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# Facies analysis and sequence stratigraphy of lower-middle Miocene Euphrates formation (WadiHajar), West of Iraq

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## Abstract

The section located in WadiHajar, Haditha area, west of Iraq was sampled for microfacies analysis of the Euphrates Formation. Microfacies analysis led to the recognition of eleven microfacies association types; Mudstone, Peloidalgrainstone, ooidsgrainstone, Miliolids-Peneroplidsgrainstone, Peneroplidsgrainstone, Echinoidalwackestone, Miliolidswackestone, Alveolinidswackestone, Bioclasticpackstone, Peneroplidspackstone and Rotaliidspackstone, were deposited in restricted marine, shoal, and open marine environments. The study of the vertical succession of microfacies shows four primary $4^{th}$ order cycles (1, 2, 3, and 4) each show a different episode of stills tands sea level rises. Cycle 1 is represented by LST of basal conglomerate followed by a thick succession of open marine facies of TST, overlain by sh0rt episode of still stand. According to minor sea level changes, cycle 2 is subdivided into 2a, 2b, and 2c consisting TST of bioclastic, miliolids, peloidswackestone to packstone, followed by thin HST consisting restricted marine facies. Cycle 3 consists of a short episode of sea level rise of TST followed by a long episode of sea level still standing and subdivided into 3a and 3b. Cycle 4 is marked by open marine facies (TST), overlain by HST of restricted marine facies. The low subsidence rate and eustatic sea-level fluctuation are the main factors that affect the study area.

***Keywords:*** *Sequence stratigraphy, Facies analysis, Microfacies, Euphrates, Iraq.*

## 1. Introduction

The Euphrates Formation was exposed along the Euphrates River valley, specifically from the Al-Baghdadi area to the Al-Qaim area on the Syrian-Iraqi border, in addition to its presence in the Samawah and Al-Busayyah areas in the south. The type section of this Formation located in WadiFuhaimi near old Anah town consists of 8 meters of chalky, shelly, well-bedded recrystellized limestone, a maximum thickness of 100 meters was reported elsewhere in surface and subsurface sections (Buday 1980).Al-Mubarak (1974**)** classify Euphrates Formation into 3 units A,B and C. Sissakian (1997) named the Nfayil Formation instead of unit C.Al-Ghreri (2007) made a very detailed evaluation of the fauna and determined its age to be Lower Miocene and Early Middle Miocene. Buday (1980) mentioned that Euphrates Formation was deposited under shallow marine –reef and lagoonal conditions, with local coral and lithophytic reefs and with the intermittently occurring fore-reef condition on the one side , and lagoonal condition on another side. Many researchers studied this Formation for different aims;Al-Ghreri et al. (2010) recognized 12 microfacies types of Euphrates Formation in the area between Al-Baghdadi and Haditha which deposit in restricted marine, shoal and open marine environments, while Al-Dabbas (2014) mentioned 4 main microfacies types (mudstone, wackestone, packstone and rare grainstone) with 10 submicrofacies typed deposits in shallow marine environments. Awadh and Al-Ankaz (2016) study the origin of bitumen that intruded in Euphrates and Fatha formations in the Hit area. Awadh and Al-Qwaidi (2020) proved that the marl bed in Euphrates Formation is a good alternative to clay that provides silica-aluminaand ferrite, whereas Al-Hetty et al. (2021) study the cave phenomena within basal conglomerate between Anah Formation (Upper Oligocene-Lower Miocene) and Euphrates Formation. This study is concerned with the carbonate succession of the Euphrates Formation in (WadiHajar), located in the Haditha area of western Iraq (Fig 1). The main objectives of the current study are to reconstruct the paleoenvironment of the Euphrates formation by analyzing the microfacies of carbonate succession and interpreting the sequence that developed in the study area.

## 2. Geological setting

The Western Desert is part of a stable shelf of the Arabian Platform which is divided into two parts, a stable one to the west and an unstable one to the north

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and east. The boundary between the two parts of the platform is marked by Anah Abu Jir Fault Zones. The western part of the West Desert is characterized by horizontal beds, with regional dip towards the east and northeast (Buday and Jassim 1987)At the beginning of the Miocene the sea covered most of the east and north parts of the West Desert, while at the Middle Miocene period sediments covered the two sides of the Anah _Abu Jir Fault containing extensive syndepositional deformational features indicating the seismic activity of Anah _ Abu Jir Fault System, however late Miocene age was the beginning of the emergence of continental deposits (Fouad 2007).

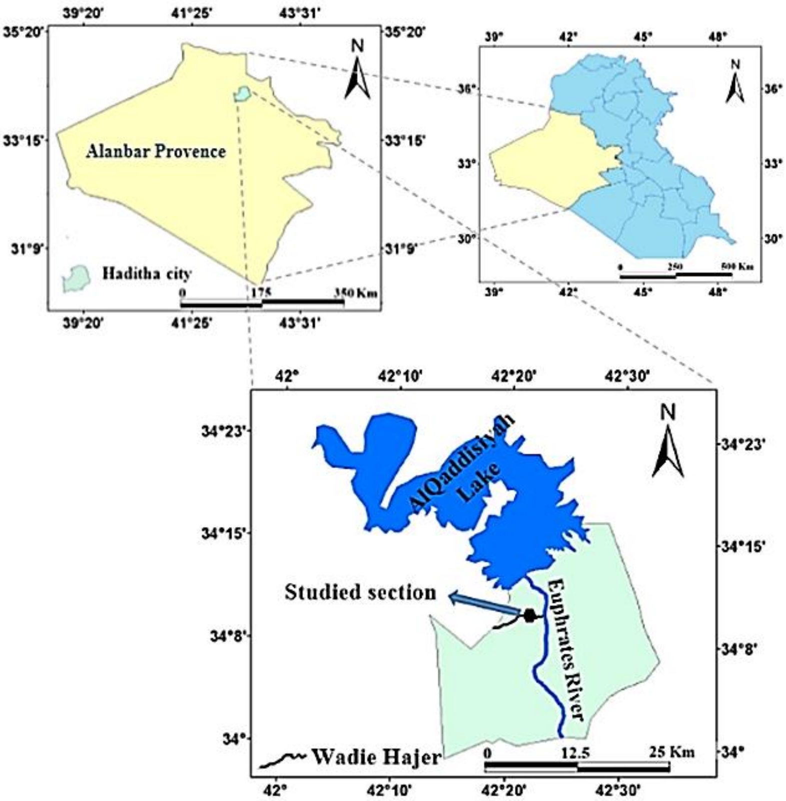


Fig 1. Location of studied section

The denudation processes have exposed a sequence of marine and continental sediments, which range in age from Permocarboniferous to Pleistocene.Stratigraphy Euphrates Formation consists of hard, bedded, fossiliferous limestone in the lower part while the upper parts are composed of yellowish, chalky limestone interbedded with marly limestone. Euphrates Formation overlies various formations all unconformably and with thick basal conglomerate, near Anah and Haditha area the formation overlies Upper Oligocene Anah Formation in Khan Al-Baghdadi area it overlies Lower Oligocene Sheikh Alas Formation (Fig 2). In the southern desert, the Euphrates Formation overlies various units of the Dammam Formation (Buday 1980). In the studied area Euphrates Formation were underlain and overlain unconformably (conglomerate layers) by Anah and Fat'ha formations respectively with a thickness of 35 meters. It is classified in two distinct lower and upper units according to variations in the lithologic characters and the fossil content.The "basal conglomerates" layer of the lower unit contains reworked fossils and consists of hard massive, mainly crystalline, rich in fossils, with coralline algal (Al-Ghreri and Al-Bakkal 1993). The "Limestone unit" of the upper unit is divided into thick bedded of dolomitic limestone and limestone in the lower part and white fossiliferous, chalky limestone interbedded with green color marls in the upper part as shown in the WadiHajar section.

Benthic foraminifera (miliolids, peneroplids, alveolinids androtaliids), echinoderms ooids, peloids, molluscan and the skeletal debris particles with few amounts of algae are the main component of Euphrates Formation limestone (Al-Ghreri 2007). According to its stratigraphic attitude and fossils content, the Euphrates Formation is assigned to the Middle Miocene age (Al-Sayyab et al, 1988; Abid 1997; GhasemShirazi et al. 2014; Al – Ghreri et al, 2014).

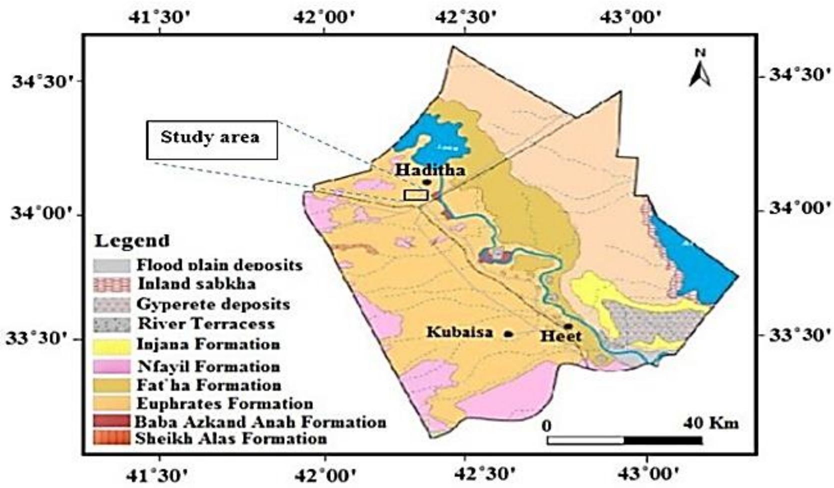


Fig 2. The geological map of the study area (Modified after Bayan 2010)

## 3. Methodology

Twenty samples were collected to make forty slides for petrographic and sedimentological analysis of carbonate rocks by examination under a polarizing microscope. Examination includes the determination of major petrographic constituents as well as textural parameters for the definition of microfacies. All examined thin sections represent a carbonate-rich rock type, so Dunham (1962) classification was applied to define microfacies and its nomenclature.Sequence stratigraphic subdivision followed in order to interpret the **4**th order cyclist and sequence development.

## 4. Results

### 4.1. Microfacies Analysis

In the study area, eleven carbonate sedimentary facies of the Euphrates Formation were identified. These facies are associated with three depositional settings restricted marine, shallow and open marine of a carbonate platform.

### 4.1. Restricted marine facies

It is subtidal areas located behind barrier, which might be reefs or shoals. This environment is sheltered from open ocean waves and current influencing mainly by tidal currents, local wind and storm (Tucker 1990; Ahr 1989). This environment is represented by the following microfacies:

#### *4.1.1. MF1: Mudstone microfacies (Fig 3a)*

This facies corresponds to the basal conglomerate layer, and it's recorded in four horizons with different thicknesses in the limestone units. It is also recorded in the upper parts of the upper unit with a thickness of five meters, consisting of white chalky, fossiliferous (foraminifera and mollusks) limestone with a lesser amount of fossils, interbedded with marl. In thin section, this facies consists of micrite and microsparite which formed by aggrading neomorphism, they aremostly recrystalized to sparry calcite and form about 8% of the rock represented by skeletalparticles of foraminifera and mollusks.

### 4.2. Shoal facies association

The shoal environment is a belt of high tidal current and wave activity located along the seaward margin carbonate platform. The depositional depths of this environments are less than (5-10) meters above wave-base (Tucker 1990). This facies association with Euphrates formation represented by the following microfacies:

#### *4.2.1. MF 2: Peloidal grainstonemicrofacies (Fig 3b)*

This facies occurs in the upper part of the Euphrates Formation and has a thickness of 1.5 meters of grey, massive, hard, and burrowed limestone. The peloids are well sorted having subspherical to ovoidalshap and don't have any evident structures, usually deposited within a high energy shoals (Wilson 1975). This type of facies contains 78% peloids, 8% ooids, 7% sparry calcite cement, 5% miliolids and 2% rotaliids .

#### *4.2.2. MFS 3: Ooids grainstonemicrofacies (Fig 3c)*

This microfacies type has distinct middle and upper section consisting of bedded limestone with a thickness of 2 meters. The important allochemcial grains are 77% ooids 10%, peliods and less than 5% shell fragments The ooids arewell sorted, small concentric laminates, some of them are micritized and a few are dissolved. Flügel (2004) suggested that ooids are primarily formed in equatorial area, with an active currents environment, and mention that tidal deltas and bars, or beaches (marine or lacustrine) are the best environments for ooids formation where superficial grains are kept in daily motion

#### *4.2.3.MF4:"Miliolids-Peneroplids grainstonemicrofacies " (Fig 3d)*

This facies is 1.5 meters thick and includes the upper and middle parts of the Formation, consisting of skeletal particles and spary calcite as cement. Miliolids was the most common foraminiferal particles in this facies and sparry calcite cement are the main binding materials between the skeletal particles. Miliolids represent more than (35%)*(Quinqueloculina* sp.,*Triloculina sp.)* besides, 20% Peneroplids, 3-6% small Rotaliids, 2% ooids and less than 2%peloids.

***4.2.4. MF5:"Peneroplids grainstonemicrofacies"(Fig 3e)***

This microfacies type consists of imperforated benthic foraminifera (*Peneroplisfarsensis)*> 35%, 10% *Spirolina* sp., 5%*Dendretina* sp., 3% peloids, and shell fragments, its mainly found in the upper section. In modern sea peneroplids lives in shallow-water, low-energy areas (Hottinger 1997). The occurrence of imperforated foraminiferal tests (Peneroplids) indicates that sedimentation take place in shelf lagoon environment (Geel 2000).

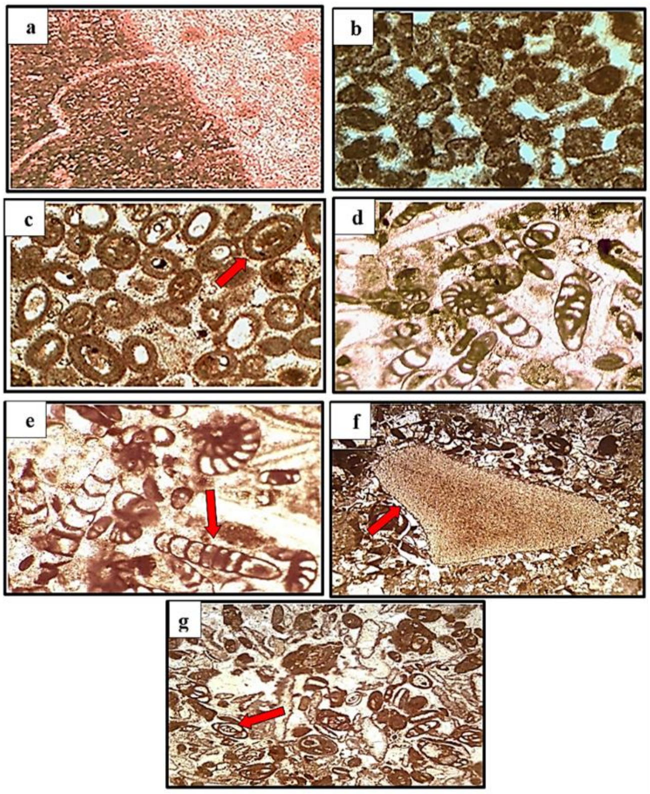

Fig 3. a) Mudstone microfacies(MF1) X, 45, b) Peloidsgrainstonemicrofacies (MF2) X, 35, c) Ooidsgrainstonemicrofacies (MF3) X, 60, d) Miliolids-Peneroplidsgrainstonemicrofacies (MF4) X 60,e) Peneroplidsgrainstonemicrofacies (MF5) X, 60, f) Echinoidalwackestonemicrofacies (MF6) X, 35,g)Miliolidswackestonemicrofacies (MF7) X, 35.

**4.3."Open marine facies association**

This environment represents an open platform, subjects to vigorous oceanic activity ranging in depth from a few meters to several hundred meters. The deposition is largly below wave-base in this environment, it may restrict if ponded behind a reef-rimmed shelf that has only sluggish circulation (Ahr 1989). This environment is represented by the following microfacies:"

***4.3.1. MF6:"Echinoidal wackestonemicrofacies"(Fig 3f)***

It has been observed in middle – upper part of the formation, with 1.5 meters thick, consists of white chalky fossiliferous limestone. In this section, the rock consists of 15% echinoids, less amount of miliolids, peneroplids and rotaliids. In modern seas, echinoids inhabit reef and associated environments, locally in great numbers (Tucker 2001).This microfacies had different wackestone to packstone textures which indicate"normalmarine conditions, and sediments are deposited in moderate - low energy (Multer 1977).

***4.3.2. MF7:"Miliolids "wackestone"microfacies"(Fig 3g)***

This type of facies consists of hard gray, laminated"limestone. It is composed ofabout 30%miliolids, 10% peneroplids,5% molluscs, and less than 3% shell fragments. This type of Microfacies show low diversity skeletal fauna, lack of subaerial exposure and the stratigraphic position which indicate deposition in restricted lagoon environment with low energy."(Flügel 1982).

***4.3.3. MF8:"Alveolinids wackestonemicrofacies"(Fig 3c and d)***

It is occurred in the upper part with 5 meters thickness overlain by lime mudstone, consisting of whitish to brownish fossiliferous limestone and chalky limestone. The main benthic foraminifera in this microfacies type are 20% alveolinids*Ammoniabeccarii*, 5% miliolids, *3% Elphedium* sp., 2% echinoids plates, less than 2% intraclasts and few skeletal particles scattered in a micritic matrix. This microfacies deposited in shallow marine inner shelf open lagoons - restricted circulations"(Wilson 1975).

***4.3.4. MF9:"Bioclastic Packstonemicrofacies"(Fig 3f)***

Bioclasticmicrofacies occurs usually with a thickness of 1.5 meters in two beds at the lower and middle parts of the studied section consisting of 45% of bioclasts, 20% peloids, 5% rotaliids&peneroplids, and less than 4% of miliolids, algae and ostracods".

***4.3.5.MF10:"Peneroplids""packstone icrofacies"(Fig 4d)***

This microfacies composed of"45% peneroplids (*Peneroplisfarsensis*, *Peneroplisevolutus*, *Peneroplis* sp.), 10% miliolids, 5% rotaliids and less than 3% of shell fragments of other components.

The total thickness of this facies is 4 meters, overlain by rotaliidspackstonemicrofacies type, this type distinct the lower and upper part of section. All the"peneroplidae (including the genus Peneroplis) prefer to live in shallow marine, attached to to near-shore weeds (Bandy 1961).

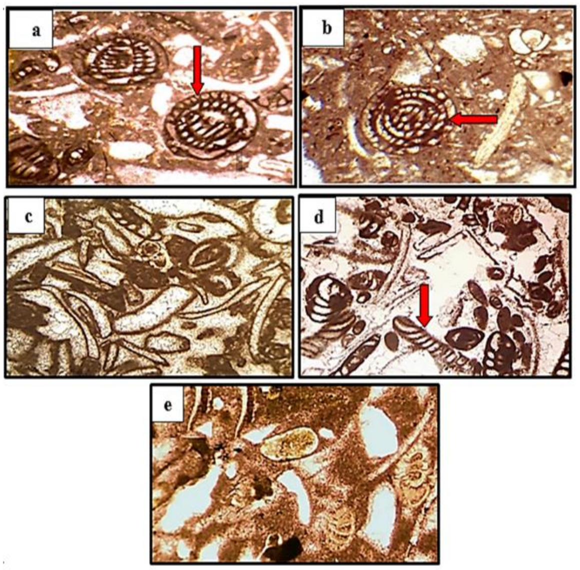


Fig 4. (a and b ) Alveolinidswackestonemicrofacies X 60(MF8), c) Bioclastic Packstonemicrofacies X 45 (MF9), d) Peneroplidspackstonemicrofacies X. 45 (MF10), e) Rotaliidspackstonemicrofacies X 6(MF11).

***4.3.6. MF11:"Rotaliids packstonemicrofacies"(Fig 4e)***

This type "consists of 30% rotaliids, 20% miliolids, 10% peneroplids, 5% alveolinids, 2% mollusks and a few amount algal fragments. All rotaliidsappearance in the Late Miocene including the species*Ammoniabeccarii*. The occurrence of *Ammonia beccarii* with miliolids and bivalve debris, indicates to the depositional environment is slightly hypersaline and such an assemblage is described to be associated with an inner ramp environment (Wilson 1975; Flügel 1982 and 2004).

## 5. Sequence Stratigraphy

The Euphrates Formation succession in the wadiHajarsection with a thickness of 35 meters includes four asymmetrical fourth-order sequences. These cycles are bounded at the top and bottom by the SB1 sequence boundary which represents a successive episode of stillstands and sea level rise (Fig 5). The first cycle started with LST faces represented by a lower unit "basal conglomerate" layer, followed with a thick succession of open marine deposits of TST which shows a long episode of sea-level rise, followed by a thin succession of restricted marine deposits which represent a short episode of stillstand, this underlain by Anah Formation. The second cycle is asymmetrical and itsmicrofacies association can be grouped into Transgrasive and High stand Systems Tracts (TST & HST). Bioclastic, miliolidal, peloidalwackestone-packstonemicrofacies represent TST, followed by thin Highstand System Tracts which are marked by restricted marine deposits. According to the minor eustatic fluctuation, cycle 2 is subdivided into 2a, 2b and 2c. Subdivision cycle 2a shows open marine deposits which indicate TST, followed by restricted marine deposits of HST. Subdivision cycle 2b is symmetrically characterized by the TST of open marine deposits followed by the HST of shoal deposits. The subdivision cycle 2c was marked by TST of peloidalpackstonefacies overlain by a short episode of restricted marine deposits (HST). Asymmetrical third cycle composed of short period of sea level rise of TST followed by long episode of sea level still stand. It was divided into two sub-cycles 3a and 3b. Subcycle 3a consists of bioclasticfacies representing TST, followed by shoal facies of HST, while subcycle 3b is marked by a long episode of sea level rise open marine deposits followed by a short episode of sea level still stand.

The fourth sequence (cycle 5) is symmetrical and reflects the balanced situation between open marine deposits of TST, followed by restricted marine deposits of HST. The upper boundary of cycle 4 is the Sequence boundary SB1 overlain by Fatha Formation. The main factors that affect the Euphrates succession in the study area are eustatic sea level change, and show low rate of subsidence represented by a short episode of HST.The Euphrates succession was deposited on a slowly subsiding carbonate platform as a result of a major transgression where successive episode of sea level rise were responsible for the formation of a number of fourth order cycles.

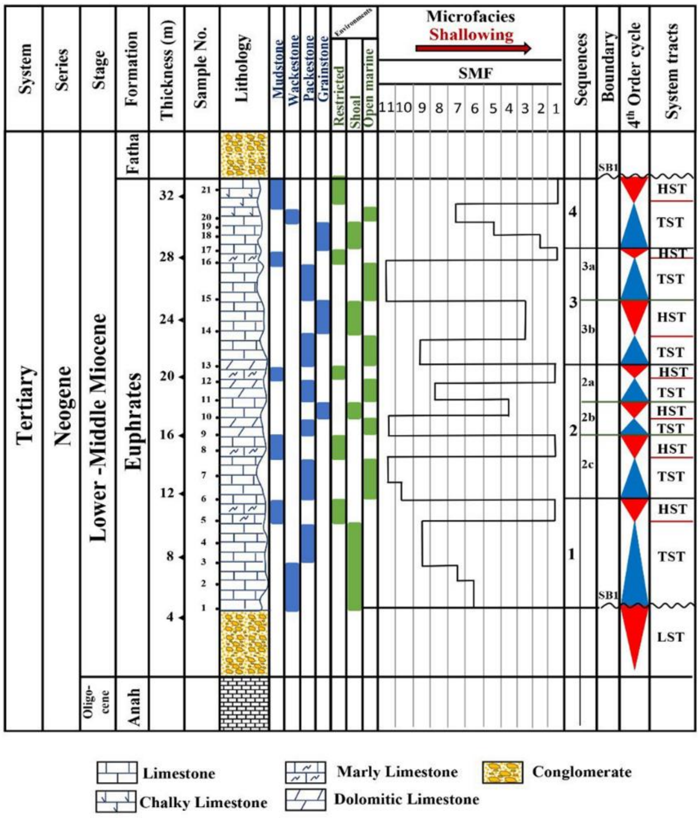


Fig 5.Microfacies and sequence stratigraphy of Euphrates Formation at WadiHajar.

## 6. Conclusions

Rock succession of Euphrates Formation cropping out in the wadiHajar area consists of hard, bedded limestone, and chalky limestone interbedded with green marl in upper part, this overlying by hard, massive silicified limestone.

The results showed the possibility of distinguishing 3 facies associations (including 11 microfacies) ranging fromrestricted marine, shoal to open marine.Microfacies analysis and sequence stratigraphic conception, based on field observations showed that the Euphrates succession wasdeveloped in an area of low subsidence which reflects the major effect of eustacy as the main controlling factor in sequence development.

Sequential stratigraphy shows that the Euphrates formation includes four $^{4th}$ order cycles. Cycle 1 is reflecting the LST of the basal conglomerate followed by thick succession of open marine facies of TST, overlain by a short episode of still stand. According to minor sea level changes, the second cycle could be subdivided into

2a, 2b, and 2c consisting of transgressive system tract (TST) of bioclastic, miliolids, peloidswackestone to packstone, followed by thin HST consisting restricted marine facies. Cycle 3 consists of a short episode of sea-level rise of TST followed by long episode of sea-level still stand and this is subdivided into 3a and 3b. Cycle 4 is marked by open marine facies (TST), overlain by a high stand system tract (HST) of restricted marine facies.

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