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High-Resolution Sequence Stratigraphy Analysis and Diagenesis Evolution of a Barremian Carbonate Platform (Kharaib Formation), Onshore Abu Dhabi, United Arab Emirates

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ABSTRACT

The aim of this study is to propose a stratigraphic and sedimentary framework though the integration of available sedimentary, diagenetic and petrophysical data, which will be utilized in the construction of a high resolution stratigraphic framework, as an input into comprehensive review and update of an existing model of heterogeneous carbonate reservoir in a mature field in Abu Dhabi, UAE.

Depositional facies have been defined in cored wells, subsequently were associated taking into account the biologic and sedimentary processes in response of carbonate growing and sea level changes, allowing the identification of the main stratigraphic surfaces.

Surfaces can extend the correlation along the field and define the model of facies that, with the evidence provided by cores, can recreate and predict the different regressive-transgressive cycles in high resolution which the carbonate platform were undergone during its evolution.

Diagenetic evolution, interpreted through laboratory observations, was integrated with facies and petrophysical evaluation allowing the understanding of the spatial distribution of petrophysical properties within a heterogeneous reservoir and define a new set of facies which will be used in the generation of geological static model.

Application of sequence stratigraphy methods in cores, and extended in logs allowed the identification of six depositional sequences, with thicknesses of 2 to 4 meters each, corresponding to the phases of carbonate platform growth. Within each depositional sequences, typical cycles were defined that support the understanding in the association of facies and their relationship during the deposition.

The identification of sedimentological cycles not only genetically organizes the facies and predicts the stacking pattern, but also makes possible to find an excellent correspondence between cycles from lowstand system track intervals with good to excellent permeability values, and cycles from transgressive system track intervals with low permeabilities.

Many of the sequence stratigraphy published articles driven for the most important reservoirs along the Arabian Plate, provide an excellent tool in the regional correlation. However, they are not enough to be used in the reservoir characterization in detail that is required during the development of the field neither as input data in the generation of geological static models that use the sedimentary trends as constrain to populate the petrophysical properties.

GEOLOGICAL BACKGROUND

The area of study is located in the onshore southwestern part of Abu Dhabi Emirate. It has a slightly elongated low relief structure with a NNE-SSW trend located between two giant fields (Figure 1). It produces from the Lower Cretaceous Kharaib and Lekwair formations.

Kharaib Formation is a unit of lower Cretaceous and composed predominantly of shallow-marine limestones. It forms part of the Thamama Group, and lateral age-equivalent formations in the Gulf Region has been recognized in Qatar, UAE and Oman, and consists of two limestones reservoir units (Figure 2). In the subsurface in Abu Dhabi, The Kharaib Formation is subdivided into two reservoir units designed by the letter B to C from top to base. Overall, the facies in the studied field were deposited in a moderate to high energy, shallow water, barrier to fore- and back-barrier facies on a broad eastward dipping ramp. Reservoir quality is strongly linked to the sedimentary facies. In upper Kharaib reservoir, the porosity in average is between 18 to 27 % and permeability 25 to 70 mD, however, averages are not representative to identify, either thin layer of high permeability streaks with values above 800 mD or very low permeabilities below 1 mD.

MATERIAL AND METHODS

In this study, the database for the present study includes 8 vertical wells from the main oilfield studied, which have a total 357 meters of whole core and 6 cored wells from two nearby oilfileds that recovered 94 m and 208 m of core, respectively. Cores were used to describe sedimentary facies (Jackson & Galluccio, 2012), which were later more closely characterized by the petrographic study. Subsequently, sedimentary facies have been grouped genetically related into facies associations (FA) that reflect deposition in distinct environments. Conventional core analyses (CCA) of helium porosity, gas permeability and grain density were performed. Finally, standard wireline log data were used for petrophysical characterization of the sedimentary facies in order to allow the extrapolation of stratigraphic surfaces in uncored wells.

FACIES ASSOCIATION AND DEPOSITIONAL ENVIRONMENT.

Based on lithological composition, grains types, sedimentary textures and faunal content, 21 sedimentary facies were grouped into six facies associations, which represent the depositional settings and are characterized by the following assemblages: (1) an association of mudstone-rich facies, commonly describes a low-energy open platform below fair weather wave base and characterizes lower ramp to basin; (2) and association of benthonic foraminifera commonly associated with echinoderms wackestone-rich facies characterizes middle ramp; (3) an association of miliolids and other skeletal foraminifera and peloid packstone characterizes upper ramp and protected platform; (4) an association of partially leached *Lithocodium/Bacinella* lumps with a generally packstone matrix, characterizes the bioconstructed upper ramp; (5) an association of bioturbated grainstones comprising peloids characterizes the high-energy, grainy platform top shoal; and (6) a mixed, miliolids and other foraminifera, fragments of echinoderms, algae, and molluscs, associated with peloids packstone, eventually with the presence of fragments of rudists and other molluscs in packstone matrix characterizes by the restricted platform.

Sequence stratigraphy – Barremian Sequences

The Barremian interval, in the area of study, correspondents to Kharaib Formation, in large scale, is encompassed in the second-order Barremian Supersequence AP8 (Sharland *et al*., 2001), and in medium scale, is subdivided from the base in a complete third-order depositional sequence (van Buchem *et al.*, 2010). The most remarkable characteristic is the notorious intern ciclicity in high-frequency, showed trough the thin thickness of rudist intervals interlaminated with mudstone-rich facies as well as the excellent continuity of the cycles mainly at the base and the top of the third-order depositional sequence.

The stacking pattern of HSST is comprised by basic cycles. Those demonstrate a geological recurrence and indicate a periodicity of dominant control factors during the deposition of sediments. The adopted premise to the definition of stratigraphic surfaces in high-resolution is that the interval is conditioned to the highstand system track in 3rd order (van Buchem *et al*., 2010), which is generated in the continue reduction of accomodation space and entails with the progradation of shallower environments.

- ***Stratigraphic Surfaces Definition***

In a same stratigraphic position, by the means of the vertical distribution of facies in the interpreted sedimentary cycles and starting from an initial level sea (N_0) in time period (T_0), are recognized two periods which impact in the description of identified cycles.

The first period is described in the lower part of HSST, near to MFS of 3rd order, in conditions where the accommodation space is still too high (AS), and the influence of carbonate organic growth (COG), system energy (SE) and relative sea level variation (RSL) are minimized due the thick water column in which the sediments are deposits. This period corresponds to **OPEN PLATFORM PERIOD** (OPP, Figure 3.a).

Whereas, the second period is described in the upper part of HSST, near to the subaerial unconformininty K70, in conditions where the accommodation space is reduced up create a thin water column, hence, the COG, SE as well as the RSL variation become to be important in the heterogeneity of facies described. This period corresponds to **RESTRICTED PLATFORM PERIOD** (RPP, Figure 3.b). In this period, occurs the activation of rudist organic growth with the development of macrofaunal growing, influenced by the RSL over restricted platform limited by the AS.

In OPP, relative rise of sea level generate in the incremement of water column, which turn from algae growth to pelagic sedimentation in deeper environments. Period can be summarized by thick thickness of pelagic facies (OSW, SW & SPWP) from environments of lower to middle ramp.

In RPP, it is during the period of relative rise of sea level that the rudists developed until then in the shoal environment, are exported toward the inner shoal and the restricted platform. This is reflected in the presence of coarse-grained carbonates in packstone/wackestone matrix (RPF), poorly selected and interlaminated with SPP facies in subtidal environment. The abundance of RPF in the restricted platform is directly proportional in continue having the ideal conditions to continue with the growth of rudists before to be sufocated toward MFS.

- ***Basic cycles definition - Open Platform (OPP) period***

Before the sedimentary cycles definition, is to be highlighted that in this vertical interval studied, the accommodation space is too high, therefore, the influence of relative sea level variation becomes minimized and the conditions for the rudist growing not favorable. However, eventually, during periods of relative sea level falls in high-frequency, the conditions may turn favorable for allowing the depositation of thin layers of packstone-rich facies (SPP), rarely algae facies (ASPF/ASFB, in upper cycles only), from upper portion of the platform (Figure 3.a).

The deepest interval (blue triangle) started at the base of ASPF/ASFB or SPP facies, and then, during a rise of relative sea level (basin expansion) the facies described are mud-supported facies, which indicate the available accommodation space for the sedimentation of carbonates in a low energy environment and comprised in deeper FA.

- ***Basic cycles definition - Restricted Platform (RPP) period***

Taking into consideration the AS created during the RSL, the vertical position of 3rd order RPP periods impose a reduction of space in more efficient manner than OPP periods, therefore, the water column would achieve the vertical position of sediments, at least during lowstand eustatic period. The cycles differ from the OPP due to the presence of thin layers of rudists, which indicate the somerization of the system (Figure 3.b).

The deepest interval started either at the base of grainstone or algal facies (FA shoal), and expresses the shallowest period of the platform. Physically, the cycles start with a thin layers of SPG and CgSG facies interpreted by the quickly development of massive to moderately bioturbated grainstones on the shoal in a *catch-up* process while velocity of relative sea level is starting to increase gradually until the velocity of sea level rising will be superior to the rate of COG and the system will turn around in a *give-up* process and the sediment will be represented by packstone facies.

At the top of the cycle, is frequently found the occurrence of depositional hiatus due the relative sea level fall associated together with the carbonate organic growth in a *catch-up* process.

STRATIGRAPHIC CORRELATION AND PETROPHYSICAL CHARACTERIZATION

In total, 13 Transgressive/Regressive cycles in high resolution are defined bounding the HSST. Surfaces are laterally correlatable between the cored wells and through integration rock-logs into uncored intervals throughout the studied area. Stratigraphic framework is represented in a south-north cross section (Figure 4), showing the distributions of facies and their lateral variation.

HSST is subdivided by cycles, where the contact between the intervals is most of the time characterized by a very tight or low permeabilities carbonates that isolates hydraulically these reservoirs and are defined as MFS per each cycle. Averages are not quite representative to identify, either thin layers of high permeability streaks with values above 800 mD or very low permeabilities with values below 1 mD and high vertical tortuosity of fluid.

CONCLUSIONS

A sequence-stratigraphic framework has been defined for the Barremian strata where are recognized two order of sequences: a complete Barremian third order sequence, which is divided in thirteen four-order sequences.

The identification of sedimentological thirteen cycles not only genetically organizes the facies and predicts the stacking pattern, but also makes possible to find an excellent correspondence between cycles from lowstand system track intervals with good to excellent permeability values, and cycles from transgressive system track intervals with low permeabilities.

REFERENCES

Jackson, C & Galluccio, L. 2012. Integration report of the Bu Hasa Integrated study (Phase III), UAE (Weatherford, Badley Ashton)

Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D. & Simmons, M.D. 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2. Gulf PetroLink, Bahrain, 371p.

Van Buchem, F.S.P., Al-Husseini, M.I., Maurer, F., Droste, H.J. & Yose, L.A. 2010. Sequence-stratigraphic synthesis of the Barremian – Aptian of the eastern Arabian Plate and implications for the petroleum habitat. In F.S.P. van Buchem, M.I. Al-Husseini, F. Maurer and H.J. Droste (Eds.), Barremian – Aptian stratigraphy and hydrocarbon habitat of the eastern Arabian Plate. GeoArabia Special Publication 4, Gulf PetroLink, Bahrain, v. 2, p. 503-548.

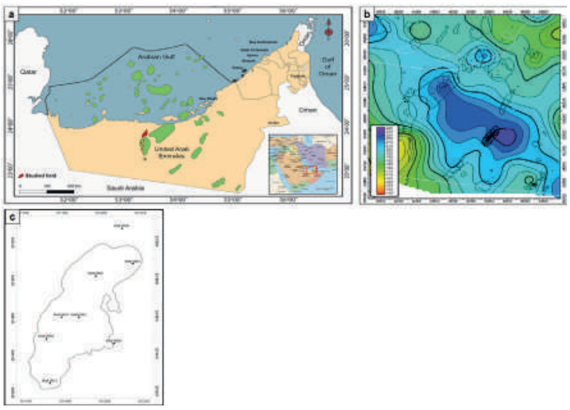

Figure 1 - Location maps. (a) Geographical map of United Arab Emirates with location of the onshore and offshore fields of Abu Dhabi with the studied area indicated. Red circles show the well locations and position of the semi-regional stratigraphic cross section. (b) Map showing the variation of thickness in Upper Kharaib Reservoir. Black polygons represent the boundaries of onshore oil fields and black circles show the well locations used in the map. (Balza, 2017).

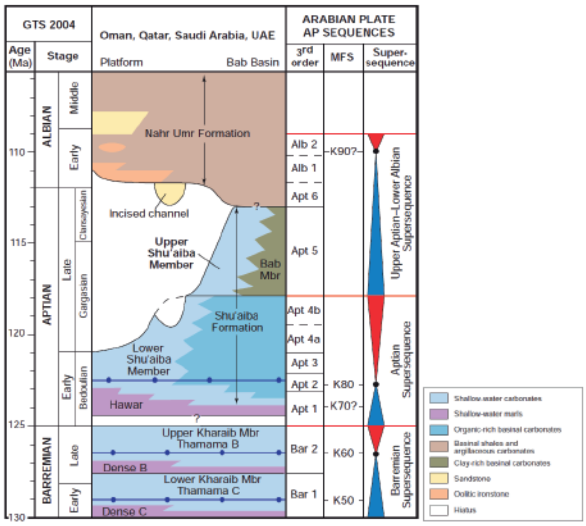

Figure 2 - Barremian to Lower Albian chronostratigraphy and lithostratigraphic nomenclature applied by van Buchem et al., 2010. Present study is focused in Barremian Sequence.

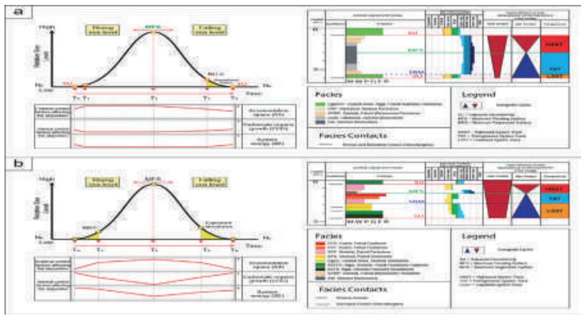

Figure 3 – High-resolution sequence stratigraphy analysis in the HSST of Barremian interval. (a) Open Platform Period. (b) Restricted Platform Period. Left, relative sea level variation curve, in a same vertical position and in an initial time T0 to T4 of a basic cycle. Curves below represents the maximum (+) and minimum (-) in each variable for the accomodation space (AS), carbonate organic growth (COG) and system energy (SE). Right, Scheme showing the variation of ideal basic cycles together with depositional environment interpreted of sedimentary facies and representation of system tracks in high frequency through Karogodin triangles.

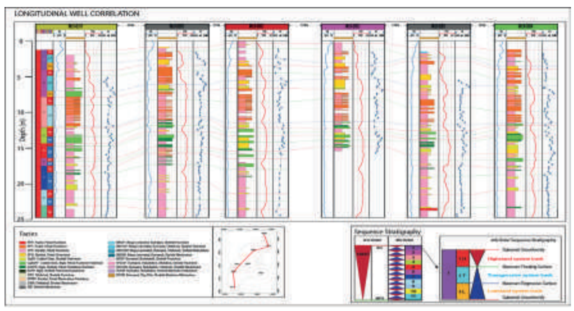

Figure 4 – South - North transect of interval of Upper Kharaib Formation in studied area. Red line on top of section, represents the top of HSST at 3rd order. The distribution of facies is indicated as well as total poro-