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Sequence Stratigraphy for Optimize Development Strategy, Ahmadi Carbonates, Case Study, South Iraq Oil Fields.

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Abstract

The Early Cenomanian Ahmadi carbonates succession in selected oil-wells in south Iraqi oil fields have undergone; into sequence stratigraphic analysis as new reservoir stratigraphy optimization understanding. The sequence stratigraphy context: has applied on the mentioned carbonate reservoir in selected oil-wells from West-Qurna and Majnoon oil fields, with respect to Arabian-plate (AP) chronosequence stratigraphy and chrono-markers setting.

A meso-genetic buildup has infra-structured the studied Formation based-on; smallest-set of the genetically-related high-frequency lithofacies-cycle and cycles-set modeling. A genetic sequence (meso-sequence one MS1) is described as a well-encountered buildup between the (MFS-K120 of lower Ahmadi shale) and (MFS-K125 of upper Ahmadi shale) chrono-markers, with key-surfaces (K121 to K123a). HST-facies-buildup has distinguished by (K122 and K123a) key-surfaces, and TST-facies-buildup by (K123a and top of Ahmadi Formation). The maximum flooding surface (MFS-K125) is confirmed by this study as a local stratigraphic term terminates the sequence MS1. The lithostratigraphic member (Mc2) of the Ahmadi is well described as; carbonate-buildups of progradational-HST high-frequency-cycles, followed by retrogradational-TST high-frequency-cycles. The Ahmadi multi-carbonate reservoirs are well defined by downward shift shoals and isolated Rudistid-banks. The shoals are well-encountered between the key-surfaces (K122 and K123a) of good to very-good reservoir characteristics, whereas; the Rudistid-banks encountered between (K123a and base of MFS-K125), differently behave in reservoir characteristics owing to open marine facies effects. The reservoir facies and distribution framework of the clino /or shingled shoal-bodies, are well developed from the platform-site (western-flank) toward the basinal-site of the field (eastern-flank). For reservoir optimization strategy, it is highly advised to apply the sequence steering schedule by building the high frequency lithofacies cycles into selective-perforation/isolation plan in the well completion agenda.

Keywords: sequence stratigraphy, Ahmadi carbonates, South Iraq Oil Fields.

التتابعية الطباقية وإستراتيجية التطوير الأمثل: مكمن الأحمدي الكلسية / جنوب العراق

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الخلاصة

تم في هذه الدراسة تطبيق مبادئ الطباقية والأسطح الكرونولوجية للصفيحة العربية (AP)، على التتابع الكلسي للسينومانيان المتقدم في الحقول النفطية لجنوب العراق/مكمن الأحمدي/دراسة تطبيقية؛ لغرض تحديث

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الصورة المكمنية لمكمن الأحمدي في آبار مختارة من حقلي مجنون وغرب القرنة جنوب–شرق العراق. تؤكد الدراسة على أهمية تحديث وتقسيم مكمن الأحمدي الكلسية وفق الوحدات المتزامنة رسوبياً (Syn–Layers) ضمن البناء التتابعي الرسوبي (Highstand System Tract HST) أولاً حيث حددت بوحدتين مكمنية (L21 & L22) ، وثانياً ضمن التتابع (Transgressive System Tract TST) الذي حددت بالوحدة المكمنية (L20). تم تحديد أفضل إتصالية توافقية لهذه الوحدات المتزامنة مكمنياً (sedimentary continuity/permanency) بين آبار الدراسة لغرض بناء صورة أولية لمضاهاة الآبار وكما حددت في المقطع المرفق بالدراسة، مع المقارنة البتروفيزيائية للوحدات في الحقلين. كما تؤكد الدراسة أيضاً على ضرورة إتباع أسلوب (Syn–Layering System) بالتقسيم المكمني الجديد لوضع أمثل برنامج إكمال وتثقيب الآبار لجعل الوحدات المكمنية بأفضل إتصالية للإنتاج المستديم بأقل تضرر نفوذي ممكن.

Introduction

The Early-Cenomanian shale – carbonates succession; was originally defined by Rabanit in 1952, at the Zubair well number-3, in the Zubair oil field, (25Km) southwest of Basra city - south Iraq. The study area is located in the Basra sub-zone of the Mesopotamian fore-deep of the tectono-sedimentary framework of Iraq. The studied succession is well encountered in almost complete and well-defined section in the giant Majnoon and West-Qurna oil fields, (80-85Km) north of Basra city (Figure-1). Both fields are almost of north – south asymmetrical-anticlinal structures, each; with geometry around 50Km long and 8-12Km width, at the top of Ahmadi Formation in Majnoon field (Figure-2). The pioneer studies pointed out; the succession, is particularly made-up by lower & upper shale members interbedded with the Tuba limestone buildup [1, 2, 3, 4]. The Ahmadi Formation; has lithostratigraphically subdivided into upper shale member, middle carbonate (Tuba Limestone) member, and a lower shale member, in the whole south Iraq oil fields [5, 6, 7, 8].

Many studies [9-15] have properly mentioned lower and upper shale members, with interbedded carbonate buildup of regressive to transgressive succession. A high-resolution sequence stratigraphic context; principally based-on AP-chronostratigraphic-concepts for Cenomanian multi-carbonates, and related synchronous reservoir buildups; was infra-structured [6, 8]. A preliminary sequence stratigraphic approach has attempted, to build data-bank for new rock-static/dynamic philosophy of the Cenomanian reservoirs.

The scope of the Study

The aim of this study focuses mainly on applying the AP-chronosequence stratigraphic concepts on the Ahmadi carbonate succession in south Iraq oil fields using the genetic sequence stratigraphic principals. As well as; the importance of the sequence buildups in carbonates reservoirs development agenda of Ahmadi Formation.

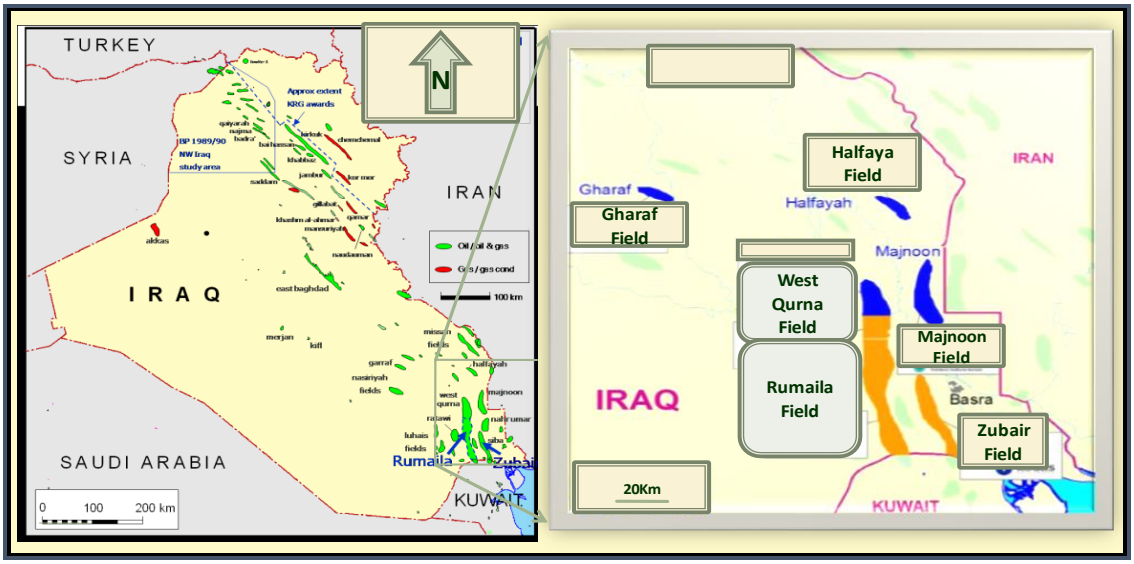

Figure 1-Location map, showing the geographic position of the supergiant Rumaila, West-Qurna and Majnoon oil fields

Specific Explanation of Ahmadi Formation

The Cenomanian multi-carbonates lithofacies-succession mainly the open-marine to climbing-shoal-buildups and bioaccumulated-bank; highly performs a unique stratigraphic architecture of multi-reservoir HF-cycle-stacking/spatial-continuity pattern of a single HF-lithofacies-cycle. The single HF-lithofacies-cycle; mainly distinguished by shallowing-upward succession of mud/grain-dominated bioclastic wackestone and Rudistid bafflestone facies, progressed to; grain-dominated bioclastic packstone (floatstone/rudstone) facies and coated-grain (bioclastic) to peloidal grainstone facies [5, 16 ,17]. The Petrophysical characteristics of these carbonates display; total porosity from less-than 8% to around 25%, and calculated absolute permeability (Ka) of less-than 0.2 to more than 500 mD, at the West-Qurna and Majnoon oil fields. The general thickness of Ahmadi Formation in both oil fields ranges between (100-150m). This study for Majnoon oil field based-on the concepts used for oil-well WQ-11[8], as a proto-type for complete genetic sequence stratigraphic analysis based on Galloway concepts [18, 19, 9, 14], and has taken (MJ-2, MJ-3, and MJ-11) Majnoon oil-wells, (Figure-2), as well as; West-Qurna oil-well/11, as prototype oil wells due to; the availability of the logs and well-data.

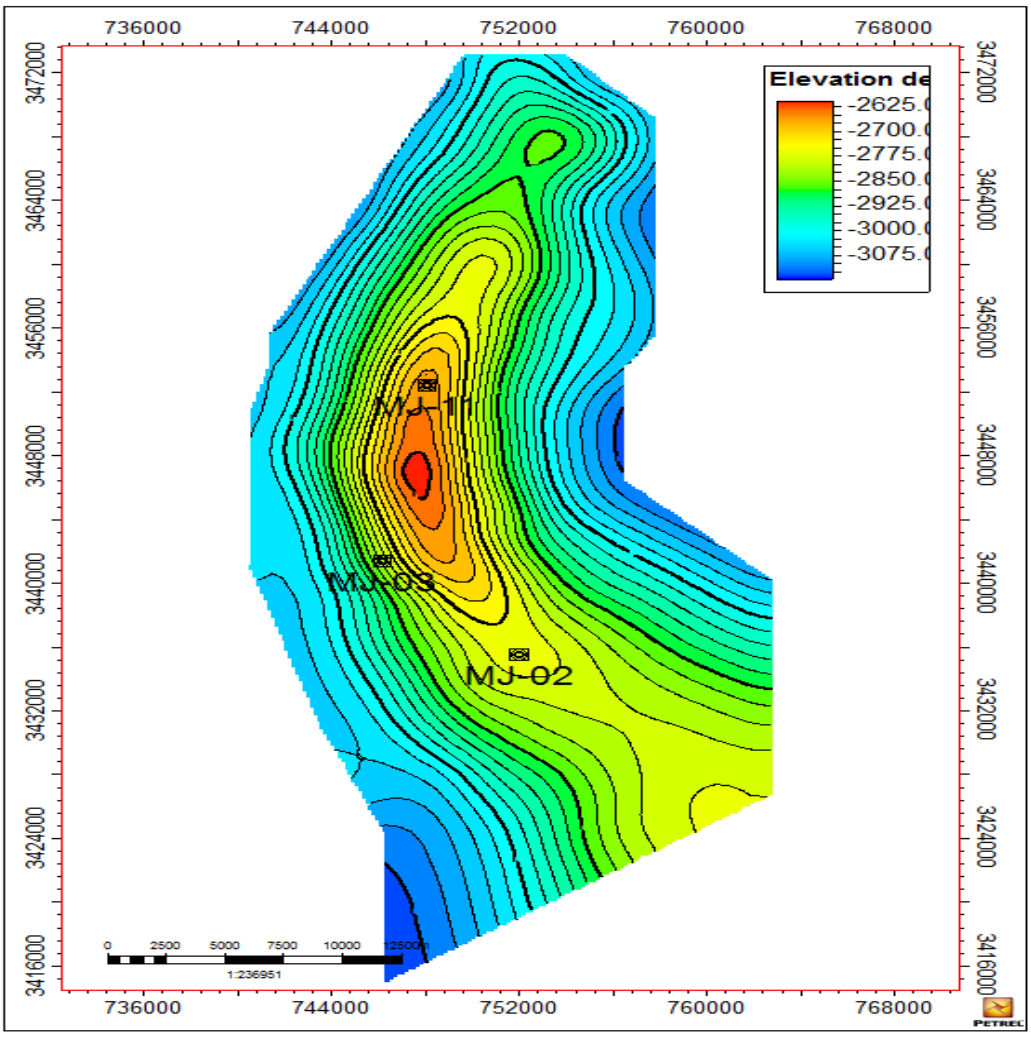

Figure 2-Structure contour map on the top of Ahmadi formation, Majnoon oil fields, showing locations of MJ-2, MJ-3 & MJ-11.

DISCUSSION

Based on; the Arabian plate (AP) chronosequence stratigraphic context, the Early Cenomanian Ahmadi succession, has basically identified; by MFS-K120 Chrono-marker [15], at the lower Ahmadi shale member, and by MFS-K125 marker [6] at the upper Ahmadi shale member. The first Cenomanian genetic sequence stratigraphic buildup is termed mesosequence one (MS1) [6] (Fgure-3).

It is mostly signified the Ahmadi lithofacies buildups, whereas; the other ascending mezzo-sequences represent the Mishrif lithofacies buildups.

In this study both terminologies of elf and Sharland; have used to combine into a united one terminology, representing the carbonate factory of Late Albian/Earliest Cenomanian (Mauddud Formation) – Early Cenomanian (Ahmadi & Rumaila Formations), and Mishrif middle/Late Cenomanian – Early Turonian succession. Starting; from the middle part of this factory; Ahmadi sedimentary series; is clearly represented and bounded by; MFS-K120 and MFS-K125 [6]. The latter marker; has taken a regional consistent well developed and correlated key-surface, in the southern Iraq oil fields [8 & 20]. It has properly taken as a second Cenomanian key-marker. The Rumaila carbonates are encountered; within the first-HST-unit of the meso-sequence MS2, furthermore; the meso-sequences up to MS7; represent the Mishrif carbonates, *whereas*; meso-sequence MS8 represents the Khasib Facies buildup [6 & 8], (Figure-4). The Tuba limestone member of Ahmadi has taken chronologically equivalent to Mc2 litho-unit of Mishrif Formation. The unit characterized by; good shoals/Rudistid-banks development at the northern-sector of West-Qurna & Majnoon fields, *whereas*; typifies open marine facies toward the Rumaila-Ratawi and Luhais areas.

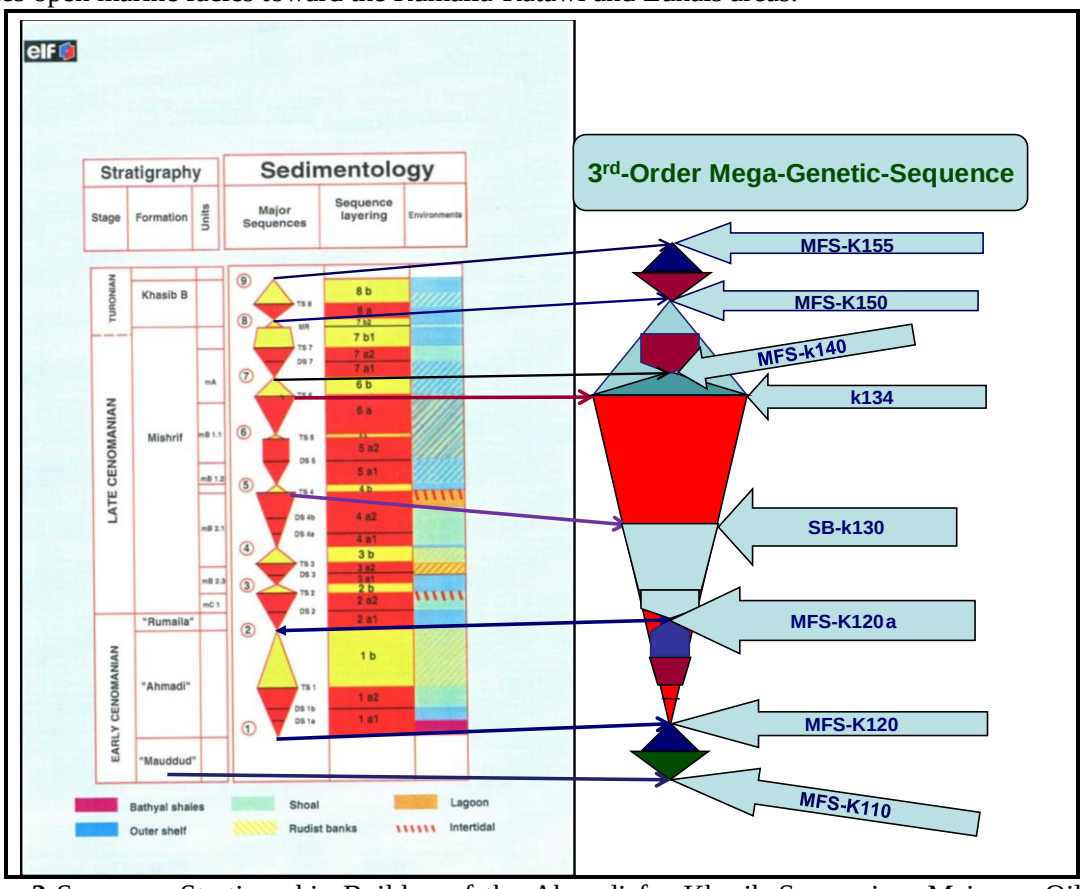

Figure 3-Sequence Stratigraphic Buildup of the Ahmadi for Khasib Succession, Majnoon Oil field [21], Modified by Awadeesian, 2012 and 2018.

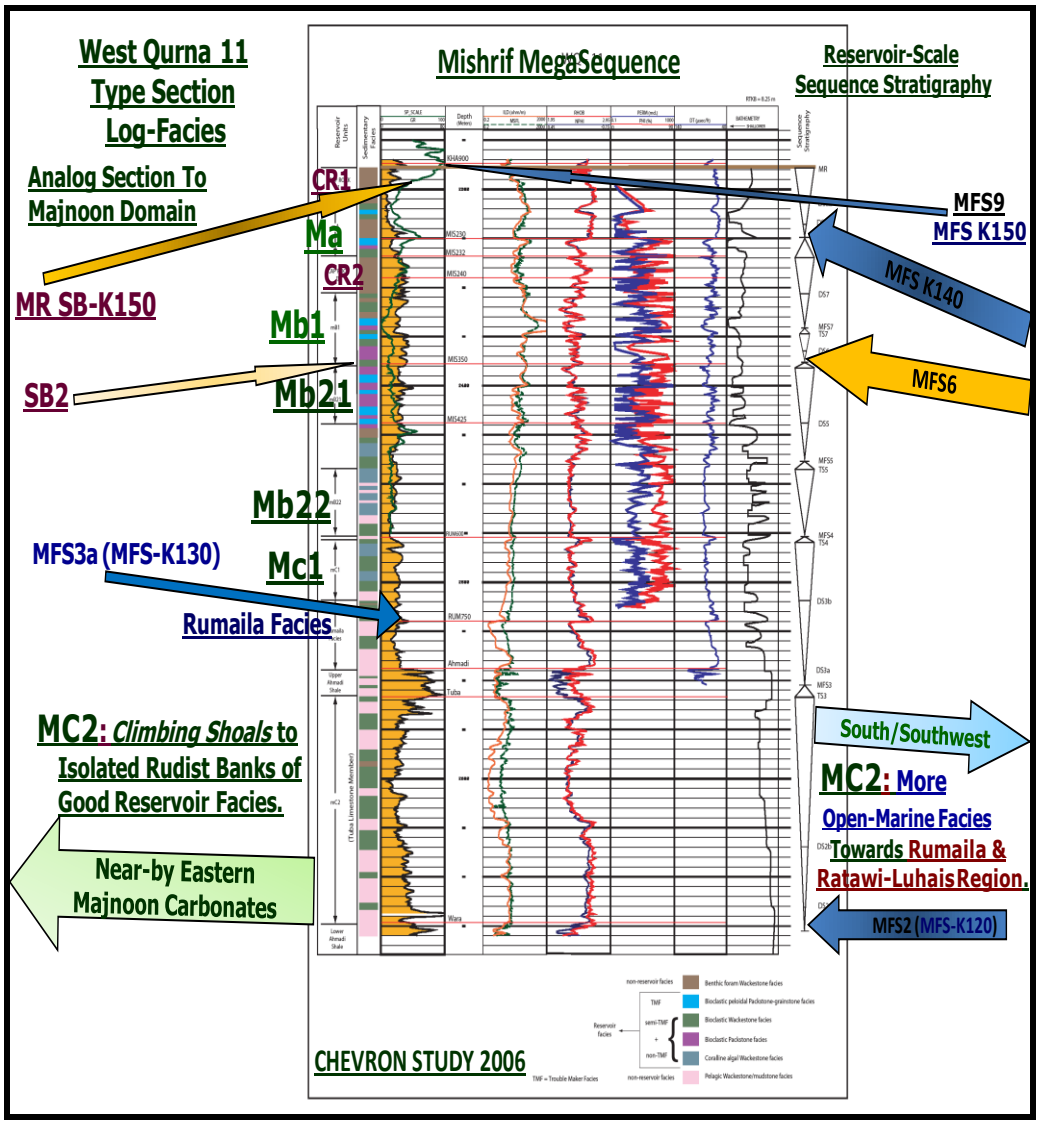

Figure 4-Sequence Stratigraphic Section of Ahmadi for Mishrif Succession In West-Qurna/oil-well11 [8]; Modified by Awadeesian in 2012 and 2018

Mesosequence One MS1

The first itemized maximum flooding surface (MFS) of the Cenomanian succession is the MFS-K120 chrono-marker of Sharland 2001 and 2004; represent maximum full-depth-sedimentation of Bathyal condensed section, mainly of shale and shaly lime mudstone facies buildup, signify the lower-shale-member of Ahmadi Formation. The second Cenomanian MFS is the MFS-K125; which considered as a local key-marker [6, 8], that terminates the MS1 sequence in the southern Iraqi oil fields.

The first Cenomanian carbonate factory taken as the first genetic-sequence buildup (mesosequence one MS1) that is well-encountered between the (MFS3 of Awadeesian A. 2008, MFS-K120 of Sharland, 2004, lower Ahmadi shale member) and (MFS3.1, MFS-K125, of Awadeesian A. 2010 2012 and 2018, upper Ahmadi shale member) chrono-markers. The related key-surfaces (K121 to K123a), refer to Figures-(3, 4 & 5). The downward-shift-facies markers DS-surfaces and transgressive facies markers TS-surfaces are good pieces of evidence for the sea-ward-stepping (SS) and land-ward-stepping (LS) depositional aspects, respectively.

The key-surfaces are properly designated as: (K)-markers.

The meso-sequence MS1 is exclusively characterized by long HST facies buildup, manifested by (K121 & K123a) key-surfaces, and medium/long TST-facies-buildup by (K123a & top of Ahmadi Formation). The Tuba-limestone member (Mc2) of the Ahmadi; is well described by Awadeesian A. 2012 2018 as; carbonate-buildups of progradational-HST followed by retrogradational-TST-climax,

Figures-(5 and 9). These carbonates are well-defined by multi-downward-shift-shoals, progressed-to backstepping-shoals & Rudistid-banks.

The syn-layer bounded by MFS-K120 & K121 represents the first Bathyal shale facies section of lower Ahmadi shale member, the layer (L24) of *Awadeesian A. 2012,* followed by open shallow marine facies buildup, well encountered between key surfaces (K121 and K122) (L23), of low reservoir characteristics. The climbing-shoals-buildup; manifested by K122 to K123 key-surfaces, and syn-reservoir-layer (L22) maintains the good-to-very-good facies-pore system, Figure-5. The syn-layer L22 is lithostratigraphically considered (Mc23)-unit of the original Mishrif litho-subdivisions. The overall shoal buildups; progressed to open shallow marine facies towards the eastern flank of the field. *Whereas*; The Fore-shoals/open-shallow-marine facies buildup is manifested by the key-surfaces K123.1 to K123a, (L21) or (Mc22)-unit, characterized by; moderate-good facies-poro-perm-system. The reservoir layer L21 highly depends on open marine facies existence & interfingering effects.

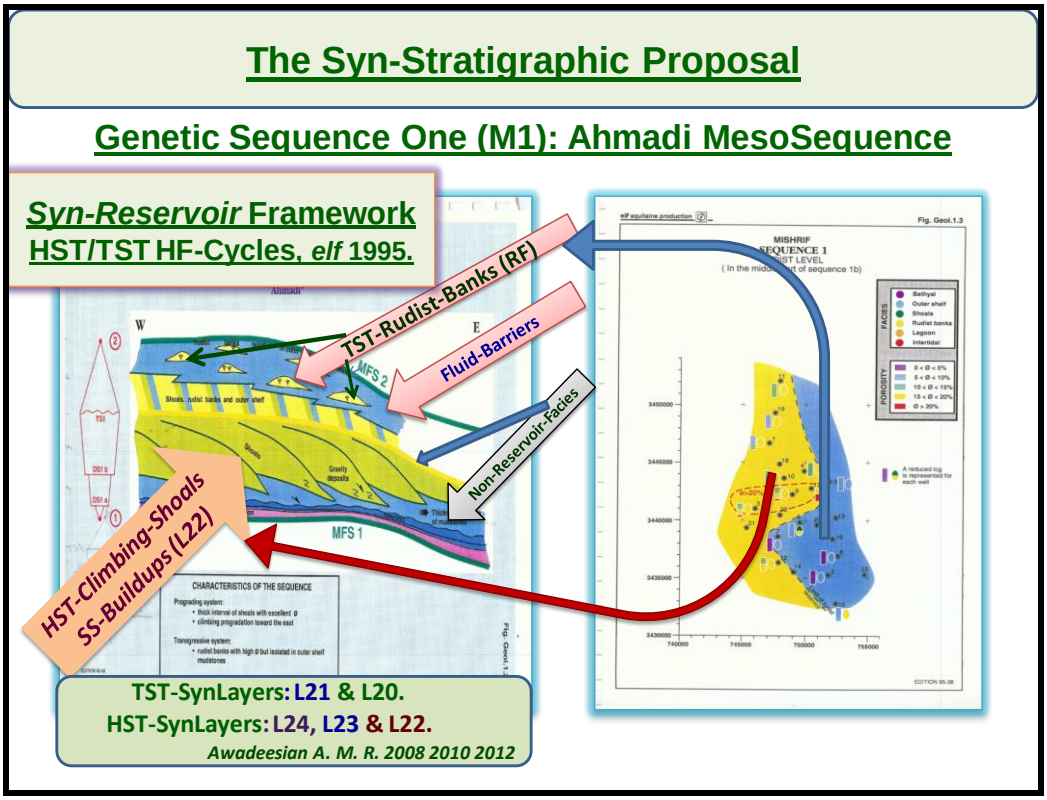

Figure 5-Ahmadi mesosequence (MS1): progradational to retrogradational and related carbonate buildups Majnoon field [21], Modified by Awadeesian in 2012.

The stratigraphic buildup; from K123a key-surface to the base of the MFS-K120 key-marker, represent syn-reservoir-layer (L20). It is specifically made-up by land-ward-stepping isolated Rudist-bank facies and opens shallow marine facies, specified by different reservoir characteristics of facies-pore-system, because of the intertounging character & effects of the latter type facies on overall reservoir buildup. This reservoir layer equivalent to (Mc21)-unit of SOC-Terminology. The deep open marine facies of litho-unit Mc2 of Mishrif carbonates, at the western/southwestern regions of southern Iraq, is time equivalent to shallow-marine/shoals and isolated Rudist banks of the Tuba limestone of Ahmadi, along with the northern-part of West-Qurna and Majnoon fields towards Halfaya/Buzurgan fields in Missan directorate.

According to; CHEVRON/SOC study, this litho-unit has put as the lower-mesosequence (MS1) of the Mishrif megasequence. It shows well-developed reservoir characteristics toward WQ-11 at the northern part of West-Qurna field, Figure-6. *Whereas*; characterized by open shallow to deep marine non-reservoir facies toward the southern and southwestern areas, along with the Rumaila, Ratawi and Luhais fields, refer to Figures-(1, 4).

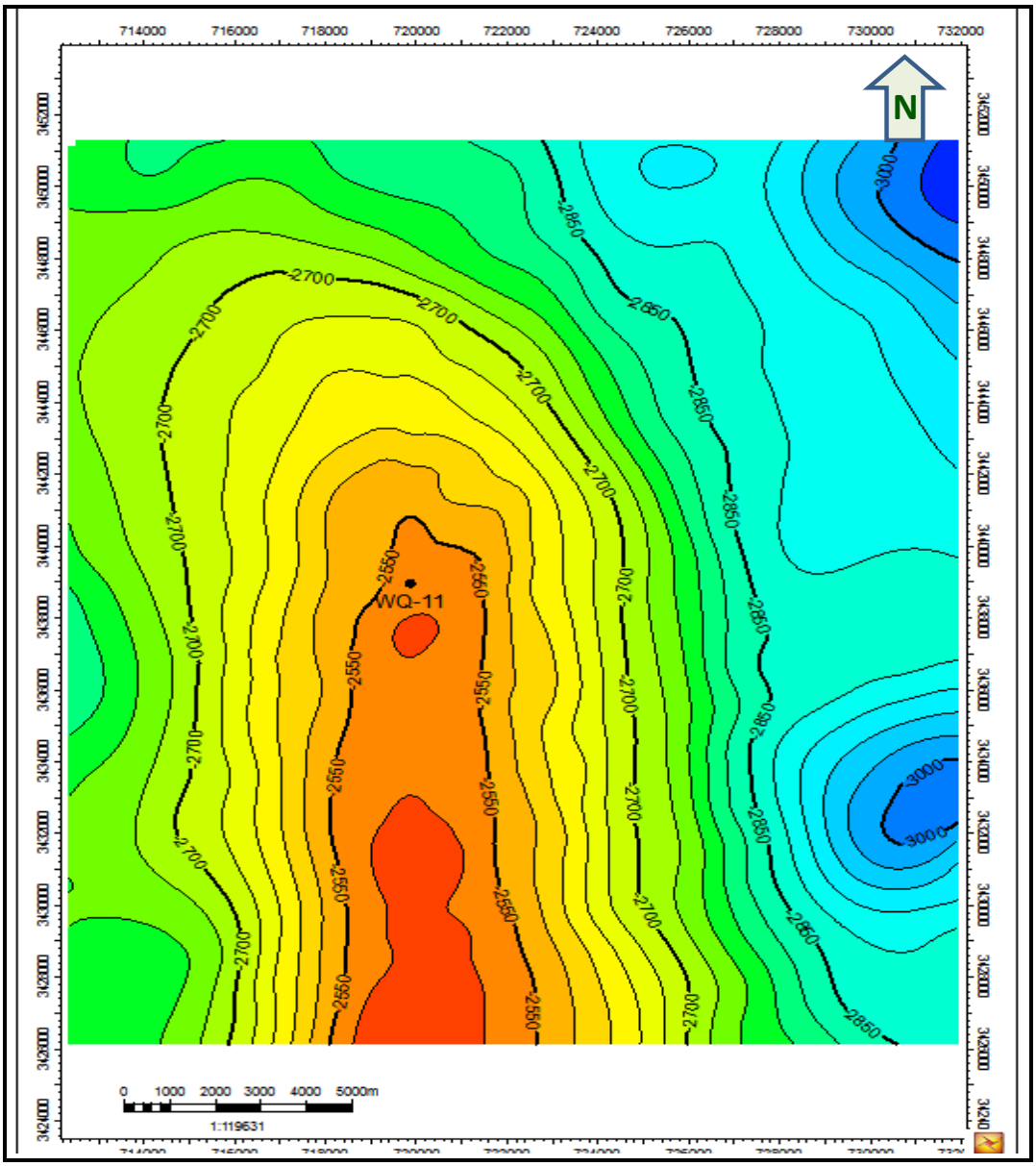

Figure 6-Structure Contour Map on Top of Ahmadi formation, West-Qurna oil field.

Reservoir Syn-Layer Model

The Cenomanian Chronostratigraphically-based subdivision introduced by elf-Aquitaine 1995 and Awadeesian A. M. R. 2012 2018 for Majnoon oil field, have issued 24-syn-layer-model. The 15-reservoir-syn-layers and related sequence key-markers/surfaces; as in the direction of drilling, the Ahmadi syn-layers are L20, L21 & L22, with associated stratigraphic settings and lithofacies buildups.

MR - K142 = L1 = CR1	MFS4 - K127 = L14… (Lower Mb21)	K127 - K126 = L15… (Mb23)
K142 - K141 = L2 = Ma1	MFS6 - K132 = L7	K126 - MFS3 = L16
K141 - MFS-K140 = L3 = Ma2	K132 - K131 = L8	MFS3 - K125 = L17… Base of Mb23 = Open Marine Facies
MFS-K140 - K134 = L4	K131 - MFS-K130 = L9	K125 - K124 = L18… (Mc1)
K134 - K133 = L5 = CRII	MFS-K130 - K130 = L10	K124 - Top of MFS2 = Rumaila Facies = L19
K133 - MFS6 = L6	K130 - K129 = L11…	
K128 - MFS4 = L13...	K129 - K128 = L12	

Ahmadi Syn-Layers:
MFS-K120a(MFS2) - K123a = L20

K123a - K123 = L21

K123 - K122 = L22

K122 - K121 = L23 = Open Marine Facies

K121 - MFS-K120 = L24 = Bathyal Condensed Section.

Reservoir Layer L20 (Base of MFS-K125 – K123a)

It is the first reservoir-syn-layer of Ahmadi; made-up of mud/grain-dominated basal bioclastic wackestone facies, and mud-to-grain-dominated bioclastic packstone (floatstone) facies, followed by Rudistid-packstone/bafflestone facies of micritic core, influenced by open marine facies. The layer represents; isolated Rudist banks in lime-mudstone facies of open marine setting. The open shallow marine facies sandwiches the micritic-bafflest-core, as far as Majnoon field is concerned. These buildups are of medium-to-good facies-poro-system, and of moderate/good reservoir characteristics, represent Mc21 unit of SOC-terminology, Figure-7 (1). The Mishrif and Ahmadi Rudists especially Eoradiolite is not wave-resistant reef-builders, *whereas*; the Radiolitid Rudist is of growth-framework. The Rudist-facies are capable of trapping/baffling micritic matrix, forming micritic bafflestone core, slumped in-situ under its own weight below the wave base, stabilized within the fair-weather wave base. Represents low-energy bioaccumulated-bank [5 & 21], Figure-7 (1 & 2).

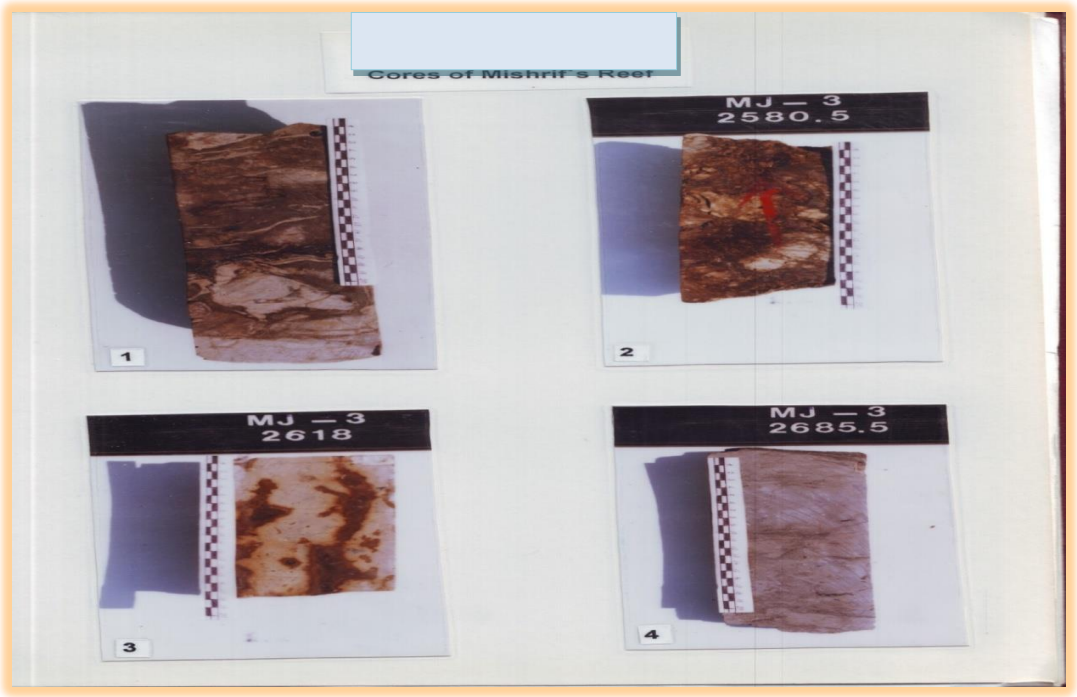

Figure 7-(1)*Radiolitid Rudist* in growth position, at the lower part of a slabbed-core, of inclined dismantled cup-shaped valve & wavy horizontally *Condrodonta* shells of low-energy bank.
(2) Mud-to-grain dominated floatstone/rudstone facies, with Rudist fragments, back-shoal to bank facies, oily impregnated. RF101/RF102. Mishrif MJ-3: 2580.5 to 2580.68m, upper Ma, reservoir layer2 (L2). (**3)**Composite pore-system, mega-vugs/solution-enlarged-voids with micro to meso-vugs and molds, mottled structure, lagoonal facies, Mishrif MJ-3: 2618 to 2618.18m, upper Mb1, L6/7. (**4)** Dense-compact argillaceous lime mudstone/wackestone facies of lagoonal setting, barrier type facies. Mishrif MJ-3: 2685.5m.

Reservoir Layer L21 (K123.1 – K123a)

This second reservoir-syn-layer of the Ahmadi Formation; is essentially made-up of well-developed mud/grain-dominated bioclastic wackestone facies and mud to grain-dominated bioclastic packstone (floatstone) facies, graded to; coated-grain bioclastic grainstone facies (rudstone), occasionally affected by open marine facies. This reservoir-syn-layer, deposited within the fore-shoals/open shallow marine setting, with occurrences of deep marine facies at the basal-part of the HF-lithofacies cycle. These buildups; are of medium-to-good facies-poro system, and of moderate to good reservoir characteristics. Represents Mc22 unit, Figure-8

Reservoir Layer L22 (K122 – K123)

This third reservoir-syn-layer of Ahmadi formation; is essentially made-up of well-developed grain-dominated bioclastic wackestone facies/grain-dominated bioclastic packstone (floatstone) facies, graded to; coated-grain bioclastic grainstone facies (rudstone). This reservoir-syn-layer mainly deposited within the back-shoals/fore-shoals setting, with intermittent occurrences of open shallow marine facies at the basal-part of the HF-lithofacies cycle, as far as; the eastern flank of Majnoon field is concerned. The HST/seaward-stepping of prograded climbing-shoals-buildup; towards the northeastern/eastern areas, might prograde shoal-dimension of 100's m to 1-3 Km geo-bodies, either; clino /or shingle types. The thickness, generally varies between; tens to around a hundred meter. The cyclicity-hierarchy; of the downward-shift shoal-bodies of this syn-layer, is mainly from MJ-3, MJ-11 to MJ-2 and eastward, Figure-9. These buildups; behave good-to-very-good facies-poro-perm-system, and of good reservoir characteristics, resemble the facies in Fgure-8.

The HST-prograded climbing-shoals; towards the northeastern/eastern areas, prograde to shoal-dimension of 100's m to 1-3 Km geo-bodies. The thickness varies between; tens to around hundred meter. The cyclicity-hierarchy of the shoals of this syn-layer is mainly distributed from MJ-3, MJ-11 to MJ-2 and eastwards.

The buildups are of good to a very-good poro-perm system and behave good reservoir characteristics. The shoal-mechanism weather clinoform or interfingering; both are of vital importance in the field-wide development-scale of the MS1 sequence in the Majnoon oil field, and within the West-Qurna oil field, as well.

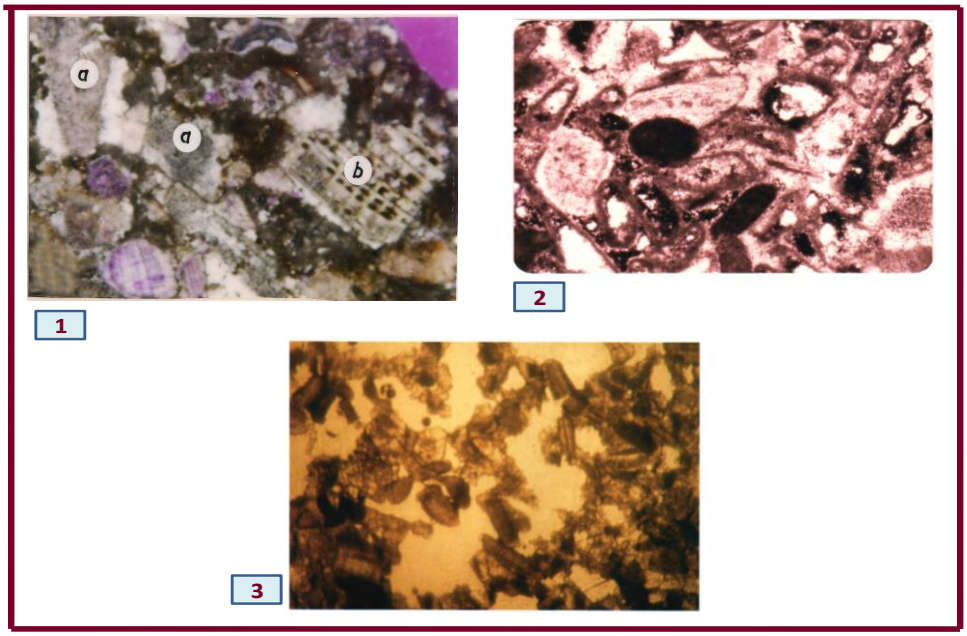

Figure 8- Rudistid bioclastic packstone-grainstone (floatstone) facies.
(1) The Rudist fragment (b) with isopachous rims, Echinoids (a) with cyntaxial-rim-cement, less than 2mm in size. The pore system is of micro-meso type, 5 up to 20 microns in size. Mishrif Mj-3: 2756m X20.
(2)peloidal bioclastic grainstone facies, Rudist and mollusk-debris are with isopachous-rims, Echinoids with cyntaxial-rim-cement.. Separate vuggy-pores of dissoluted bioclasts. The facies reflect HST-progradation of Rudist-bank of shoal tendency of (Mb1) litho-unit, reservoir facies type in

Majnoon oil field. The facies types specify the reservoir layers L21 & L22, of good poro-perm link, West-Qurna well WQ-16, 2447.20m X12.5.

(3)grain-dominated bioclastic packstone facies, floatstone; bioclasts are mostly of less than 2mm. The Rudist debris coated by isopachous-rims, *whereas*; the cyntaxial-rims typify the Echinoid plates, bank flank capping facies of upper shore-face setting. Separate to composite vuggy-porosity/open channel system. The facies of Mishrif Mb1-unit, North Rumaila, NR-36, 2277.35m X12.5; it resembles the Ahmadi reservoir Layer L22.

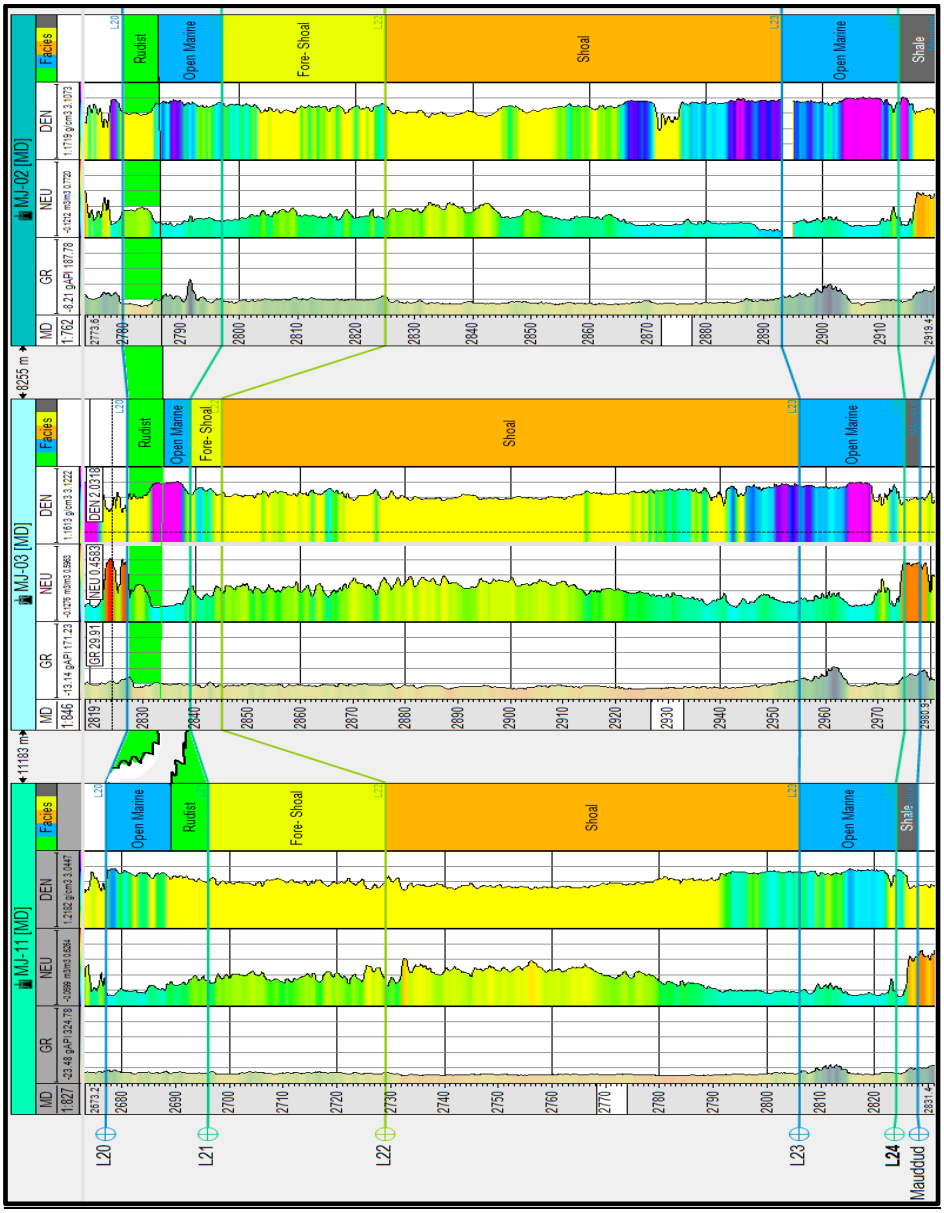

Figure 9-Sequence Stratigraphic correlation of Ahmadi formation between MI-11, MI-3, MI-2

Conclusions & Recommendations

1. The study confirms the genetic sequence stratigraphy of Ahmadi carbonates represented by regressive-to-transgressive framework, termed meso-sequence one (MS1).

2. This study endorses the (MFS-K125) as a local key-marker terminates the MS1 sequence.

3. The HST-climbing-shoals of west-to-east buildup (Mc22) has termed syn-reservoir-layer (L22) of good to very-good reservoir characteristics, prograded to TST-isolated-Rudist-bank buildups (Mc21) termed reservoir-syn-layer (L21), of medium/good reservoir characteristics.

4. It is highly recommended to extend the study to cover the possibility of existing clino /or shingled-type shoal-geo-bodies in field-wide scale, to evaluate the whole reservoir facies performance and

distribution framework both in the platform & basinal sites of the field; for development optimization agenda in the Majnoon and West-Qurna oil fields.
5. It is recommended to take full-core-set from new wells both in the platform & basinal sites of the field; for complete facies-poro-perm analysis.
6. For reservoir optimization, it is highly advised in well completion plans to apply; the sequence steering agenda via, scheduling selective-perforation/isolation agenda.

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