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MICROFACIES ANALYSIS AND BASIN DEVELOPMENT OF THE CENOMANIAN - EARLY TURONIAN SEQUENCE IN THE RAFAI, NOOR AND HALFAYA OIL FIELDS, SOUTHEASTERN IRAQ

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ABSTRACT

The stratigraphic sequence of Cenomanian-Early Turonian is composed of Ahmadi, Rumaila, and Mishrif formations in the Rifai, Noor and Halfaya Oil Fields within the Mesopotamian Zone of Iraq, which is bounded at top and bottom by unconformity surfaces. The microfacies analysis of the study wells assisted the recognition of five main environments (open marine, basinal, shallow open marine, Rudist biostrome, and lagoon); these microfacies were indicative of a normal lateral change facies from shallow water facies to deeper water and open marine sediments.

Ahmadi Formation (Early Cenomanian) is characterized by open marine sediments during the transgressive conditions, and would become deep basinal environment upward to deposition the Rumaila Formation. Rumaila Formation (Middle Cenomanian) was deposited in the deeper part of the intrashelf basin; it comprises basinal sediments mainly, and includes an abundant of open marine fauna supportive of Middle Cenomanian age. Rumaila Formation is represented as time equivalent basin to the Mishrif Formation, where they were deposited during highest and system tract (HST). The Cenomanian- Early Turonian sequence can be subdivided into three cycles displaying coarsening upward cycles :Mishrif A, Mishrif B, and Mishrif C; which comprises a highest and system tract dominated by rudistid packstone to grainstone or rudistid biostrome facies separated by transgressive units (CR I and CR II).

Keywords: Cenomanian, Microfacies, Mishrif, Southeastern, Turonian.

INTRODUCTION

Ahmadi, Rumaila, and Mishrif succession was deposited during Cenomanian-Early Turonian cycle. The intra-shelf basin developed during the Cenomanian age by dominated shallow water of carbonate ramps (Robertson, 1987; Patton and O'Connor, 1988; Sharland *et al*., 2001). This event was due to growth of Oman-Zagros peripheral bulge associated with obduction of the ophiolites, but the possibility resulted from compressional tectonic system along Arabian Plate margin (Al-Badry, 2005).

The Ahmadi Formation was deposited during the Cenomanian age in a shallow marine basin with fine clastic sediment supply from the south. The Ahmadi Formation is usually

overlain conformably and gradationally by the Rumaila Formation and unconformably underling by the Mauddud Formation (Jassim and Goff, 2006).

The Rumaila Formation is the most widespread Cenomanian formation in South and Southwest of Iraq and extends as far north as the Makhul area in the North. This formation was deposited in a relatively deeper basin which was locally restricted in the north. In the south of Iraq the formation is conformably overlain by the Mishrif Formation (Jassim and Goff, 2006).

The Mishrif Formation represents a heterogeneous formation originally described as organic detrital limestones, with beds of algal, rudist, and coral-reef limestones, capped by limonitic fresh water limestones (Bellen *et al*., 1959). The Mishrif Formation is deposited above the high barrier or on the detached platform, which extend from south Kuwait to the southeastern Iraq (Burchette, 1993). In parts of Southern Iraq, where the Kifl Formation is present (i.e. in the basin roughly to the west of the Musaiyib-Nahr Umr palaeoridge) the upper contact is conformable. Where the Kifl is absent the top of the Mishrif Formation is marked by an unconformity (Jassim and Goff, 2006).

The study area is located in the southeastern of Iraq (Missan Province) within the Mesopotamian Zone, which includes the study of the wells Noor -1 Rifai-1 and Halfaya-1 (Map1).

The purpose of the present study is a microfacies analysis and stratigraphic development with knowledge of the tectonic events for this succession during Cenomanian-Early Turonian period.

MATERIALS AND METHODS

Field work

Five oil wells were selected for the study that contains the largest amount of thin sections, and then the description is made so as to identify texture, grains size, and type of pores between the grains, and to determine depositional environments.

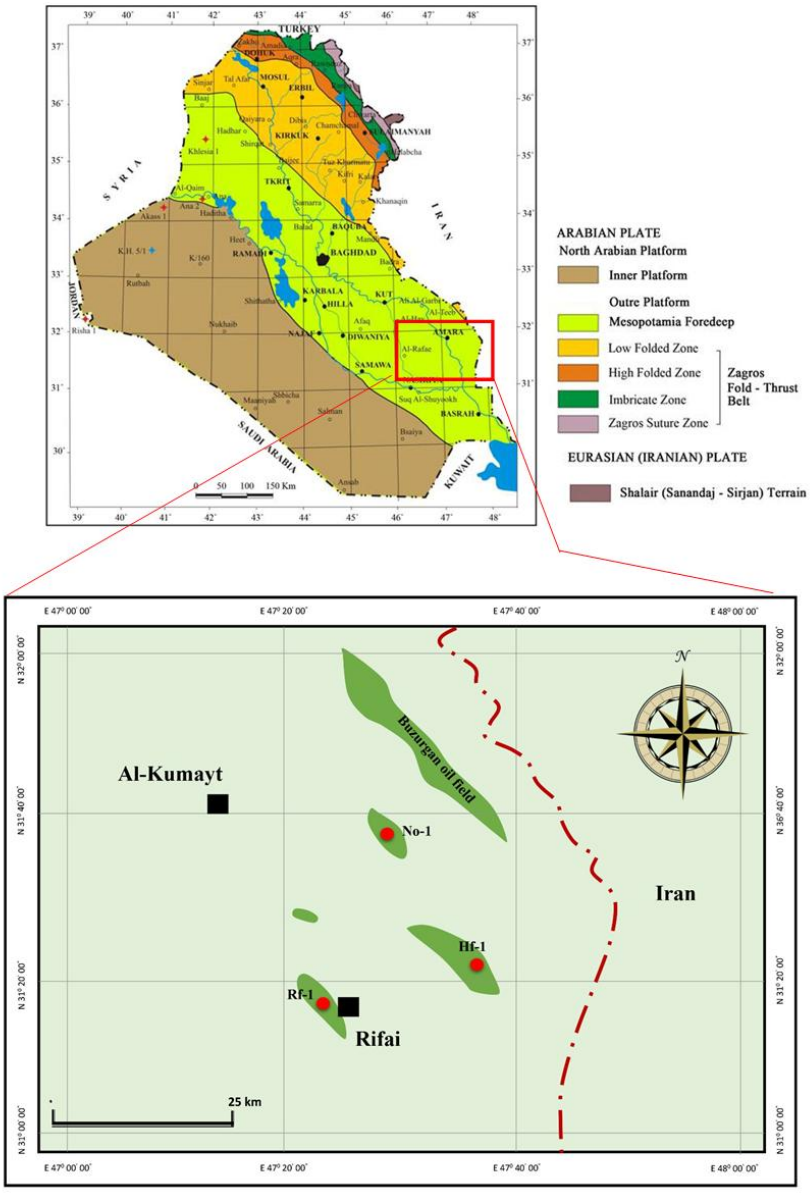
The Sampling was made by taking rock samples from the cutting and core available to the Cenomanian-early Turonian succession, and then making a thin section, the sampling was done one sliced per meter.

Laboratory work

1- Petrographic and microfacies investigation for the current study was based mainly on the Dunham (1962) classification by using transmitted light microscope in the petrographic laboratory of the Department of Geology, University of Baghdad. The petrographic study was based on the more than (300) thin sections from cores and/ or cutting of the study wells.

2-The well-logging tried to compare the micro-facies which were extracted from the laboratory work (Electrofacies), diagnostic of the horizontal and vertical facies change, and use well-log data to get the petrophysical characteristics for the study area wells.

3- Location map and columnar sections for the studied wells were draw by using the Corel Draw X7 and Rock work 16 programs.



Map (1): Location map of the study area with tectonic subdivisions according to Fouad (2012).

RESULTS

Microfacies analysis: Carbonate depositional textures and microfacies were described following Dunham classification (1962), and rudist- bearing facies were classified according to Embry and Klovan's (1971). The microfacies were compared with the models of standard microfacies and depositional environment belts of carbonates proposed by Wilson (1975) and Flugel (2010).

Facies association: A depositional environment can be defined in terms of physical, biological, chemical, or geomorphic variables (Reineck and Singh, 1973); thus, sedimentary environment is a geomorphic unit in which deposition takes place. The diagnosis of the microfacies Cenomanian-Early Turonian succession and comparing with the standard microfacies (Wilson, 1975), which contributed to the identification five facies associated (open marine, basin, shoal, Rudist biostrome, and lagoon).

Basinal facies association: These facies make the beginning of the first sedimentary cycle, which started with deep basin deposits supported by pelagic lime mudstone that contained calcispheres, sponge spicules and rare of planktonic foraminifera (Pl.1-a); these facies zones represent the Ahmadi and the Basal Rumaila Formations (Diags. 1, 2, 3).

Open marine facies association: Open marine facies association consists of fine grained skeletal lime mudstones to wackstones; the skeletal grains consist mainly of planktonic foraminifera such as, Hedbergella. The bioclasts are mostly fine and unidentifiable, spicules and lesser amounts of small Echinoderms were also present (Pl.1-c); wells (Rf-1 and No-1) (Pl.1- b, Diags. 2, 3).

Shallow open marine facies association: This facies association represents one of the most common facies in the Mishrif carbonates in the study area; it consists mainly of bioclastic or foraminiferal bioclastic wackstones and packstones, the bioclasts are silt to sand in size and in some cases coarser. Other important fossils included in this facies association are benthonic foraminifera, calcareous algae, coral, echinoderms, sponge spicules, and molluscs (Pl. 1- a), (Pl. 1- d, e) (Diags. 1, 2, 3).

Shoal facies association: These sediments are sited on the marginal shelf, which is composed of packstone- grainstone benthic foraminifera such as Plate (1-c, d), or concentrations of their skeletal grains with rudistid debris, and culmination of the coarsening upward sequence (Diags. 1, 3).

Rudist biostorm facies association: This facies is made up of very coarse-grained bioclastic rudstone and floatstone containing a more diverse intact fauna than lithofacies association shoal, dominated by rudistid debris (Pl.1- e). These are spread in the most of studied wells, and uppermost of the Mishrif Formation in the Rf-1and No-1 wells (Diags. 2, 3).

Restricted facies association: Area of relatively shallow, quiet water separated from the open marine conditions by a barrier (may be a coral reef). The lagoonal environment is characterized by the presence of abundant of miliolids as Plate (1-f); associated with mollusks, rudist debris, echinoderm, and peloidal in lime mudstone to wackestone in the shallow marine restricted water. These deposits spread in the most of Hf-1 and Rf-1 wells succession (Diags. 1, 2).

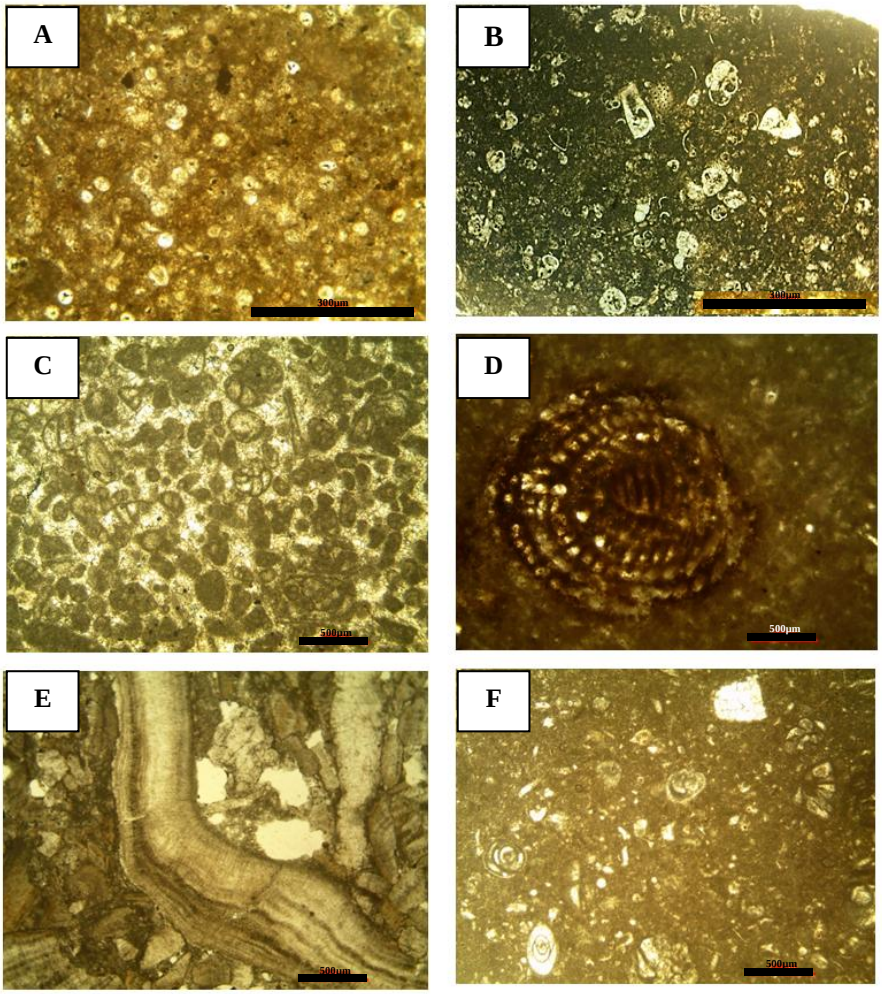


Plate (1): The major microfacies of Mishrif Formation in the studied sections; (A) Basinal facies, with abundant of Calcispheres (XPL), Well (Noor-1), at depth (3720 m), (B) Open marine facies (Oligosteginids, *Heterohelix* sp., and *Hedbergella* sp. (PPL). Well (Halfaya-1), at depth (3280 m), (C) Shoal facies with diversity of skeletal grains such as (benthic foraminifera, rudist fragments, echinoderms and mollusks (PPL). Well (Noor-1), at depth (3520 m), (D) Shallow open marine with benthic foraminifera (*Praealveolina tenuis*) (PPL). Well (Noor-1), at depth (3360 m), (E) Rudist (PPL). well (Rifai-1), at depth (2880 m), (F) Restricted facies, with abundant of miliold foraminifera (*Quinqueloculina* sp.). Well (Noor-1), at depth (3320 m).

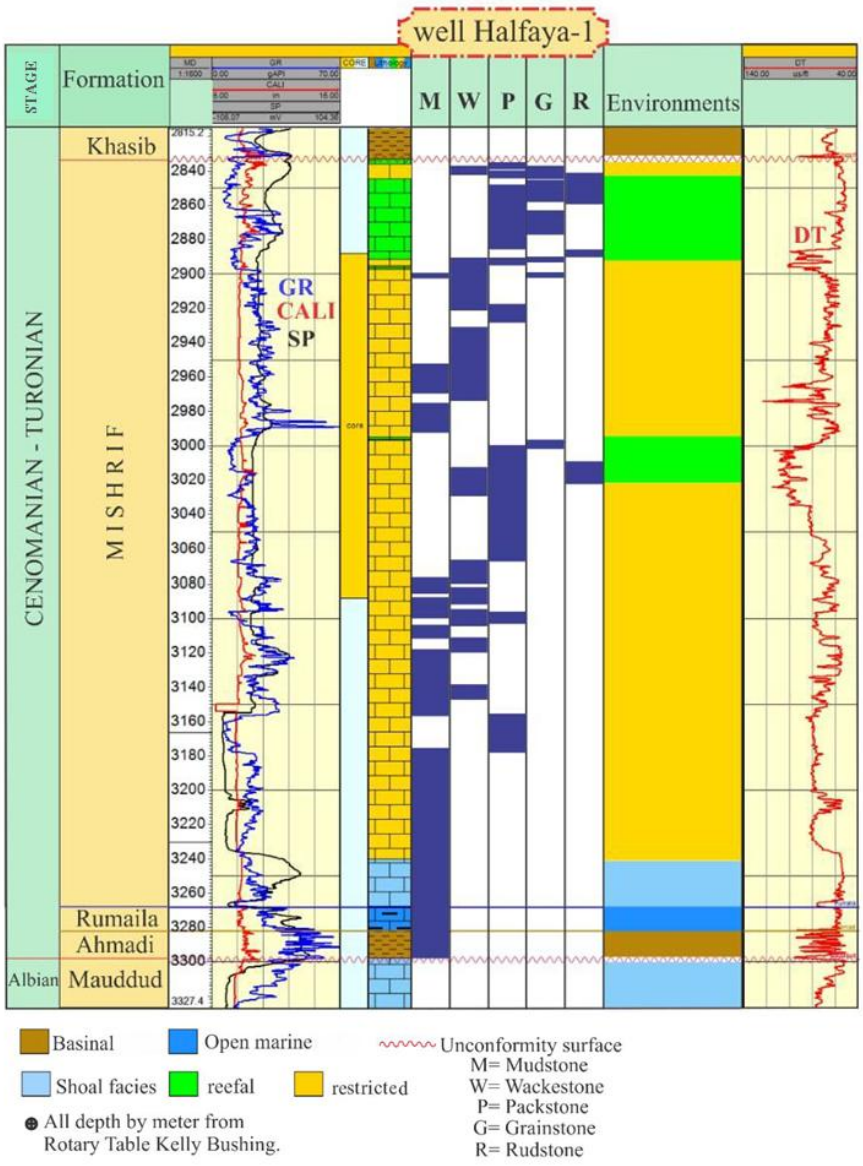


Diagram (1): Microfacies description of the Cenomanian–Early Turonian succession response to well logs at well Halfaya-1.

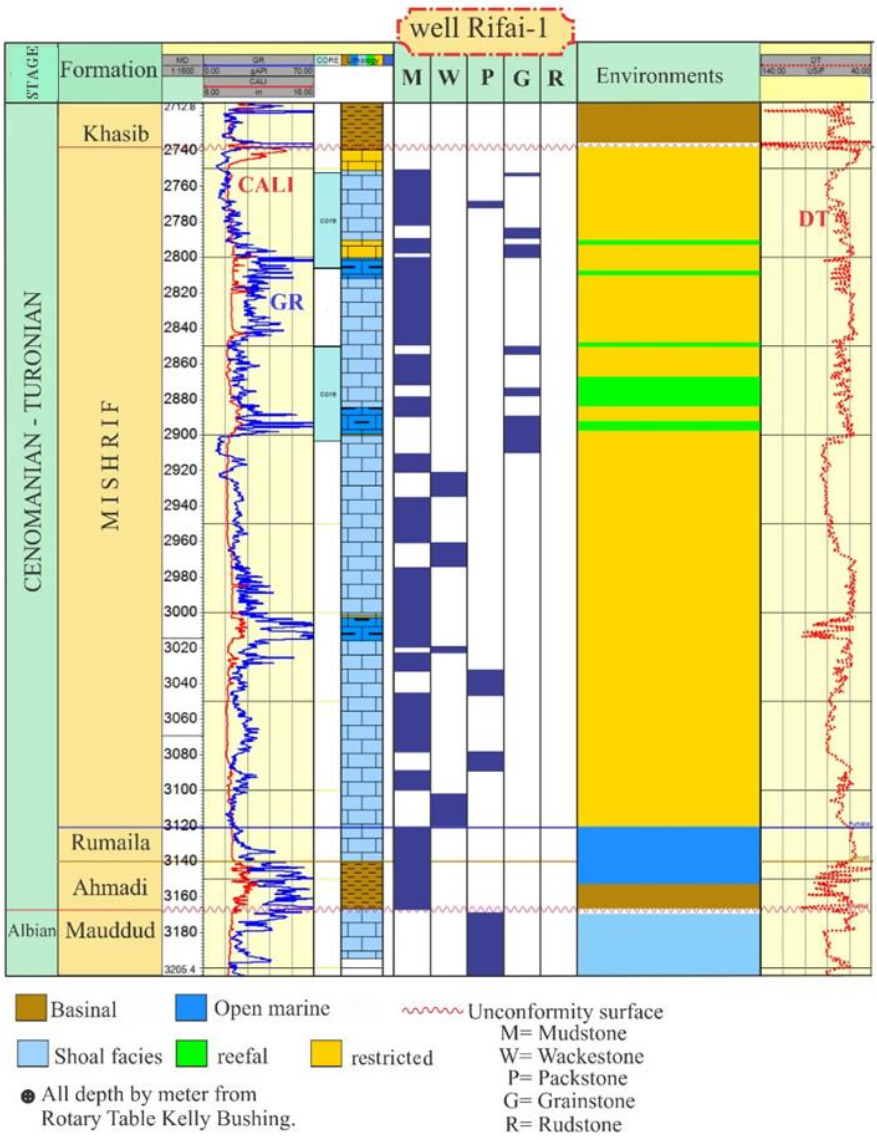


Diagram (2): Microfacies description of the Cenomanian–Early Turonian succession response to well logs at well Rifai-1.

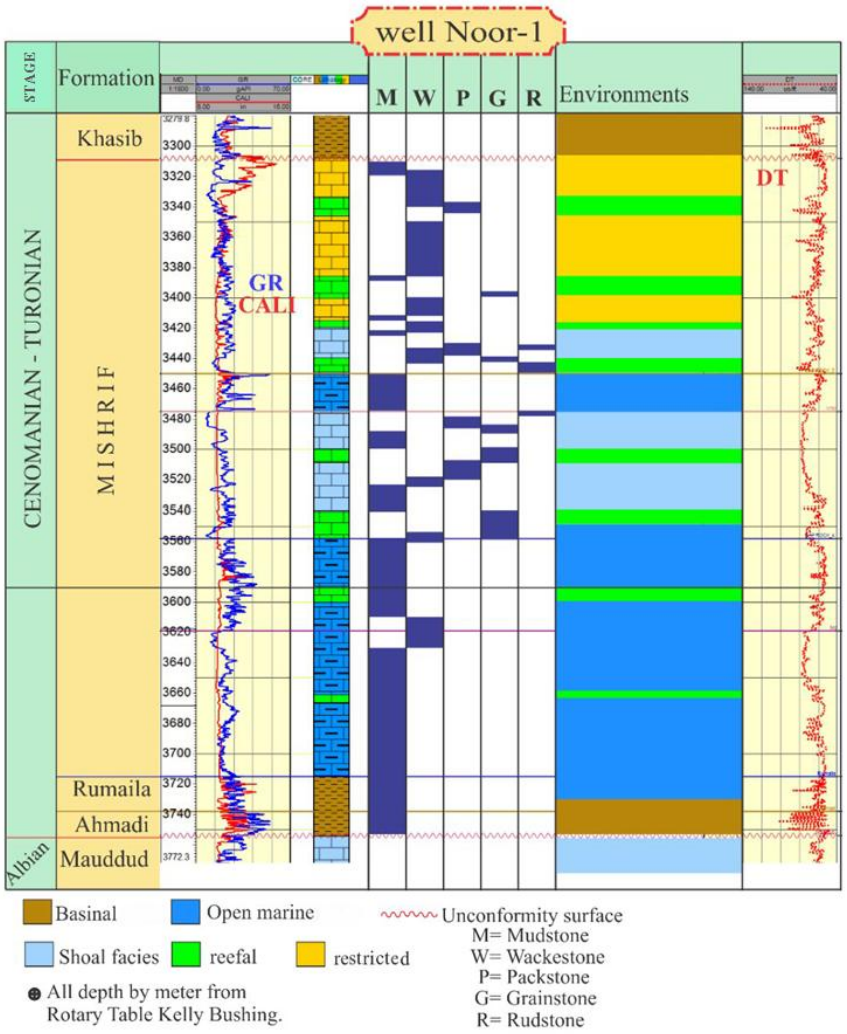


Diagram (3): Microfacies description of the Cenomanian–Early Turonian succession response to well logs at well Noor-1.

Sequence stratigraphy: Standard carbonate microfacies models are widely used to interpret paleoenvironment, but they do not show how carbonate platforms are affected by relative sea level change, a realization of how the carbonate factory responds to relative sea level changes and the role played by other environmental factors towards influencing the formation of carbonate platforms, which allows differentiating platform type and helps establish depositional sequence and system tract models. The sequence defined: depositional sequences bounded by subaerial unconformities and their marine correlative conformities (Wilson, 1975; Vail, 1987; Posamentier and Vail, 1988).

Stratigraphic Cenomanian- early Turonian sequence: The Cenomanian-early Turonian Megasequence started by transgressive system tract (Ahmadi Formation), and terminated in the high stand system tract (Mishrif Formation); the studied sequence is subdivided into three main cycles as coarsening upward cycles. These cycles consist of Mishrif A, Mishrif B, and Mishrif C which separated by compacted rock CR I and CR II units (Diags. 4, 5, 6).

Mishrif A: This unit represents upper regressive cycle, which ends by the regional unconformity surface; Mishrif A is characterized by the abundance of benthic foraminifera that indicate the lagoon environment in all studied wells.

Compact rock (CR I): This unit is located below the Mishrif A unit and it is distinguished by a high GR and low DT logs. This stratigraphic unit consists of lime mudstone and free of fossils with pyrite.

Mishrif B*:* The Mishrif B unit was deposited in the differentiated basin, because it represents lateral biofacies change from deep basin sediment as Rf-1 and No-1 wells (Diags. 5, 6), to the rudist biostrome with open shelf lagoon facies at Hf-1 wells, (Diag.4).

Compact rock (CR II): This unit is located below the unit (Mishrif B) and can be distinguished by a high (DT and GR) logs. The stratigraphic unit consists of lime mudstone (micrite) and free of fossils.

Mishrif C: The stratigraphic unit represents lower regressive cycle, which was deposited during early highest and system tract; and it comprises the transitional sediments from deep marine facies at wells Rf-1 and No-1(Diags. 5, 6), to the rudistid packstone- grainstone, with abundance of benthic foraminiferal grainstone in the lagoonal facies at well (Hf-1) (Diag.5).

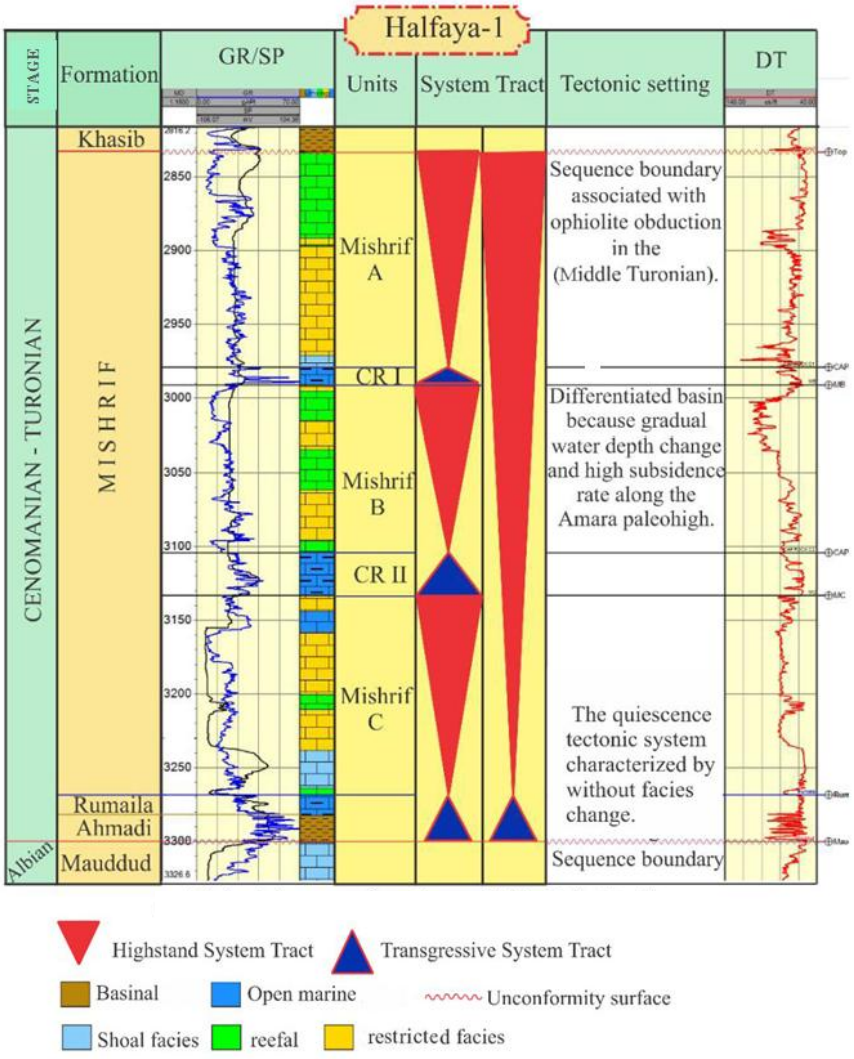


Diagram (4): Stratigraphic columnar section of the Cenomanian – Early Turonian sequence at well Halfaya-1.

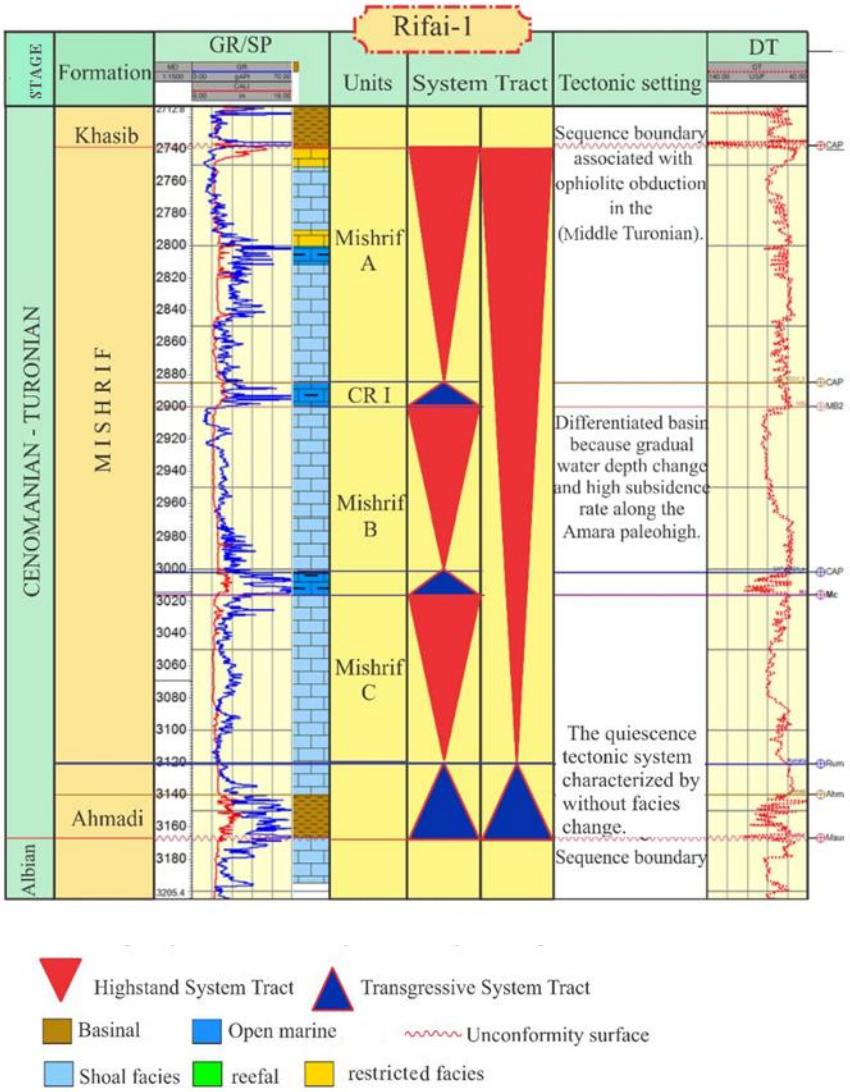


Diagram (5): Stratigraphic columnar section of the Cenomanian – Early Turonian sequence at well Rifai-1.

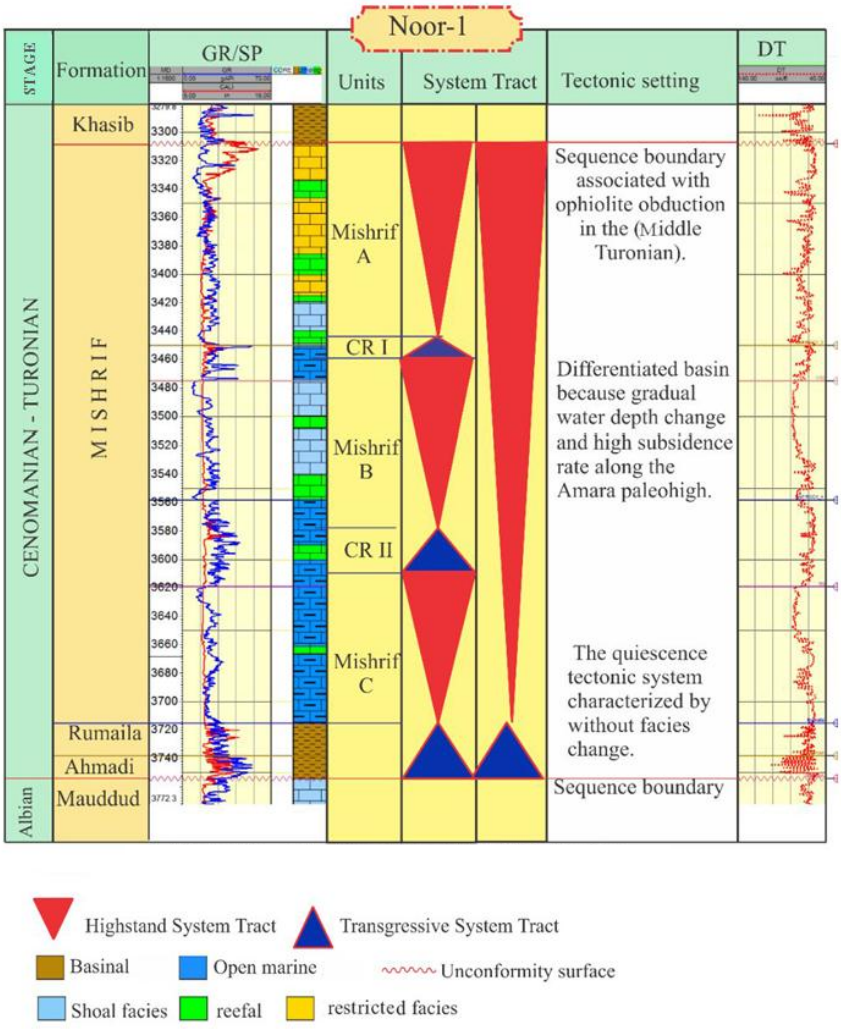


Diagram (6): Stratigraphic columnar section of the Cenomanian – Early Turonian sequence at well Noor-1.

Basin development: In order to study the development of this cycle in the southeastern Iraq in more details, structural proposed model shows the vertical and horizontal facies change, and the determining of the main factors which control the intrashelf sedimentary basin (tectonic and sea level change); this cycle was divided into three stages (Diag. 4, 5 and 6):

Stage (A): The tectonic setting contributed to the emergence of the Passive margin in the east and northeast Arabian plate, and made it facing the Neo-Tethys (Sharland *et al*., 2001). The abrupt discontinuity of the Mauddud sediments is underlaying the studied sequence;

then it is followed by the open marine sediments of Ahmadi Formation which deposited during transgressive conditions on the gentle slope of the carbonate platform model; this succession is characterized by no facies change with wide extension and the quiescent tectonic.

Stage (B): As a result of the up growth of compressional tectonic system (initial collision), which produced the peripheral Bulge in the Middle Cenomanian along the southeastern Arabian plate edge; this event contributed to deposition the Mishrif Formation as coral barrier and rudistid biostrome association facies (Chatton and Hart, 1961; Burchette, 1993). This stage is distinguished by beginning of the emergence an intrashelf basin, which shows a moderate slope resulting of wide extension of the Mishrif Formation.

Stage (C): The continuation of the compressional tectonic system, contributed to the development of the sedimentary basin, and the appearance of the facies change (Differentiated basin); the marly limestone facies of the Rumaila Formation passes to the bioclastic shoal, reef, and back- reef facies (Mishrif Formation). The high stand system tract was caused of growth the carbonate factory, and accompanies the progradation facies towards the basin center. In the last regressive cycle, continuance of the progradation shelf margins (rudistid biostrome) to become overlies basinal sediments in the Rifai-1 and Noor-1 wells; while the lagoonal facies progradation, and overlie the reefal buildups is appeared in the Halfaya-1 well. The Cenomanian- Early Turonian sequence ended with appearance of the erosional surface in the Middle Turonian, which resulted of compressional tectonic system that causes ophiolite obduction along the northern and northeastern of Arabian plate (Sharland *et al*., 2001).

DISCUSSION

The Cenomanian- Early Turonian succession is composed of Ahmadi, Rumaila, and Mishrif Formations; the intra-shelf basin development during the Cenomanian age was made by dominated shallow water of carbonate ramps that was due to growth of Oman-Zagros peripheral bulge (Jassim and Goff, 2006). Petrographic study and microfacies analysis help recognize five main environments: open marine, basin, shoal, Rudist biostrome, and lagoon); these are open marine facies which consist mainly of pelagic lime mudstone which contains calcispheres, sponge spicules and rare of planktonic foraminifera, the basinal facies consist of the calcareous sediments which consist of pelagic organisms plus fine detritus moved off from adjacent shallow shelves. Shoal facies are represented by packstone- grainstone benthic foraminifera and concentrations of skeletal grains with rudistid debris, the Rudist biostrome consists of masses of organic rudstone facies, and this facies is made up of very coarse-grained bioclastic rudstone and floatstone, lagoonal facies which consist of benthonic foraminiferal wackestone and mudstone with miliolids and peloidal.

The Ahmadi Formation overlies the Mauddud Formation unconformably so as to deposit during the transgressive stage; in the studied area the lower boundary of the Rumaila Formation with the Ahmadi Formation is conformable and gradational during the same stage. The Mishrif Formation is deposited above the high barrier or on the detached platform within the Rumaila basin. The studied succession is consisting of shallowing upward cycle, and is associated with continuation of the compressional tectonic system which led to the unconformity surface at the top the Mishrif Formation, being overlain by the Khasib Formation.

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تحليل السحنات الدقيقة و تطور حوض تتابع السينوماني – التوروني المبكر في حقول نفط الرفاعي و نور و الحلفاية، جنوب شرق العراق

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الخلاصة

يتكون التتابع الطباقي للسينوماني -التروني المبكر من تكوينات الأحمدي ، والرميلة ، والمشرف في حقول نفط الرفاعي والنور والحلفاية ضمن نطاق بين النهرين في العراق، والتي تحد من الأعلى والأسفل بسطوح غير متوافقة.

لقد ساعد التحليل السحني الدقيق للابار المدروسة على التعرف على خمسة بيئات رئيسية وهي : سحنة بحرية مفتوحة، و حوضية، و ضحلة بحرية مفتوحة ، بيوديستروم ، ولاغونية. حيث تشير هذه السحنات الدقيقة إلى تغيّر جانبي طبيعي من بيئة المياه الضحلة إلى المياه العميقة ومن ثم االبيئة البحرية المفتوحة. ان تكوين الأحمدي (السينوماني المبكر) يتميز برواسب بيئة بحرية مفتوحة خلال ظروف تقدم بحري ، ولتصبح رواسب حوض عميق إلى أعلى (تكوين الرميلة).

تم ترسيب تكوين الرميلة (السينوماني الاوسط) في الجزء الأعمق من الرف القاري ، والذي يتكون بشكل اساسي من ترسبات عميقة ، والذي يتضمن وفرة من الاحياء البحرية لبيئة البحر المفتوح الداعمة للعمر السينوماني الاوسط. يمثل حوض تكوين الرميلة حوضًا مكافئًا زمنيا لحوض تكوين المشرف، وقد تم ترسيبه أثناء نظام الترسيب الاعلى. يمكن تقسيم تتابع السينوماني -التوروني المبكر إلى ثلاث دورات تنعم نحو الاعلى وهي:- دورة المشرف أ، دورة المشرف ب و دورة المشرف ج، التي ترسبت خلال مرحلة النظام الترسيب الاعلى حيث تميزت بشيوع سحنة الروديستيدية المتراصة و الحبيبية أو سحنة البايوستورم الروديستي التي تفصلها وحدات ترسبت اثناء التقدم البحري (CRI و CRII).