليات التحويرية لتكويني الرص والجل لعمر الايوسين الاسفل في محافظتي النجف والمثنى جنوب العراق. يتألف تكوين الرص بصورة رئيسية مع نسبة ثانوية من الحجر الجيري. تتميز المتبخرات بالبنية العقدية (خيطي متجمع، خيطي،عديم البنية والبنية الفسيفسائية) مع القليل من البنية المتطبقة في المقاطع قيد الدراسة. البنية الخيطية المتجمعة والخيطية هي السائدة. يتألف تكوين الجل غالبا من الصخور الجيرية. الصخور الكاربونيتية هي حجر جيري مدلمت وحجر مدلمت كتلي و حاوية على المتحجرات و متكهفة و في بعض الاحيان متفتتة ومتعرضة للفعاليات الحياتية في الجزء الاسفل. يحتوي تكوين الجل على طبقات من المتبخرات رقيقة السمك واحيانا عقدية ويحتوي على بلورات الجبس وعروق الجبس الرقيقة السمك. يكشف حيود الأشعة السينية أن المعادن غير الطينية الغالبة هي الدولوميت والجبس والكالسيت. والمعادن الطينية الموجودة في تكوين الرص: اللألايت و السمكتايت و الكلورايت والكاؤلينايت. المعادن الطينية الرئيسية في تكوين الجل هي الألايت والسمكتايت. تشير المعادن الطينية إلى مناخ شبه جاف إلى جاف.

Introduction:

The Rus Formation is of lower Eocene age and is part of the Tectonostratigraphic Megasequence AP10 [1]. The name Rus Formation was first used by Bramkamp, in 1946, in Saudi Arabia [2]. For Iraq a supplementary type section was introduced by Owen and Nasr (1958) in the Zubair well no.3 at

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the Mesopotamian Zone of southern Iraq [3].The formation consists, in the type area, of anhydrites alternating with marls, shales, and limestones, in its middle parts, of dolomitized limestones below and soft chalky limestones above them. The amount of anhydrites i.e. the mutual relation of the carbonates and sulphates is variable [4].The supplementary type section in Iraq consists predominantly of anhydrite, with some unfossiliferous limestone, blue shale, and marl [2]. Rus Formation is devoid of any diagnostic fossils determined according to its stratigraphic position and its age lower Eocene (Ypresian) [2]. The lower contact of the formation is conformable in Iraq and Saudi Arabia. The upper contact is disconformable, marked by breccia. The thickness of the formation in S Iraq is 200 m [5].

Jil Formation was first informally introduced through unpublished reports of the Iraq Geological Survey. Tamar-Agha (1982) first introduced the sequence under the name Salman Formation and then changed to Jil Formation, Al-Mubarak and Amin (1983), introduced the sequence under the name Jil Member and finally Jassim and co-workers (1984), suggested the succession to be called Jil Formation [6]. Formerly Jil Formation was considered as the lower part of Dammam Formation. The age of the Dammam Formation in its type section in Saudi Arabia and its supplementary type section in Iraq is middle –upper Eocene and is bound by two unconformities, at is lower and upper contacts. The stratigraphic status of the lower part of the Dammam Formation in its exposure area in south and southwest Iraq was contested by Bellen [2]. He synthesized a proposal interrelating the Paleocene and Eocene rock units in the area. Further geological surveys and drillings, complied with Bellen's proposal (Tamar-Agha, 1982 and 1983 and Al-Mubarak and Amin, 1983) led to the separation of the lower part into a separate formation named the Jil Formation [7].

Methodology

The work in this study falls into two stages: field work and, laboratory and office work. The field work includes the description and sampling of four wells namely, Samawa 8, Samawa 13, Nasiria 22 and Najaf 23 Figure-1. These wells are selected on the bases of their completeness of the formations, thickness, location and distance between them. The cores are described in the field according to the variations in lithology, colour, hardness, texture, fossils content, sedimentary structure and nature of contacts. Samples are collected from four fully-cored boreholes drilled by the Iraq Geological Survey in Samawa and Najaf located in the southern part of Iraq.

Table 1-Location of the drilled bore holes

Wells	Governorate	location		Drilling (depth m) from upper contact	Number of samples
		Latitude	longitude		
BH 8 Samawa	Al-Muthanna	45° 06′ 15″	30° 29′ 16″	45	25
BH 13 Samawa	Al-Muthanna	44° 49′ 30.9″	3o° 46′ 35.3″	50.6	20
BH 22 Nasiriya	Al-Muthanna	45° 28′ 48″	30° 48′ 42″	48	11
BH 23 Najaf	Najaf	44° 11′ 53.4″	31° 46′ 32.4″	100	14

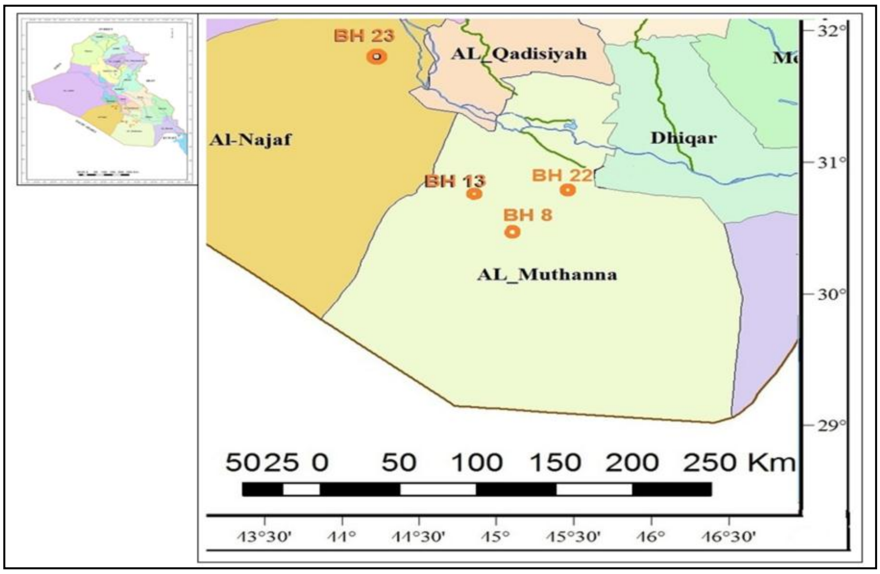


Figure 1- location map of the study area

The laboratory work involves making thin sections (about 75 thin sections) prepared in the workshop of the Department of Earth Science, in College of Science / University of Baghdad. Carbonate thin sections are stained with Alizarin red S. The thin sections are studied under petrographic microscope. Ten samples were digested with weak acetic acid (1.3%) in order to check the insoluble residues. Six out of them samples are examined by X-ray diffractometry. The main aim of this work is to study the petrology, mineralogy and diagenesis of Rus and Jil Formations in Samawa and Najaf southern Iraq.

Petrology of Evaporites

The term evaporites are used to include all those sedimentary rocks formed by evaporation of saline waters. Evaporite deposits are composed dominantly of varying proportions of halite (NaCl), anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \cdot 2H_2O$), although numerous other minerals may be present in minor amounts [8].

Classification of evaporites

Evaporites, especially gypsum and anhydrite, are the most characteristic and dominant minerals in the Rus Formation. Maiklem and co. Workers (1969) proposed a useful scheme for the structural classification of anhydrites. Many anhydrites are characterized by distorted fabrics that result from volume changes owing to dehydration of gypsum and rehydration of anhydrite during diagenesis. This classification divides anhydrites into about two dozen structural types, which can be grouped into three fundamental structural groups: nodular evaporites, laminated evaporites, and massive evaporites [9].

A- Nodular evaporites consist of irregularly shaped lumps of anhydrite that are partly or completely separated from each other by a salt or carbonate matrix.

Mosaic evaporite is a type of nodular anhydrite in which anhydrite mass or lumps are approximately equidimensional and are separated by very thin stringers of dark carbonate mud or clay (Plate 1a). **Chickenwire structure** is a term used for a particular type of mosaic or nodular anhydrite that consists of slightly elongated, irregular polygonal masses of anhydrite separated by thin dark stringers of other minerals such as carbonate or clay minerals (Plate 1b). The nodules in the Rus Formation had different shape and not matching this classification, therefore used another classification proposed by Holiday (1971) to describe the nodular structure.

B-Laminated evaporites, sometimes called laminites, consist of thin, nearly white anhydrite or gypsum laminations that alternate with dark-grey or black laminae rich in dolomite or organic matter. The laminae are commonly only a few millimeters thick and rarely attain a thickness of one centimeter. Many thin laminae are remarkably uniform with sharp planar contacts that can be traced laterally for long distances. Laterally persistent laminae are believed to form by precipitation of evaporites in quiet water below wave base. Some laminated anhydrite may form by coalescence of growing anhydrite nodules, which expand laterally until they merge into a continuous layer. Layers formed by this mechanism are thicker, less distinct and less continuous than laminae formed by precipitation. A special type of contorted layering that has resulted from coalescing nodules has been observed in some modern sabkha deposits where continued growth of nodules creates a demand for space. The lateral pressures that result from this arrangement cause the layers to become contorted, forming ropy bedding or **enterolithic structures**.

The laminated structure is only found in the lower part of well BH 22 followed upwards by nodular laminated structure. This structure occurs in lakes or in deep marine water environments. The enterolithic structure is observed in the middle part of well BH 13 and BH 8 in several levels. The nodular laminated structures is seen in the lower part of BH 8 and the middle part of BH 13 (Plate 1c and 1d)

C-Massive evaporite is evaporite that lacks perceptible internal structures. True, completely massive anhydrite is less common than nodular and laminated anhydrite, and its origin is poorly understood. Presumably, it represents sustained, uniform conditions of deposition [8]. This type is not found in the studied sections.

The nodular evaporites can be classified using Holliday's scheme (1971) into five categories [10] Figure-2 as:

Compound Mosaic, Compound Wispy, Mosaic Structure, Wispy Structure and Structureless. The nodular structure (compound wispy (Plate 1e), mosaic structures (Plate 1a, 1b), wispy (Plate 1f) and structureless (Plate 1g) are observed in the studied evaporites. The nodular structure (compound wispy to wispy structure) is dominant Figure-3, 4 and 5.

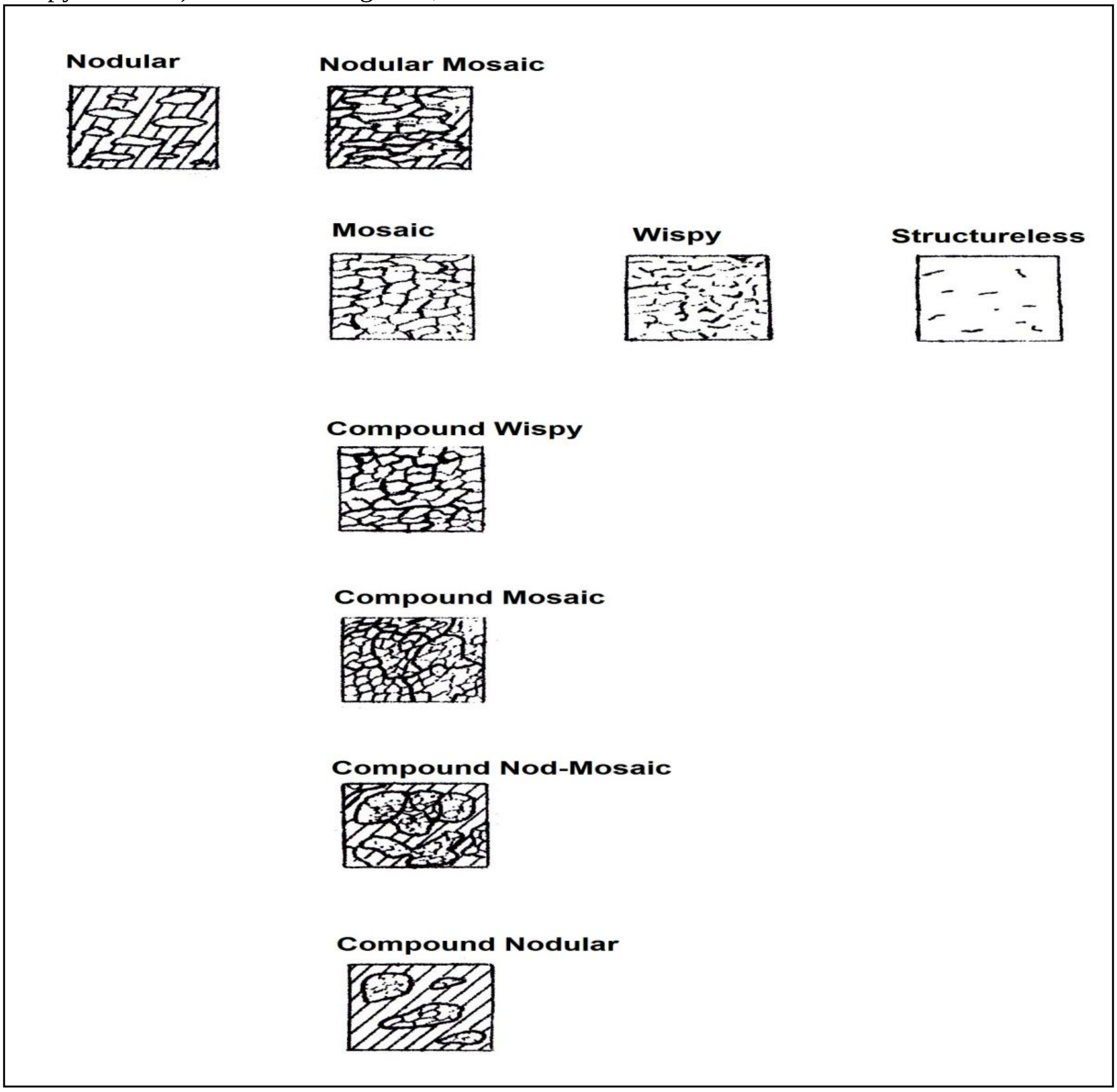


Figure 2- Types of nodular evaporites (Holliday, 1971 modified by Mustafa, 1980).

Secondary Evaporites

A.Selenite:

Selenite is characterized by yielding broad foliated form which is cleaved into several colourless and transparent cleavage folious sheets. They occur either as veins or clusters growing within the vugs of massive gypsum body. The size of individual crystal varies from microscopic size up to many centimetres. Secondary gypsum in the Rus Formation is not common and is of microscopic size sometimes reaches to 1cm (Plate 1h). Through in well BH 23 the selenite crystals varies from microscopic size in the middle part and reach to 8cm in the upper part of the succession.

B. Satin-Spar:

It is also called "fibrous gypsum". It has silky luster. Length of individual crystal ranges from microscopic up to 15cm. In the present study, the satin-spar veins are abundant in all the studied sections. Usually they occur along fractures, bedding planes, vugs, or follow the boundaries of nodules. They occur in different sizes, levels and are generally horizontal and rarely inclined. These veins are single or clustered sometimes separate by marl wisp (Plate 1i).

In the present study, the evaporite rocks are more abundant than carbonate rocks in the Rus Formations. The thickness of evaporites in the wells ranges 25 to 40 metres. The nodular structure (compound wispy to wispy structure) is dominant in the evaporitic beds of the studied sections with some enterolithic structure and a lot of satin- spar veins at different levels with different sizes ranging from microscopic to about 15cm. The deposition of the nodular gypsum as thick beds may represents sediment of a very shallow, arid, semi-restricted marine environment which undergone “reflux” and “influx” processes. These processes keep the salinity of basin water in the field of sulphates precipitation [10]. The frequent association of satin-spar and selenite veins within the weakness areas of the main gypsum bodies, in addition to the well-developed enterolithic structures, may be used as a clue for the conversion of anhydrite to gypsum. This conversion is, however, a formation feature in the sulphate beds.

In well BH 23, the lithology of the sequence is different from other wells. The total thickness of the sequence is about 100 meter whereas the thickness of evaporite beds is about 2m Figure-6. The evaporite mineral in this well is gypsum only. The gypsum beds have nodular structure and white and light grey colour. The nodular structure in the upper part is solitary and coalesces, different in size, formed by displacement and replacement. In the middle section and upper part of the lower section is formed mostly by replacement and the nodules are structureless. The thickness of beds or lenses does not exceed 0.5m.

The secondary gypsum in wells BH 23 is selenite and satin-spar. The size of selenite crystals varies from microscopic up to 8 cm transparent and foliated. The satin-spar veins are often small in size and inclined.

Plate 1- Structures and textures of evaporites in the study area

a) Mosaic anhydrite is separated by thin films of marl from Rus Formation at B.H. 8 depths (135.4 m).
b) Chickenwire anhydrite from Rus Formation at BH 8 depth (135.6 m).
c) Enterolithic structure from Rus Formation at BH 13 depth (110.3 m).
d) Laminated of evaporite with carbonates lamina at BH 22 depth (142m).
e) Compound wispy structure from Rus Formation at BH 13 depth (109 m).

f) Wispy structure from Rus Formation at BH 22 depth (124 m).
g) Structureless from Rus Formation at BH 13 at depth (110.8 m).
h) Selenite crystal of gypsum atBH 23 depth (m).
i) Vein of satin-spar gypsum from the Rus Formation at BH 8 depth (121m).

Petrography of evaporites

Petrographic study carried out on the present study evaporites (gypsum &anhydrite) revealed the following textures:

* Albastrine texture: In the Rus Formation, the albastrine in the field is massive, dense, white to beige in colour and present as beds or lenses. In thin sections most of albastrine is anhydrite, sometimes recrystallized to medium size (Plate 2a).
* Porphyrotopic texture: - This texture is common in the studied sections. A thin section of evaporites contains more than one size and more than one texture (Plate 2b).
* Satin-spar (Fibrous) texture: - This texture is found in the veins of gypsum and with lamellar twining (Plate 2c).
* Poikilotopic texture: It is found in most thin sections of studied area and at different levels. The background mineral is gypsum with inclusion of subhedral to euhedral of gypsum and or anhydrite (Plate 2d).

Diagenesis of Evaporites

-Dehydration

This process means the removal of water of crystallization from gypsum leading to the formation of anhydrite. Anhydrite crystals are developed in selenite due to dehydration. Gypsum releases structural water as it converts with burial to nodular mosaic anhydrite (Plate 2e). The nodular anhydrite is recorded in some of the studied sections, with thickness less than 25 cm. Most of the nodules mineralogy is gypsum or transition stage contain gypsum and anhydrite. The albastrine anhydrite is recorded in wells BH 22 and BH 13 as bed or lenses.

Hydration

At the other extreme of the burial cycle is the conversion of exhumed and uplifted evaporite beds. Most common is the conversion of anhydrite beds into diagenetically regenerated gypsum. Two common place gypsum fabrics are the result of exhumation, coarse porphyroblastic gypsum and fine-grained alabastrine gypsum [11]. The hydration process is more common than dehydration process in the Rus Formation as in ferret from the dominance of gypsum nodules and satin –spar veins are dominant (Plate 2f).

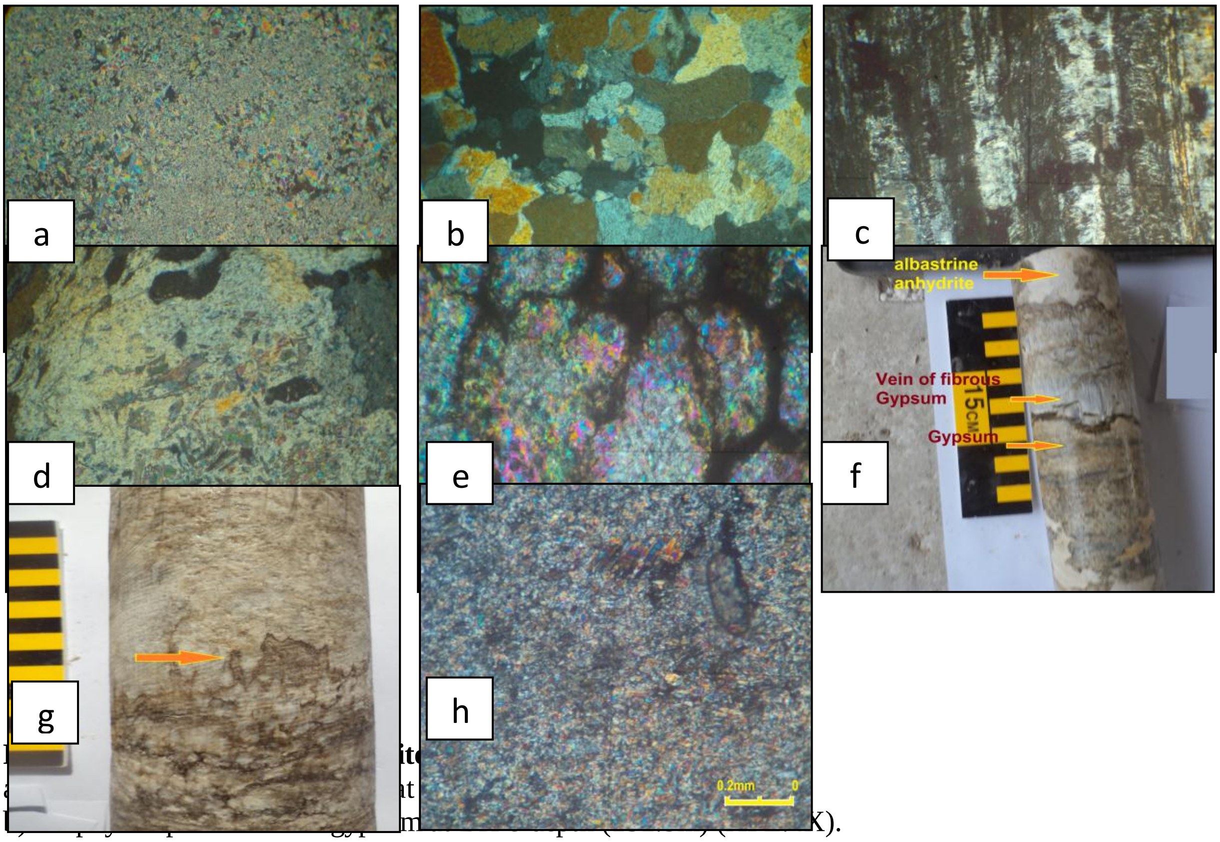
Compaction and Stylolitization

Stylolite is a sutured interlocking surface characterized by thin seams of clay and other insoluble materials [12]. Stylolites in evaporite beds are not common and not necessarily form by such deep burial. Some have argued that anhydrite and halite cannot exist at the pressure necessary to form stylolites without pervasive recrystallization [11].

The stylolite surface is marked by a thin seam of clay in the studied cores of the Rus Formation (Plate 2g). This results from pressure solution and the dissolution of gypsum, stylolites and microstylolites, which are recorded from the selenitic gypsum. The stylolite is recorded in well BH 22 in the middle and lower part and in the middle part of well B.H. 13. In well BH 8 is not recorded.

Aggrading Neomorphism

Anhydrite of secondary origin also shows aggrading recrystallization. The largest crystals represent the youngest stage of deformation, and this could be explained as a result of recrystallization, a process which required stability in environmental conditions throughout the period of deformation. The mechanism of the process is most probably due to dissolution and rapid reprecipitation [13]. The recrystallization of evaporite minerals is observed in the most of the studied thin section (Plate 2h). In the studied sections the evaporite minerals have more than one texture in the same sample. This is possibly due to the nature of these minerals that is more affected by diagenesis processes.



c) Large –scale fibrous gypsum at BH 8 depth (121.5m) (XPL.4X).
d) Poikilotopic texture of gypsum contains inclusion of anhydrite at BH 8 depth (139m) (XPL.4X).
e) Nodular anhydrite at BH 8 depth (135.5m) (XPL.4X).
f) Hydration processes convert anhydrite to gypsum at BH 22 depth (142m) (XPL.4X)
g) Stylolite in gypsum rock from the Rus Formation at BH 22 depth (103m).
h) Recrystallization in anhydrite from the Rus Formation at BH 22 depth (111m) (XPL.10X).

Petrography of carbonates

For carbonate petrographic study Dunham's classification (1962) is adopted with some of Folk's (1965) terminology [14-15]. This research discusses the petrographic examination of thin sections of samples that contain carbonate with embedded evaporites wisp from the selected wells in the studied sections.

Carbonate components:

Framework grains

- **Skeletal grains**

Very little skeletal grains are recognized in the Rus Formation (wells BH 8, BH 13, BH 22) represented by algal mat, red alge (such as lithothamnium, which is reported only in the upper part of BH 8 most possibly transported from deeper area) foraminifera (miliolids and textularia) and biomolds (Plate 3 a-c). The bioclast recognized in the Rus Formation are bone fragments especially in the upper part of well BH 13.

In well BH 23 (Jil Formation) the skeletal grains are more abundant than that found in other wells. The skeletal grains are represented by mollusks (gastropods and bivalves). They are abundant in the lower and middle parts. Biomolds, most probably of nummulites, are comman in the upper and middle parts whereas textularia biomolds in the middle part of this well and few algal mat grow along the cavity of solution breccia samples in the middle part of this well (Plate 3 d-g).

- **Non- skeletal grains**

Non-skeletal grains are inorganic particles of carbonates. They are divided into coated grains such as (ooids, pisoids) and non-coated grains such as (Intraclast and extraclast). Non- skeletal grains are more abundant in the Rus Formation than skeletal grains. They are represented by peloids, which appear as dark colour, micritic, rounded, with uniform size ranging from 0.05mm to 0.3mm. Many peloids, especially those with well rounded, symmetrical shapes, are of fecal origin. Peloids are recorded in well BH 22 at many horizons and rarely seen in well BH 8 (Plates 3h, 3i). The coated grains are recognized only in well BH 8 at different levels represented by ooids and pisoids (Plate 3j). Intraclast are the infrequent between the non-skeletal grains recorded in the middle part of well BH 22 with fenestral porosity. In well BH 23 the non-skeletal grains are less abundant than those found in the other wells. Peloids and intraclast are recognized in the middle part of this well.

Matrix

Micrite is recorded in most of the studied thin section in the Rus Formation. Some of the matrix is neomorphosed to microsparite.

The petrography of the contact between the Rus Formation and Dammam Formation is disconformable (erosional surface) marked by conglomerate. It belongs to the Dammam Formation separating two formations. It contains rounded gravel (extraclast), phosphatic fragment (bioclast), fecal pellets and the carbonate matrix (dolomitic limestone). The contact also contains algal boring. The diagenesis processes that effect on the contact are dolomitization, dissolution and cementation (Plate 3k, 3l). This contact records in BH 8 and BH 22.

Diagenesis

Several diagenetic processes had affected the carbonate horizons in the Rus and Jil Formation in all studied bore holes. The diagenetic processes that affected the formation are represented by neomorphism, dissolution, dolomitization, cementation and authigenic minerals.

Neomorphism

This process is recorded in most of the studied thin section in the studied bore holes (Plate 4a). Neomorphism in Rus and Jil Formation included the transformation of micrite into microsparite and sometimes to sparite.

Dissolution:

The dissolution is an important process which is shown in most shells of fossils. It is the result of solution conditions of unstable minerals (aragonite or high–Mg calcite) and the chemistry of the pore water. Carbonate solubility increases with decreasing temperate and increasing acidity (decreasing pH) [17]. This process is dominant in the studied succession of the Rus and Jil Formation causing vugs, moldic pores and intrecrystalline, i. e., it is responsible for forming the porosity in carbonate rocks. In the upper part of formation and in its lower part, the pores are porosity filled with gypsum. That is possibly indicated to the relationship between the ground water level and porosity. Two main types of porosity can be observed according to their time of formation; primary porosity and secondary porosity. The pore spaces which can be recognized microscopically in these formations classified according to Choquette and Pray (1970) [18].

1. **Fabric- selective pores**, which is controlled by the components of the original rock, such as: Intraparticle porosity, Moldic porosity, Intercrystelline porosity, Fenestral porosity (Plate 4a).
2. **Non – fabric selective pores**: This term is used where the pores are developed independent of original textures, such as: Vugs, Fracture and veinlets
3. **Fabric-selective or not**: includes burrow and boring porosity these types found in well BH 23 in almost strata (Plates 4b, 4c).

Cementation

The cementation process is recorded only in the Rus Formation at the upper part of well BH 13 represented by blocky cement fill the cavity. The cement rarely fills the pores in well 23 because only in the middle part of solution breccia samples are cemented by granular calcite. Because dissolution processes are the really effected.

Dolomitization

Dolomitization is commonly known as a secondary rather than primary process. The effect of dolomitization on the Rus Formation is common in the study area. It is characterized by moderately fine to medium size and sometimes floating rhombs. Some dolomite crystals have cloudy core clearly rim (CCCR) (Plate 4d). It is developed in the upper part of well BH 8. The zoning in dolomite is indicative of changes in the geochemistry of formation fluids during the growth of dolomite crystals.

In well BH 23 high effect of dolomitization in rocks that characterized by fine size of dolomite crystals.

Dolomitization Models

Dolomites form by precipitation of CaMg $(CO_3)_2$ from solution (primary dolomite), by dolomite cementation in pore spaces of sediment, and by replacement (dolomitization) of precursor carbonate sediment ($CaCO_3$) with CaMg $(CO_3)_2$. Most dolomite is postdepositional. The formation of postdepositional dolomite by replacement requires circulation of large volumes of magnesium-rich fluid through porous and permeable precursor carbonate sediments [8].

Models for dolomitization that have been invoked to fulfill this requirement fall into four basic categories [8]:

1. **Reflux dolomitization**, which occurs in hypersaline environments.
2. **Mixing-zone** (mixed freshwater and seawater) dolomitization.
3. **Seawater dolomitization** at shallow and near-surface burial depths.
4. **Burial dolomitization** at intermediate–deep depths.

Fluid circulation in the reflux model is provided by downward flow, through underlying sediment, of brines generated within hypersaline environments in lagoonal or shallow-marine settings. These brines are denser than seawater and are enriched in magnesium. Reflux flow can apparently extend to depths of several hundreds of metres or deeper. Reflux flow of these chemically evolved brines appears to be an effective dolomitizing mechanism, and has been invoked to explain dolomitization on a scale ranging from small to platform-wide.

The studied formation is found in a hypersaline brine waters derived from intense evaporation in sabhkas and restricted environment. It is associated with large amount of evaporites. The dolomitization model in which many parts of Rus and Jil Formations formed is most probably of reflux model.

Compaction

The studied area was subjected to chemical compaction. The chemical compaction is represented by stylolites. The Stylolite surface shows accumulation of iron oxides which appear in the upper part of well BH 8.

Authigenic minerals

Authigenic minerals grow after sediment deposition during diagenesis [16]. Gypsification, iron oxides and pyrite are the main recognized authigenic minerals in the studied thin section.

1- Gypsification

Authigenic gypsum is common in limestone and dolomite. It is recognized in the lower part of the studied rocks. (Plate 4g)

2-Iron oxides

Replacement of iron oxides is limited, which occurred in the diagenetic history of the studied thin sections partial replacement iron oxides which can be speared within matrix (Plate 4e), which is recorded in the upper part of wells BH 8 and BH 13

3- Pyrite

Pyrite (FeS_2) is the most abundant iron sulphate mineral found in carbonate sediments. Pyrite present as euhedral or anhedral form as replacement masses, In the studied samples of the Rus Formation (Plate 4f). In well BH 23 the authigenic pyrite exhibit botryoidal spheres formed by anaerobic bacteria. It is reported in the upper part of this well.

Sedimentary structures:-

Few sedimentary structures are recognized in the succession of the studied rocks such as; In the Rus Formation the recognized structures are; lamination, flaser beds and birdseye texture (Plates 4 h-j). The recognized structures in the Jil Formation are birdseye, slump structure, solution breccia and bioturbation (Pleates4 k and 4l). Flaser beds typically form in tidal environments. And the birdseye voids are preserved in supratidal and intertidal sediment, but never occur in subtidal sediments [19].

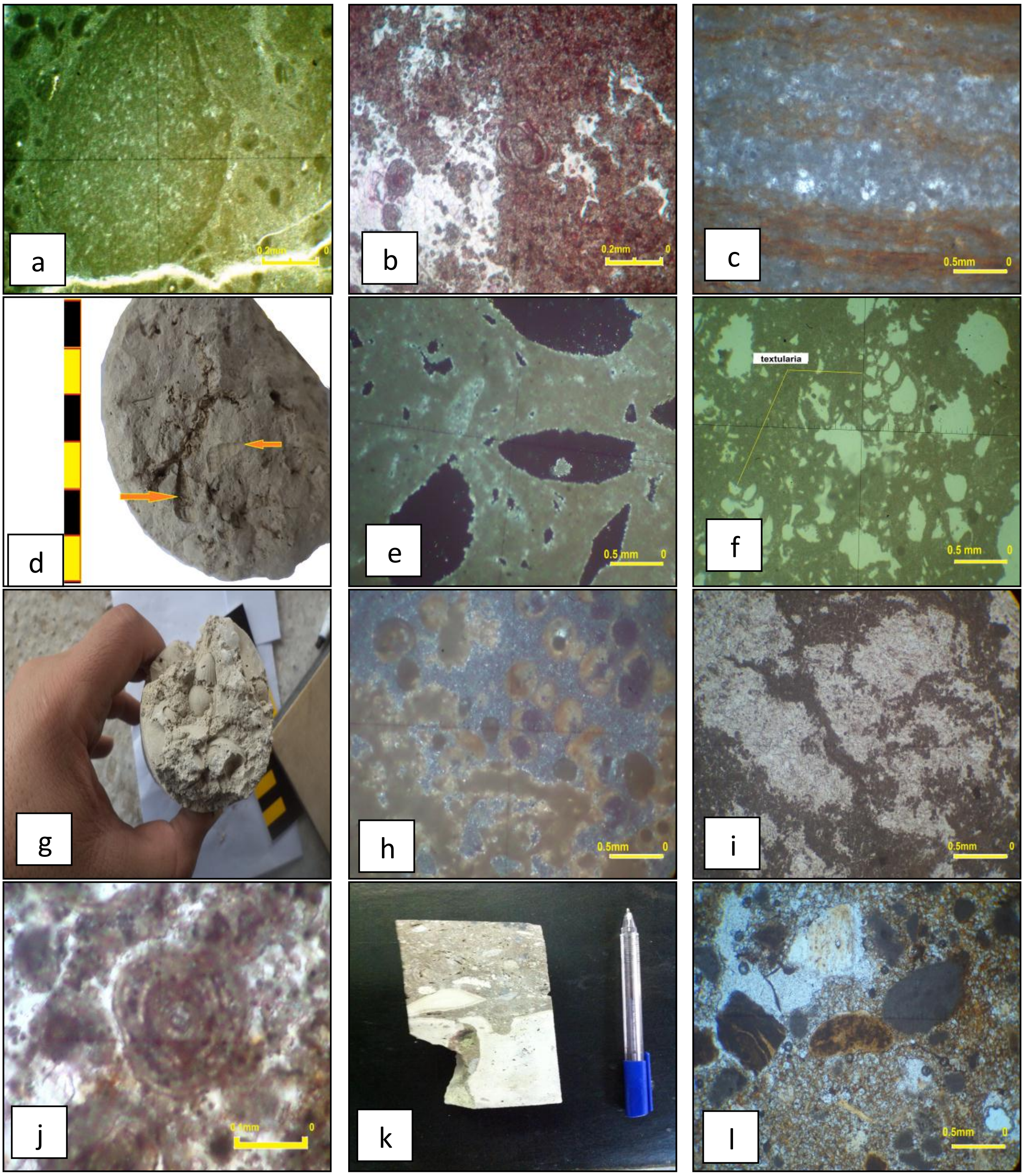


Plate 3- Carbonate components in the study area

a) Red algal at BH 8 depth (109m) (XPL. 10X). b) Miliolide at BH 8 depth (145m) (XPL. 10X) c) Mollusks (gastropods) at BH 23 depth (172m). d) Mollusks (bivalves) at BH 23 depth (185m). e) Biomolds of most probably Nummulites at BH 23 depth (162m) (XPL.4X). f) Textularia biomolds at BH 23 depth (192m) (PPL.4X). g) Laminated Algal mats in thin section at BH 8 depth (146m) (XPL.4X). h)Peloidal grains from the Rus Formation at BH 22 depth (101m) (XPL. 4X). i) Fecal pellets at BH 22 depth (142m). j) Ooide grain at BH 8 depth (145m) (XPL. 25X). k) The unconformity contact between Rus and Dammam Formation at BH 8 depth (105m). l) Phosphatic fragment (bioclast) and fecal pellets at BH 8 depth (105m) (PPL.4X).

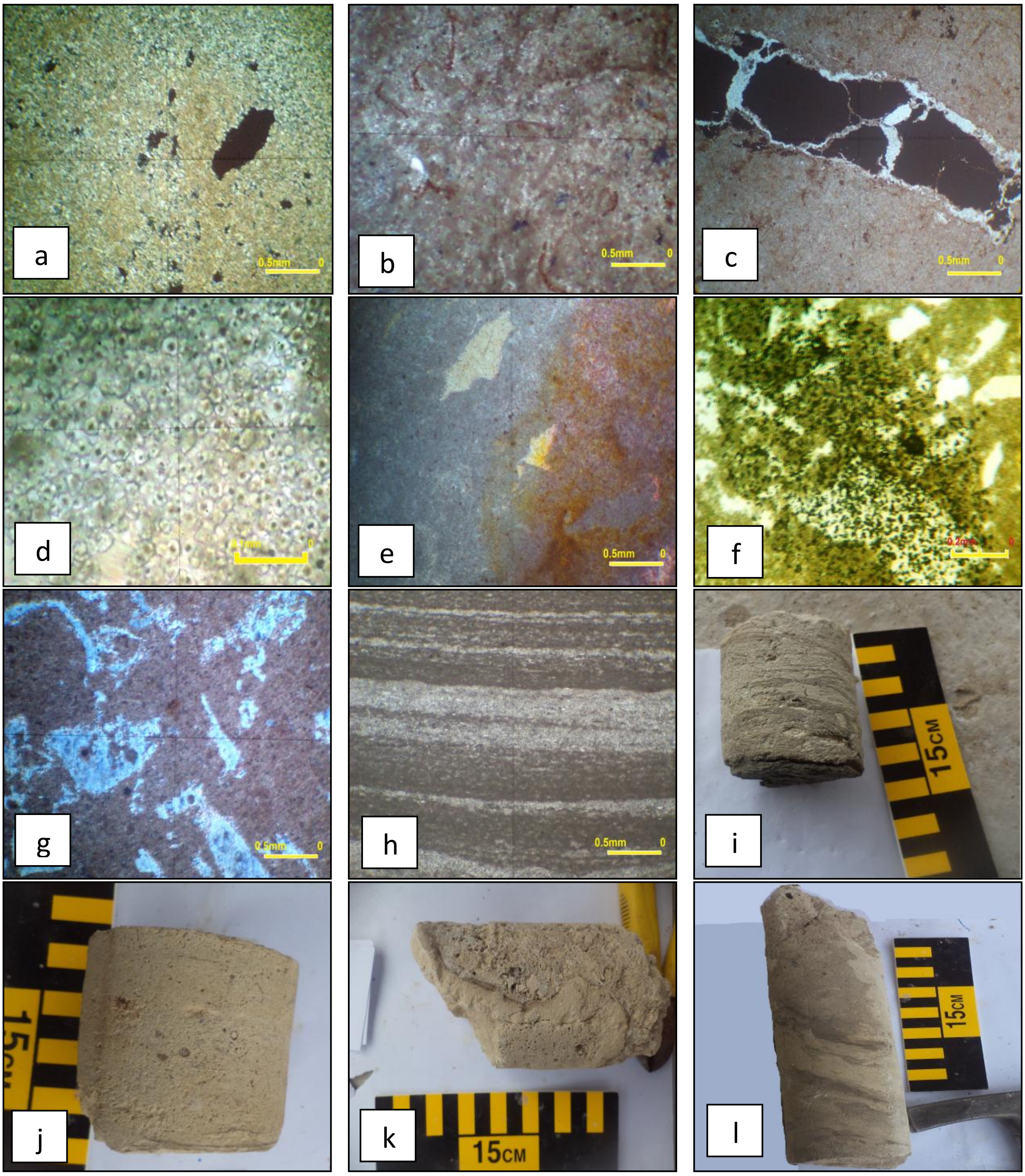


Plate 4- Diagnosis processes and sedimentary structure in the study area

a) Neomorphism and dissolution at BH 8 depth (118.5m) (XPL. 4X). b) Burrow porosity atBH 23 depth (144m) (PPL.4X). c) Boring porosity filled by hydrocarbon at atBH 23 depth (144m) (PPL.4X). d) Dolomite cloudy center at BH 8 depth (109m) (PPL.25X). e) Authigenic Iron oxides at BH 13 depth (100m) (XPL.4X). f) Authigenic pyrite at BH 8depth (119m) (XPL. 10X). g) Authigenic gypsum at BH 8 depth (145m) (XPL. 4X). h) Laminated carbonate in thin section at BH 8 depth (136.5m) (PPL. 4X). i) Flaser beds at BH 8 depth (107m). j) Birds eye structure from the Rus Formation at BH 8 depth (145m). k) Slump structure at BH 23 depth (236m). l) Solution breccia at BH 23 depth (224.5 m).

Mineralogy of the clay

In the present study used XRD technique to diagnose the clay and non-clay mineral constituents in selected samples. Ten representative samples are analyzed for their weak-acid (0.15 acetic acid) Table-1. Six out of the residence are analyzed by X-Ray Diffractometry.

In the Rus and Jil Formations, the results show that the non-clay minerals are dolomite (as the main mineral), gypsum, calcite and halite as the main non-clay minerals Figure-7 and 8. The clay minerals are present in the Rus Formation: illite, smectite, chlorite and kaolinite whereas in the Jil Formation they are illite and smectite only Figure-10 and 11.

Table 2- Show insoluble residue in carbonate samples

Sample No.	Well No.	IR∗ (%)
27	8	**14.8**
28	8	**8.15**
48	8	**45.5**
53	8	**26**
4	23	**4.75**
10	23	**8.5**
12	23	**6.6**
18	23	**1**
66	23	**1**
73	23	**12.6**

∗ IR: - is insoluble residue

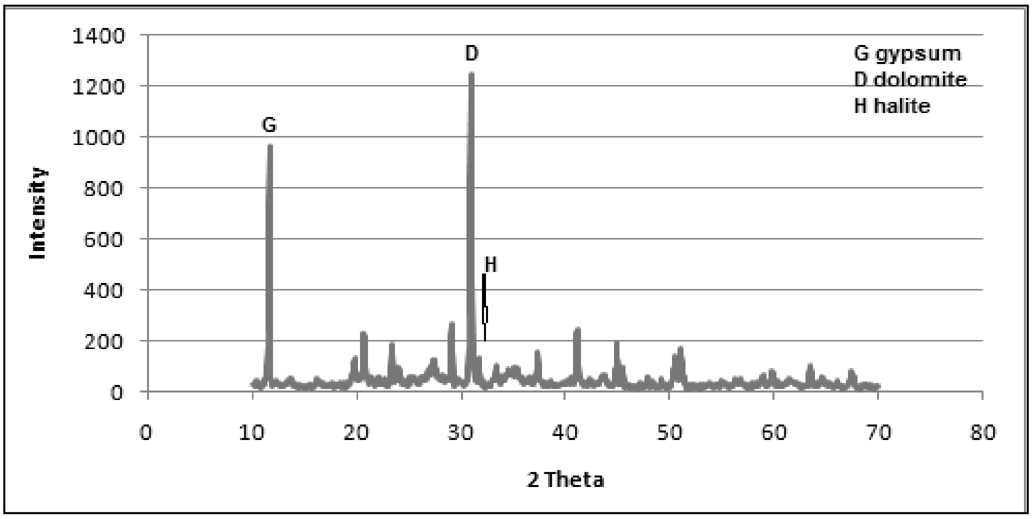


Figure 7- Mineral contents in the sample 48 in Rus Formation.

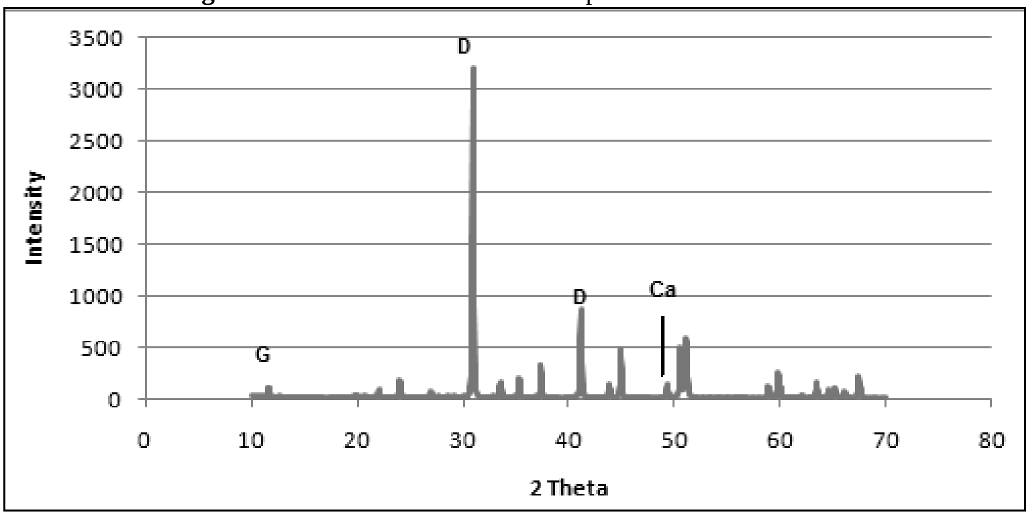


Figure 8- Mineral contents in the sample 10 in Jil Formation.

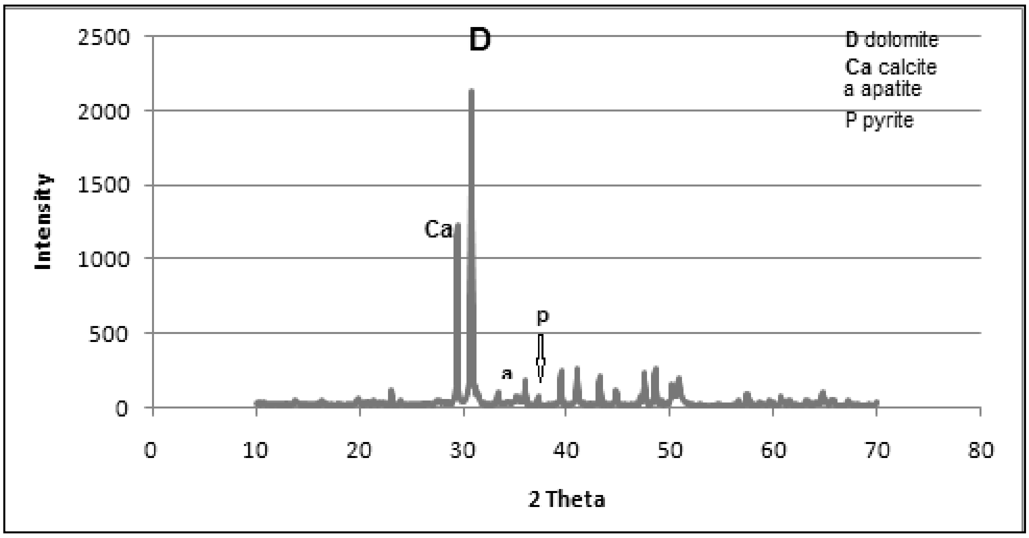


Figure 9- Mineral contents in the sample 27 represent the contact between Rus and Dammam Formations.

The formation of chlorite and illite represents condition of intensive leaching of the cations is prevented and hence represent arid to semi-arid climate. The clay minerals assemblage in the studied samples seems to be of detrital origin supplied by the source area. The clay minerals present in the studied area suggest that the environment of their formation at the source areas is likely to be characterized by arid to semi arid climate which is dominated in the region.

Field evidence as well as petrographic studies indicates that the contact between Rus and Dammam Formations is conglomerate (Plate 3k). X-ray diffractometry showed that the major content is calcitic dolomite Figure-9. The greenish grey colour which characterized the contact is attributed to high content of organic matter because high reactive with hydrogen peroxide lead to absent greenish grey colour to creamy colour.

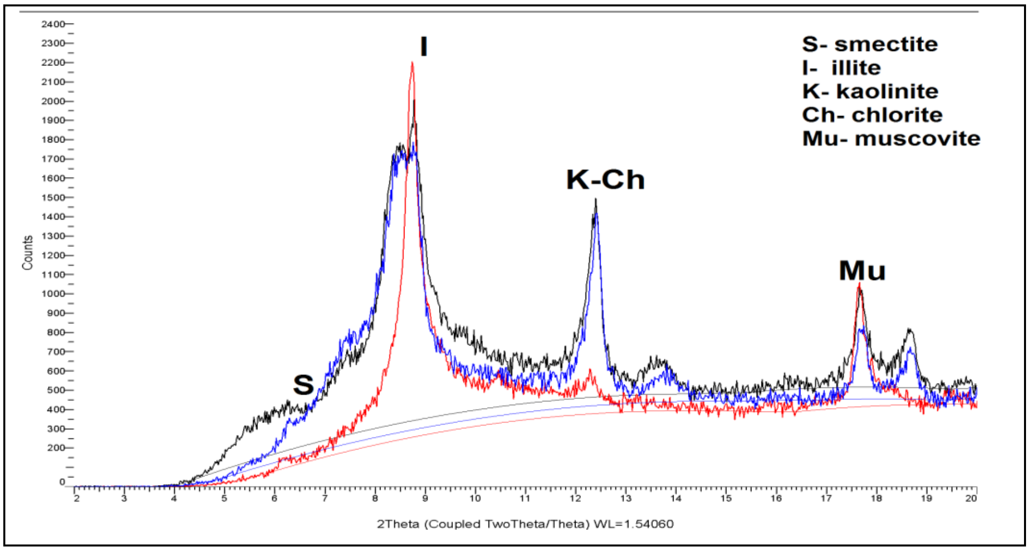


Figure 10- Clay mineral contents in the sample 48 in the Rus Formation.

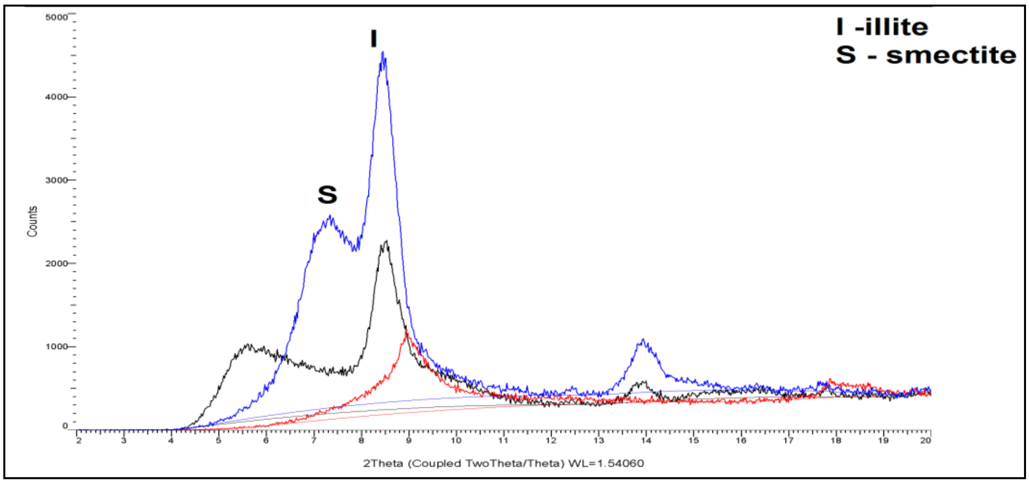


Figure 11- Clay mineral contents in the sample 10 in the Jil Formation.

Summary and Conclusion

- The evaporite rocks are more abundant than carbonate rocks in the Rus Formations. The thickness of evaporites in the wells is between 25 to 40 metres. The nodular structure (compound wispy to wispy structure) is dominated in evaporitic beds at the studied sections. The carbonates of Rus Formation are composed mainly of dolomatic limestone and dolomite.
- From the details of the petrographic study of evaporites units (gypsum and anhydrite), the following types of textures are recognized: albastrine, porphyrotopic, satin-spar (fibrous) and poikilotopic textures. The diagenetic processes that affected the evaporites of the Rus Formation are: dehydration, hydration, compaction and stylolitization and aggrading neomorphism.
- The Jil Formation consists mainly of carbonate, dolomatic limestone and dolomite, with occasional evaporite nodules. The thicknesses of carbonates are up to 79m whereas the evaporites about 2m. The carbonate rocks are dolomatic limestone and dolomite, massive, sometime friable, bioturbated in its lower part, fossiliferous and cavernous. The Jil Formation contains evaporites as thin bed sometimes nodular and contains selenite gypsum and very thin veins of satin-spar.
- The studied formations are found in the hypersaline brine waters derived from intense evaporation. The dolomitization model in which many parts of Rus and Jil Formations formed is most probably reflux model.
- The clay minerals present in the studied rocks suggest that the environment of their formation at the source areas is characterized by arid to semi arid climate. This is supported by the abundance of evaporites.
- Field evidence as well as petrographic studies indicates that the contact between Rus and Dammam Formations is conglomerate. X-ray diffractometry showed that the major content is calcitic dolomite. The greenish grey colour which characterized the contact is attributed to high content of organic matter.

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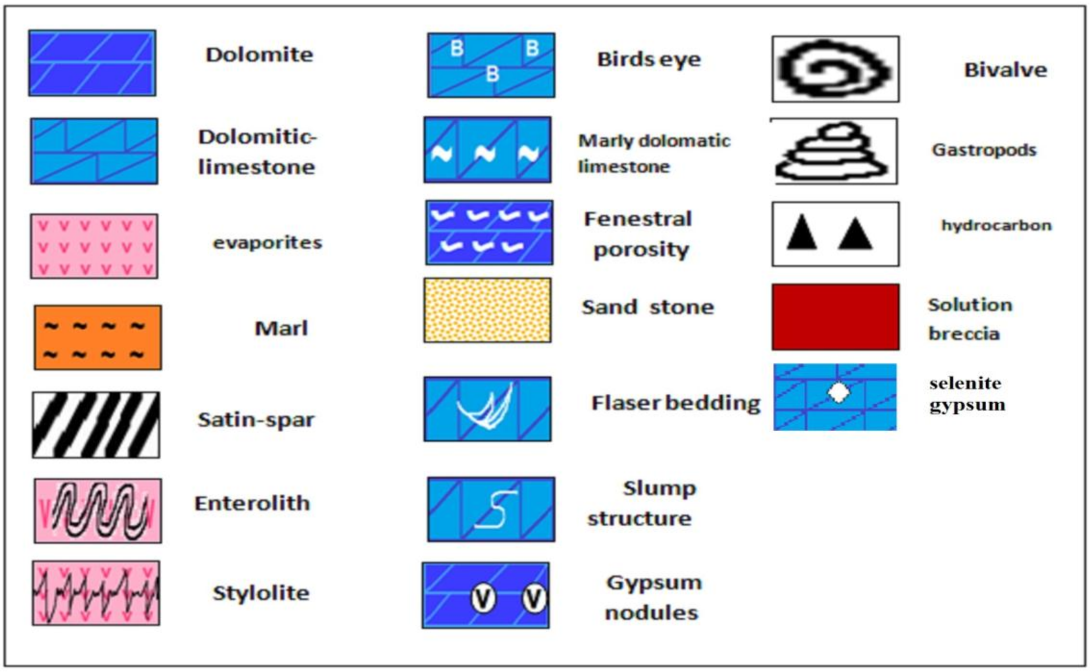
Legend



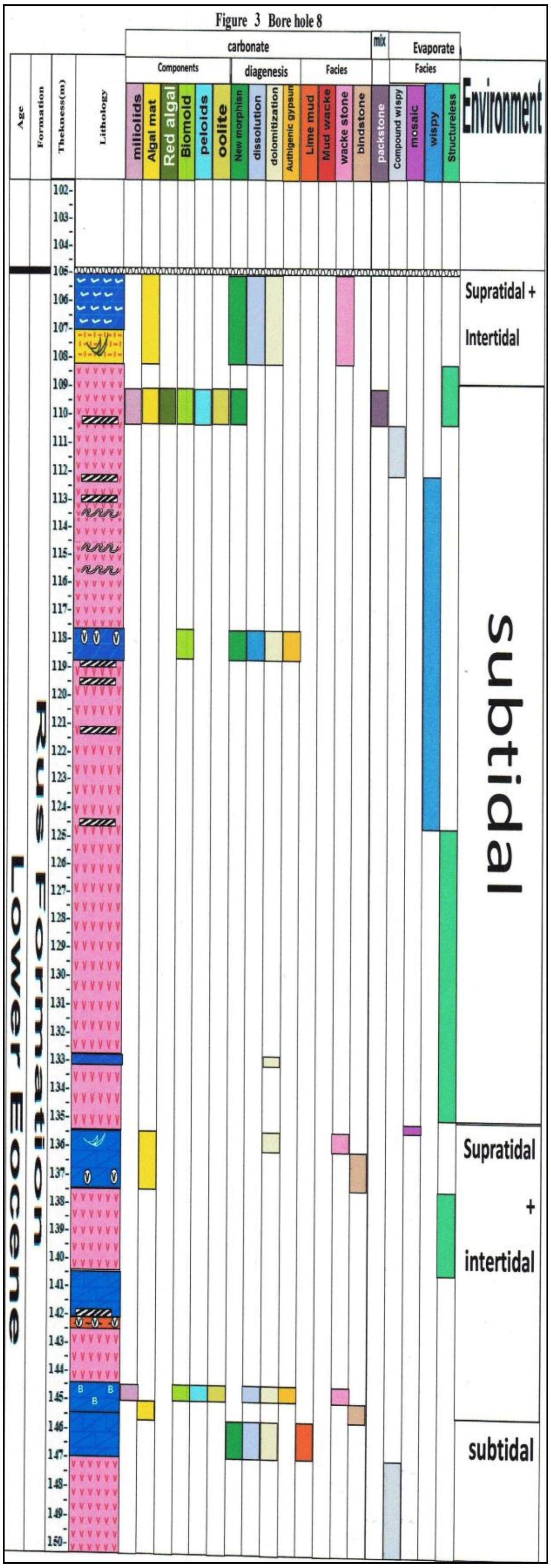


Figure 3- Bore hole 22 in Samawa area

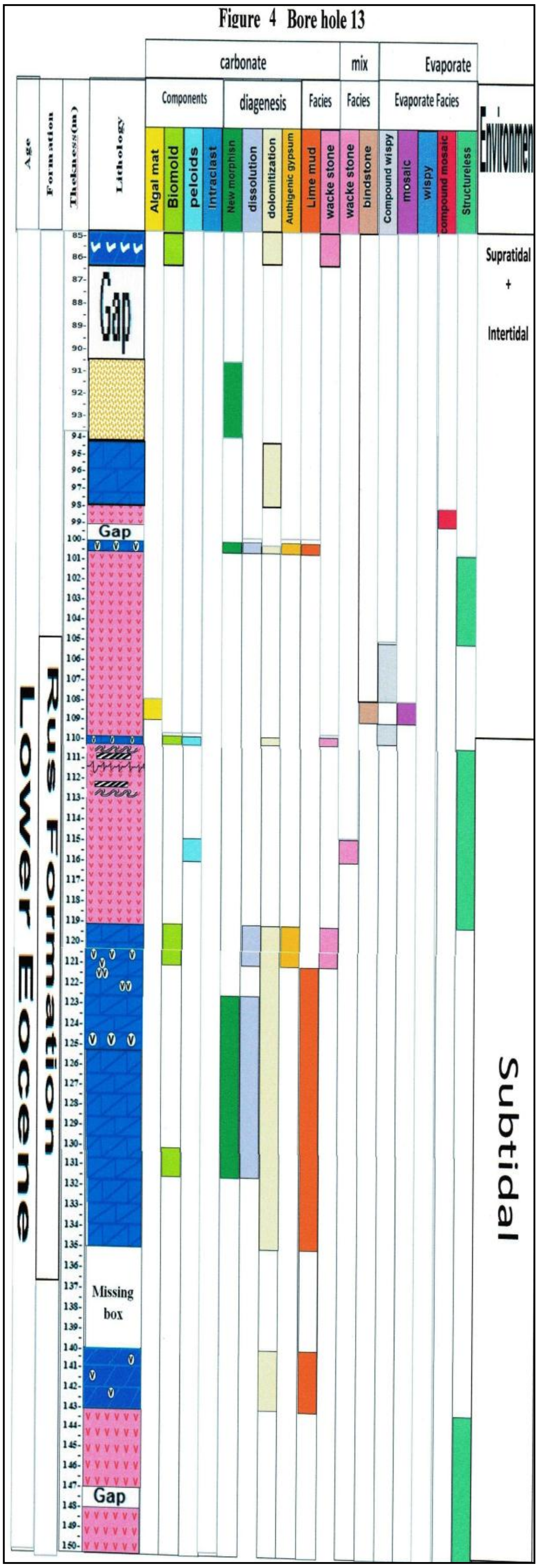


Figure 4- Bore hole 23 in Samawa area

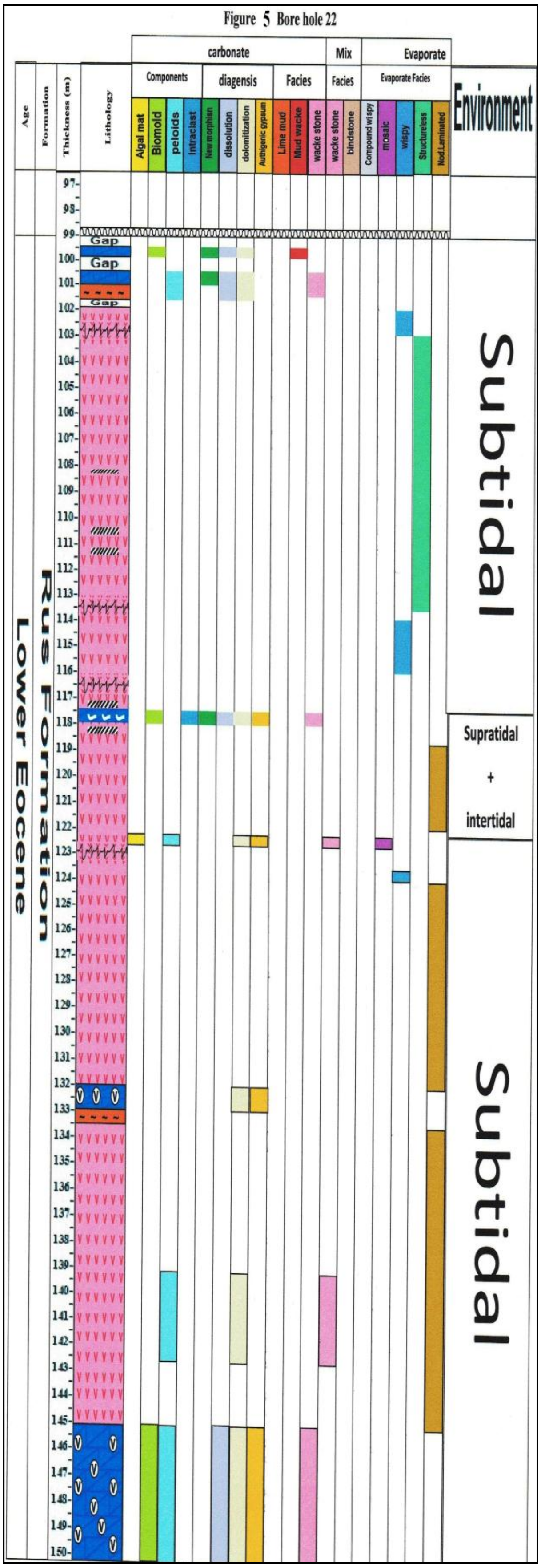


Figure 5- Bore hole 22 in Samawa area

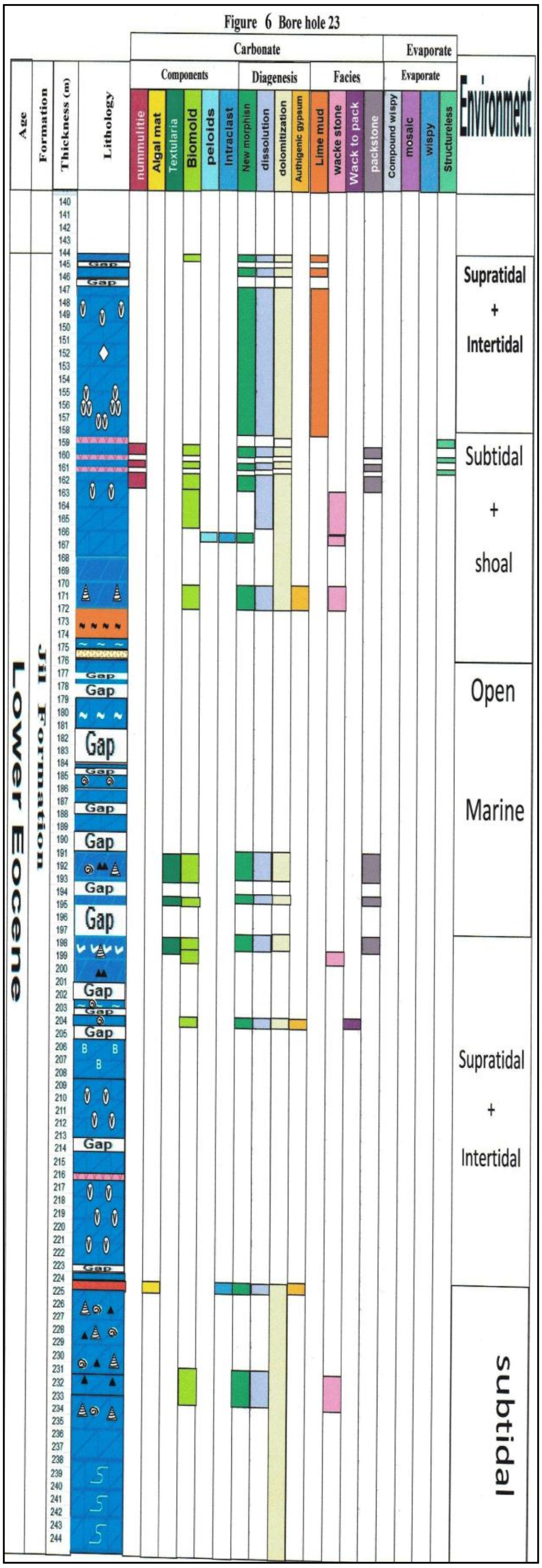


Figure 6- bore hole 23 in Najaf area