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Sequence Stratigraphy Cenomanian - Early Turonian Cycle and Development of the Reservoir units in Selected Oil Fields, Southeastern Iraq

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Abstract: ***Sequence stratigraphic of Cenomanian-early Turonian cycle is composed of (Ahmadi, Rumaila, and Mishrif) formations, which bounded at top and base by unconformities surface. The lithofacies of this cycle in the southern Iraq indicate to a normal lateral change facies from shallow water facies through deeper water and open marine sediments, Ahmadi Formation (early Cenomanian) characterized by open marine sediments during the transgressive conditions, and passes up into deep basinal sediments (Rumaila Formation) by conformably surface. Rumaila Formation (middle Cenomanian) was deposited in the deeper part of the intrashelf basin, and comprises of a mainly basinal sediments, and includes an abundant of open marine fauna supportive of middle Cenomanian age. Rumaila Formation is represented time equivalent basin to the Mishrif Formation, and they deposited during highstand system tract. The Cenomanian-early Turonian cycle can be subdivided into three medium sequences displays coarsening upward cycles (Mishrif A, Mishrif B, and Mishrif C), which comprises of one reservoir pay zone dominated by rudistid packstone to grainstone or rudistid biostrome facies separated by barriers (dense non- porous) units (CR I and CR II). The effective porosity increases toward the rudistid reefal build up and shoal microfacies more than the lagoonal facies. The microfacies analysis of the study wells assisted the recognition of five main environments (open marine, basinal, shallow open marine, Rudist biostrome, and lagoon). The diagenetic processes were affected on that sedimentary cycle by: Dolomitization, dissolution, neomorphism, micritization, cementation, and pressure solution. The most effective are dolomitization, neomorphism, and dissolution.***

Keywords: Missan oil field, Oil Iraqi fields, south eastern Iraqi oil field

1. Introduction

The study area is located in the southeastern of Iraq (Missan Province) Figure (1) which includes study wells (Dujaila -1, East Abu Amood -1, Amara -1, Halfaya-1 and Huwaiza-1), these five wells chosen for covered most of the sedimentary basin from lagoonal environments through shelf margin to basin center, they consist of the (Cenomanian - early Turonian) formations, and penetrated by study wells at different depth and thickness.

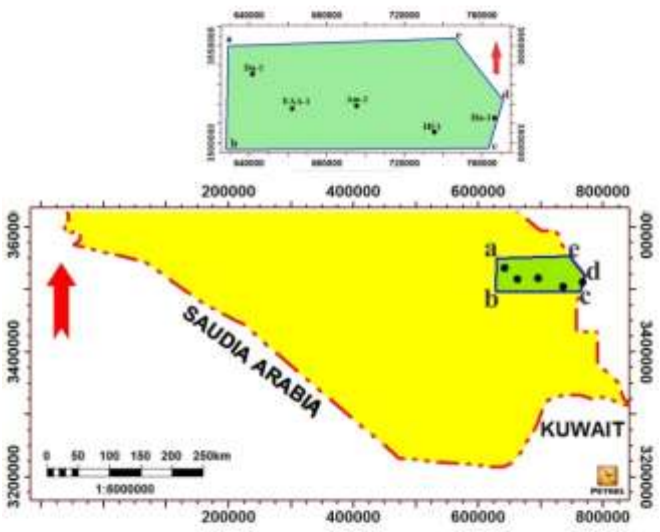

Figure 1: location map of the study area.

The basin analysis study to the (Cenomanian- Early Turonian) cycle, identify sedimentary facies distribution, and the affecting of diagenesis processes, then preparation of the geological model depend on the concepts of sequence Stratigraphy and linking of the petrophysical characteristics with the geological model until to construct a petrophysical model, which shows the locations and development direction of the granular belts that formed the hydrocarbon reservoir units

2. Tectonic Evolution

The intra-shelf basin development during the Cenomanian age by dominated shallow water of carbonate ramps [1]. [2];[3] that 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 Figure (2).

[4] pointed out that the Mishrif Formation is deposited above the high barrier or on the detached platform, which extend from south Kuwait to the southeastern Iraq, that is consistent with the model presented by [5] and in the figure above, which has been adopted in our current study.

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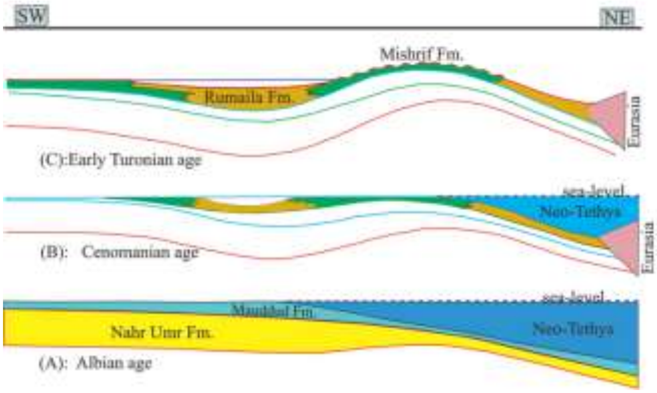

Figure 2: A scheme showing the stages of growth peripheral bulge Albian - Turonian.

(A) Albian. Passive margin sedimentation of Nahr Umr and Mauddud formations followed by initial differentiation into intra-cratonic basins and platforms.
(B) Emergence and development of interior basin and commence progradational pattern of the Mishrif shallow water carbonate platforms.
(C) Early Turonian age. Development of initial peripheral bulge and exposure of the top Mishrif Formation. (after Burchette, 1993).

The Mishrif Formation consists of shallowing upward cycle, and associated with continuation of the compressional tectonic system led to the emergence of the unconformity surface at the top the Mishrif Formation, and overlying by the Turonian Khasib Formation.

3. Microfacies Analysis

Microfacies are the total of all paleontological and sedimentological criteria which can be classified in the thin-section, the study of the carbonate microfacies is characterized by complex of biolithofacies buildup, and the relationship with the diagenesis processes, that affecting of the Mishrif Formation.

The carbonate microfacies discuss by examining the thin section under the microscope to the determination of the sedimentary environments.

3.1 Facies Association

A depositional environment can be defined in terms of physical, biological, chemical, or geomorphic variables [6]. Thus, sedimentary environment is a geomorphic unit in which deposition takes place. Such a place of characterized by an unique set of physical, biological, and chemical processes operating at a specified rate and intensity which impart sufficient imprint on sediment, so that a characteristic deposit is produced.

After the diagnosis of the microfacies Cenomanian - early Turonian succession and comparing with the standard microfacies [7], which contributed to the identification five facies associated (open marine, basin, shoal, Rudist biostrome, and lagoon) Figure (3).

3.1.1 Open marine are formed in the center of deep intra-shelf basin, it is beginning of the first sedimentary cycle, which started with deep basin deposits supported by pelagic lime mudstone that contains calcispheres, sponge spicules and rare of planktonic foraminifera, plate (1-a). These facies zones represent of the Ahmadi and the Basal Rumaila formations Figure (4). These deposits have been penetrated in all study wells.

3.1.2 Basinal facies represents from the toe of slope to the deep center intra-shelf basin; the calcareous sediments consist of pelagic organisms plus fine detritus moved off from adjacent shallow shelves. These sediments are characterized by dark to light fine-grained limestone, organic-rich lime mudstone containing a pelagic biota such as (Oligosteginids, Hedbergella sp., and other planktonic foraminifera), which contribute to form of the Rumaila Formation.

These sediments are spread over most of the Rumaila Formation in the wells (EAA-1 and Du-1) plate (1- b).

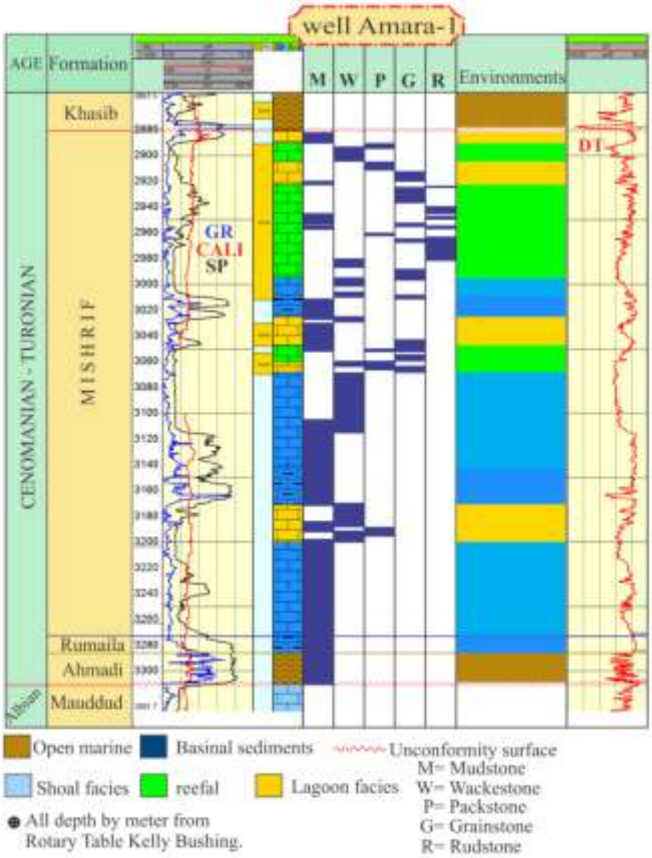

Figure 3: Description of the Cenomanian – early Turonian succession based on thin-section (cores & cutting) and well logs at well Amara-1

3.1.3 Shoal facies sediments sited on the marginal shelf, that composed of packstone- grainstone benthic foraminifera such as Plate ((1-c) and (1-d)), or concentrations of their skeletal grains with rudistid debris, and culmination of the coarsening upward sequence.

3.1.4 Rudist biostrome

Masses of organic rudstone facies, which may be filled with lime mudstone in downslope reefs or banks of packstone to grainstone facies in upper slope accumulations. 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, Plate (1- e). These are spread in the most of (Halfaya-1, Amara-1 and Huwaiza-1) wells, and uppermost of the Mishrif Formation in the (East Abu Amood-1and Dujaila-1) wells (Fig. 4).

3.1.5 Lagoonal facies area of relatively shallow, quiet water situated in a coastal environment and having access to the sea but separated from the open marine conditions by a barrier (may be a coral reef). The lagoonal environment is characterized by present 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 represent a zone of sediment mixing between shoal and interior lagoon, they overlie the coarsening upward Mishrif succession and interbedded in several-meter-thick intervals with lagoonal sediments, this environment spread in the most of well (Huwaiza-1) succession.

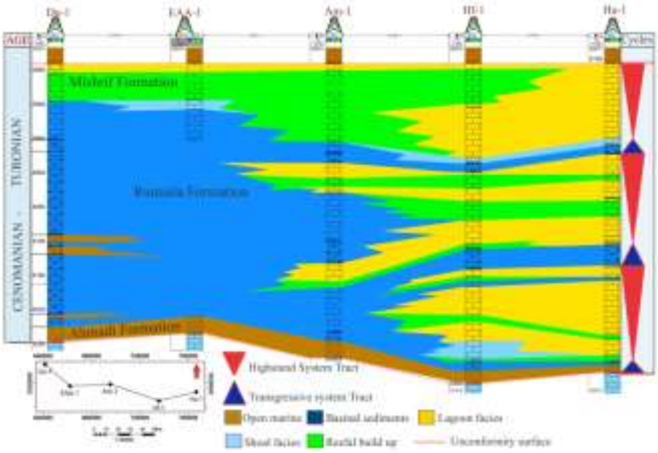

Figure 4: Cross section view of the Cenomanian – early Turonian succession to the study wells

3.2 Diagenetic processes

Primary pore systems in sediments are modified by diagenetic processes to give the pore geometry as seen in subsurface reservoir rock. The chief diagenetic factors which influence reservoir characteristics are (Micritization, Cementation, Dissolution, Neomorphism recrystallization, dolomitization, and compaction). The diagenetic processes effect on the (Cenomanian – early Turonian) cycle through three stages (near surface, marine, and deep burial)

The carbonate rocks are characterized by good porosity during deposition. The diagenetic processes such as (cementation and compaction) contribute to decrease of the porosity, some of the diagenetic processes as (dissolution and dolomitization) result to increase of the porosity [8]. Porosity in the carbonate rocks are divided into two types:-

Primary porosity

Primary porosity is formed during the sedimentation, which consists of space pore between carbonate grains or shell fragment.

Secondary porosity

This porosity is formed after the depositional, and by diagenetic processes, some of these processes lead to increase or decrease of the porosity Figure (5).

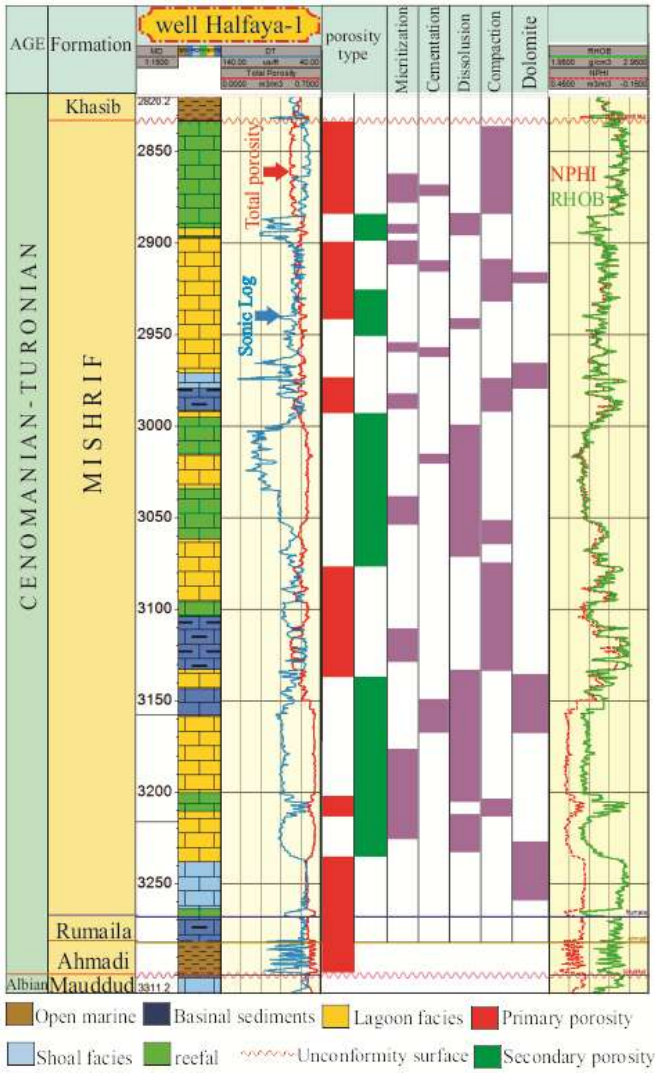

Figure 5: Description of the diagenetic processes in the Cenomanian – early Turonian succession based on thin-section (cores & cutting) and well logs at well Halfaya-1.

3.3 Evolution Porosity of the Mishrif Formation

Mishrif Formation is characterized by the different types of porosity, depending on the classification [9], fabric selective such as intergranular, intragranular, moldic, and intercrystalline porosities and not fabric selective associated with fracture and vugs porosities.

As it is distinguishing, recognizing, and interpretation the genesis of different types of porosities is essential for locating and developing stratigraphic reservoirs in order to estimate reservoir in different settings of Mishrif environments.

The basic porosity is primary which occurs during the deposition of sediments, from another hand the porosity which was considered to be from modification of original sediments after deposition was designated as secondary porosity improving the primary porosity, which enhancement and evolution of the porosity in the Mishrif Formation such as the dissolution process lead to form vuggy, channel, and moldic porosity, and increase the permeability.

The secondary porosity depends upon the presence of a considerable amount of primary porosity which was necessary in order to allow fluid movement through the sediments for development of secondary porosity [10].

4. Sequence Stratigraphy

Standard carbonate microfacies models are widely used to interpret paleoenvironment, but they do not treat 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 (e. g., [11]; [12]; [13]. Sequence stratigraphy is applied to describe the ways that sedimentary basins fill and stratal geometry, the strata arrange into a predictive depositional framework for correlation, and show the spatial and temporal relationships of the reservoir, and to correlate the strata to global sea level records [14].

4.1 Systems tract

Systems tracts can be seen to be comprised of a number of distinct depositional packages. They were observed in the depositional basins were not uniform and continuous but occurred in a series of discrete 'packets'. These packages generally were arranged in a predictable style in the majority of sequences they observed on seismic section, these packages are known as ***systems tract***.

4.1.1 Lowstand systems tract

Shoreline are moving, and rarely remaining stationary for long periods of time, and will migrate depending upon eustatic, tectonic, subsidence, and rate of depositional supply [15], when sea-level has dropped below the shelf margin, the once flooded platform is now subaerially exposed and unable to produce sediments.

The formation of karst features at and below sequence boundaries during lowstands of sea level attaches a distinctive facies overprint to the previously deposited highstand strata.

4.1.2 Transgressive systems tract

A rapid relative sea-level rise and can force the loci of terrigenous sediment deposition to retreat with the shoreline leading to the deposition of laterally extensive nearshore deposits known the transgressive system tract, these deposits can form an aggradational to backstepping, or retrogradational stacking pattern succession of Parasequences [13]. The transgressive conditions consist of deepening upward cycle [16]. Maximum transgression commonly leads to sedimentation in the starvation basin, and platform drowning, the deposition of himepelagic and pelagic sediments over a large area of the shelf, thus consists of the condensed section [17].

4.1.3 High stand systems tract

Highstand conditions deposition occurs in the late eustatic rise, a stillstand, and the early eustatic fall [13]. During that interval, shallow marine sedimentation rates commonly exceed subsidence and the eustatic rise, thus leading to deposition of aggradational to progradational stacking pattern to shelf, shelf margin, and slope [18], although dependent on accommodation space and relative sea level change, carbonate sedimentation is usually greatest during highstands conditions because the range of platform flooding and, therefore, the carbonate factory are greatest then. According to [12]; [13], a downlap surface records maximum flooding surface, separates the transgressive system tract and highstand system tract [18], and record the regional progradation of shelf margin toward center basin.

4.2 Sequence Stratigraphy (Cenomanian- early Turonian Succession)

The Albian cycle was ended by emergence of a major sequence boundary [19]; [20], and following by Cenomanian-early Turonian sediments. These sediments in the southern Iraq indicate to a normal lateral change facies from shallow water facies through deeper water neritic and sub-basinal (Mishrif, Rumaila, and Ahmadi) formations.

4.3 Originated and development (Cenomanian-Early Turonian) cycle

In order to study of the Mishrif Formation in southeastern Iraq in a more detailed, with structural proposed model shows the vertical and horizontal facies change, and additional the determining of the main factors which control on the development of the intrashelf sedimentary basin (tectonic and sea level change).

The Cenomanian-early Turonian cycle, and was divided into three stages depended on tectonic and sea level change Figure (6):

Stage (A)

The tectonic setting contributed to the emergence of the Passive margin in the east and northeast Arabian plate, and making it facing of the Neo-Tethys [1]. The abrupt discontinuity of the Mauddud sediments, and the appearance of the sequence boundary in the early Cenomanian 98Ma [1], and followed by the open marine sediments (Ahmadi Formation) during transgressive conditions.

The Cenomanian-early Turonian deposits began on the gentile slope of the carbonate platform model (Ahmadi platform), these deposits characterized by the no-facies change with wide extension and the quiescent tectonic inherited from the previous Albian platform sediments.

Stage (B)

As a result of the upgrowth of compressional tectonic system (initial collision), which produce the peripheral Bulge in the middle Cenomanian, along of the southeastern Arabian plate edge, This event resulted of appearance an arch, which was deposited of the Mishrif Formation, and formed a coral barrier and rudistid biostrome [21]; [5].

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.

Intra-shelf basin is spread along passive continental margins, with prolonged shelf, and bounded by shelf margins. Where basin development is associated with high rates of relative sea level rise that leads to stimulate the platform may be to vertical growth, with development of shelf margin.

The shallow water facies represents the beginning of the Mishrif Formation during the highstand conditions, which are characterized by wide expanses of shallow carbonate sediments of grainstone-biostrome units.

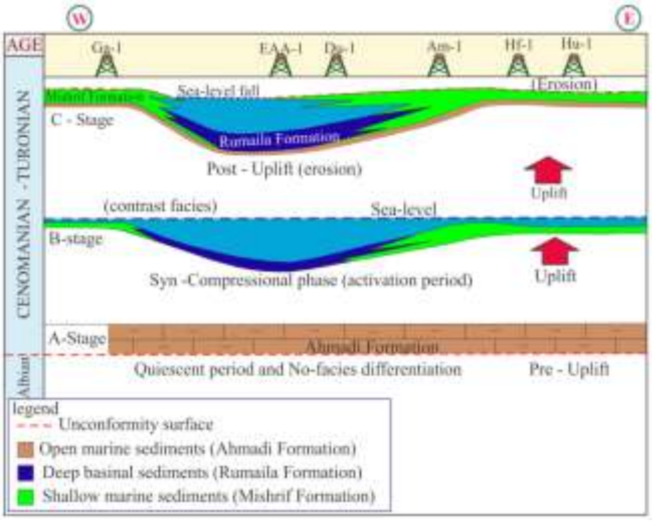

Figure 6: The Cenomanian-Early Turonian cycle divided into three tectonic phases: (A) represents the quiescence tectonic where the sedimentation of the Ahmadi Formation characterized by no-facies change. (B) Mention to the beginning of the compressional tectonic system that contributed to the appearance of (Bioclastic grainstone or rudistid Biostrome) of the Mishrif Formation. (C) Point out to the continuation of the compressional tectonic system and associated with restricted sea level that contributed to the progradational of rudistid facies toward the (Duijila-1 and East Abu Amood-1) wells. This sedimentary cycle ended by appearance of sequence boundary associated with ophiolite obduction in the (middle Turonian).

Stage (C)

The continuation of the compressional tectonic system, contributed to the development of the sedimentary basin, and appearance of the facies change (Differentiated basin), marly limestone facies of the Rumaila Formation passes to the bioclastic shoal, reef, and back-reef facies (Mishrif Formation).

The highstand system tract causes to growing of the carbonate factory, and accompanied the progradation facies towards the basin center. In the last regressive cycle with continuance of the progradation shelf margins (rudistid biostrome) to become overlie basinal sediments in the (Dujaila-1 and East Abu Amood-1) wells, while the lagoonal facies progradation, and overlie the reefal buildups in the (Amara -1 and Halfaya -1) wells.

The Cenomanian-early Turonian sequence ended with appearance of the erosional surface in the middle Turonian, resulted of compressional tectonic system that causes ophiolite obduction along the northern and northeastern of Arabian plate [1].

4.4 Stratigraphic Cenomanian - early Turonian cycle

The Cenomanian - early Turonian megasequence started by transgressive system tract (Ahmadi Formation), and terminated in the highstand system tract (Mishrif Formations), which overlie by sequence boundary, the megasequence subdivided into three main mesosequences, because all most sequences displays coarsening upward cycles, that described through thin section and wireline logs information for the study wells, which are generally composed of carbonate grain supported and carbonate mud supported, these units consist of reservoir unit represented by packstone to grainstone and/or rudistid biostrome facies separated by compacted rock (CR I and CR II) units, but the granular units are named (Mishrif A, Mishrif B, and Mishrif C), Figure (7).

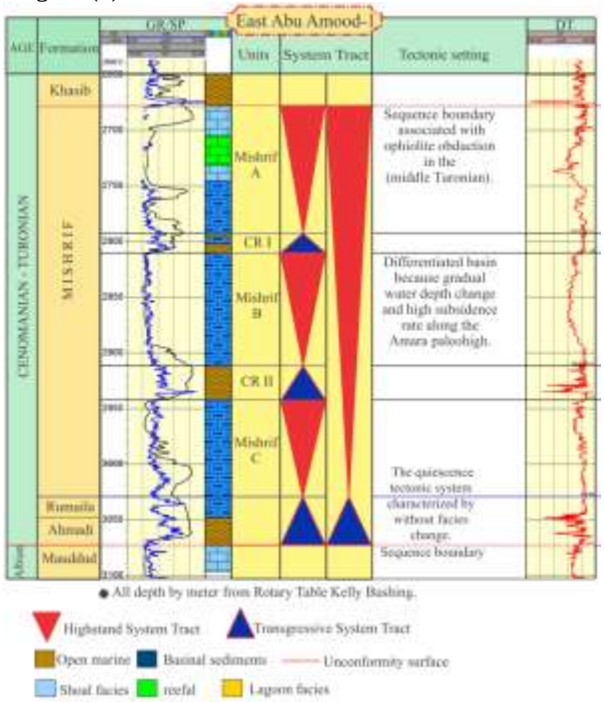

Figure 7: Vertical succession of the Cenomanian – early Turonian subdivided into three regressive mesosequences, at well East Abu Amood-1.

- Mishrif A

The stratigraphic unit represents upper regressive cycle, which ends by the emergence of regional unconformity surface that separates between (Khasib and Mishrif) formations, but the lower boundary with the compact rock unit (CR I), Mishrif A is characterized by the abundance of benthic foraminifera that indicate the open lagoon environment in (Am -1, Hf-1 and Hu-1) wells.

- Compact Rock (CR I)

This unit is located below the (Mishrif A) unit and can be distinguished by a high GR and low DT logs. The stratigraphic unit consists of lime mudstone and free of fossils with pyrite, and separated between upper and middle granular units.

- Mishrif B

The stratigraphic unit was deposited in the differentiated basin, because represents of lateral biofacies change from deep basin sediment as (Du-1 and EAA-1) wells, to the rudistid biostrome with open shelf lagoon facies at (Am-1, Hf-1, and Hu-1) wells, Figure (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, and separated between middle and lower granular units.

- Mishrif C

The stratigraphic unit represents lower regressive cycle, which deposited during early highstand system tract, and comprises the transitional sediments from deep marine facies at wells (Du-1, EAA-1 and Am-1) to the rudistid packstone - grainstone, with abundant of benthic foraminiferal grainstone in the lagoonal facies at wells (Hf-1 and Hu-1).

5. Reservoir Characterization

The well logs data are tools used for many of the characteristics, such as (identify stratigraphic units, sedimentary environment, hydrocarbon units, and type of rocks), these data for the preparation of the geological model involved the distribution of microfacies and petro-physiological properties in three-dimensional model.

5.1 Environmental geological model

Environmental model of Cenomanian- early Turonian cycle in the study wells were built depending on the microfacies description with well logs data, and other geological data.
Cenomanian- early Turonian cycle consists of from three formations (Ahmadi, Rumaila, and Mishrif), these penetrated in the all study wells. Figure (8), Mishrif Formation is divided into three lithofacies units (Mishrif A, Mishrif B, and Mishrif C):-

- The Lower unit (MC) shows a moderate slope resulting of wide extension of the Mishrif platform; the shoal facies represents the beginning of the Mishrif Formation during the highstand conditions.

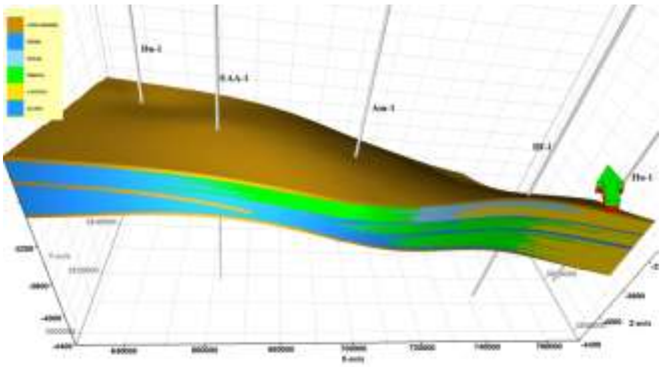

Figure 8: Distribution the sedimentary environments of the Cenomanian - early Turonian cycle, which represented by (Ahmadi, Rumaila, and Mishrif) in the (3D) geological model.

- The middle unit (MB) this unit is characterized by the dominance of deep marine sediments in the direction of wells (EAA-1 and Du-1), but the lagoonal sediment toward the (Hu-1) well, and the wells (Hf-1 and Am-1) represented abundance of rudistid buildups facies.
- The upper unit (MA) is composed mostly of rudistid grainstone to rudstone, but the predominance of the lagoonal facies in the upper part of this unit. It is also one of the important reservoir units at the wells (Du-1 and EAA-1), resulting of granular progradational toward basin center.

The environmental model of the Cenomanian- early Turonian cycle shows the Mishrif Formation has many stratigraphic traps, and following by the Khasib Formation that consist of cap rock.

5.2 Effective porosity

The amount of void space that is interconnected, and so able to transmit fluids, is called (Effective Porosity), but the isolated pores and the pore volume occupied by absorbed water are excluded from a definition of effective porosity [22].

Effective porosity is the percentage volume of void space, in the rock sample to the size of the total rock. Effective porosity can be obtained as wire log of effective porosity Figure (9).

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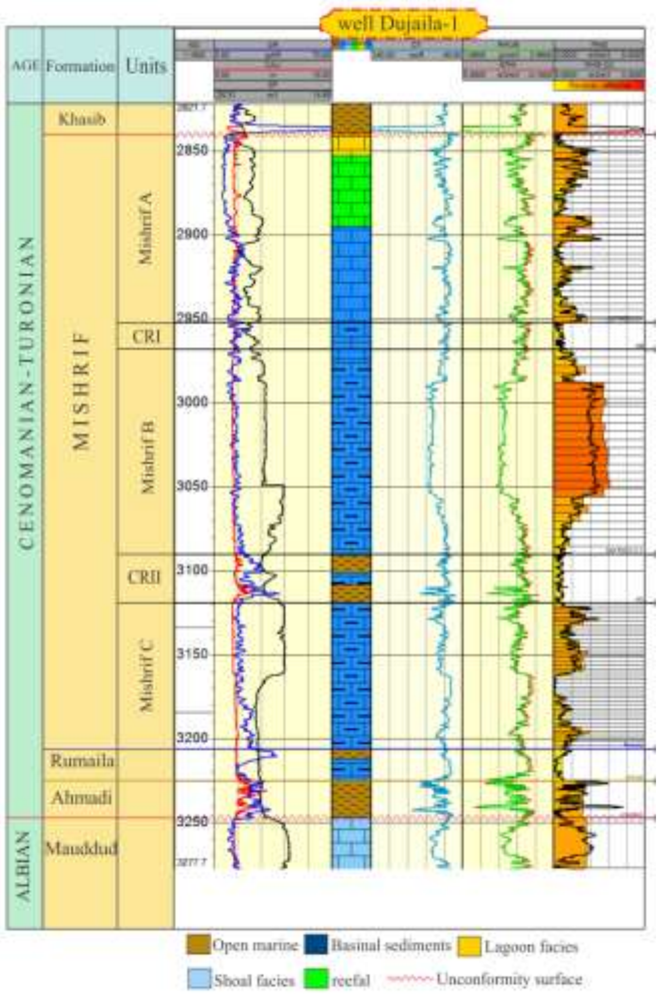

Figure 9: wire logs data of the well Du-1

5.3 5 Development of Porosity

The model is contained from (Ahmadi and Rumaila) formations, and Mishrif Formation consists of three reservoir units (MA, MB, and MC), which separated by barriers (dense non- porous) units (CRI and CRII). The 3D model appears three main units have effective porosity from (low to high) porosity, which associated with rudistid build-ups.

The petrophysical model shows each reservoir unit of Mishrif Formation (MA, MB, and MC) the effective porosity increase toward the rudistid reefal build up, and shoal microfacies more than the lagoonal facies, but decrease toward the basinal facies Figure (10).

Effective porosity in the (Mishrif A, Mishrif B, and Mishrif C) characterized by relatively by a good porosity such as:

- Mishrif C reservoir unit

This unit has a good porosity toward at wells (Am-1, Hf-1, and Hu-1), because these units represented reef to back reef facies, rather than at wells (EAA-1 and Du-1) that represented the basinal sediments. This unit is characterized by the presence of secondary porosity in the wells (Am-1, Hf-1, and Hu-1), but decrease toward at well (EAA-1) and disappear in the well (Du-1).

- Mishrif B reservoir unit

MB unit is represented a main reservoir unit in the Mishrif Formation. This unit characterizes by a relatively higher effective porosity along the slope facies toward the lagoonal facies, and reflected the abundance of rudistid bioclastic along the Mishrif platform.

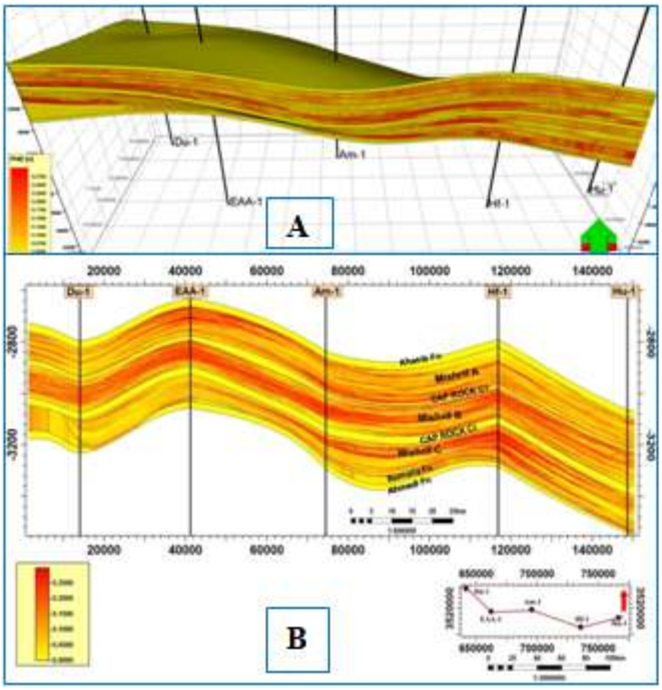

Figure 10: (A) Distribution of the effective porosity (EPHI) in the Cenomanian - early Turonian cycle, and subdivided the Mishrif Formation into three reservoir units and compacted units in between, the (3D) geological model. (B) Intersection view for the effective porosity of the Cenomanian - early Turonian cycle, with the three reservoir units and compacted units in of the Mishrif Formation.

- Mishrif A reservoir unit

This unit is the upper reservoir unit in the Mishrif Formation below the sequence boundary, and characterized by the migration of the rudist build up toward at wells (EAA-1 and Du-1), therefore shows the effective porosity enhancement there, but decrease of toward at well (Hu-1), because of dominance of the lagoonal facies at there.

6. Conclusion

Cenomanian-early Turonian succession is composed of (Ahmadi, Rumaila, and Mishrif) formations. The intra-shelf basin development during the Cenomanian age by dominated shallow water of carbonate ramps that event was due to growth of Oman- Zagros peripheral bulge, the Mishrif Formation is deposited above the high barrier or on the detached platform.

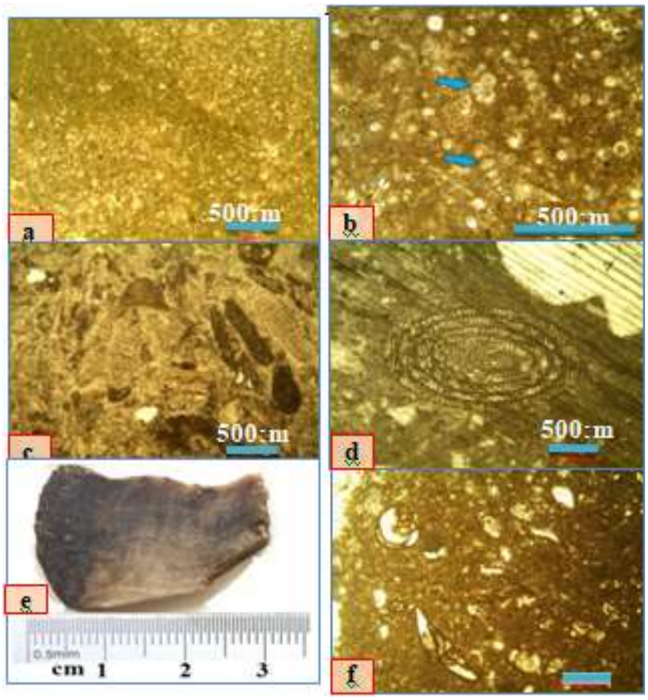

Plate 1

a) Open marine facies, with abundant of Calcispheres, Well (Dujaila-1), at depth (3214m).
b) Basinal facies(Oligosteginids, Heterohelix sp., and Hedbergella sp.). Well (Dujaila-1), at depth (3214m).
c) Shoal facies with diversity of skeletal grains such as (benthic foraminifera, rudist fragments, echinoderms and mollusks. Well (Halfaya-1), at depth (3000.5m).
d) Shoal facies with benthic foraminifera (Praealveolina tenuis). Well (Amara-1), at depth (2926.4 m).
e) Solitary Rudist, well (Amara-1), at depth 2972m.
f) lagoonal facies, with abundant of miliold foraminifera (*Quinqueloculina sp.*). Well (Amara-1), at depth (2927.5 m).

The Mishrif Formation consists of shallowing upward cycle, and associated with continuation of the compressional tectonic system led to the emergence of the unconformity surface at the top the Mishrif Formation, and overlying by the Khasib Formation.

Petrographic study and microfacies analysis assist to recognition of five main environments (open marine, basin, shoal, Rudist biostrome, and lagoon).

These are open marine facies consists mainly pelagic lime mudstone that contains calcispheres, sponge spicules and rare of planktonic foraminifera, The basinal facies consists of the calcareous sediments consist of pelagic organisms plus fine detritus moved off from adjacent shallow shelves, Shoal facies is 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 consists of benthonic foraminiferal wackestone and mudstone with miliolids and peloidal.

The diagenetic processes were affected by (Micritization, Cementation, Dissolution, Neomorphism recrystallization, dolomitization, and compaction); most effective are dolomitization, neomorphism, and dissolution, but other processes (pressure solution, cementation, and micritization) less effective.

Primary and secondary porosities determined by using (Neutron, Density and Sonic) logs. Primary porosity is the most effective, but the secondary porosity appears to be related with dolomitization and dissolution.

Three reservoir units were recognized in the Cenomanian-early Turonian succession. These units are characterized by high total effective porosity, reservoir units lie within shallow facies including rudist biostrome and shoal where the porosity may be due dissolution related to the upper unconformable boundary, such porosity may have been reserved after deep burial. The upper reservoir unit is located above the deep marine facies at wells (Du-1 and EAA-1), but the lower and middle reservoir units disappear there.

7. Acknowledgements

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