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DIAGENETIC UNDERSTANDINGS BASED ON QUANTITATIVE DATA, MIOCENE CARBONATE BUILDUP, OFFSHORE SARAWAK, MALAYSIA

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Abstract

The Central Luconia is one of the major carbonate province formed by 200 carbonate buildups with gas reserves of 63 Tcf. Structurally, the Central Luconia represents an area of low degree of structural deformation. It is located between areas of compression in south and subsidence in north. Carbonate sediments, were mainly deposited during the Upper Miocene (locally referred to as cycles IV and V). The reservoir quality of the carbonate sequence is largely controlled by diagenesis. Hence, understanding of diagenetic process and products (pore types/cements) is of prime importance for predicting reservoir quality in the subsurface. In this study, about 1150 feet of core and 160 thin sections from well X are used to calculate the qualitative and quantitative description. The platform is grain dominated (32%), dominant components are corals and foraminifera (53%). The dominant porosity type is mouldic (30%), carbonates are poorly cemented with blocky equant calcite cement (35%) having as dominant cement. However, diagenesis has altered these original minerals HMC (High Mg Calcite)/aragonite into LMC (Low Mg Calcite) and dolomite. Based on our observations, we can conclude that the platform was near to clastic source, highly dolomitized, porosity secondary in nature and coral facies are more diagenetically altered. Paragenetic sequence comprises of micritization, dissolution, dolomitization, cementation, mechanical compaction and stylolitization.

***Keywords**: Central Luconia; diagenesis; reservoir; Offshore Sarawak.*

1. Introduction

The carbonate build-up in the Central Luconia provides an excellent opportunity to reveal diagenetic pattern that largely controls the reservoir properties (Figure 1). This province presents, 200 platforms distributed over 40,000 km^2 covered by high resolution 3D seismic, 15km core, +300 wells and 40 years of production (Figure 1).

The carbonate deposition in Central Luconia started in Upper Miocene (mainly after cycle III), on structure highs developed during the Upper Eocene to Lower Miocene [1-3]. The carbonate petrography and diagenesis were discussed by [2-5] and provides a starting point for diagenetic workflow.

There is a lack of 3D genetic model(s) explaining the pore/cement type distribution in Central Luconia and isolated platforms in general. Porosity and permeability association with diagenetic body geometries are poorly understood. Although there have been studies on sedimentology and stratigraphy of Central Luconia, only few have addressed the question of distribution of limestone diagenetic features and the dolomitization process [2].

Following are few examples of studies done on diagenesis and sedimentology of Central Luconia carbonates [2,3,6-12], however, interpretations are often not clear as the data is only available in subsurface, with no outcrop analogues [7-10, 12].

The primary objective of this study is to produce a predictive model for limestone diagenesis based on an understanding of patterns of pore/cements type distribution and inferred processes.

1. To designate various microfacies, cements and pore types.
2. To do qualitative and quantitative description of each diagenetic phase present.
3. To propose preliminary diagenetic sequence.

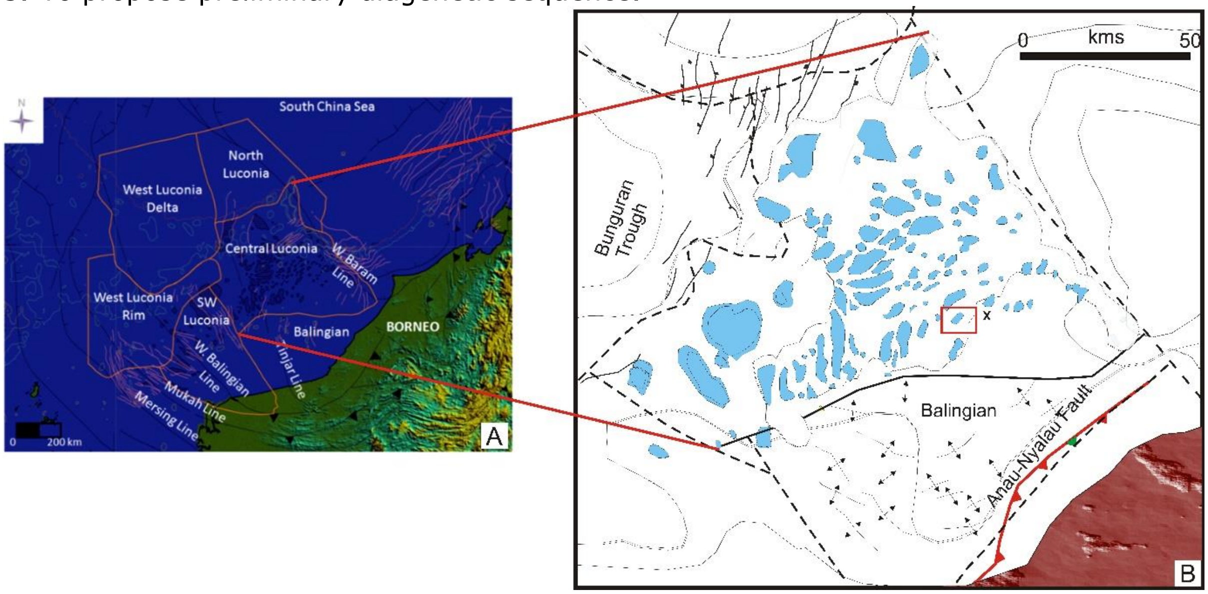

Figure 1. A) Location map of Central Luconia province with adjacent provinces, Offshore Sarawak Basin, Malaysia [3,6], B) Location of X buildup

2. Methods and datasets

A total of 1150ft (350.52m) of core and about 160 thin sections were used in this study representing, cycle IV and V carbonates. The methodology includes the description and digitization of the core sheet using WellCad software package, of well X-2 in Central Luconia. Main importance was given to semi-quantitative description of the platform based on lithology, facies, cement, pore, Dunham classification and components. The thin sections were described using sketches and Jmicrovision© software for point counting.

Conventional microscope (Olympus digital BX 43, with DP 72 Camera) was used for petrographic part and cement phases were established using cathodoluminescence microscopy of about 100 samples using Relion inst. CL device with vacuum below 60 µtorr with voltage 12 to 15 kV and current around 250A [13,14].

3. Results and discussions

3.1. Lithostratigraphy

The platform is divided in to five stratigraphic sequences based on six flooding surfaces [15], mostly marked by argillaceous limestones (Figure 2). The sequence starts with the SS1. The lowermost part of the platform is dominated by shale dominated facies (Figure 3A), middle of the sequence is dominated by platy coral dominated facies with rare land plants. The upper part by interlayering of foraminiferal dominated wackestone and platy coral rudstone facies (Figure 3D & 3F).

SS2 marks the onset of carbonate buildup growth. This sequence is dominated by branching and massive coral float/rudstone facies (Figure 3C). It is dolomitic limestone to dolomite. SS3 is made up of dolomite and limestone lithologies, with branching and massive corals rudstone/floatstone facies and moderate red algal wackestone facies. The dominant depositional environment of the sequence is shallow lagoon. SS4 majorly, composed of limestone with large variety of grain types e.g. red algae, foraminifera, mollusc and corals. The dominance of foraminiferal packstone to wackestone facies indicate that this sequence was deposited in deep lagoon. The final SS5 is dominated by a variety of lithologies ranging from limestone, dolomitic limestone and dolomite (Figure 3D). The top of this sequence marks the final drowning (?) of the platform. The dominant grain types are red algae and minor foraminifera in middle part of the sequence. The depositional environment of this sequence is shallow lagoon same as SS3.

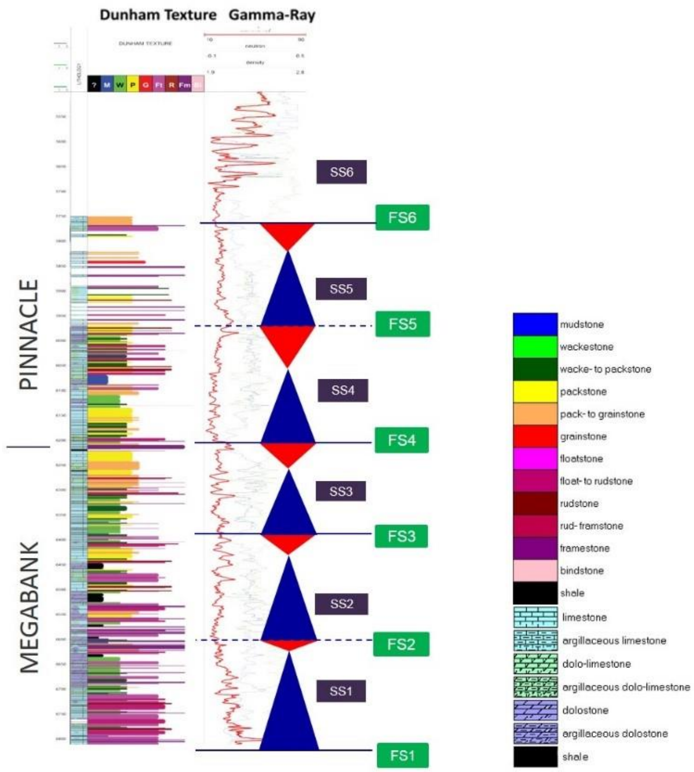

Figure 2. Vertical stratigraphic distribution of various facies in Well X-2, sequences and signatures of flooding surfaces on the Gamma ray log as well.

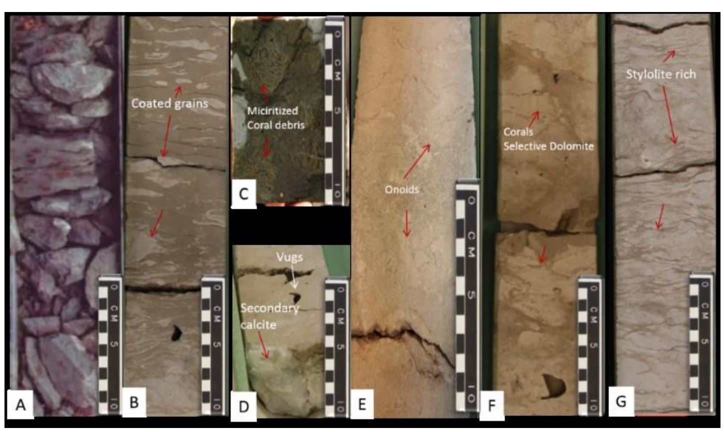

Figure 3. Key diagenetic features on core, A-Basal mixed carbonate-siliciclastic facies (cycle III-cycle IV boundary), B- Coated grain packstone facies with coral debris, C-Coral(massive) lime-packstone facies, D- Skeletal lime/dolomitic packstone facies, open vugs normally result of dissolution and closed vugs filled by secondary calcite cements, E-Oncolite lime grain dominated packstone, F-Coral(platy) lime mud dominated packstone facies, F- Coral (branching) lime dominated pack-grainstone facies.

Table1. Example of data-set resulting from microfacies, dominant cement and pores types from X-2 well

Depth core, (ft)	Microfacies	Cement types	Pore type
6200	Rhodolith floatstone-bindstone MF-7	Micrtic	Minor fracture pores
6210	Amphistegina packstone-wackestone MF-3	Micritic/Equant	Micropores
6215	Amphistegina packstone-wackestone MF-3	Micritic/Equant	Mouldic
6225	Cycloclypeus-lepidocyclinids rudstone-floatstone MF-2	Blocky/equant	Mouldic
6235	Soritids(miliolid)-encrusting packstone-wackestone MF-4	Blocky/equant	Mouldic
6245	Amphistegina packstone-wackestone MF-3	Micrtic	Mouldic
6255	Miogypsina bryozoan packstone-grainstone MF-1	blocky/micrite	Mouldic/intraparticle
6265	Austrotrillina mudstone-wackestone MF-5	Equant/blocky	Mouldic
6270	Rhodolith floatstone-bindstone MF-7	Sucrosic dolo./microdolo-mite	Intercrystal-line/vugs
6285	Miogypsina bryozoan packstone-grainstone MF-1	Micrite/equant	Mouldic
6295	Coral framestone/floatstone MF-8	Blocky/equant	Mouldic/micropores
6315	Operculinid packstone- grainstone MF-6	Equant/blocky	Mouldic
6330	Echinoid packstone- grainstone MF-10	Equant	Mouldic/micropores
6340	Soritids(miliolid)-encrusting packstone-wack-estone MF-4	Equant/blocky	Mouldic/vugs
6350	Operculinid packstone- grainstone MF-6	Micrite/equant	Mouldic
6380	Soritids(miliolid)-encrusting packstone-wack-estone MF-4	Equant/blocky	Mouldic/micropores
6390	Miogypsina bryozoan packstone-grainstone MF-1	Micrite/equant	Micropores
6400	Amphistegina packstone-wackestone MF-3	Equant/blocky	Micropres

3.2. Core-based and petrographic description

The platform consists of 55% limestone, 20% dolomitic limestone, 15% dolomite and 10% argillaceous limestone (Figure 2). The texture of the X field is grain rich throughout, with mud-dominated packstone is forming the muddiest portions. Packstone composes 45%, grainstone 38%, rudstone 13% and mudstone 4% of the cored intervals (Figure 3&4). The grains are moderately to poorly sorted. The grainsize varies from fine sand to coarse gravel, mud is virtually absent.

The 12 reported microfacies of the X-buildup based on lithological composition, components and other diagenetic features, some important microfacies are discussed here. Foraminiferal pack-wackestone microfacies, the microfacies has a mud to grain supported texture in a micritic matrix (36%) (Figure 4A). The majority of allochems are larger foraminifera (12%), corals (10%), echinoids (4%), red algae (1%) and broken mollusc shells (rare). Dolomitized massive/branching coral framestone microfacies, components are corals (39%), red algae (1%), miliolids (1%) bivalves (traces) and brachiopods (traces) (Figure 4B). Foraminiferal (miliolid) wacke- to mudstone, the microfacies have a mud supported texture in a micritic matrix of about 39% (Figure 4C) The majority of allochems are miliolid (10%) echinoids (8%), and planktonic foraminifera (2%). Sucrosic dolo-mudstone microfacies, in terms of petrographic observations this facies is characterized by fine to coarsely crystalline (60-100 μm) crystals that are loosely cemented (Figure 4D). The majority of allochems are red algae (4%) and unidentified skeletal debris (2%).

The dominant components (Figure 5) are corals (37%), foraminifera's (28%), red algaes (21%), echinoderms (6%), molluscs (5%), brachiopods (<1%), bryozoans (<1%) and green algae (<1%).The depositional sub-environments of the atoll as interpreted in core are: coral debris dominate facies represents shallow lagoon and foraminifera dominate facies signifies deep lagoon.

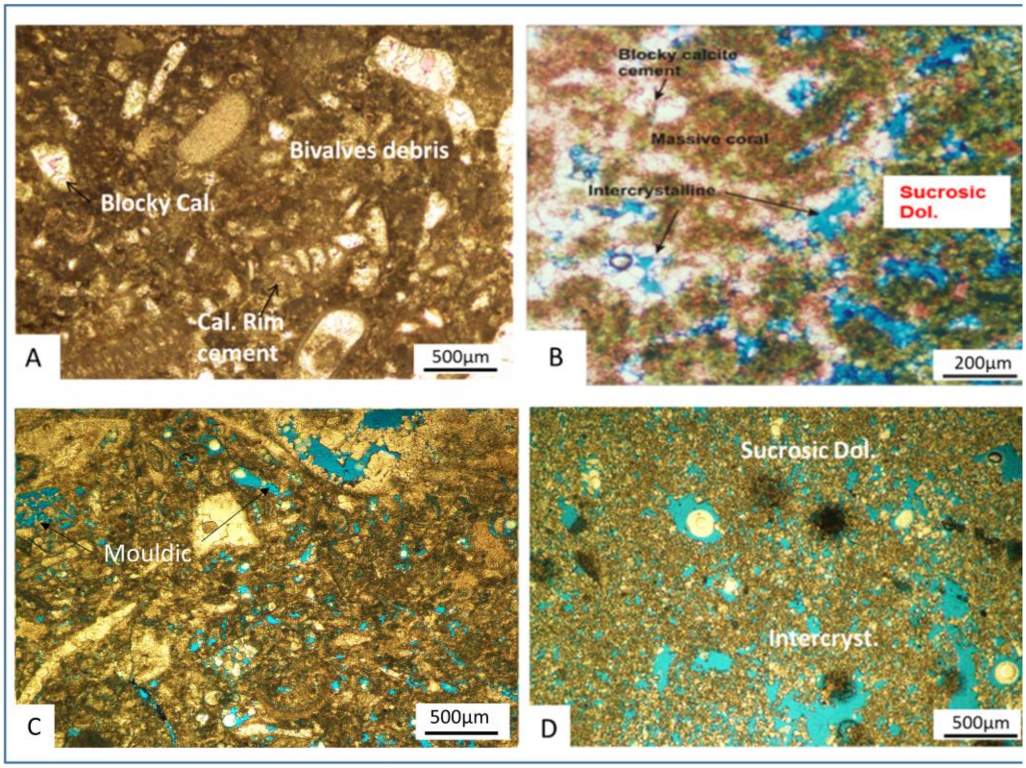

Figure 4. (A) Foraminiferal pack-wackestone microfacies with total porosity (1%), (B) Dolomitized massive/branching coral framestone, total porosity (13%), intragranlur (8%) and intercrytalline (5%), (C) Miliolid wacke-mudstone microfacies, total (25%), mouldic (20%) and vuggy (5%). (D) Sucrosic dolo-mudstone microfacies, total porosity (30%), intercrytalline (13%), vuggy (13%) and microporosity (4%)

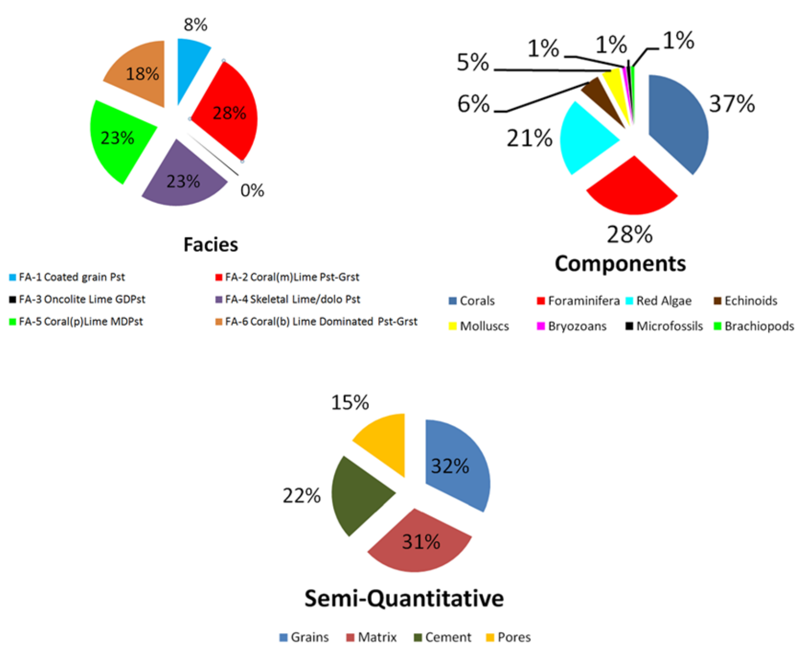

Figure 5. Quantitative description of X-Field, based on facies, components and semi-quantitative

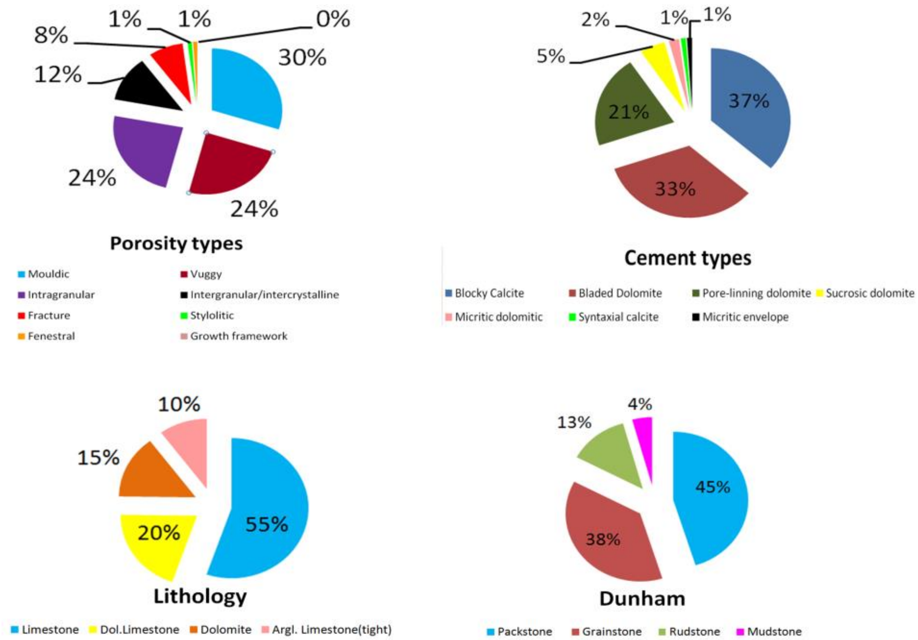

Figure 6. Quantitative Description of X-Field, based on porosity types, cement types, lithology and Dunham's name

The original mineralogy can be inferred from the observed grains, e.g., 29% LMC (foraminifera, brachiopods) are mostly preserved, 43% aragonite (corals, molluscs, bryozoans) are largely re-crystallized, whereas 27% HMC (red algae, echinoderms) are mostly well preserved (Figure 5). Diagenesis has altered these original minerals into Low-Mg calcite and dolomite.

The main types of cements (by shape -Figure 6) are: 35% blocky equant calcite cement, 32% bladed calcite cement, 20% pore lining, blocky hypidiomorphic dolomite cement, 5% sucrosic dolomite cement, 5% micro-crystalline dolomite cement, 2% micritic/micro-sparitic calcite cement and <1% syntaxial/rim calcite cement (Figure 6)

3.3. Sequence stratigraphy

Carbonate sequence in buildup X represents three petrophysically distinct sections:

- *Flooding*: Argillaceous limestone (Figure 2 & 3F) mostly in mudstone facies, few skeletal fragments and high abundant bioturbations. These are characterized by poor reservoir quality and high values on gamma ray logs.
- *Aggradation and progradation:* The aggradation starts with foram-red algal wacke- mudstone facies that leads. The upper half of the sequence sees full development of coral debris facies association. The upper part of the sequence has excellent reservoir potential (Figure 7).
- *Exposure*: The karst indicates large gaps having lateral infill. Good reservoir facies exist below the karst surface, with vuggy pores, that indicate intense leaching (Figure 7).

3.4. Cement stratigraphy and paragenetic sequence

Paragenetic sequence includes early and burial diagenetic features (Figure 8): The 3 generations of dolomitization. The diagenetic changes vary stratigraphically within the X platform: The first stage of dissolution and leaching took place before the early calcite cementation (that destroyed all the generated pore spaces). Later dissolution and corrosion occurred after the dolomitization event and are related to burial diagenesis.

Based on cathodoluminescence observations the buildup is comprised of four stages of calcite (Figure 8A), three dolomites (Figure 8B), and one pyrite cementation stage.

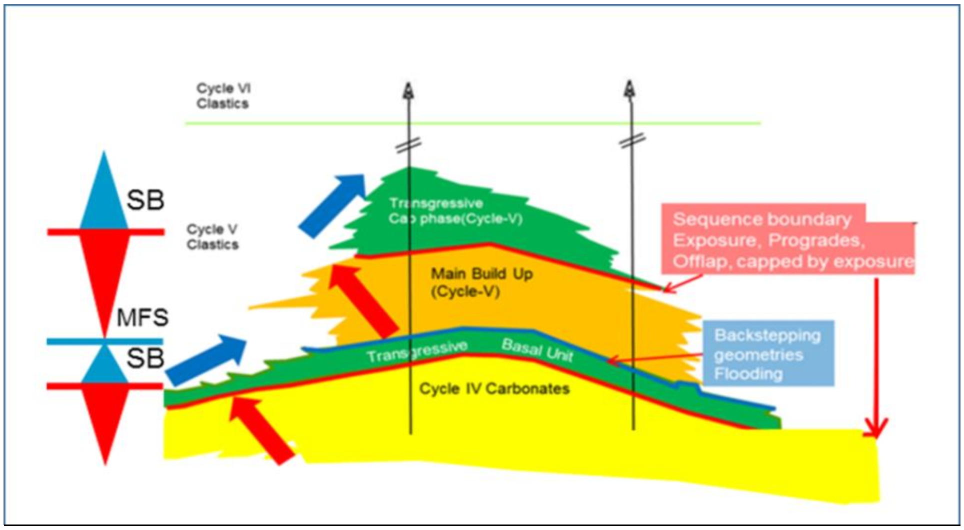

Figure 7. A typical growth pattern of a Central Luconia carbonates buildup[3], the sequence boundaries present more dolomitization, while the Maximum Flooding Surfaces (MFS) are more cemented in the reservoir

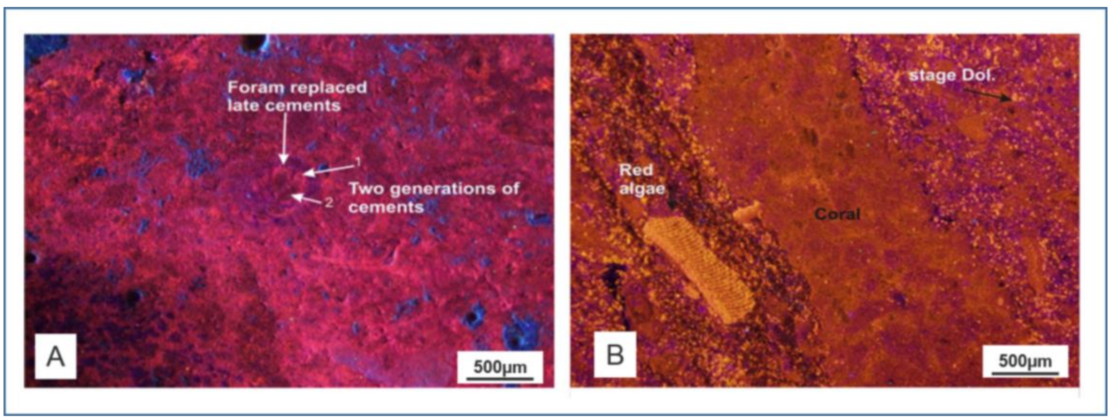

Figure 8. (A)Complex zonations in Foraminifera (Foram-Pack-Wackestone), (B) Calcite cement filling an intraparticle pores in coral with fabric destructive replacement dolomite (stage Dol-1)

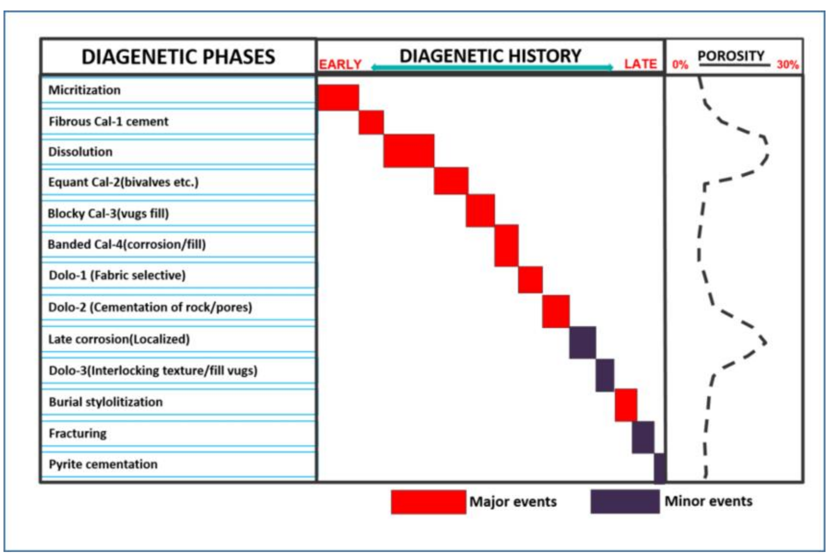

Figure 9. Paragenetic sequence within the X-Field

4. Conclusions

Based on the quantitative information from the core and thin sections, buildup X, is located close to a clastic source.

- Platform is partially dolomitized (dolomitic limestone 20%; dolomite 15%). Strongest alterations are observed in coral-rich facies (reefal debris/shallow lagoon).
- Diagenesis occurs cyclically and corresponds to seismically detectable buildup geomorphology. The paragenetic sequence generated includes micritization, dissolution, dolomitization, cementation, mechanical compaction and stylolitization.
- Burial diagenesis moderately alters the pore structure in certain parts of the buildup.

Acknowledgments

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